

# Ponašanje visoke zgrade izvedene konstrukcijskim sustavom potpornih rešetki i različitim tlocrtnim oblicima s obzirom na djelovanje vjetra

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Sveučilište u Zagrebu

GRAĐEVINSKI FAKULTET

Ariana Rajković

**PONAŠANJE VISOKE ZGRADE IZVEDENE  
KONSTRUKCIJSKIM SUSTAVOM POTPORNIH  
REŠETKI I RAZLIČITIM TLOCRTNIM OBLICIMA  
S OBZIROM NA DJELOVANJE VJETRA**

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Mentor: izv. prof. dr. sc. Ivan Lukačević

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University of Zagreb

FACULTY OF CIVIL ENGINEERING

Ariana Rajković

**BEHAVIOUR OF A TALL BUILDING WITH  
OUTRIGGER STRUCTURAL SYSTEM AND  
DIFFERENT SHAPES REGARDING WIND  
LOAD**

MASTER THESIS

Supervisor: izv. prof. dr. sc. Ivan Lukačević

Zagreb, 2024.



OBRAZAC 3

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(Naslov teme diplomskog rada na hrvatskom jeziku)

Behaviour of tall building with outrigger structural system and different plan shapes regarding wind load

(Naslov teme diplomskog rada na engleskom jeziku)

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## ZAHVALE

Zahvaljujem mentoru, izv. prof. dr. sc. Ivanu Lukačeviću na strpljenju i stručnom vodstvu tijekom izrade ovog rada.

Također zahvaljujem svojim najbližima na bezuvjetnoj podršci tijekom cijelog studija.



## SAŽETAK

U radu se razmatra ponašanje visoke zgrade izvedene konstrukcijskim sustavom potpornih rešetki i različitim tlocrtnim oblicima s obzirom na djelovanje vjetra. Odabrana je zgrada visine 176 metara sa tlocrtnom površinom 1296 m<sup>2</sup> po etaži s ukupno 38 etaža. Razmatrani su kvadratni tlocrt sa stranicama 36x36 m, te okrugli tlocrt promjera 40,62 m. Potporne rešetke postavljene su na polovici i vrhu zgrade i visine su 2 etaže. Provedene su statička i dinamička analiza te dimenzioniranje za oba razmatrana tlocrta. Uspoređeni su rezultati analiza s obzirom na veličinu sile vjetra, opterećenja na elemente i težinu konstrukcije. Analize su pokazale značajne razlike u raspodjeli naprezanja i deformacija u konstrukciji, kao i u ukupnoj težini konstrukcije u korist kružnog tlocrta.

**Ključne riječi:** potporne rešetke, opterećenje vjetrom, utjecaj tlocrtnog oblika, visoka zgrada

## SUMMARY

The thesis examines the behaviour of a tall building constructed with an outrigger system and various floor plan shapes in response to wind loads. A building with a height of 176 meters, a floor area of 1296 m<sup>2</sup> per floor, and a total of 38 floors was selected. A square floor plan with sides of 36x36 m and a circular floor plan with a diameter of 40,62 m were considered. Outriggers were placed at the mid-height and top of the building and are 2 stories high. Static and dynamic analysis as well as design were carried out for both floor plans. The analysis results were compared in terms of wind force magnitude, element loads, and mass of structures. The analyses showed significant differences in the distribution of stresses and deformations in the structure, as well as in the total mass of the structure in favour of the circular floor plan.

**Key words:** outrigger, wind load, influence of the floor plan shape, tall building

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## 1. UVOD

Razvojem urbanog društva pojavila se potreba za visokim zgradama koje nude maksimalnu iskoristivost prostora. Svojom velikom korisnom površinom na maloj tlocrtnoj površini dobar su izbor za velike i gusto naseljene gradove. Međutim, porastom visine pojavljuju se brojni inženjerski izazovi u oblikovanju i gradnji. Jedan od njih je utjecaj vjetra. Djelovanja vjetra rastu s porastom visine i uzrokuju značajne sile i deformacije, te je oblikovanje zgrade od iznimne važnosti za smanjenje utjecaja vjetra.

Predmet ovog rada je dimenzioniranje dva različita tlocrtna oblika visoke zgrade, te usporedba utjecaja oblika visoke zgrade na opterećenje vjetrom, te posljedično na sile i deformacije koje se pojavljuju. Razmatrana su dva tlocrta, jedan kvadratni i jedan okrugli uz zadržavanje iste površine i iste visine. Uspoređena je masa pojedinog sustava kao pokazatelj utroška materijala.

Postavljena hipoteza bila je da će deformacije i sile na zgradu okruglog tlocrta biti manje nego kod zgrade kvadratnog tlocrta zbog veće aerodinamičnosti okruglog tlocrta u odnosu na kvadratni.

## 2. SUSTAVI S POTPORNIM REŠETKAMA

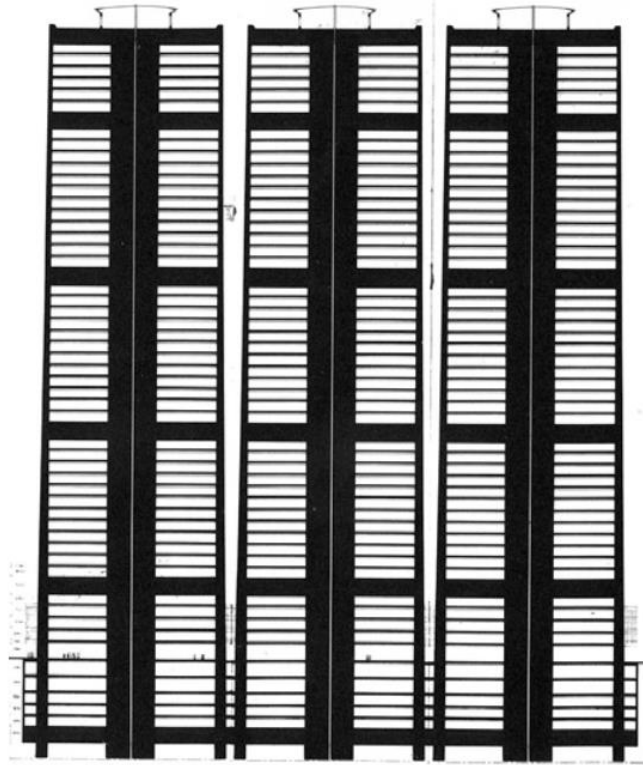
### 2.1. Povijest i razvoj

Vođeno ekonomskim razlozima, kasnih 1800-ih došlo je do želje za povećanjem rentabilnih prostora građenjem u vis. Potreba za prirodnim svjetlom i visinom dovela je do razvoja novih tehnologija građenja poput čeličnih okvirnih konstrukcija. Takve konstrukcije bile su lagane i malih presjeka, pa se velike otvore na fasadi moglo popuniti staklom.

Početak 20. stoljeća počela je utrka u gradnji najviše zgrade, te je do 1930-ih izgrađena prva zgrada sa preko 100 katova. Te početne visoke zgrade oslanjale su se na predimenzionirane elemente zbog nedostatka naprednih analiza konstrukcije.

Do 1960-ih, najčešće su u upotrebi bili kruti okviri, no razvojem cijevnih sustava te boljih načina analiza i računala, taj se način gradnje postupno napustio [1].

1962. izgrađena je prva visoka zgrada s potpornim rešetkama (engl. outrigger), Place Victoria (Montreal Stock Exchange Tower). Pier Luigi Nervi primijetio je da se kod tadašnjih zgrada u stupovima pojavljuju i tlačne i vlačne sile, ovisno o smjeru vjetra. Njegova je ideja bila koristiti rjeđe, ali veće stupove, koji bi uvijek bili u tlaku, neovisno o vanjskom opterećenju, povezanih sa posmičnom jezgrom pomoću greda. Sustav koji je razvio bio je baziran na hijerarhijskoj podjeli: primarni sustav koji preuzima horizontalna opterećenja i sekundarni koji nosi međukatnu konstrukciju, prikazano na slici 1. Analogija koju je koristio bio je skijaš s raširenim rukama koje mu pružaju poprečnu stabilnost. Nažalost, zbog raznih ekonomskih razloga i zahtjeva novih investitora, samo se jedna od 3 planirane zgrade izgradila. Na slici 2 vidljivi su stupovi u uglovima zgrade koji su glavni nosivi stupovi zgrade [2].

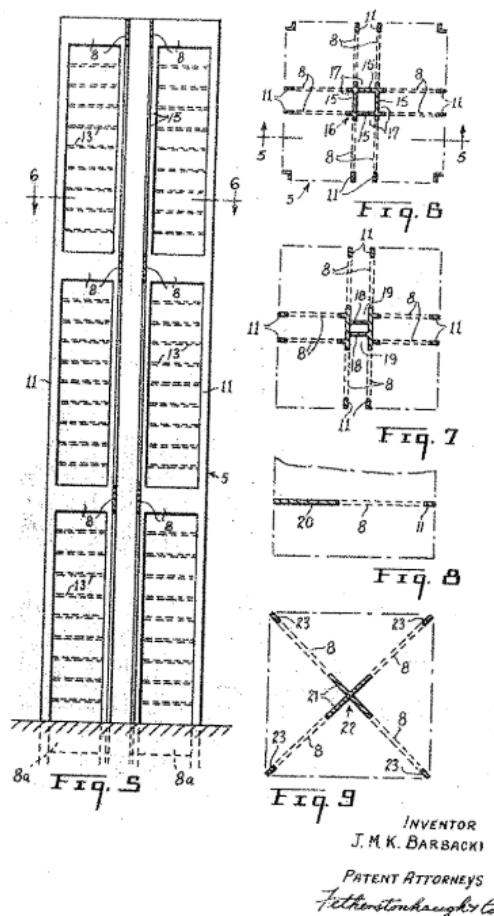


Slika 1. Rani prikaz dijagonalnog presjeka Place Victoria, s prikazom jezgre, outriggera i glavnih stupova (Izvor: [2])



Slika 2. Montreal Stock Exchange Tower (Izvor: [3])

1963. Jacek M. K. Barbacki, koji je surađivao s Nervijem na shemi za Stock Exchange Tower, patentirao je sustav koji je nazvao „T-okvirni sustav za vjetar i potres“. Modificirao je Nervijevu ideju te je umjesto armiranog betona, koji je korišten za Stock Exchange Tower, u patentu dozvolio korištenje svih do tada poznatih konstrukcijskih materijala. Još je jedna razlika u odnosu na Nervijevu ideju, a to su posmični zidovi paralelni sa zidovima fasade, što kod Stock Exchange Towera nije bio slučaj, gdje je jezgra bila postavljena dijagonalno u odnosu na fasadu. Na slici 3 je prikazan patent, gdje je vidljivo par mogućih konfiguracija spajanja posmičnih stupova s vanjskim stupovima [4].



Slika 3. Barbackijev patent za T-okvir (Izvor: [4])

1972. izgrađen je BHP House u Melbourneu, a 1974. First Wisconsin Center u Milwaukeeju. Ovdje je Fazlur Khan, koji ih je i razvio, upotrijebio pojasne rešetke (engl. belt truss). Pojasne rešetke su konstrukcijski elementi koji ojačavaju vanjsku zidnu konstrukciju na razini outriggera i preuzimaju vertikalna opterećenja na fasadu te je prenose do jezgre preko outriggera. Također, korištenjem pojasnih rešetki povećalo se učesće vanjskih stupova u

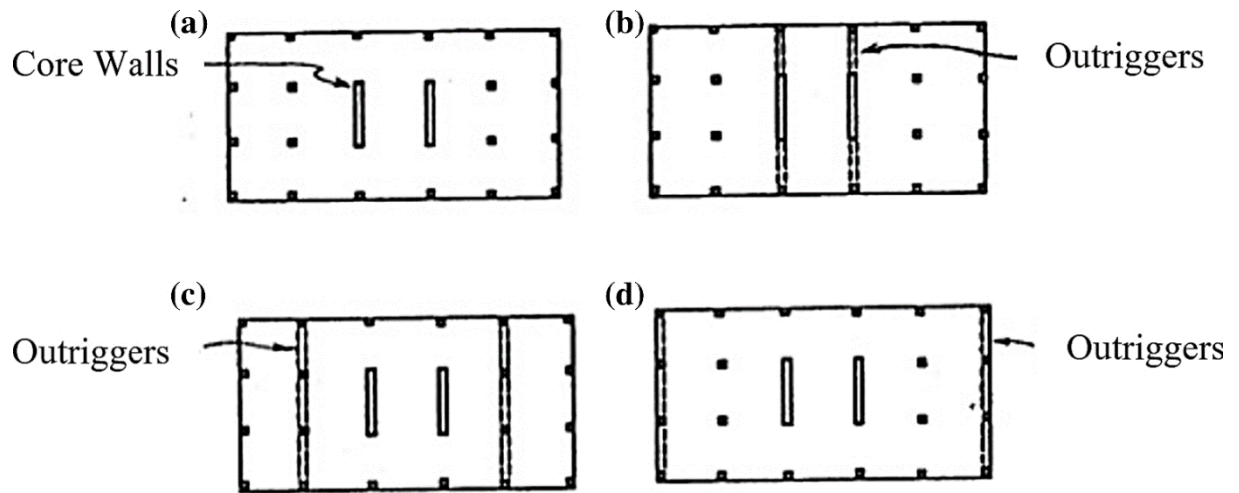


nosivosti. Za razliku od prethodno spomenutih sustava, Khan je koristio rešetke, a ne pune armirano-betonske presjeke [4]. Na slici 4 prikazan je First Wisconsin Center, gdje su vidljive pojasne rešetke.



**Slika 4. First Wisconsin Center, 1974. (Izvor: [5])**

1996. Stafford Smith i ostali predložili su sustav izmaknutih outriggera, gdje outriggeri nisu povezani s jezgrom već su izmaknuti [6]. Na slici 5 je prikazano par takvih sustava (c i d). Jedna od zgrada koja koristi takav sustav je Dubai Towers Doha koja još uvijek nije završena (slika 6).

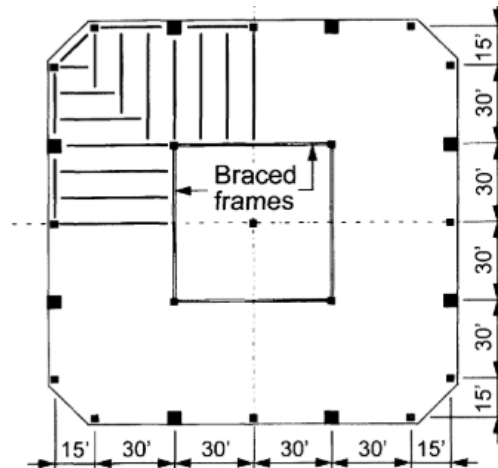


Slika 5. Prikaz položaja outrigera kod uobičajenih i izmaknutih outrigera (Izvor: [7])



Slika 6. Dubai Towers Doha (Izvor: [8])

1998. Shankar Nair predložio je "virtualni" outrigger, tj. outrigger koji nije direktno povezan sa jezgrom, već kruta dijafragma međukatne konstrukcije prenosi sile između pojasnih rešetki i jezgre (slika 7) [9]. Jedan od primjera zgrade s virtualnim outriggerima je Plaza Rakyat Tower, kod koje je gradnja započeta 1996., no nikada nije završena.



Slika 7. Idealizirani tlocrt karakterističnog kata zgrade s virtualnim outriggerima  
(Izvor: [9])

2004. Završen je Taipei 101, koji je sa svojim 101 katom tada postao najviša zgrada na svijetu (slika 8).



Slika 8. Taipei 101 (Izvor: [10])

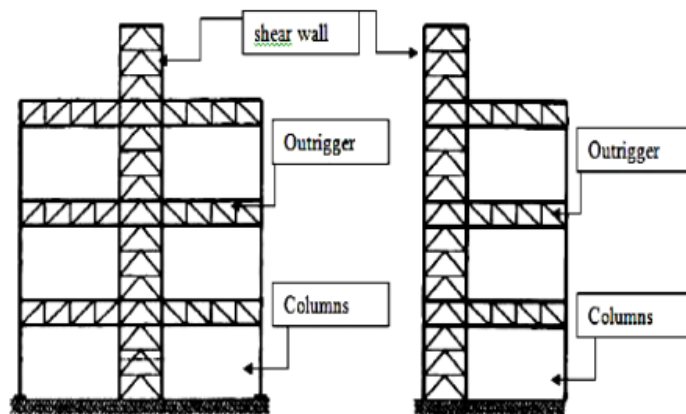
2008. je završen Shanghai Tower, koji je sa svojih 128 katova tada postao najviša zgrada na svijetu. Do danas je najviša zgrada s outriggerima na svijetu (slika 9).



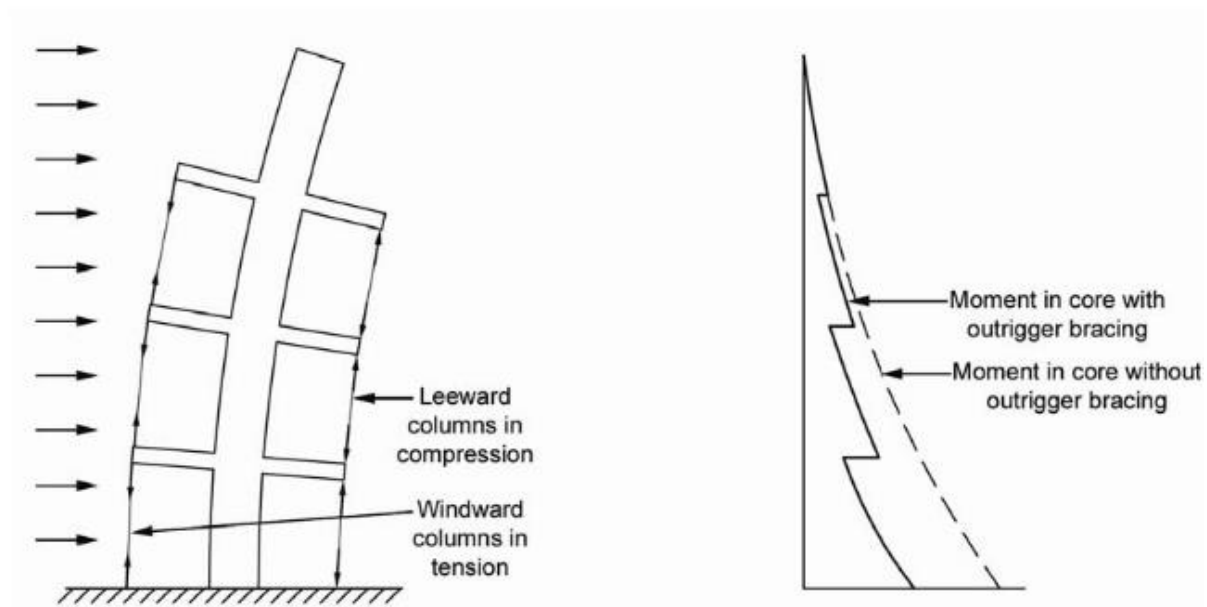
**Slika 9. Shanghai Tower (Izvor: [11])**

## 2.2. Princip rada

Potporne rešetke služe kao ukrućenje sustava i stvaraju parove sila u stupovima na suprotnim stranama. Jezgra u sustavima može biti postavljena centralno ili s jedne strane zgrade (slika 10). Parovi sila smanjuju momente savijanja jezgre (Slika 11)

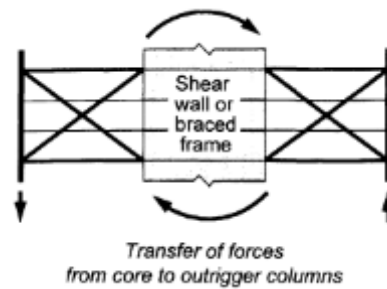


Slika 10. Dvostruki i jednostruki outriggeri (Izvor: [12])



Slika 11. Smanjenje momenta u jezgri uslijed djelovanja outriggera (Izvor: [1])

### 2.2.1. Uobičajeni outrigger sustav



Slika 12. Način rada outriggera (Izvor:[9])

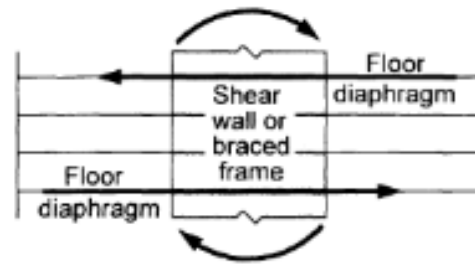
Kao što je prikazano na slici 12, kod uobičajenih outriggera, potporne rešetke ne dopuštaju rotaciju jezgre i prenose dio momenta savijanja na vanjske stupove. Događa se mala rotacija jezgre, ali ta je rotacija dovoljno mala da se jezgra savija u suprotnom smjeru ispod razine potporne rešetke [9].

Nedostatak sustava je to što potporne rešetke zauzimaju i do nekoliko katova, te se te etaže ne mogu korisno iskoristiti, već samo kao tehnički katovi. Još jedan nedostatak takvog sustava su vrlo komplicirani spojevi potporne rešetke.

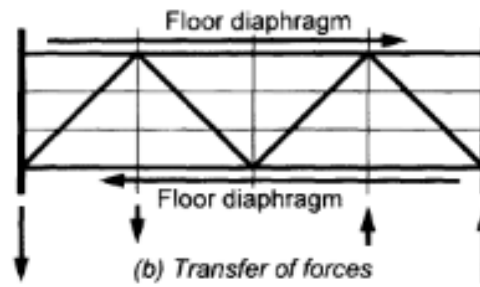
### 2.2.2. Virtualni outrigger sustav

Za razliku od uobičajenog sustava, moment prevrtanja prenose stropne dijafragme u obliku horizontalnog para sila od jezgre do pojasne rešetke, koja onda dalje sile prenosi u stupove.

Način prijenosa sila prikazan je na slici 13. Kod ovakvog načina prijenosa sila ne postoje problemi kao kod uobičajenog, kao što su tehnički katovi i komplicirani priključci.



(a) Transfer of forces  
from core to floor diaphragms



(b) Transfer of forces  
from floor diaphragms to columns  
through belt truss

Slika 13. Način prijenosa sila virtualnog outriggera (Izvor: [9])

### 3. ANALIZA OPTEREĆENJA

#### 3.1. Statička djelovanja

##### 3.1.1. Stalno opterećenje

###### Međukatna konstrukcija

Trapezni čelični lim, $t= 1,25\text{mm}$ .....	0,2 kN/m <sup>2</sup>
Betonska ploča, $h= 11\text{cm}$ .....	2,75 kN/m <sup>2</sup>
Dodatno stalno (slojevi poda) .....	1,50 kN/m <sup>2</sup>
Instalacije .....	0,50 kN/m <sup>2</sup>
Pregradni zidovi .....	0,70 kN/m <sup>2</sup>
<b>UKUPNO:</b> .....	<b>5,65 kN/m<sup>2</sup></b>

Fasada- staklena, debljine 20 mm ..... $4,40\text{ m} * 0,02\text{ m} * 25\text{ kN/m}^3 = 2,20\text{ kN/m}$

###### Konstrukcija krova

Trapezni čelični lim, $t= 1,25\text{mm}$ .....	0,2 kN/m <sup>2</sup>
Betonska ploča, $h= 11\text{cm}$ .....	2,75 kN/m <sup>2</sup>
Dodatno stalno (slojevi poda) .....	1,50 kN/m <sup>2</sup>
Šljunak .....	0,50 kN/m <sup>2</sup>
Instalacije .....	0,50 kN/m <sup>2</sup>
<b>UKUPNO:</b> .....	<b>5,45 kN/m<sup>2</sup></b>

##### 3.1.2. Uporabno opterećenje

###### Međukatna konstrukcija

Zgrada je poslovne namjene (kategorija B2) ->  $q_{k,l} = 3,0\text{ kN/m}^2$



## Konstrukcija krova

Krov je kategorije H (nedostupni krovovi, osim za redovito održavanje i popravak).

Krov je kategorije H te je nagib manji od  $20^\circ$  ->  $q_{k,krov} = 0,6 \text{ kN/m}^2$

### 3.1.3. Opterećenje snijegom

Opterećenje snijegom

$$s = \mu_i \cdot C_e \cdot C_t \cdot s_k \text{ [kN/m}^2\text{]} = 0,8 \cdot 0,8 \cdot 1,0 \cdot 0,5 = 0,32 \text{ [kN/m}^2\text{]}$$



Slika 14. Karta snježnih područja (Izvor: [13])

Za građevinu u 1. području (priobalje i otoci, slika 14), do 100 m nadmorske visine:

Karakteristično opterećenje snijegom na tlu  $s_k$  određeno je iz tablice 1 iz HRN EN 1991-1-3:2012/NA:2016 i iznosi  $0,5 \text{ kN/m}^2$

Tablica 1.: Preporučene vrijednosti koeficijenta  $C_e$  s obzirom na različite oblike terena  
(Izvor: [14])

Oblik terena	$C_e$
Izložen vjetru <sup>a</sup>	0,8
Uobičajen <sup>b</sup>	1,0
Zaklonjen <sup>c</sup>	1,2

<sup>a</sup> Izložen vjetru: ravan, nezaklonjena područja izložena sa svih strana, bez zaklona ili s vrlo malo zaklona terenom, višim građevinama ili drvećem.  
<sup>b</sup> Uobičajen oblik terena: područja gdje ne dolazi do značajnijeg premještanja snijega na građevini zbog vjetra, terena, drugih građevina ili drveća.  
<sup>c</sup> Zaklonjen oblik terena: područja gdje je predmetna građevina značajno niža od okolnog terena ili okružena visokim drvećem i/ili okružena drugim višim građevinama.

Koeficijent izloženosti  $C_e$  određen je iz tablice 1 s obzirom na oblik terena, koji je u ovom slučaju izložen vjetru i iznosi 0,8

Toplinski koeficijent  $C_t$  iznosi 1,0 za sve građevine gdje se ne smanjuje opterećenje snijegom na krovovima s velikom toplinskom propusnošću

Koeficijent oblika opterećenja snijegom  $\mu_i$  iznosi 0,8 za ravne krovove (tablica 2)

Tablica 2.: Koeficijenti oblika opterećenja snijegom (Izvor: [14])

Kut nagiba krova $\alpha$	$0^\circ \leq \alpha \leq 30^\circ$	$30^\circ < \alpha < 60^\circ$	$\alpha \geq 60^\circ$
$\mu_1$	0,8	$0,8 (60 - \alpha) / 30$	0,0
$\mu_2$	$0,8 + 0,8 \alpha / 30$	1,6	–

### 3.1.4. Opterećenje vjetrom

Osnovna brzina vjetra:

$$v_b = v_{b,0} \cdot c_{dir} \cdot c_{season}$$

Gdje je:

$v_b$  osnovna brzina vjetra

$v_{b,0}$  temeljna vrijednost osnovne brzine vjetra, određena prema slici

$c_{dir}$  faktor smjera, preporučena vrijednost je 1,0

$c_{season}$  faktor godišnjeg doba, preporučena vrijednost je 1,0



Slika 15. Karta osnovne brzine vjetra RH (Izvor: [15])

Sa slike 15 je očitana temeljna vrijednost osnovne brzine vjetra  $v_{b,0}=30$  m/s

Zatim je

$$v_b = 30 \cdot 1,0 \cdot 1,0 = 30 \text{ m/s} \quad \text{osnovna brzina vjetra}$$

Srednja brzina vjetra na visini z iznad terena iznosi:

$$v_m(z) = c_r(z)c_o(z)v_b$$

Gdje je:

$c_r(z)$  faktor hrapavosti

$c_o(z)$  faktor vertikalne razvedenost, za prosječni nagib kosine terena uz vjetar manji od  $3^\circ$  može se zanemariti i iznosi 1,0

Hrapavost terena

$$c_r(z) = k_r \ln \left( \frac{z}{z_0} \right) \quad \text{za} \quad z_{\min} \leq z \leq z_{\max}$$

$$c_r(z) = c_r(z_{\min}) \quad \text{za} \quad z \leq z_{\min}$$

Gdje je:

$z_0$  duljina hrapavosti

$k_r$  faktor terena ovisan o duljini hrapavosti

$$k_r = 0,19 \left( \frac{z_0}{z_{0,II}} \right)^{0,07}$$

Gdje je:

$z_{0,II}$  0,05 (tablica 3, kategorija terena II)

$z_{\min}$  najmanja visina (tablica 3)

$z_{\max}$  jednaka 200 m

Tablica 3.: Kategorije i parametri terena

Kategorija terena		$z_0$ [m]	$z_{\min}$ [m]
0	More ili priobalna područja izložena otvorenom moru	0,003	1
I	Jezerca ili ravna i horizontalno položena područja sa zanemarivom vegetacijom i bez prepreka	0,01	1
II	Područja s niskom vegetacijom, npr. travom, i izoliranim preprekama (drveće, zgrade) s razmakom najmanje 20 visina prepreke	0,05	2
III	Područja sa stalnim pokrovom od vegetacije ili zgrade ili područja s izoliranim preprekama s razmakom najviše 20 visina prepreke (npr. sela, predgrađa, stalna šuma)	0,3	5
IV	Područja s najmanje 15 % površine pokrivene zgradama čija prosječna visina premašuje 15 m	1,0	10

NAPOMENA: Kategorije terena prikazane su na slikama u točki A.1.

$$k_r = 0,19 \left( \frac{z_0}{z_{0,II}} \right)^{0,07} = 0,19 \left( \frac{1,0}{0,05} \right)^{0,07} = 0,2343$$

Za poredbenu visinu  $z_s = 0,6h = 105,6$  m:

$$c_r(z) = k_r \ln \left( \frac{z}{z_0} \right) = 0,2343 \cdot \ln \left( \frac{105,6}{1} \right) = 1,0919$$

$$v_m(z_s) = 1,0919 \cdot 1,0 \cdot 30 = 32,76 \text{ m/s}$$

Turbulencija vjetra

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_I}{c_o(z) \ln(z/z_0)} \quad \text{za} \quad z_{\min} \leq z \leq z_{\max}$$

$$I_v(z) = I_v(z_{\min}) \quad \text{za} \quad z \leq z_{\min}$$

Gdje je:

$k_I$  faktor turbulencije, preporučena vrijednost je 1,0

$\sigma_v$  standardna devijacija turbulencije

$$\sigma_v = k_I v_b k_I = 0,2343 \cdot 30 \cdot 1,0 = 7,029 \text{ m/s}$$

Za poredbenu visinu  $z_s = 0,6h = 105,6 \text{ m}$ :

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{7,029}{32,76} = 0,2146$$

Tlak pri vršnoj brzini

$$q_p(z) = [1 + 7 \cdot I_v(z)] \cdot \frac{1}{2} \rho v_m^2(z) = c_e(z) q_b$$

$$q_p(z) = [1 + 7 \cdot 0,2146] \frac{1}{2} 1,25 \cdot 32,76^2 = 1678 \text{ N/m}^2 = 1.678 \text{ kN/m}^2$$

Gdje je:

$\rho$  gustoća zraka, iznosi  $1,25 \text{ kg/m}^3$

$c_e(z)$  faktor izloženosti

$q_b$  tlak pri osnovnoj brzini

Tlak pri osnovnoj brzini:

$$q_b = \frac{1}{2} \rho v_b^2 = \frac{1}{2} \cdot 1,25 \cdot 30^2 = 562.5 \text{ N/m}^2 = 0.562 \text{ kN/m}^2$$

Faktor izloženosti:

$$c_e(z) = \frac{q_p(z)}{q_b}$$

### 3.1.4.1. Koeficijenti tlaka i sile zgrade kvadratnog tlocrta

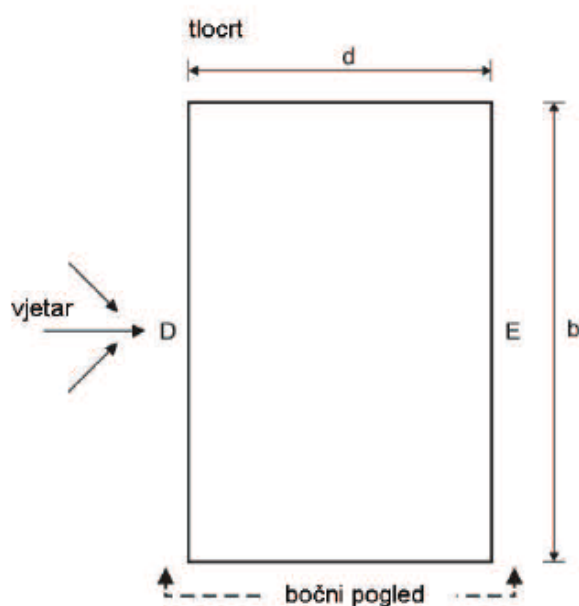
#### Koeficijent tlaka

Tlak vjetra na površine

$$w_e = q_p(z_e) \times c_{pe}$$

Gdje je:

$c_{pe}$  koeficijent vanjskog tlaka, određen iz tablice 4 za površine sa slike 16



Slika 16. Oznaka površina za određivanje  $c_{pe}$  (Izvor:[15] )

Tablica 4.: Preporučene vrijednosti koeficijenata vanjskog tlaka(Izvor: [15])

Područje	A		B		C		D		E	
	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,7	
1	-1,2	-1,4	-0,8	-1,1	-0,5		+0,8	+1,0	-0,5	
≤ 0,25	-1,2	-1,4	-0,8	-1,1	-0,5		+0,7	+1,0	-0,3	

U tablici 5 su prikazane vrijednosti tlaka i sile vjetra za zgradu kvadratnog tlocrta.

Tablica 5.: Vrijednosti tlaka i sile vjetra za zgradu kvadratnog tlocrta

Etaža	z [m]	Područje udara vjetra						Područje zavjetrina						c <sub>pe</sub>	F <sub>ve</sub> [kN]	Ukupna sila F <sub>ve</sub> [kN]		
		z <sub>0</sub> [m]	q <sub>0</sub> [kN/m <sup>2</sup> ]	c <sub>d(z)</sub>	w <sub>d(z)</sub> [m/s]	l(z)	q <sub>d(z)</sub> [kN/m <sup>2</sup> ]	z <sub>0</sub> [m]	q <sub>0</sub> [kN/m <sup>2</sup> ]	c <sub>d(z)</sub>	w <sub>d(z)</sub> [m/s]	l(z)	q <sub>d(z)</sub> [kN/m <sup>2</sup> ]					
Prizemlje	0.0																207.62	356.03
	1	4.4															207.62	356.03
2	8.8																207.62	356.03
3	13.2																207.62	356.03
4	17.6	1	36.0	0.84	25.19	0.28	1.17	2.08	0.94								207.62	356.03
5	22.0																207.62	356.03
6	26.4																207.62	356.03
7	30.8																207.62	356.03
8	35.2																207.62	356.03
9	39.6		44.0	0.89	26.60	0.26	1.26	2.24	1.01	4.4	36	159.69					207.62	367.31
10	44.0		48.4	0.91	27.27	0.26	1.30	2.32	1.04	4.4	36	165.16					207.62	372.78
11	48.4		52.8	0.93	27.88	0.25	1.34	2.39	1.07	4.4	36	170.21					207.62	377.83
12	52.8		57.2	0.95	28.44	0.25	1.38	2.46	1.10	4.4	36	174.91					207.62	382.53
13	57.2		61.6	0.97	28.96	0.24	1.42	2.52	1.13	4.4	36	179.31					207.62	386.93
14	61.6		66.0	0.98	29.45	0.24	1.45	2.58	1.16	4.4	36	183.45					207.62	391.07
15	66.0		70.4	1.00	29.90	0.24	1.48	2.63	1.18	4.4	36	187.35					207.62	394.97
16	70.4		74.8	1.01	30.33	0.23	1.51	2.68	1.21	4.4	36	191.04					207.62	398.66
17	74.8		79.2	1.02	30.73	0.23	1.54	2.73	1.23	4.4	36	194.55					207.62	402.17
18	79.2		83.6	1.04	31.11	0.23	1.56	2.78	1.25	4.4	36	197.89					207.62	405.51
19	83.6		88.0	1.05	31.47	0.22	1.59	2.82	1.27	4.4	36	201.08					207.62	408.70
20	88.0	2	92.4	1.06	31.81	0.22	1.61	2.87	1.29	4.4	36	204.14					207.62	411.76
21	92.4		96.8	1.07	32.14	0.22	1.63	2.91	1.31	4.4	36	207.07					207.62	414.69
22	96.8		101.2	1.08	32.45	0.22	1.66	2.95	1.33	4.4	36	209.88					207.62	417.50
23	101.2		105.6	1.09	32.75	0.21	1.68	2.99	1.34	4.4	36	212.59					207.62	420.22
24	105.6		110.0	1.10	33.04	0.21	1.70	3.02	1.36	4.4	36	215.21					207.62	422.83
25	110.0		114.4	1.11	33.32	0.21	1.72	3.06	1.37	4.4	36	217.73					207.62	425.35
26	114.4		118.8	1.12	33.58	0.21	1.74	3.09	1.39	4.4	36	220.17					207.62	427.79
27	118.8		123.2	1.13	33.84	0.21	1.76	3.12	1.40	4.4	36	222.53					207.62	430.15
28	123.2		127.6	1.14	34.08	0.21	1.77	3.16	1.42	4.4	36	224.82					207.62	432.44
29	127.6		132.0	1.14	34.32	0.20	1.79	3.19	1.43	4.4	36	227.04					207.62	434.66
30	132.0		136.4	1.15	34.55	0.20	1.81	3.22	1.45	4.4	36	229.19					207.62	436.81
31	136.4									4.4	36						207.62	438.86
32	140.8									4.4	36						207.62	440.86
33	145.2									4.4	36						207.62	442.86
34	149.6									4.4	36						207.62	444.86
35	154.0	3	176.0	1.21	36.34	0.19	1.94	3.46	1.55	4.4	36	246.24					207.62	446.86
36	158.4									4.4	36						207.62	448.86
37	162.8									4.4	36						207.62	450.86
38	167.2									4.4	36						207.62	452.86
39	171.6									4.4	36						207.62	454.86

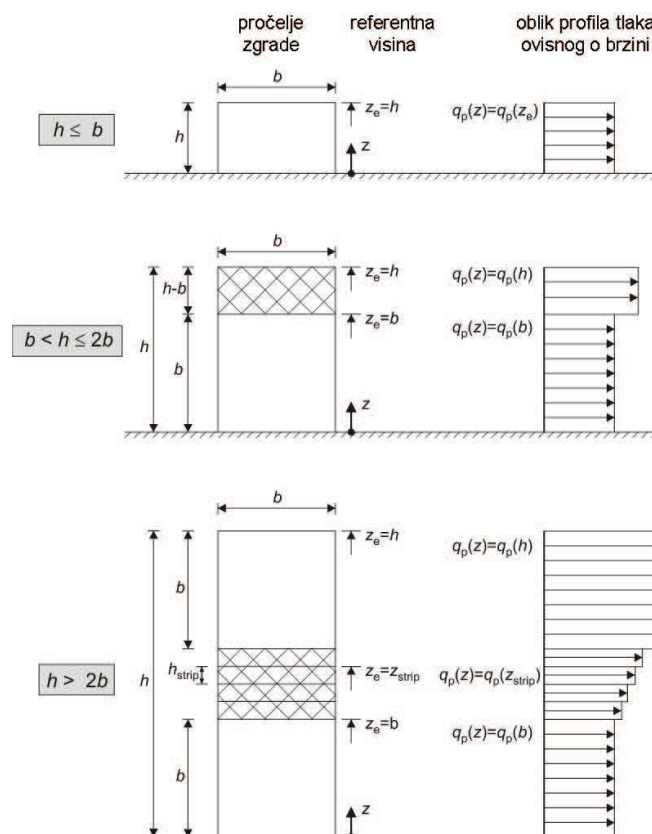
## Koeficijent sile

Pravokutne zgrade čija je visina  $h$  veća od  $2b$  smiju se proračunati kao da se sastoje od više dijelova koji obuhvaćaju:

donji dio koji se proteže od tla prema gore, do visine jednake  $b$ ; gornji dio koji se proteže od vrha prema dolje i visina mu je jednaka  $b$  i srednje područje, između gornjeg i donjeg dijela, koje se smije podijeliti u horizontalne trakove visine  $h_{\text{strip}}$  kao što je pokazano na slici 17.

Visina objekta ( $h=176 \text{ m} > 2b= 72 \text{ m}$ ) → visina objekta se dijeli na 3 zone:

- 1) Najniži dio koji se proteže uvis na visinu jednaku  $b$  i u kojem je poredbena visina jednaka  $z_e = b = 36 \text{ m}$ .
- 2) Srednji dio između najnižeg i najvišeg dijela razdijeljen je u toliko dijelova koliko ovdje ima etaža  $i$  i u kojem je poredbena visina najmanje jednaka  $z_e = b = 36 \text{ m}$  do najviše  $z_e = h - b = 140 \text{ m}$
- 3) Najviši dio koji se proteže od vrha zgrade prema dolje za visinu jednaku  $b$  i u kojem je poredbena visina  $z_e = h = 176 \text{ m}$ .



Slika 17. Raspodjela tlaka vjetra s obzirom na visinu (Izvor:[15])



Sila vjetra

$$F_w = c_s c_d c_f q_p(z_e) \times A_{ref}$$

Gdje je:

$c_s c_d$  konstrukcijski faktor

$c_f$  koeficijent sile

$A_{ref}$  površina na koju djeluje sila

Određivanje konstrukcijskog faktora  $c_s c_d$

Određuje se nakon preliminarnog dimenzioniranja (točka 3.1.5 )

Osnovna frekvencija zgrade:

$$n_1 = \frac{46}{h} [\text{Hz}] = \frac{46}{176} = 0,26 \text{ Hz}$$

Logaritamski dekrement prigušenja:

$$\delta = \delta_s + \delta_a + \delta_d = 0,05 + 0,02 \approx 0,07$$

Gdje je:

$\delta_s$  Logaritamski dekrement konstrukcijskog prigušenja u osnovnom obliku titranja, za čelične zgrade iznosi 0,05

$\delta_a$  Logaritamski dekrement aerodinamičkog prigušenja

$\delta_d$  Logaritamski dekrement posebnih naprava, ovdje iznosi 1,0

Logaritamski dekrement aerodinamičkog prigušenja:

$$\delta_a = \frac{c_f \cdot \rho \cdot b \cdot v_m(z_s)}{2 \cdot n_1 \cdot m_e} = \frac{1,4175 \cdot 1,25 \cdot 36 \cdot 32,76}{2 \cdot 0,26 \cdot 198000} = 0,02$$

Gdje je:

$m_e$  ekvivalentna masa

Ekvivalentna masa, izračunata na temelju preliminarnog dimenzioniranja

$$m_e = \frac{\int_0^1 m(s)\Phi_1^2(s)ds}{\int_0^1 \Phi_1^2(s)ds}$$

$$m_e = \frac{\int_0^{176} 198000 \cdot \frac{z^2}{176} dz}{\int_0^{176} \frac{z^2}{176} dz} = 198000 \text{ kg/m}$$

Za prirodnu frekvenciju zgrade <5 Hz:

$$c_{s,c_d} = \frac{1 + 2k_p I_v(z_s) \sqrt{B^2 + R^2}}{1 + 7I_v(z_s)} = \frac{1 + 2 \cdot 3,27 \cdot 0,21 \cdot \sqrt{0,51 + 0,44}}{1 + 7 \cdot 0,21} = 0,99 \approx 1,0$$

Gdje je:

$k_p$  vršni faktor

$B$  faktor podloge

$R$  faktor rezonantnog odziva

Vršni faktor  $k_p$ :

$$k_p = \sqrt{2 \ln(vT)} + \frac{0,6}{\sqrt{2 \ln(vT)}} \quad \text{ili} \quad k_p = 3, \text{ uzima se veća vrijednost}$$

Gdje je:

$v$  frekvencija promašaja

$T$  srednja brzina vjetra određena za vrijeme od  $T=600$  s

$$k_p = \sqrt{2 \ln(0,19 \cdot 600)} + \frac{0,6}{\sqrt{2 \ln(0,19 \cdot 600)}} = 3,27$$

Faktor podloge:

$$B^2 = \frac{1}{1 + 0,9 \left( \frac{b+h}{L(z_s)} \right)^{0,63}}$$

Gdje je:

$L(z_s)$  mjera turbulentne duljine

Mjera turbulentne duljine:

$$L(z) = L_t \left( \frac{z}{z_t} \right)^\alpha \text{ za } z \geq z_{\min}$$

$$L(z) = L(z_{\min}) \text{ za } z < z_{\min}$$

Gdje je:

$L_t$  visina turbulentnog sloja, iznosi 300 m

$z_t$  referentna visina 200 m

$$\alpha = 0,67 + 0,05 \ln(z_0) = 0,67 + 0,05 \ln(1,0) = 0,67$$

$$L(z_s) = L_t \left( \frac{z}{z_t} \right)^\alpha = 300 \cdot \left( \frac{105,6}{200} \right)^{0,67} = 195,5 \text{ m}$$

$$B^2 = \frac{1}{1 + 0,9 \left( \frac{36 + 176}{195,5} \right)^{0,63}} = 0,51$$

Frekvencija promašaja:

$$v = n_{1,x} \sqrt{\frac{R^2}{B^2 + R^2}}; v \geq 0,08 \text{ Hz}$$

$$v = 0,26 \sqrt{\frac{0,61}{0,51 + 0,44}} = 0,18$$

Faktor rezonantnog odziva:

$$R^2 = \frac{\pi^2}{2\delta} S_L(z_s, n_{1,x}) R_h(\eta_h) R_b(\eta_b) = \frac{\pi^2}{2 \cdot 0,07} \cdot 0,09 \cdot 0,14 \cdot 0,49 = 0,44$$

Gdje je:

$S_L$  bezdimenzijska funkcija spektralne gustoće

$R_h, R_b$  funkcije aerodinamičkog pristupa

Funkcije aerodinamičkog pristupa:

$$R_h = \frac{1}{\eta_h} - \frac{1}{2\eta_h^2} (1 - e^{-2\eta_h}) = \frac{1}{6,54} - \frac{1}{2 \cdot 6,54^2} (1 - e^{-2 \cdot 6,54}) = 0,14$$

$$R_b = \frac{1}{\eta_b} - \frac{1}{2\eta_b^2} (1 - e^{-2\eta_b}) = \frac{1}{1,34} - \frac{1}{2 \cdot 1,34^2} (1 - e^{-2 \cdot 1,34}) = 0,49$$

uz

$$\eta_h = \frac{4,6h}{L(z_s)} f_L(z_s, n_{1,x}) = \frac{4,6 \cdot 176}{195,5} \cdot 1,58 = 6,54$$

$$\eta_b = \frac{4,6b}{L(z_s)} f_L(z_s, n_{1,x}) = \frac{4,6 \cdot 36}{195,5} \cdot 1,58 = 1,34$$

Koeficijent sile

$$c_f = c_{f,0} \psi_r \psi_\lambda = 2,1 \cdot 1,0 \cdot 0,675 = 1,4175$$

Gdje je:

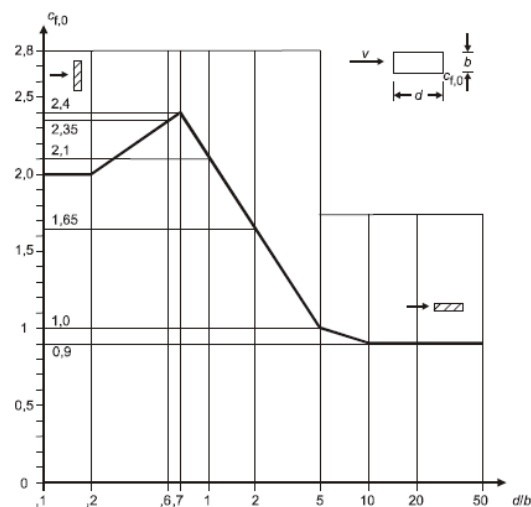
$c_{f,0}$  koeficijent sile za pravokutne profile s oštrim uglovima i bez toka preko slobodnog kraja

$\psi_r$  faktor smanjenja za kvadratne profile sa zaobljenim uglovima, za profile bez zaobljenih rubova iznosi 1,0

$\psi_\lambda$  faktor učinka kraja za elemente s tokom preko slobodnog kraja

Osnovni koeficijent sile, prema slici 18:

Za  $d/b = 36 \text{ m}/36 \text{ m} = 1,00 \rightarrow c_{f,0} = 2,1$



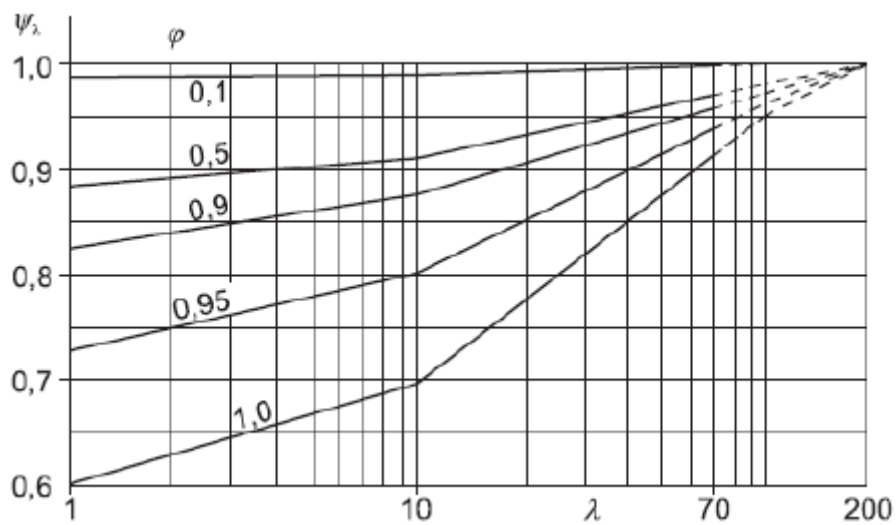
Slika 18. Koeficijenti sile za pravokutne profile s oštrim uglovima i bez toka preko slobodnog kraja (Izvor:[15])

Faktor učinka kraja:

Određuje se prema slici 19 u ovisnosti o proračunskoj vitkosti

Proračunska vitkost:

$$\lambda = \frac{2 \cdot h}{b} \cdot \frac{2}{c_{f,0}} = \frac{2 \cdot 176}{36} \cdot \frac{2}{2,1} = 9,31$$



Slika 19. Orijentacijske vrijednosti faktora učinka kraja (Izvor: [15])

Gdje je  $\varphi$  omjer punoće, u ovom slučaju iznosi 1,0

Očitano:  $\psi_{\lambda} = 0,675$

U tablici 6 su prikazane izračunate vrijednosti sile vjetra.

Tablica 6.: Vrijednosti sile vjetra na zgradu

Etaža	z [m]	područje	z <sub>e</sub> [m]	c <sub>s</sub> c <sub>d</sub>	q <sub>p</sub> [kN/m <sup>2</sup> ]	c <sub>f</sub> (z)	v <sub>m</sub> (z) [m/s]	l <sub>f</sub> (z)	q <sub>f</sub> (z) [kN/m <sup>2</sup> ]	c <sub>e</sub> (z)	c <sub>f</sub>	visina [m]	širina [m]	F <sub>w</sub> [kN]
Prizemlje	0	1	36	1	0.562	0.84	25.19	0.28	1.17	2.08	1.4175	4.4	36	262.96
1	4.4											36		
2	8.8											36		
3	13.2											36		
4	17.6											36		
5	22											36		
6	26.4											36		
7	30.8											36		
8	35.2	2	44	1	0.562	0.89	26.60	0.26	1.26	2.24	1.4175	4.4	36	282.95
9	39.6											36		
10	44											36		
11	48.4											36		
12	52.8											36		
13	57.2											36		
14	61.6											36		
15	66											36		
16	70.4											36		
17	74.8											36		
18	79.2											36		
19	83.6											3	88	
20	88	36												
21	92.4	36												
22	96.8	36												
23	101.2	36												
24	105.6	36												
25	110	36												
26	114.4	36												
27	118.8	36												
28	123.2	36												
29	127.6	36												
30	132	3	136.4	1	0.562	1.10	33.04	0.21	1.70	3.02	1.4175	4.4	36	381.32
31	136.4											36		
32	140.8											36		
33	145.2											36		
34	149.6											36		
35	154											36		
36	158.4											36		
37	162.8											36		
38	167.2											36		
39	171.6	36												
			176			1.21	36.34	0.19	1.94	3.46				436.30

## 3.1.4.2. Koeficijenti tlaka i sile zgrade okruglog tlocrta

Koeficijent vanjskog tlaka

Koeficijenti tlaka ovise o Reynoldsovom broju:

$$Re = \frac{b \cdot v(z_e)}{\nu}$$

Gdje je:

b      promjer

$\nu$       kinematska viskoznost zraka  $\nu = 15 \cdot 10^{-6} \text{ m}^2/\text{s}$

$v(z_e)$  vršna brzina vjetra:

$$v = \sqrt{\frac{2q_p}{\rho}}$$

Koeficijent vanjskog tlaka  $c_{pe}$  određuje se iz izraza:

$$c_{pe} = c_{p,0} \psi_{\lambda\alpha}$$

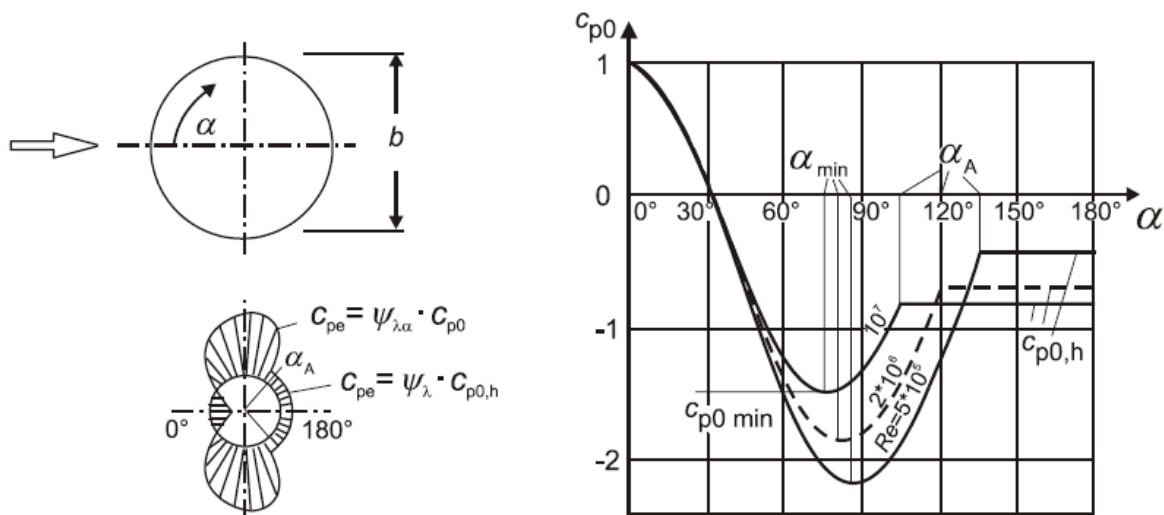
Faktor učinka kraja  $\psi_{\lambda\alpha}$  određuje se prema:

$$\psi_{\lambda\alpha} = 1 \quad \text{za } 0^\circ \leq \alpha \leq \alpha_{\min}$$

$$\psi_{\lambda\alpha} = \psi_\lambda + (1 - \psi_\lambda) \cos \left( \frac{\pi}{2} \left( \frac{\alpha - \alpha_{\min}}{\alpha_A - \alpha_{\min}} \right) \right) \quad \text{za } \alpha_{\min} \leq \alpha \leq \alpha_A$$

$$\psi_{\lambda\alpha} = \psi_A \quad \text{za } \alpha_A \leq \alpha \leq 180^\circ$$

Koeficijent vanjskog tlaka  $c_{p,0}$  određuje se pomoću grafa sa slike 20. Kružni valjak pojednostavljen je oblikom šesnaesterokuta, koji se prema EC 1991 računa kao kružni valjak. Vrijednosti  $\alpha$  određuju se iz tablice 7 s obzirom na vrijednost Reynoldsovog broja.



Slika 20. Graf za određivanje vrijednosti  $c_{p0}$  i područja utjecaja tlaka s obzirom na kut (Izvor: [15])

Tablica 7.: Vrijednosti za raspodjelu tlaka za kružne valjke (Izvor: [15])

$Re$	$\alpha_{\min}$	$c_{p0, \min}$	$\alpha_A$	$c_{p0, h}$
$5 \times 10^5$	85	-2,2	135	-0,4
$2 \times 10^6$	80	-1,9	120	-0,7
$10^7$	75	-1,5	105	-0,8

gdje je:  
 $\alpha_{\min}$  položaj najmanjeg tlaka u [°]  
 $c_{p0, \min}$  vrijednost najmanjeg koeficijenta tlaka  
 $\alpha_A$  položaj razdvajanja toka u [°]  
 $c_{p0, h}$  koeficijent tlaka u podnožju

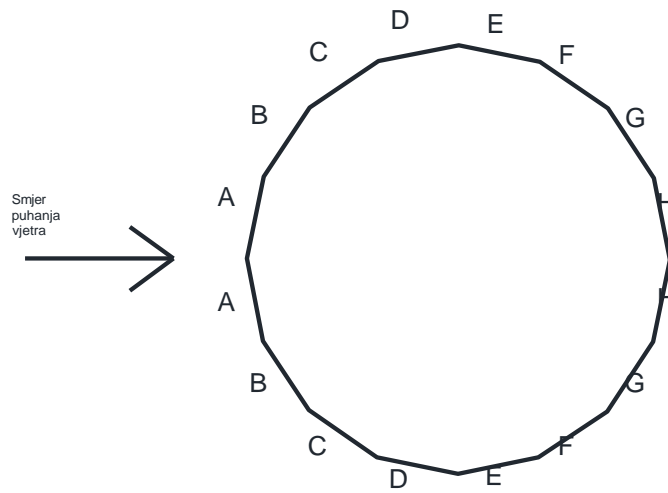
Za vrijednosti Reynoldsovog broja  $> 10^7$ , ekstrapolirale su se vrijednosti pomoću tablice 8.

Tablica 8.: Pomoćna tablica za interpoliranje vrijednosti raspodjele tlaka

$Re$	$\alpha_{\min}$	$c_{p0, \min}$	$\alpha_A$	$c_{p0, h}$
$5 \times 10^5$	85	-2.2	135	-0.4
$2 \times 10^6$	80	-1.9	120	-0.7
$10^7$	75	-1.5	105	-0.8
$4 \times 10^7$	72.5	-1.3	97.5	-0.85
$2 \times 10^8$	67.5	-1	85	-1



Na slici 21 su prikazane površine na koje djeluju pojedini tlakovi.



Slika 21. Površine za djelovanje tlakova

U nastavku su dane tablice (tablice 9, 10 i 11) koeficijenta tlaka i tlaka na površine

Tablica 9.: Koeficijenti tlaka na površine A, B i C

Etaža	Površina A				Površina B				Površina C			
	$\Psi_{\lambda a}$	$C_{po}$	$C_{pe}$	$W_e$ [kN/m <sup>2</sup> ]	$\Psi_{\lambda a}$	$C_{po}$	$C_{pe}$	$W_e$ [kN/m <sup>2</sup> ]	$\Psi_{\lambda a}$	$C_{po}$	$C_{pe}$	$W_e$ [kN/m <sup>2</sup> ]
Prizemlje	1	0.8	0.8	0.31	1	-0.1	-0.1	-0.04	1	-0.7	-0.7	-0.27
1	1	0.8	0.8	0.49	1	-0.1	-0.1	-0.06	1	-0.7	-0.7	-0.43
2	1	0.8	0.8	0.61	1	-0.1	-0.1	-0.08	1	-0.7	-0.7	-0.53
3	1	0.8	0.8	0.70	1	-0.1	-0.1	-0.09	1	-0.7	-0.7	-0.61
4	1	0.8	0.8	0.77	1	-0.1	-0.1	-0.10	1	-0.7	-0.7	-0.67
5	1	0.8	0.8	0.83	1	-0.1	-0.1	-0.10	1	-0.7	-0.7	-0.73
6	1	0.8	0.8	0.88	1	-0.1	-0.1	-0.11	1	-0.7	-0.7	-0.77
7	1	0.8	0.8	0.93	1	-0.1	-0.1	-0.12	1	-0.7	-0.7	-0.81
8	1	0.8	0.8	0.97	1	-0.1	-0.1	-0.12	1	-0.7	-0.7	-0.85
9	1	0.8	0.8	1.01	1	-0.1	-0.1	-0.13	1	-0.7	-0.7	-0.88
10	1	0.8	0.8	1.04	1	-0.1	-0.1	-0.13	1	-0.7	-0.7	-0.91
11	1	0.8	0.8	1.07	1	-0.1	-0.1	-0.13	1	-0.7	-0.7	-0.94
12	1	0.8	0.8	1.10	1	-0.1	-0.1	-0.14	1	-0.7	-0.7	-0.97
13	1	0.8	0.8	1.13	1	-0.1	-0.1	-0.14	1	-0.7	-0.7	-0.99
14	1	0.8	0.8	1.16	1	-0.1	-0.1	-0.14	1	-0.7	-0.7	-1.01
15	1	0.8	0.8	1.18	1	-0.1	-0.1	-0.15	1	-0.7	-0.7	-1.03
16	1	0.8	0.8	1.21	1	-0.1	-0.1	-0.15	1	-0.7	-0.7	-1.06
17	1	0.8	0.8	1.23	1	-0.1	-0.1	-0.15	1	-0.7	-0.7	-1.07
18	1	0.8	0.8	1.25	1	-0.1	-0.1	-0.16	1	-0.7	-0.7	-1.09
19	1	0.8	0.8	1.27	1	-0.1	-0.1	-0.16	1	-0.7	-0.7	-1.11
20	1	0.8	0.8	1.29	1	-0.1	-0.1	-0.16	1	-0.7	-0.7	-1.13
21	1	0.8	0.8	1.31	1	-0.1	-0.1	-0.16	1	-0.7	-0.7	-1.14
22	1	0.8	0.8	1.33	1	-0.1	-0.1	-0.17	1	-0.7	-0.7	-1.16
23	1	0.8	0.8	1.34	1	-0.1	-0.1	-0.17	1	-0.7	-0.7	-1.17
24	1	0.8	0.8	1.36	1	-0.1	-0.1	-0.17	1	-0.7	-0.7	-1.19
25	1	0.8	0.8	1.37	1	-0.1	-0.1	-0.17	1	-0.7	-0.7	-1.20
26	1	0.8	0.8	1.39	1	-0.1	-0.1	-0.17	1	-0.7	-0.7	-1.22
27	1	0.8	0.8	1.40	1	-0.1	-0.1	-0.18	1	-0.7	-0.7	-1.23
28	1	0.8	0.8	1.42	1	-0.1	-0.1	-0.18	1	-0.7	-0.7	-1.24
29	1	0.8	0.8	1.43	1	-0.1	-0.1	-0.18	1	-0.7	-0.7	-1.25
30	1	0.8	0.8	1.45	1	-0.1	-0.1	-0.18	1	-0.7	-0.7	-1.27
31	1	0.8	0.8	1.46	1	-0.1	-0.1	-0.18	1	-0.7	-0.7	-1.28
32	1	0.8	0.8	1.47	1	-0.1	-0.1	-0.18	1	-0.7	-0.7	-1.29
33	1	0.8	0.8	1.49	1	-0.1	-0.1	-0.19	1	-0.7	-0.7	-1.30
34	1	0.8	0.8	1.50	1	-0.1	-0.1	-0.19	1	-0.7	-0.7	-1.31
35	1	0.8	0.8	1.51	1	-0.1	-0.1	-0.19	1	-0.7	-0.7	-1.32
36	1	0.8	0.8	1.52	1	-0.1	-0.1	-0.19	1	-0.7	-0.7	-1.33
37	1	0.8	0.8	1.53	1	-0.1	-0.1	-0.19	1	-0.7	-0.7	-1.34
38	1	0.8	0.8	1.54	1	-0.1	-0.1	-0.19	1	-0.7	-0.7	-1.35
39	1	0.8	0.8	1.55	1	-0.1	-0.1	-0.19	1	-0.7	-0.7	-1.36

Tablica 10.: Koeficijenti tlaka na površine D, E i F

Etaža	Površina D				Površina E				Površina F			
	$\Psi_{\lambda a}$	$c_{po}$	$C_{pe}$	$W_e$ [kN/m <sup>2</sup> ]	$\Psi_{\lambda a}$	$c_{po}$	$C_{pe}$	$W_e$ [kN/m <sup>2</sup> ]	$\Psi_{\lambda a}$	$c_{po}$	$C_{pe}$	$W_e$ [kN/m <sup>2</sup> ]
Prizemlje	0.96	-1.14	-1.09	-0.42	0.60	-0.88	-0.53	-0.20	0.60	-0.88	-0.53	-0.20
1	0.95	-1.10	-1.04	-0.64	0.60	-0.89	-0.54	-0.33	0.60	-0.89	-0.54	-0.33
2	0.94	-1.08	-1.01	-0.77	0.60	-0.90	-0.54	-0.41	0.60	-0.90	-0.54	-0.41
3	0.93	-1.06	-0.99	-0.87	0.60	-0.91	-0.54	-0.48	0.60	-0.91	-0.54	-0.48
4	0.93	-1.05	-0.98	-0.94	0.60	-0.91	-0.55	-0.53	0.60	-0.91	-0.55	-0.53
5	0.93	-1.04	-0.97	-1.00	0.60	-0.92	-0.55	-0.57	0.60	-0.92	-0.55	-0.57
6	0.92	-1.04	-0.96	-1.06	0.60	-0.92	-0.55	-0.61	0.60	-0.92	-0.55	-0.61
7	0.92	-1.03	-0.95	-1.10	0.60	-0.92	-0.55	-0.64	0.60	-0.92	-0.55	-0.64
8	0.92	-1.02	-0.94	-1.14	0.60	-0.92	-0.55	-0.67	0.60	-0.92	-0.55	-0.67
9	0.92	-1.02	-0.94	-1.18	0.60	-0.93	-0.56	-0.70	0.60	-0.93	-0.56	-0.70
10	0.92	-1.01	-0.93	-1.21	0.60	-0.93	-0.56	-0.73	0.60	-0.93	-0.56	-0.73
11	0.91	-1.01	-0.92	-1.24	0.60	-0.93	-0.56	-0.75	0.60	-0.93	-0.56	-0.75
12	0.91	-1.01	-0.92	-1.27	0.60	-0.93	-0.56	-0.77	0.60	-0.93	-0.56	-0.77
13	0.91	-1.00	-0.91	-1.29	0.60	-0.93	-0.56	-0.79	0.60	-0.93	-0.56	-0.79
14	0.91	-1.00	-0.91	-1.32	0.60	-0.93	-0.56	-0.81	0.60	-0.93	-0.56	-0.81
15	0.91	-1.00	-0.91	-1.34	0.60	-0.94	-0.56	-0.83	0.60	-0.94	-0.56	-0.83
16	0.91	-0.99	-0.90	-1.36	0.60	-0.94	-0.56	-0.85	0.60	-0.94	-0.56	-0.85
17	0.91	-0.99	-0.90	-1.38	0.60	-0.94	-0.56	-0.86	0.60	-0.94	-0.56	-0.86
18	0.90	-0.99	-0.90	-1.40	0.60	-0.94	-0.56	-0.88	0.60	-0.94	-0.56	-0.88
19	0.90	-0.99	-0.89	-1.42	0.60	-0.94	-0.56	-0.90	0.60	-0.94	-0.56	-0.90
20	0.90	-0.99	-0.89	-1.43	0.60	-0.94	-0.56	-0.91	0.60	-0.94	-0.56	-0.91
21	0.90	-0.98	-0.89	-1.45	0.60	-0.94	-0.57	-0.92	0.60	-0.94	-0.57	-0.92
22	0.90	-0.98	-0.88	-1.46	0.60	-0.94	-0.57	-0.94	0.60	-0.94	-0.57	-0.94
23	0.90	-0.98	-0.88	-1.48	0.60	-0.94	-0.57	-0.95	0.60	-0.94	-0.57	-0.95
24	0.90	-0.98	-0.88	-1.49	0.60	-0.94	-0.57	-0.96	0.60	-0.94	-0.57	-0.96
25	0.90	-0.98	-0.88	-1.50	0.60	-0.95	-0.57	-0.97	0.60	-0.95	-0.57	-0.97
26	0.90	-0.97	-0.87	-1.52	0.60	-0.95	-0.57	-0.99	0.60	-0.95	-0.57	-0.99
27	0.90	-0.97	-0.87	-1.53	0.60	-0.95	-0.57	-1.00	0.60	-0.95	-0.57	-1.00
28	0.89	-0.97	-0.87	-1.54	0.60	-0.95	-0.57	-1.01	0.60	-0.95	-0.57	-1.01
29	0.89	-0.97	-0.87	-1.55	0.60	-0.95	-0.57	-1.02	0.60	-0.95	-0.57	-1.02
30	0.89	-0.97	-0.86	-1.56	0.60	-0.95	-0.57	-1.03	0.60	-0.95	-0.57	-1.03
31	0.89	-0.97	-0.86	-1.57	0.60	-0.95	-0.57	-1.04	0.60	-0.95	-0.57	-1.04
32	0.89	-0.97	-0.86	-1.58	0.60	-0.95	-0.57	-1.05	0.60	-0.95	-0.57	-1.05
33	0.89	-0.96	-0.86	-1.60	0.60	-0.95	-0.57	-1.06	0.60	-0.95	-0.57	-1.06
34	0.89	-0.96	-0.86	-1.60	0.60	-0.95	-0.57	-1.07	0.60	-0.95	-0.57	-1.07
35	0.89	-0.96	-0.86	-1.61	0.60	-0.95	-0.57	-1.08	0.60	-0.95	-0.57	-1.08
36	0.89	-0.96	-0.85	-1.62	0.60	-0.95	-0.57	-1.09	0.60	-0.95	-0.57	-1.09
37	0.89	-0.96	-0.85	-1.63	0.60	-0.95	-0.57	-1.10	0.60	-0.95	-0.57	-1.10
38	0.89	-0.96	-0.85	-1.64	0.60	-0.95	-0.57	-1.10	0.60	-0.95	-0.57	-1.10
39	0.89	-0.96	-0.85	-1.65	0.60	-0.95	-0.57	-1.11	0.60	-0.95	-0.57	-1.11

Tablica 11.: Koeficijenti tlaka na površine G i H

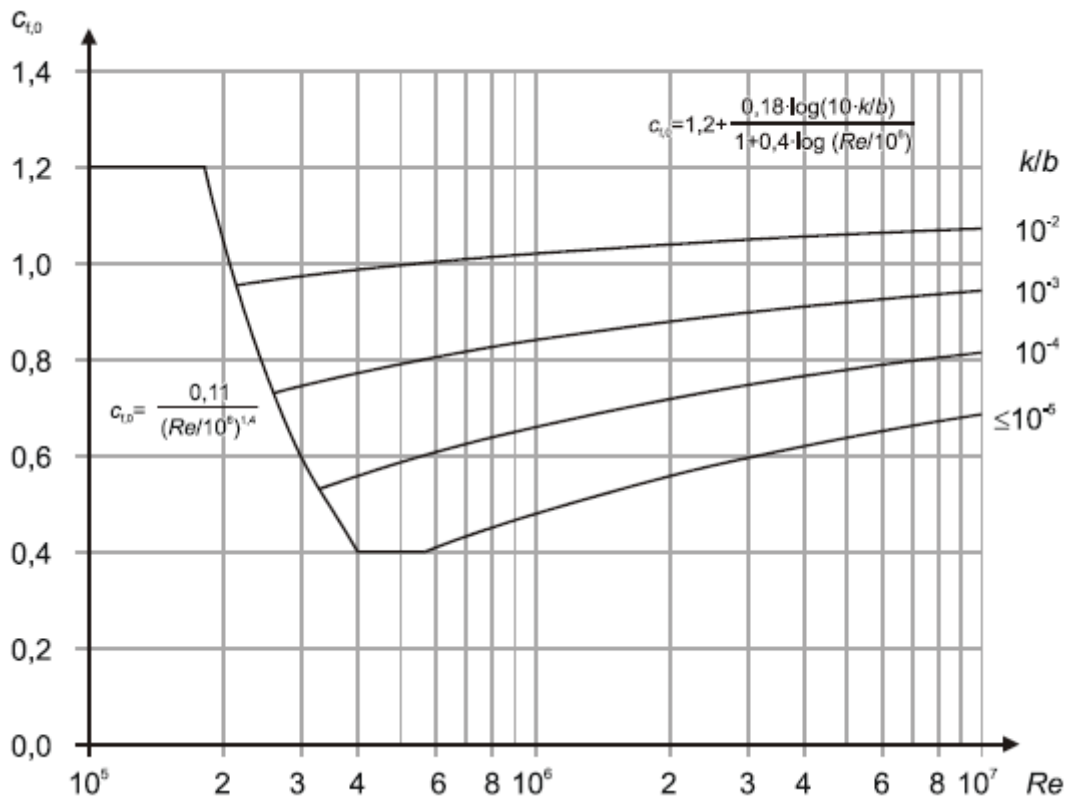
Etaža	Površina G				Površina H			
	$\Psi_{\lambda,a}$	$C_{po}$	$C_{pe}$	$W_e$ [kNm <sup>2</sup> ]	$\Psi_{\lambda,a}$	$C_{po}$	$C_{pe}$	$W_e$ [kNm <sup>2</sup> ]
Prizemlje	0.60	-0.88	-0.53	-0.20	0.60	-0.88	-0.53	-0.20
1	0.60	-0.89	-0.54	-0.33	0.60	-0.89	-0.54	-0.33
2	0.60	-0.90	-0.54	-0.41	0.60	-0.90	-0.54	-0.41
3	0.60	-0.91	-0.54	-0.48	0.60	-0.91	-0.54	-0.48
4	0.60	-0.91	-0.55	-0.53	0.60	-0.91	-0.55	-0.53
5	0.60	-0.92	-0.55	-0.57	0.60	-0.92	-0.55	-0.57
6	0.60	-0.92	-0.55	-0.61	0.60	-0.92	-0.55	-0.61
7	0.60	-0.92	-0.55	-0.64	0.60	-0.92	-0.55	-0.64
8	0.60	-0.92	-0.55	-0.67	0.60	-0.92	-0.55	-0.67
9	0.60	-0.93	-0.56	-0.70	0.60	-0.93	-0.56	-0.70
10	0.60	-0.93	-0.56	-0.73	0.60	-0.93	-0.56	-0.73
11	0.60	-0.93	-0.56	-0.75	0.60	-0.93	-0.56	-0.75
12	0.60	-0.93	-0.56	-0.77	0.60	-0.93	-0.56	-0.77
13	0.60	-0.93	-0.56	-0.79	0.60	-0.93	-0.56	-0.79
14	0.60	-0.93	-0.56	-0.81	0.60	-0.93	-0.56	-0.81
15	0.60	-0.94	-0.56	-0.83	0.60	-0.94	-0.56	-0.83
16	0.60	-0.94	-0.56	-0.85	0.60	-0.94	-0.56	-0.85
17	0.60	-0.94	-0.56	-0.86	0.60	-0.94	-0.56	-0.86
18	0.60	-0.94	-0.56	-0.88	0.60	-0.94	-0.56	-0.88
19	0.60	-0.94	-0.56	-0.90	0.60	-0.94	-0.56	-0.90
20	0.60	-0.94	-0.56	-0.91	0.60	-0.94	-0.56	-0.91
21	0.60	-0.94	-0.57	-0.92	0.60	-0.94	-0.57	-0.92
22	0.60	-0.94	-0.57	-0.94	0.60	-0.94	-0.57	-0.94
23	0.60	-0.94	-0.57	-0.95	0.60	-0.94	-0.57	-0.95
24	0.60	-0.94	-0.57	-0.96	0.60	-0.94	-0.57	-0.96
25	0.60	-0.95	-0.57	-0.97	0.60	-0.95	-0.57	-0.97
26	0.60	-0.95	-0.57	-0.99	0.60	-0.95	-0.57	-0.99
27	0.60	-0.95	-0.57	-1.00	0.60	-0.95	-0.57	-1.00
28	0.60	-0.95	-0.57	-1.01	0.60	-0.95	-0.57	-1.01
29	0.60	-0.95	-0.57	-1.02	0.60	-0.95	-0.57	-1.02
30	0.60	-0.95	-0.57	-1.03	0.60	-0.95	-0.57	-1.03
31	0.60	-0.95	-0.57	-1.04	0.60	-0.95	-0.57	-1.04
32	0.60	-0.95	-0.57	-1.05	0.60	-0.95	-0.57	-1.05
33	0.60	-0.95	-0.57	-1.06	0.60	-0.95	-0.57	-1.06
34	0.60	-0.95	-0.57	-1.07	0.60	-0.95	-0.57	-1.07
35	0.60	-0.95	-0.57	-1.08	0.60	-0.95	-0.57	-1.08
36	0.60	-0.95	-0.57	-1.09	0.60	-0.95	-0.57	-1.09
37	0.60	-0.95	-0.57	-1.10	0.60	-0.95	-0.57	-1.10
38	0.60	-0.95	-0.57	-1.10	0.60	-0.95	-0.57	-1.10
39	0.60	-0.95	-0.57	-1.11	0.60	-0.95	-0.57	-1.11

Koeficijenti sile

Koeficijenti sile  $c_f$  za kružne valjke određuju se iz izraza:

$$c_f = c_{f,0} \psi_\lambda$$

Koeficijent sile  $c_{f,0}$  određuje se pomoću Reynoldsovog broja i hrapavosti površine prema slici 22.



Slika 22. Graf ovisnosti koeficijenta sile i Reynoldsovog broja (Izvor: [15])

Određivanje konstrukcijskog faktora  $c_s c_d$

Pretpostavlja se masa i veličina konstrukcije približna konstrukciji kvadratnog tlocrta, pa se uzima  $c_s c_d = 1,0$

U tablici 12 su prikazane vjetra na konstrukciju

$$F_w = c_s c_d c_f q_p(z_e) \times A_{ref}$$

Tablica 12.: Sile vjeta na zgradu

Etaza	z [m]	z <sub>0</sub> [m]	c <sub>s</sub> c <sub>d</sub>	q <sub>p</sub> [kN/m <sup>2</sup> ]	c <sub>f</sub> (z)	v <sub>m</sub> (z) [m/s]	l <sub>p</sub> (z)	q <sub>s</sub> (z) [kN/m <sup>2</sup> ]	v(z) [m/s]	Re	c <sub>r</sub> 0	Ψ <sub>A</sub>	w <sub>g</sub> [kN/m <sup>2</sup> ]	F <sub>w</sub> [kN]
Prizemlje	0	4.4			0.35	10.41	0.67	0.39	24.92	6.75E+07	0.84	0.6	0.20	35.09
1	4.4	8.8			0.51	15.29	0.46	0.62	31.40	8.50E+07	0.85	0.6	0.31	56.25
2	8.8	13.2			0.60	18.14	0.39	0.76	34.95	9.46E+07	0.85	0.6	0.39	69.98
3	13.2	17.6			0.67	20.16	0.35	0.87	37.39	1.01E+08	0.86	0.6	0.45	80.33
4	17.6	22			0.72	21.73	0.32	0.96	39.26	1.06E+08	0.86	0.6	0.50	88.70
5	22	26.4			0.77	23.01	0.31	1.04	40.76	1.10E+08	0.86	0.6	0.54	95.76
6	26.4	30.8			0.80	24.09	0.29	1.10	42.02	1.14E+08	0.86	0.6	0.57	101.90
7	30.8	35.2			0.83	25.03	0.28	1.16	43.11	1.17E+08	0.86	0.6	0.60	107.32
8	35.2	39.6			0.86	25.86	0.27	1.21	44.06	1.19E+08	0.86	0.6	0.63	112.20
9	39.6	44			0.89	26.60	0.26	1.26	44.90	1.22E+08	0.86	0.6	0.65	116.64
10	44	48.4			0.91	27.27	0.26	1.30	45.67	1.24E+08	0.86	0.6	0.68	120.70
11	48.4	52.8			0.93	27.88	0.25	1.34	46.36	1.26E+08	0.86	0.6	0.70	124.47
12	52.8	57.2			0.95	28.44	0.25	1.38	46.99	1.27E+08	0.86	0.6	0.72	127.97
13	57.2	61.6			0.97	28.96	0.24	1.42	47.58	1.29E+08	0.86	0.6	0.73	131.25
14	61.6	66			0.98	29.45	0.24	1.45	48.13	1.30E+08	0.87	0.6	0.75	134.33
15	66	70.4			1.00	29.90	0.24	1.48	48.64	1.32E+08	0.87	0.6	0.77	137.24
16	70.4	74.8			1.01	30.33	0.23	1.51	49.11	1.33E+08	0.87	0.6	0.78	139.99
17	74.8	79.2			1.02	30.73	0.23	1.54	49.56	1.34E+08	0.87	0.6	0.80	142.61
18	79.2	83.6			1.04	31.11	0.23	1.56	49.99	1.35E+08	0.87	0.6	0.81	145.10
19	83.6	88			1.05	31.47	0.22	1.59	50.39	1.36E+08	0.87	0.6	0.83	147.49
20	88	92.4	1	0.562	1.06	31.81	0.22	1.61	50.77	1.37E+08	0.87	0.6	0.84	149.77
21	92.4	96.8			1.07	32.14	0.22	1.63	51.13	1.38E+08	0.87	0.6	0.85	151.96
22	96.8	101.2			1.08	32.45	0.22	1.66	51.48	1.39E+08	0.87	0.6	0.86	154.06
23	101.2	105.6			1.09	32.75	0.21	1.68	51.81	1.40E+08	0.87	0.6	0.87	156.09
24	105.6	110			1.10	33.04	0.21	1.70	52.13	1.41E+08	0.87	0.6	0.88	158.04
25	110	114.4			1.11	33.32	0.21	1.72	52.43	1.42E+08	0.87	0.6	0.89	159.93
26	114.4	118.8			1.12	33.58	0.21	1.74	52.73	1.43E+08	0.87	0.6	0.91	161.75
27	118.8	123.2			1.13	33.84	0.21	1.76	53.01	1.44E+08	0.87	0.6	0.91	163.52
28	123.2	127.6			1.14	34.08	0.21	1.77	53.28	1.44E+08	0.87	0.6	0.92	165.23
29	127.6	132			1.14	34.32	0.20	1.79	53.54	1.45E+08	0.87	0.6	0.93	166.89
30	132	136.4			1.15	34.55	0.20	1.81	53.79	1.46E+08	0.87	0.6	0.94	168.50
31	136.4	140.8			1.16	34.77	0.20	1.83	54.04	1.46E+08	0.87	0.6	0.95	170.07
32	140.8	145.2			1.17	34.99	0.20	1.84	54.28	1.47E+08	0.87	0.6	0.96	171.59
33	145.2	149.6			1.17	35.20	0.20	1.86	54.51	1.48E+08	0.87	0.6	0.97	173.08
34	149.6	154			1.18	35.40	0.20	1.87	54.73	1.48E+08	0.87	0.6	0.98	174.53
35	154	158.4			1.19	35.60	0.20	1.89	54.95	1.49E+08	0.87	0.6	0.98	175.94
36	158.4	162.8			1.19	35.80	0.20	1.90	55.16	1.49E+08	0.87	0.6	0.99	177.32
37	162.8	167.2			1.20	35.98	0.20	1.92	55.36	1.50E+08	0.87	0.6	1.00	178.66
38	167.2	171.6			1.21	36.17	0.19	1.93	55.56	1.50E+08	0.87	0.6	1.01	179.97
39	171.6	176			1.21	36.34	0.19	1.94	55.76	1.51E+08	0.87	0.6	1.01	181.26

### 3.1.5. Preliminarno dimenzioniranje

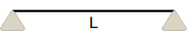
#### 3.1.5.1. Međukatna konstrukcija

Međukatna konstrukcija odabrana je ovisno o rasponu ploče i načinu podupiranja prema tablici proizvođača (slika 23).

#### Structural performance

Acceptable unweighted  $q$  values with  $g' = 0$  in  $\text{kg/m}^2$

A calculation using Cofra 5 optimises these values according to the project requirements

Single span 

Thickness of the slab [cm]	Span [m]																				
	2,00	2,10	2,20	2,30	2,40	2,50	2,60	2,70	2,80	2,90	3,00	3,10	3,20	3,30	3,40	3,50	3,60	3,70	3,80	3,90	4,00
18	2280	2834	2566	3000	3000	3000	3000	3000	1360	1287	1219	1156	1097	1043	992	944	900	858	819	782	747
17	2182	2707	2449	2229	3000	3000	3000	3000	2941	1226	1161	1100	1044	992	943	898	855	815	778	743	709
16	2084	1934	2332	2120	3000	2941	2960	2957	2796	1165	1103	1045	991	941	895	851	811	773	737	703	671
15	1986	1842	2215	2012	1836	2776	2620	2806	2651	2510	1045	990	938	891	846	805	766	730	696	664	634
14	1888	1750	1627	1903	1735	1590	2462	2327	2507	2371	2246	934	885	840	798	758	722	687	655	624	596
13	1790	1657	1540	1795	1634	1495	2305	2176	2214	2232	2113	879	832	789	749	712	677	644	614	585	558
12	1692	1565	1453	1352	1533	1401	1285	2025	1913	1955	1979	1875	779	739	701	665	632	602	573	545	-
11	1594	1473	1366	1270	1432	1307	1197	1874	1769	1816	1846	1746	1654	688	652	619	588	-	-	-	-
10	2792	1381	1279	1187	1106	1213	1109	1018	1624	1533	1584	1618	1531	1450	-	-	-	-	-	-	-
9	1910	2383	1191	1105	1028	1987	1021	-	-	1394	0	-	-	-	-	-	-	-	-	-	-
Without propping															With propping						

Slika 23. Tablica za izbor debljine ploče (Izvor:[16] )

Za raspon 3 m, bez podupiranja → debljina ploče 11 cm, debljina lima 1,25 mm

- Međukatna konstrukcija:

$$g_{\text{ploča}}^{\text{međukatna}} = \gamma_G \cdot g_k + \gamma_Q \cdot q_k$$

$$g_{\text{ploča}}^{\text{međukatna}} = 1,35 \cdot 5,65 + 1,5 \cdot 3,0$$

$$g_{\text{ploča}}^{\text{međukatna}} = 12,13 \text{ kN/m}^2 < g_{\text{dop}} = 18,46 \text{ kN/m}^2$$

- Krovna konstrukcija:

$$g_{\text{ploča}}^{\text{krov}} = \gamma_G \cdot g_k + \gamma_Q \cdot q_k + \Psi_i \cdot \gamma_Q \cdot s_k$$

$$g_{\text{ploča}}^{\text{krov}} = 1,35 \cdot 5,45 + 1,5 \cdot 0,6 + 0,5 \cdot 1,5 \cdot 0,32$$

$$g_{\text{ploča}}^{\text{krov}} = 8,49 \text{ kN/m}^2 < g_{\text{dop}} = 18,75 \text{ kN/m}^2$$

## 3.1.5.2. Sekundarni nosač

Vlastita težina sekundarnog nosača: 1,84 kN/m

Raspon sekundarnog nosača: 12 m

Raster sekundarnih nosača:  $e = 3$  m

Mjerodavna kombinacija opterećenja za sekundarni nosač:

$$g_{Ed} = \gamma_G \cdot g_k + \gamma_Q \cdot q_k$$

$$g_{Ed} = \gamma_G \cdot \left[ \frac{e \cdot l \cdot g_{k, \text{kat}}}{l} + g_{k, \text{sek.}} \right] + \gamma_Q \cdot \frac{e \cdot l \cdot q_k}{l_{\text{sek.}}}$$

$$g_{Ed} = 1,35 \cdot \left[ \frac{3 \cdot 12 \cdot 5,65}{12} + 1,84 \right] + 1,5 \cdot \frac{3 \cdot 12 \cdot 3}{12}$$

$$g_{Ed} = 38,87 \text{ kN/m}$$

Statički sustav: prosta greda

$$M_{Ed}^{\text{sredina}} = \frac{q \cdot l^2}{8} = \frac{38,87 \cdot 12^2}{8} = 700 \text{ kNm}$$

Otpornost na savijanje:

Odabran profil: HEB 500

Kvaliteta čelika: S355

$$M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{Mo}} = \frac{4815 \cdot 35,5}{1,1} = 1554 \text{ kNm} > 700 \text{ kNm}$$

**ODABRANO: HEB 500**



## 3.1.5.3. Glavni nosač

Vlastita težina glavnog nosača: 2,12 kN/m

Raspon glavnog nosača: 12 m

Raster glavnih nosača:  $e = 12$  m

Mjerodavna kombinacija opterećenja za glavni nosač:

$$g_{Ed} = \gamma_G \cdot g_k + \gamma_Q \cdot q_k$$

$$g_{Ed} = \gamma_G \cdot \left[ \frac{e \cdot l \cdot g_{k,kat}}{l_{gl.}} + \frac{n \cdot l_{sek.} \cdot g_{k,sek.}}{l_{gl.}} + g_{k,gl.} \right] + \gamma_Q \cdot \frac{e \cdot l \cdot q_k}{l_{gl.}}$$

$$g_{Ed} = 1,35 \cdot \left[ \frac{12 \cdot 12 \cdot 4,91}{12} + \frac{3 \cdot 12 \cdot 0,78}{12} + 2,12 \right] + 1,5 \cdot \frac{12 \cdot 12 \cdot 3}{12}$$

$$g_{Ed} = 152 \text{ kN/m}$$

Statički sustav: upeta greda

$$M_{Ed}^{oslonac} = \frac{q \cdot l^2}{12} = \frac{152 \cdot 12^2}{12} = 1500 \text{ kNm}$$

$$M_{Ed}^{sredina} = \frac{q \cdot l^2}{24} = \frac{152 \cdot 12^2}{24} = 912 \text{ kNm}$$

Otpornost na savijanje:

Odabran profil: HE 600 B

Kvaliteta čelika: S355

$$M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{Mo}} = \frac{6425 \cdot 35,5}{1,1} = 207352 \text{ kNcm} = 2073 \text{ kNm} > 1500 \text{ kNm}$$

**ODABRANO: HE 600 B**

## 3.1.5.4. Obodni stup

Vlastita težina stupa (HD 400x463):	4,63 kN/m
Snijeg	$S_{sk} = A \cdot s_k = 6 \cdot 6 \cdot 0,32 = 11,52 \text{ kN}$
Uporabno opterećenje krova:	$Q_{krov} = A \cdot q_{krov} = 6 \cdot 6 \cdot 0,6 = 21,6 \text{ kN}$
Uporabno opterećenje etaže:	$Q_{etaža} = A \cdot q_{etaža} = 6 \cdot 6 \cdot 3,0 = 108,0 \text{ kN}$
Međukatna konstrukcija:	$G_{med.kon.} = A \cdot g_{med.kon.} = 6 \cdot 6 \cdot 5,65 = 203,4 \text{ kN}$
Krovna konstrukcija:	$G_{krov} = A \cdot g_{krov} = 6 \cdot 6 \cdot 5,45 = 196,2 \text{ kN}$
Pregradni zidovi:	$G_{preg.} = A \cdot g_{preg.} = 6 \cdot 6 \cdot 0,7 = 25,2 \text{ kN}$
Glavni nosač:	$G_{gl.nosač} = L \cdot g_{gl.nosač} = 6 \cdot 2,12 = 12,72 \text{ kN}$
Sekundarni nosač:	$G_{sek.nosač} = L \cdot g_{sek.nosač} = 12 \cdot 0,78 = 9,36 \text{ kN}$
Fasada:	$G_{fasada} = L \cdot g_{fasada} = 6 \cdot 2,2 = 13,2 \text{ kN}$
Stupovi:	$G_{stup} = h \cdot g_{stup} = 4,4 \cdot 4,63 = 20,37 \text{ kN}$

Opterećenje stupa prizemlja:

$$N_{G,k} = n \cdot (G_{sek.} + G_{gl.}) + (n + 3) \cdot (G_{stup} + G_{fasada}) + (n - 1) \cdot (G_{med.kon.} + G_{preg.}) + G_{krov}$$

$$N_{G,k} = 38 \cdot (9,36 + 12,72) + 40 \cdot (20,37 + 13,2) + 37 \cdot (203,4 + 25,2) + 196,2 = 10836 \text{ kN}$$

$$N_{Q,k} = (n - 1) \cdot Q_{etaža} + Q_{krov} + \psi_1 S_k = 37 \cdot 108 + 21,6 + 0,5 \cdot 11,52 = 4023 \text{ kN}$$

$$N_{Ed} = \gamma_g \cdot N_{G,k} + \gamma_q \cdot N_{Q,k} = 1,35 \cdot 10836 + 1,5 \cdot 4023 = 14859 \text{ kN}$$

Kritična sila:  $N_{cr,z} = 71771 \text{ kN}$

Svedena vitkost:  $\lambda_z = 0,587$

Pomoćni faktor:  $\Phi_z = 0,767$

Faktor redukcije:  $\chi_z = 0,793$

Otpornost na izvijanje:  $N_{bz,Rd} = 19634 \text{ kN}$

$$N_{bz,Rd} = 19634 \text{ kN} > 14859 \text{ kN}$$

ODABRANO: HD 400 x 463

## 3.1.5.5. Stup jezgre

Vlastita težina stupa (HD 400x1299+ HL920x725):	20,24 kN/m
Površina međukatna:	$12 \times 6 + 6 \times 6 = 108 \text{ m}^2$
Površina Krov:	$12 \times 12 = 144 \text{ m}^2$
Snijeg:	$S_{sk} = A \cdot s_k = 144 \cdot 0,32 = 46,08 \text{ kN}$
Uporabno opterećenje krova:	$Q_{krov} = A \cdot q_{krov} = 144 \cdot 0,6 = 86,4 \text{ kN}$
Uporabno opterećenje etaže:	$Q_{etaža} = A \cdot q_{etaža} = 108 \cdot 3,0 = 324 \text{ kN}$
Međukatna konstrukcija:	$G_{med.kon.} = A \cdot g_{med.kon.} = 108 \cdot 5,65 = 610,2 \text{ kN}$
Krovna konstrukcija:	$G_{krov} = A \cdot g_{krov} = 144 \cdot 5,45 = 784,8 \text{ kN}$
Pregradni zidovi:	$G_{preg.} = A \cdot g_{preg.} = 108 \cdot 0,7 = 75,6 \text{ kN}$
Glavni nosač:	$G_{gl.nosač} = L \cdot g_{gl.nosač} = 24 \cdot 2,12 = 50,88 \text{ kN}$
Sekundarni nosač:	$G_{sek.nosač} = L \cdot g_{sek.nosač} = 36 \cdot 1,84 = 66,24 \text{ kN}$
Stupovi:	$G_{stup} = h \cdot g_{stup} = 4,4 \cdot 20,24 = 89,06 \text{ kN}$

Opterećenje stupa prizemlja:

$$N_{G,k} = n \cdot (G_{sek.} + G_{gl.}) + (n + 3) \cdot (G_{stup}) + (n - 1) \cdot (G_{med.kon.} + G_{preg.}) + G_{krov}$$

$$N_{G,k} = 38 \cdot (66,24 + 50,88) + 40 \cdot (89,06) + 37 \cdot (610,2 + 75,6) + 784,8 = 34172 \text{ kN}$$

$$N_{Q,k} = (n - 1) \cdot Q_{etaža} + Q_{krov} + \psi_i S_k = 37 \cdot 324 + 86,4 + 0,5 \cdot 46,08 = 12097 \text{ kN}$$

$$N_{Ed} = \gamma_g \cdot N_{G,k} + \gamma_q \cdot N_{Q,k} = 1,35 \cdot 34172 + 1,5 \cdot 12097 = 64278 \text{ kN}$$

Kritična sila:  $N_{cr,y} = 907626 \text{ kN}$ Svedena vitkost:  $\lambda_z = 0,345$ Pomoćni faktor:  $\Phi_z = 0,730$ Faktor redukcije:  $\chi_z = 0,728$ Otpornost na izvijanje:  $N_{bz,Rd} = 78813 \text{ kN}$ 

$$N_{bz,Rd} = 78813 \text{ kN} > 64278 \text{ kN}$$

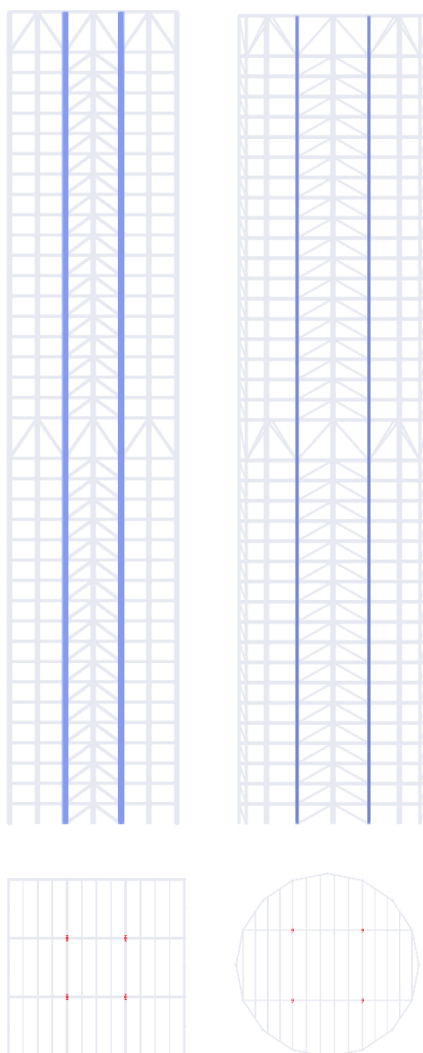
ODABRANO: HD 400x1299+ HL920x725

## 4. MODELIRANJE KONSTRUKCIJE I ANALIZA REZULTATA

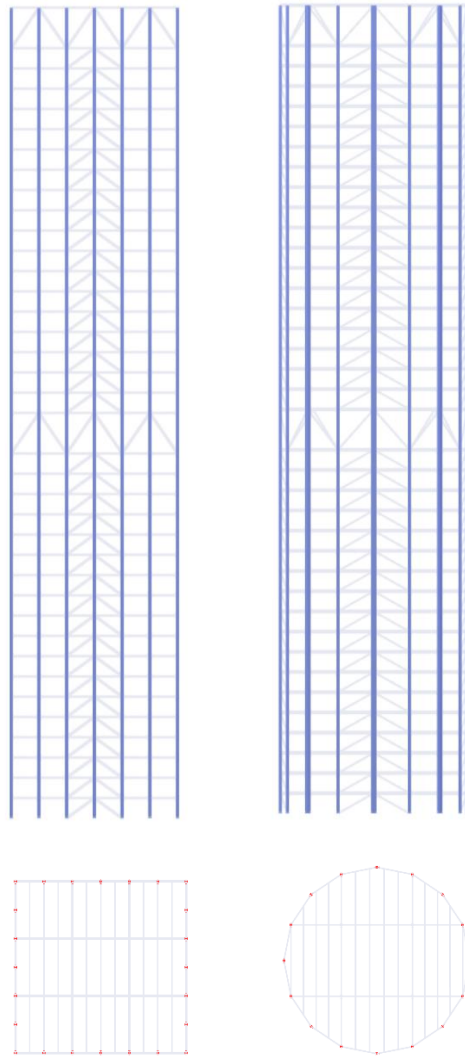
### 4.1. Modeliranje konstrukcije

#### Stupovi

Stupovi su modelirani po etažama, visine 4,4 metara. Oblikovani su korištenjem tipa elementa Beam. Elementi su kontinuirani i prenose sva opterećenja. Na slikama 24 i 25 su prikazani položaji stupova u zgradama.



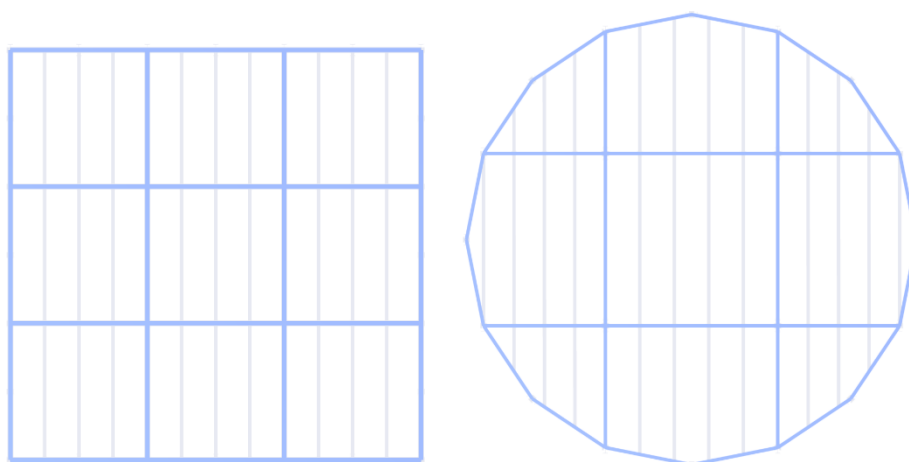
Slika 24. Položaji stupova jezgri



Slika 25. Položaji obodnih stupova

### Glavni nosači

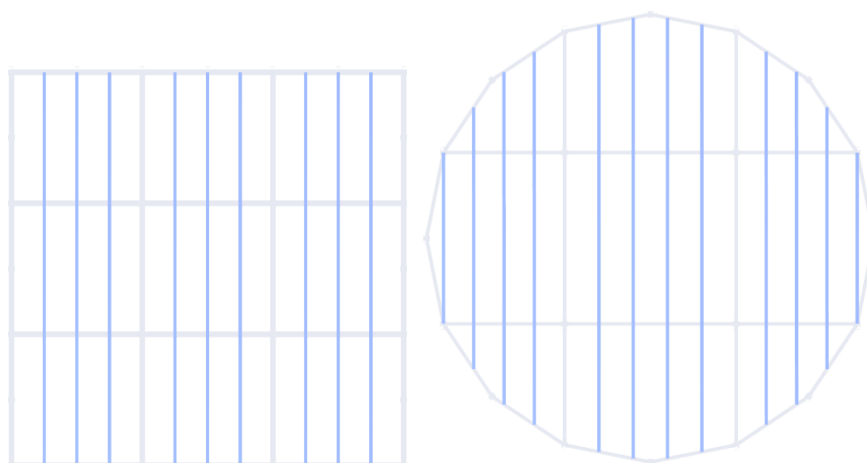
Glavni nosači su oblikovani korištenjem elementa tipa Beam. Spajaju obodne stupove po obodu, stupove posmične jezgre te obodne stupove sa stupovima jezgre. Elementi su kontinuirani i prenose sva opterećenja. Položaji glavnih nosača u tlocrtu prikazani su na slici 26.



Slika 26. Položaji glavnih nosača

### Sekundarni nosači

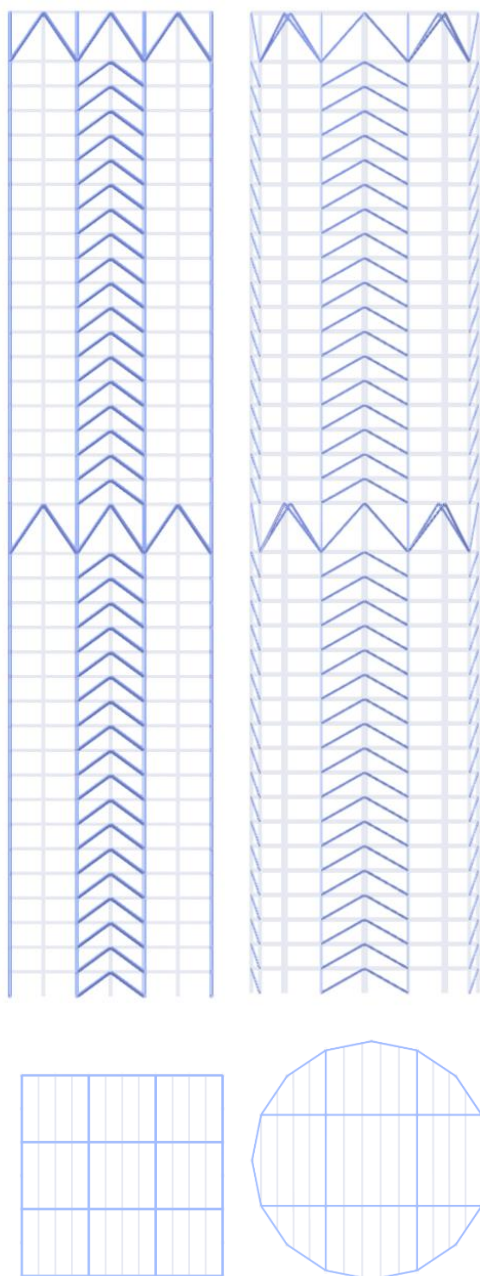
Postavljeni su u jednom smjeru, te su oblikovani kao proste grede, korištenjem elemenata tipa Beam sa otpuštenim momentima na krajevima korištenjem opcije Hinges. Položaji sekundarnih nosača prikazani su na slici 27.



Slika 27. Položaji sekundarnih nosača

### Stabilizacijske dijagonale

Stabilizacijske dijagonale oblikovane su korištenjem elemenata tipa Truss, tj. elementi prenose samo uzdužnu silu. Položaji dijagonala prikazani su na slici 28.



**Slika 28. Položaji stabilizacijskih dijagonala**

## Međukatna konstrukcija

Međukatna konstrukcija oblikovana je korištenjem krutosti ekvivalentne betonske ploče dobivene preliminarnim dimenzioniranjem, uz zanemarivanje čeličnog lima. Ploča je oblikovana bez vlastite težine. Razlog korištenja ekvivalentne betonske ploče je dobivanje približne vrijednosti ponašanja stvarne ploče. Oblikovanjem stropne ploče kao *Rigid diaphragm* nisu se postizale dobre vrijednosti prijenosa sila na glavne i sekundarne nosače, dok se korištenjem opcije *Load transfer* nisu dobivale realistične vrijednosti pomaka elemenata.

## Kombinacije opterećenja

Na slici 29 su prikazane zadane kombinacije opterećenja s pripadnim faktorima

Load Combin.	Name	To Solve	Analysis Type	Static Analysis Settings	Design Situation	LC1		LC2		LC3		LC4		LC5	
						Factor	No.	Factor	No.	Factor	No.	Factor	No.	Factor	No.
C01	Stalno+ uporabno	<input checked="" type="checkbox"/>	Static Analysis	SA2 - Second-order (P-Δ)   Newt...	ULS D51 - ULS (STR/GEO) - Perma...	1.35	G, LC1	1.35	G, LC2	1.50	Q, LC3				
C02	Vjetar x dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA2 - Second-order (P-Δ)   Newt...	ULS D51 - ULS (STR/GEO) - Perma...	1.35	G, LC1	1.35	G, LC2	1.05	Q, LC3	1.50	Qw, LC4	0.75	Q, LC9
C03	Vjetar x, snijeg dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA2 - Second-order (P-Δ)   Newt...	ULS D51 - ULS (STR/GEO) - Perma...	1.35	G, LC1	1.35	G, LC2	1.05	Q, LC3	0.90	Qw, LC4	1.50	Q, LC9
C04	Vjetar x, uporabno dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA2 - Second-order (P-Δ)   Newt...	ULS D51 - ULS (STR/GEO) - Perma...	1.35	G, LC1	1.35	G, LC2	1.50	Q, LC3	0.90	Qw, LC4	0.75	Q, LC9
C05	Vjetar y dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA2 - Second-order (P-Δ)   Newt...	ULS D51 - ULS (STR/GEO) - Perma...	1.35	G, LC1	1.35	G, LC2	1.05	Q, LC3	1.50	Qw, LC5	0.75	Q, LC9
C06	Vjetar y, snijeg dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA2 - Second-order (P-Δ)   Newt...	ULS D51 - ULS (STR/GEO) - Perma...	1.35	G, LC1	1.35	G, LC2	1.05	Q, LC3	0.90	Qw, LC5	1.50	Q, LC9
C07	Vjetar y, uporabno dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA2 - Second-order (P-Δ)   Newt...	ULS D51 - ULS (STR/GEO) - Perma...	1.35	G, LC1	1.35	G, LC2	1.50	Q, LC3	0.90	Qw, LC5	0.75	Q, LC9
C08	Vjetar x dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA1 - Geometrically linear	SLS D52 - SLS - Characteristic	1.00	G, LC1	1.00	G, LC2	0.70	Q, LC3	1.00	Qw, LC4	0.50	Q, LC9
C09	Vjetar x, snijeg dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA1 - Geometrically linear	SLS D52 - SLS - Characteristic	1.00	G, LC1	1.00	G, LC2	0.70	Q, LC3	0.60	Qw, LC4	1.00	Q, LC9
C010	Vjetar x, uporabno dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA1 - Geometrically linear	SLS D52 - SLS - Characteristic	1.00	G, LC1	1.00	G, LC2	1.00	Q, LC3	0.60	Qw, LC4	0.50	Q, LC9
C011	Vjetar y dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA1 - Geometrically linear	SLS D52 - SLS - Characteristic	1.00	G, LC1	1.00	G, LC2	0.70	Q, LC3	1.00	Qw, LC5	0.50	Q, LC9
C012	Vjetar y, snijeg dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA1 - Geometrically linear	SLS D52 - SLS - Characteristic	1.00	G, LC1	1.00	G, LC2	0.70	Q, LC3	0.60	Qw, LC5	1.00	Q, LC9
C013	Vjetar y, uporabno dominantno	<input checked="" type="checkbox"/>	Static Analysis	SA1 - Geometrically linear	SLS D52 - SLS - Characteristic	1.00	G, LC1	1.00	G, LC2	1.00	Q, LC3	0.60	Qw, LC5	0.50	Q, LC9
C014	Masa za proračun inercijskih sila	<input checked="" type="checkbox"/>	Static Analysis	SA1 - Geometrically linear	EMS D55 - Seismic/Mass Combina...	1.00	G, LC1	1.00	G, LC2	0.30	Q, LC3				

Slika 29. Kombinacije opterećenja



## Zgrada kvadratnog tlocrta

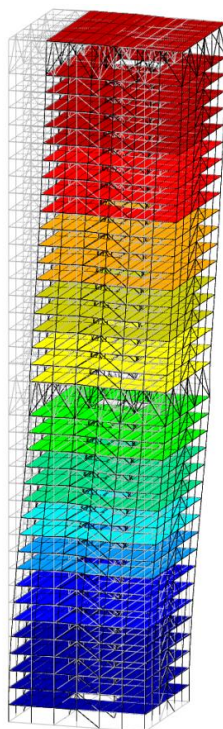
### Klasifikacija čelične konstrukcije

Provedena je analiza stabilnosti za sve kombinacije graničnog stanja nosivosti i u tablici 13 su prikazane dobivene vrijednosti  $\alpha_{cr}$ :

Tablica 13.: Vrijednosti za pojedine kombinacije

Kombinacija	$\alpha_{cr}$	Mod
C01	14.23	5
C02	15.359	12
C03	15.402	9
C04	14.250	9
C05	15.193	7
C06	15.343	7
C07	14.202	8

Na slici 30 je prikazan mjerodavni mod za kombinaciju C01.



Slika 30. 5. mod za kombinaciju C01

Uvjet za uzimanje u obzir učinke 2. reda:

$$\alpha_{cr,sw} = \frac{F_{cr,sw}}{F_d} \geq 10$$

Kako mjerodavni faktor iznosi  $>10$ , konstrukcija je nepomična i u proračunu nije potrebno uzeti u obzir učinke 2. reda. Ovdje su se ipak uzeli u obzir.

### **Zgrada okruglog tlocrta**

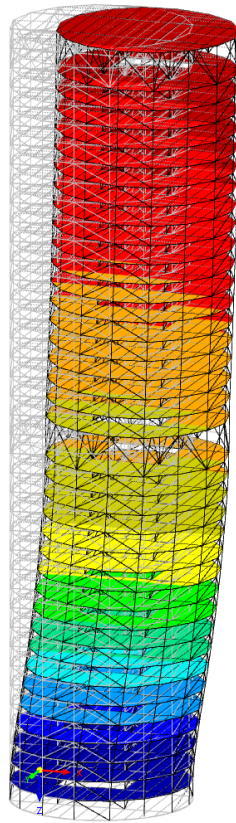
#### **Klasifikacija čelične konstrukcije**

Provedena je analiza stabilnosti za sve kombinacije graničnog stanja nosivosti i dobivene su slijedeće vrijednosti  $\alpha_{cr}$ , prikazane u tablici 14.

**Tablica 14.: Kritični koeficijenti za pojedine kombinacije**

Kombinacija	$\alpha_{cr}$	Mod
C01	8.328	1
C02	8.949	1
C03	8.960	1
C04	8.303	1
C05	8.902	1
C06	8.942	1
C07	8.288	1

Na slici 31 je prikazan oblik izvijanja za kritičnu kombinaciju C07. Kako je  $\alpha_{cr}$  mjerodavne kombinacije  $<10$ , u obzir se moraju uzeti učinci 2. reda



Slika 31. Oblik izvijanja za 1. mod kombinacije C07

### Imperfekcije okvira

Imperfekcije ovira zadaju se u softwareu na temelju početnog kuta zaokreta. Primjer načina zadavanja i imperfekcije zadane na grupe elemenata prikazani su na slici 32.

Main

**Categories**

Imperfection type  
Initial Sway

Definition type  
EN 1993-1-1

Coordinate system  
1 - Global XYZ

Imperfection direction  
X<sub>L</sub>

**Options**

Reference to list of members

**Parameters**

Basic value  
Φ<sub>0</sub> 1/ 200.000 [-]

Structure height  
h 176.000 [m]

Number of columns in one row  
m 7

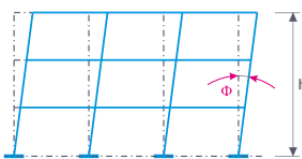
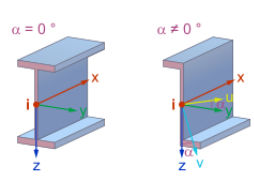
Reduction factors  
α<sub>h</sub> 0.667 [-]  
α<sub>m</sub> 0.756 [-]

Initial sway  
φ 1/ 396.863 [-]  
φ 0.003 [-]

Imperfection Type 'Initial Sway'  
Definition Type 'EN 1993-1-1'

$$\Phi = \Phi_0 \cdot \alpha_h \cdot \alpha_m$$

$$\alpha_h = \frac{2}{\sqrt{h}} \begin{matrix} \geq \frac{2}{3} \\ \leq 1,0 \end{matrix}$$

$$\alpha_m = \sqrt{0,5 \left(1 + \frac{1}{m}\right)}$$



Comment

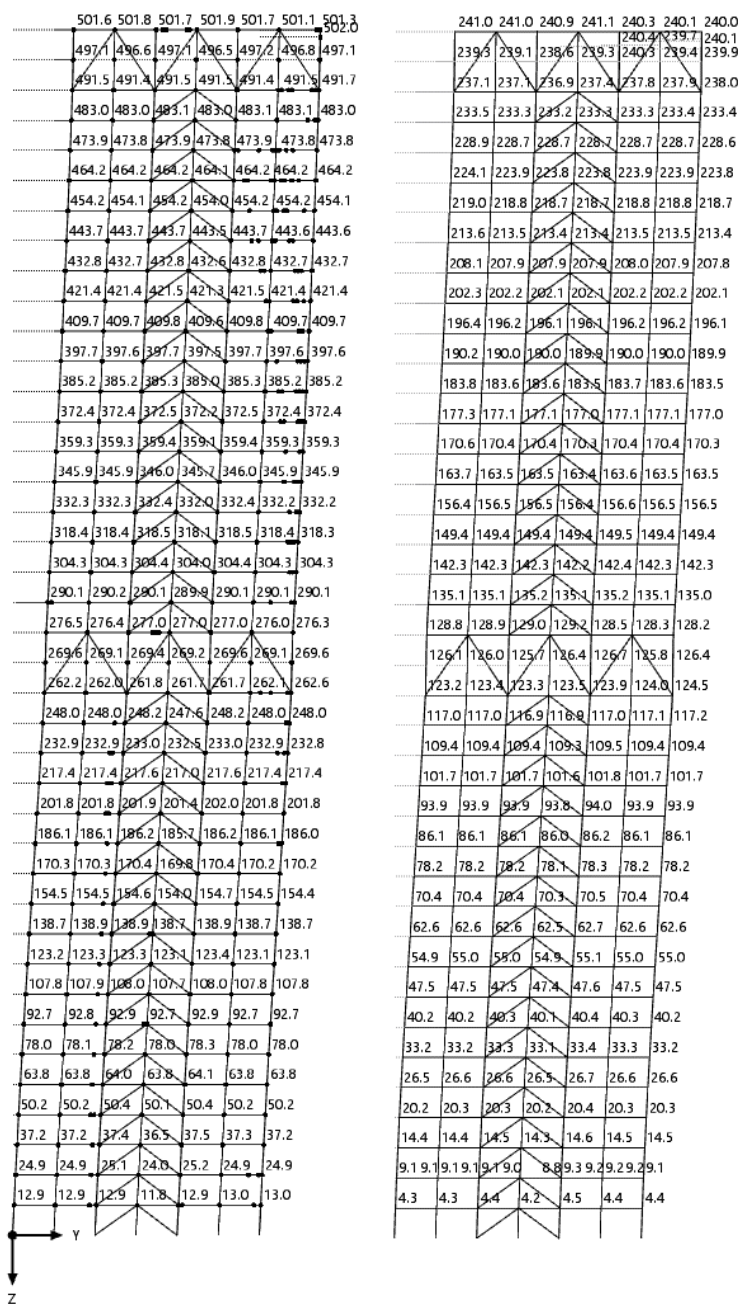
No.	Assigned to Member Sets No.	Imperfection Type	Definition Type	Coordinate System	Direction
1	1-7,21-27	Initial Sway	EN 1993-1-1	1 - Global XYZ	X <sub>L</sub>
2	8,9,13,14,19,20	Initial Sway	EN 1993-1-1	1 - Global XYZ	X <sub>L</sub>
3	10-12,15-18,28	Initial Sway	EN 1993-1-1	1 - Global XYZ	X <sub>L</sub>
4	1,7-10,13-15,18-21,27,28	Initial Sway	EN 1993-1-1	1 - Global XYZ	Y <sub>L</sub>
5	2,4,6,22,24,26	Initial Sway	EN 1993-1-1	1 - Global XYZ	Y <sub>L</sub>
6	3,5,11,12,16,17,23,25	Initial Sway	EN 1993-1-1	1 - Global XYZ	Y <sub>L</sub>

Slika 32. Zadavanje imperfekcija na konstrukciju

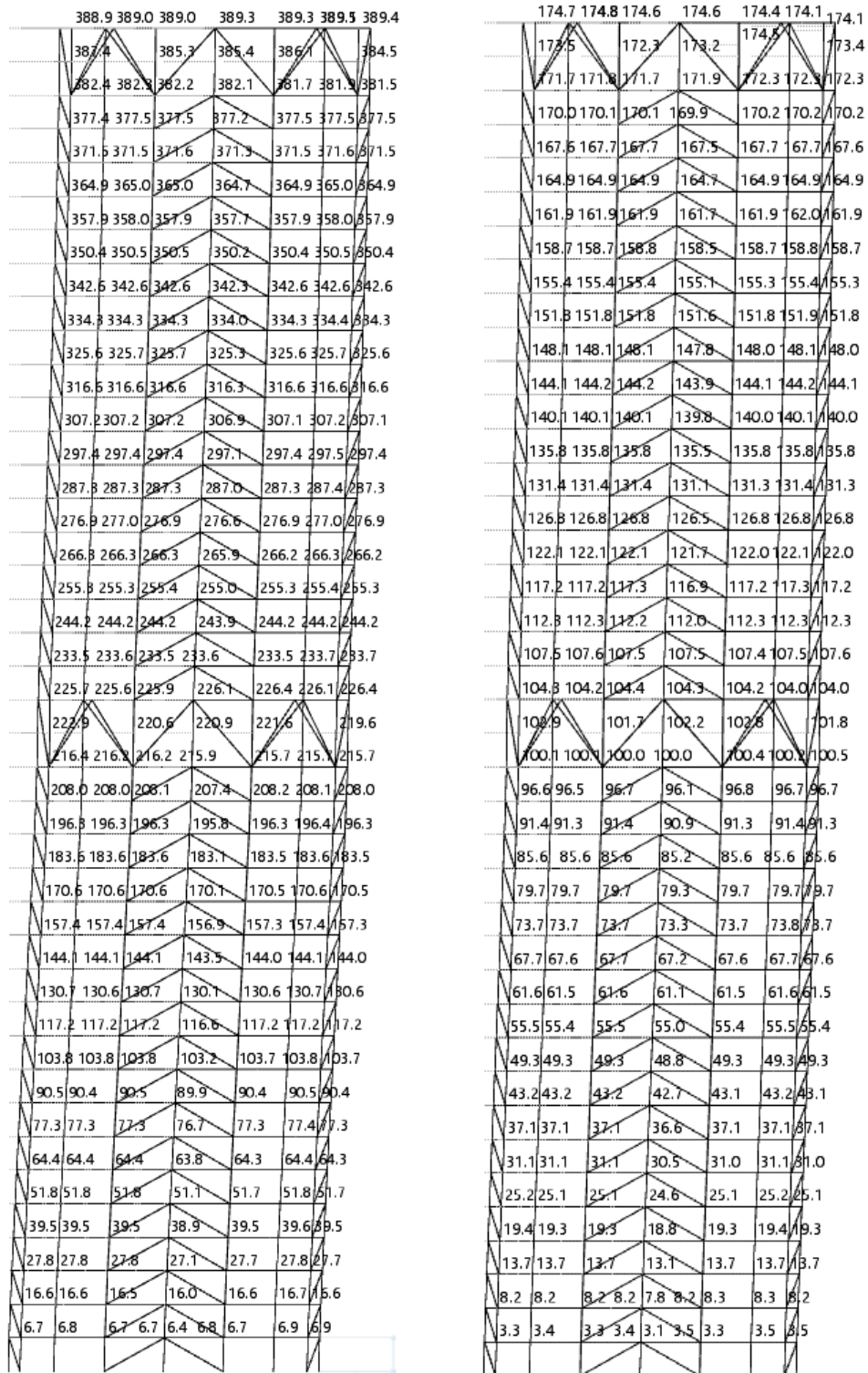
### 4.2. Rezultati analize konstrukcije

Korištenjem elemenata dobivenih preliminarnim dimenzioniranjem nisu se postigle zadovoljavajuće vrijednosti pomaka konstrukcije za granično stanje uporabljivosti koje iznosi  $u=H/500=352$  mm, što je vidljivo na slikama 33 i 34.

Poprečni presjeci povećavali su se do zadovoljavajućih vrijednosti. Nove vrijednosti elemenata prikazane su u tablicama 15 i 16.



Slika 33. Pomaci zgrade kvadratnog tlocrta prije i nakon promjene veličine elemenata



Slika 34. Pomaci zgrade okruglog tlocrta prije i nakon promjene veličina elemenata

Tablica 15.: Nove veličine elemenata zgrade kvadratnog tlocrta

	Preliminarno dimenzioniranje	Nakon povećanja elemenata
Stupovi jezgre	HD 400x1299 + HL 920x725	HD 400x1299 + HL 920x1377
Obodni stupovi	HD 400x463	HD 400x1299 + HL 920x344
Glavni nosači	HEB 600	HD 400x314

Tablica 16.: Nove veličine elemenata zgrade okruglog tlocrta

	Preliminarno dimenzioniranje	Nakon promjene elemenata
Stupovi jezgre	HD 400x1299 + HL 920x725	HD 400x1299 + HL 920x656
Obodni stupovi	HD 400x463	HD 400x1299 + HL 920x344
Glavni nosači	HEB 600	HEM 600

## Rezultati dinamičke analize

Dinamička analiza proveda se softverski uz koeficijent ponašanja  $q = 1,5$

### Zgrada kvadratnog tlocrta

Vrijednosti dobivenih prirodnih perioda i frekvencija konstrukcije za prvih 10 modova prikazane su u tablici 17, a efektivne modalne mase u tablici 18.

**Tablica 17.: Vlastite frekvencije i period za prvih 10 modova**

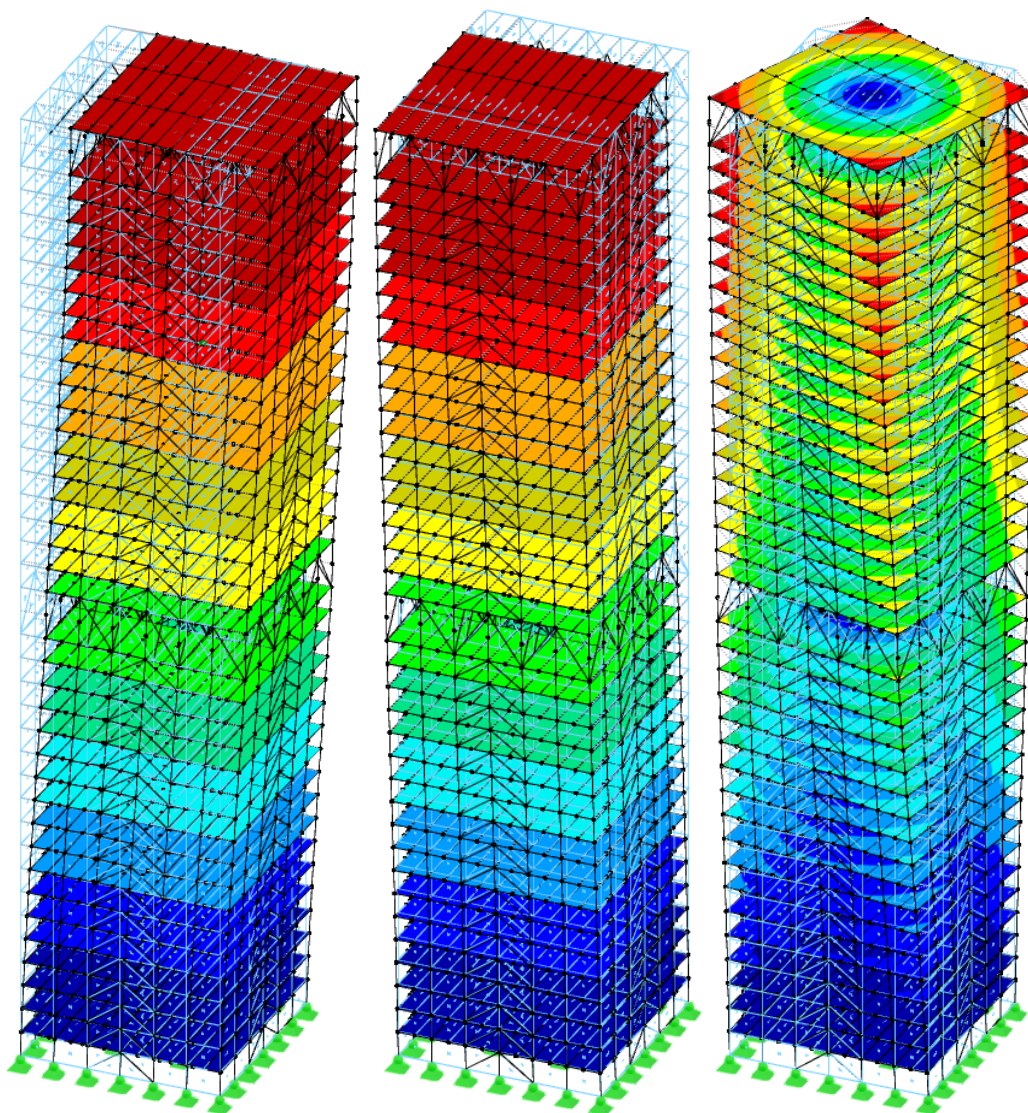
Mod	Vlastita frekvencija $\omega$ [rad/s]	Vlastita frekvencija f [Hz]	Vlastiti period T [s]
1	1.325	0.211	4.743
2	1.343	0.214	4.678
3	1.752	0.279	3.586
4	4.260	0.678	1.475
5	4.305	0.685	1.459
6	5.388	0.858	1.166
7	8.256	1.314	0.761
8	8.337	1.327	0.754
9	9.861	1.569	0.637
10	11.944	1.901	0.526

**Tablica 18.: Efektivne modalne mase za prvih 10 modova**

Mod	Modalna masa	Efektivna modalna masa - Translacija [kg]			Efektivna modalna masa - Rotacija [kgm <sup>2</sup> ]		
	Mi [kg]	meX	meY	meZ	me $\phi$ X	me $\phi$ Y	me $\phi$ Z
1	16555016.6	32814972	85.5	0.1	76495.15	29160945664.00	11571.66
2	16727131.4	86.6	32953780.0	0.0	28815951872.00	73706.06	2.00
3	8235229.7	66.8	0.0	0.0	148.05	10982.91	9550502912.00
4	18624551.7	6366534.0	22.6	0.1	173094.09	51056496640.00	31166.87
5	18536085.7	21.2	6260259.0	0.0	51613609984.00	175661.08	73.20
6	8176617.4	52.9	0.5	0.0	12534.66	811306.25	1352276864.00
7	18993811.1	2103074.8	0.5	1.7	2569.00	12861393920.00	438.45
8	18938480.3	0.6	2091869.9	0.0	12839680000.00	4148.17	247.03
9	8158788.9	6.1	0.4	0.0	360.95	66178.89	553594816.00
10	20919403.5	864869.3	1.7	270.3	17516.68	7147361280.00	86672.25
$\Sigma$	153865116.2	42149680.	41306016.	272.2	93269524480.0	100227334144.0	11456503808.0
$\Sigma M$		44106756.	44106756.	44106756.	118615883776.0	118407217152.0	12228610048.0
%		95.56	93.65	0.00	78.63	84.65	93.69



Oblici titranja prikazani su na slikama 35 i 36 za prva tri moda odziva.



Slika 35. Oblici titranja za prva tri moda odziva zgrade kvadratnog tlocrta

#### Zgrada okruglog tlocrta

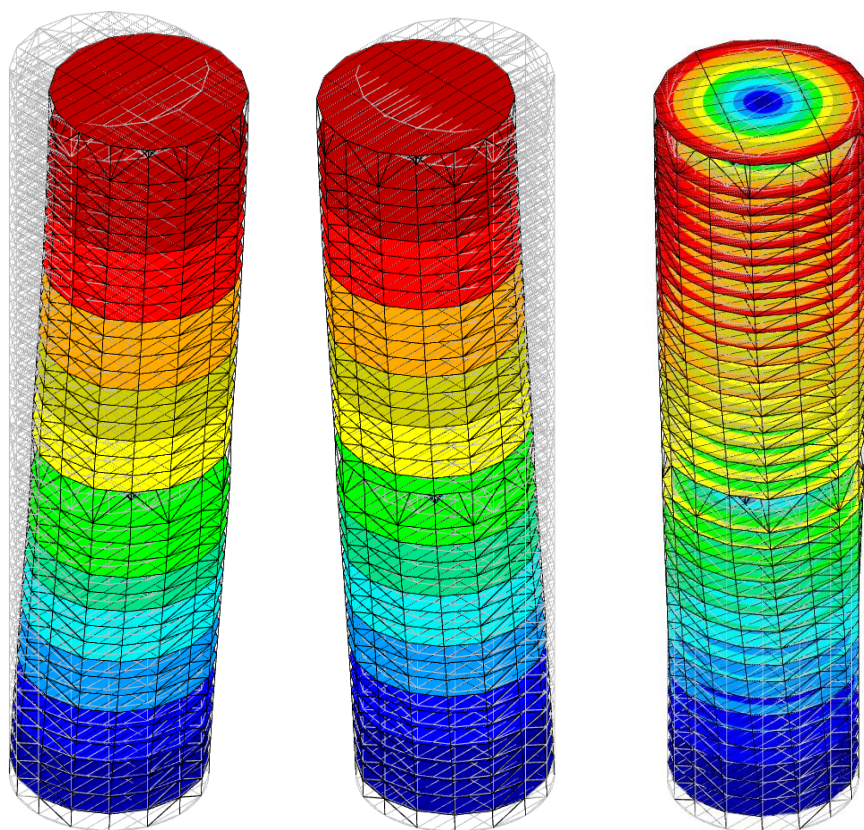
Vrijednosti dobivenih prirodnih perioda i frekvencija konstrukcije za prvih 10 modova prikazane su u tablici 19, a efektivne modalne mase u tablici 20.

Tablica 19.: Vlastite frekvencije i period za prvih 10 modova

Mod	Vlastita frekvencija	Vlastita frekvencija	Vlastiti period
	$\omega$ [rad/s]	f [Hz]	T [s]
1	1.193	0.190	5.265
2	1.446	0.230	4.344
3	2.085	0.332	3.014
4	3.694	0.588	1.701
5	4.621	0.735	1.360
6	6.363	1.013	0.987
7	7.064	1.124	0.889
8	8.866	1.411	0.709
9	9.939	1.582	0.632
10	11.408	1.816	0.551

Tablica 20.: Efektivne modalne mase za prvih 10 modova

Mod	Modalna masa Mi [kg]	Efektivna modalna masa - Translacija [kg]			Efektivna modalna masa - Rotacija [kgm <sup>2</sup> ]		
		meX	meY	meZ	me $\phi$ X	me $\phi$ Y	me $\phi$ Z
1	16915487,7	32144926	1,2	0,0	1073,43	25132081152,00	26,05
2	15750007,6	1,3	31356610,0	0,0	27548469248,00	917,55	180,15
3	12698360,0	0,1	0,7	0,0	486,53	8,07	9187883008,00
4	17615157,4	5028448,0	0,2	0,0	961,70	51148312576,00	10,58
5	17627266,9	0,1	6093059,5	0,0	51250876416,00	1408,50	28,18
6	12629866,1	0,0	0,1	0,1	1291,32	346,15	1232251776,00
7	16458971,7	1873142,9	0,0	0,0	232,21	11859741696,00	11,80
8	18484587,6	0,0	1836911,6	0,0	11069564928,00	106,65	13,64
9	17435762,6	661143,9	0,0	0,0	77,74	5667765760,00	0,21
10	12427941,8	0,0	0,0	0,2	155,99	4,71	489754752,00
$\Sigma$	158043409	39707664	39286584,0	0,3	89868910592,00	93807902720,00	10909889536,0
$\Sigma M$		41883568	41883568,0	41883568	112849117184,0	112952918016,0	11638124544,0
%		94,80	93,80	0,00	79,64	83,05	93,74



Slika 36. Oblici titranja za prva tri moda odziva zgrade okruglog tlocrta

#### Klasifikacija konstrukcije za proračunsku potresnu situaciju

U tablicama 21 i 22 su dane vrijednosti koeficijenta  $\theta$  za proračunsku potresnu situaciju 475-godišnjeg potresa.

Prema EN 1998, učinci 2- reda ne moraju se uzeti u obzir ako su vrijednosti koeficijenta  $\theta < 0,1$

$$\theta = \frac{P_{\text{tot}} \cdot d_r}{V_{\text{tot}} \cdot h}$$

Gdje je:

$\theta$  koeficijent osjetljivosti međukatnog pomaka

$P_{\text{tot}}$  gravitacijsko opterećenje na promatranom katu i iznad njega u potresnoj proračunskoj situaciji

$d_r$  proračunski katni pomak

$V_{\text{tot}}$  ukupna katna potresna poprečna sila

## H visina etaže

**Tablica 21.: Koeficijenti osjetljivosti i međukatni pomaci za potresnu situaciju 475-godišnjeg potresa zgrade kvadratnog tlocrta**

Etaža	Visina etaže $\Delta Z$ [m]	Etažne sile		Kumulativna masa		Međukatni pomak		Koeficijent osjetljivosti	
		FX [kN]	FY [kN]	$M_{x,c}$ [t]	$M_{y,c}$ [t]	$d_rX$ [mm]	$d_rY$ [mm]	$\Phi X$ [--]	$\Phi Y$ [--]
	8.800	2220	-1916	1407	1407	4.8	4.9	0.003	0.004
		-2220	1916	1407	1407	-4.8	-4.9	0.003	0.004
36	4.400	4042	-3522	2648	2648	6.4	6.0	0.010	0.010
		-4042	3522	2648	2648	-6.4	-6.0	0.010	0.010
35	4.400	5551	-4916	3828	3828	7.3	6.9	0.011	0.012
		-5551	4916	3828	3828	-7.3	-6.9	0.011	0.012
34	4.400	6807	-6153	5008	5008	7.6	7.4	0.013	0.014
		-6807	6153	5008	5008	-7.6	-7.4	0.013	0.014
33	4.400	7806	-7224	6187	6187	8.0	7.7	0.014	0.015
		-7806	7224	6187	6187	-8.0	-7.7	0.014	0.015
32	4.400	8570	-8127	7367	7367	8.3	8.1	0.016	0.017
		-8570	8127	7367	7367	-8.3	-8.1	0.016	0.017
31	4.400	9142	-8870	8547	8547	8.7	8.4	0.018	0.018
		-9142	8870	8547	8547	-8.7	-8.4	0.018	0.018
30	4.400	9581	-9471	9726	9726	8.9	8.7	0.021	0.020
		-9581	9471	9726	9726	-8.9	-8.7	0.021	0.020
29	4.400	9954	-9954	10906	10906	9.2	8.9	0.023	0.022
		-9954	9954	10906	10906	-9.2	-8.9	0.023	0.022
28	4.400	10321	-10351	12086	12086	9.4	9.1	0.025	0.024
		-10321	10351	12086	12086	-9.4	-9.1	0.025	0.024
27	4.400	10725	-10696	13266	13266	9.7	9.3	0.027	0.026
		-10725	10696	13266	13266	-9.7	-9.3	0.027	0.026
26	4.400	11179	-11022	14445	14445	9.8	9.5	0.029	0.028
		-11179	11022	14445	14445	-9.8	-9.5	0.029	0.028
25	4.400	11673	-11358	15625	15625	10.0	9.7	0.030	0.030
		-11673	11358	15625	15625	-10.0	-9.7	0.030	0.030
24	4.400	12185	-11723	16805	16805	10.1	9.8	0.032	0.032
		-12185	11723	16805	16805	-10.1	-9.8	0.032	0.032
23	4.400	12680	-12125	17984	17984	10.5	9.9	0.034	0.033
		-12680	12125	17984	17984	-10.5	-9.9	0.034	0.033
22	4.400	13103	-12560	19162	19162	10.3	9.9	0.034	0.034
		-13103	12560	19162	19162	-10.3	-9.9	0.034	0.034
21	4.400	13475	-13018	20342	20342	10.2	9.9	0.035	0.035
		-13475	13018	20342	20342	-10.2	-9.9	0.035	0.035
20	4.400	13807	-13480	21522	21522	10.2	9.8	0.036	0.035

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		-13807	13480	21522	21522	-10.2	-9.8	0.036	0.035
19	4.400	14109	-13931	22702	22702	9.1	8.5	0.033	0.032
		-14109	13931	22702	22702	-9.1	-8.5	0.033	0.032
18	8.800	14497	-14470	24167	24167	6.9	7.4	0.013	0.014
		-14497	14470	24167	24167	-6.9	-7.4	0.013	0.014
17	4.400	14880	-14912	25408	25408	9.1	8.6	0.035	0.033
		-14880	14912	25408	25408	-9.1	-8.6	0.035	0.033
16	4.400	15258	-15289	26587	26587	10.3	9.9	0.041	0.039
		-15258	15289	26587	26587	-10.3	-9.9	0.041	0.039
15	4.400	15630	-15613	27767	27767	10.4	10.1	0.042	0.041
		-15630	15613	27767	27767	-10.4	-10.1	0.042	0.041
14	4.400	15985	-15892	28947	28947	10.4	10.2	0.043	0.042
		-15985	15892	28947	28947	-10.4	-10.2	0.043	0.042
13	4.400	16311	-16141	30127	30127	10.4	10.2	0.044	0.043
		-16311	16141	30127	30127	-10.4	-10.2	0.044	0.043
12	4.400	16604	-16382	31306	31306	10.4	10.2	0.045	0.044
		-16604	16382	31306	31306	-10.4	-10.2	0.045	0.044
11	4.400	16870	-16635	32486	32486	10.3	10.1	0.045	0.045
		-16870	16635	32486	32486	-10.3	-10.1	0.045	0.045
10	4.400	17126	-16922	33666	33666	10.1	9.9	0.045	0.045
		-17126	16922	33666	33666	-10.1	-9.9	0.045	0.045
9	4.400	17395	-17255	34846	34846	9.9	9.7	0.045	0.045
		-17395	17255	34846	34846	-9.9	-9.7	0.045	0.045
8	4.400	17701	-17636	36025	36025	9.6	9.5	0.045	0.044
		-17701	17636	36025	36025	-9.6	-9.5	0.045	0.044
7	4.400	18061	-18059	37205	37205	9.3	9.2	0.044	0.043
		-18061	18059	37205	37205	-9.3	-9.2	0.044	0.043
6	4.400	18480	-18506	38385	38385	9.0	8.9	0.042	0.042
		-18480	18506	38385	38385	-9.0	-8.9	0.042	0.042
5	4.400	18941	-18953	39564	39564	8.5	8.5	0.041	0.040
		-18941	18953	39564	39564	-8.5	-8.5	0.041	0.040
4	4.400	19415	-19373	40744	40744	8.1	8.0	0.038	0.038
		-19415	19373	40744	40744	-8.1	-8.0	0.038	0.038
3	4.400	19861	-19739	41924	41924	7.5	7.4	0.036	0.036
		-19861	19739	41924	41924	-7.5	-7.4	0.036	0.036
2	4.400	20234	-20029	43104	43104	6.9	6.8	0.033	0.033
		-20234	20029	43104	43104	-6.9	-6.8	0.033	0.033
1	4.400	20499	-20225	44283	44283	6.1	6.0	0.030	0.030
		-20499	20225	44283	44283	-6.1	-6.0	0.030	0.030
0	4.400	20630	-20320	45469	45469	5.5	5.5	0.028	0.028
		-20630	20320	45469	45469	-5.5	-5.5	0.028	0.028

**Tablica 22.: Koeficijenti osjetljivosti i međukatni pomaci za potresnu situaciju 475-godišnjeg potresa zgrade okruglog tlocrta**

Etaža	Visina etaže $\Delta Z$ [m]	Etažne sile		Kumulativna masa		Međukatni pomak		Koeficijent osjetljivosti	
		FX [kN]	FY [kN]	M <sub>x,c</sub> [t]	M <sub>y,c</sub> [t]	d <sub>r</sub> X [mm]	d <sub>r</sub> Y [mm]	$\phi_X$ [--]	$\phi_Y$ [--]
37	8.800	1313	-1374	1327	1327	8.1	7.8	0.009	0.009
		-1313	1374	1327	1327	-8.1	-7.8	0.009	0.009
36	4.400	2383	-2488	2459	2459	6.0	6.1	0.014	0.014
		-2383	2488	2459	2459	-6.0	-6.1	0.014	0.014
35	4.400	3347	-3492	3537	3537	8.1	7.1	0.020	0.016
		-3347	3492	3537	3537	-8.1	-7.1	0.020	0.016
34	4.400	4233	-4428	4614	4614	9.4	7.7	0.023	0.018
		-4233	4428	4614	4614	-9.4	-7.7	0.023	0.018
33	4.400	5031	-5291	5691	5691	10.4	8.3	0.027	0.020
		-5031	5291	5691	5691	-10.4	-8.3	0.027	0.020
32	4.400	5747	-6078	6768	6768	11.2	8.8	0.030	0.022
		-5747	6078	6768	6768	-11.2	-8.8	0.030	0.022
31	4.400	6391	-6790	7845	7845	12.0	9.3	0.034	0.024
		-6391	6790	7845	7845	-12.0	-9.3	0.034	0.024
30	4.400	6981	-7432	8922	8922	12.8	9.8	0.037	0.027
		-6981	7432	8922	8922	-12.8	-9.8	0.037	0.027
29	4.400	7536	-8011	9999	9999	13.6	10.2	0.041	0.029
		-7536	8011	9999	9999	-13.6	-10.2	0.041	0.029
28	4.400	8074	-8539	11076	11076	14.3	10.6	0.045	0.031
		-8074	8539	11076	11076	-14.3	-10.6	0.045	0.031
27	4.400	8606	-9027	12153	12153	15.0	11.0	0.048	0.034
		-8606	9027	12153	12153	-15.0	-11.0	0.048	0.034
26	4.400	9137	-9488	13230	13230	15.7	11.4	0.052	0.036
		-9137	9488	13230	13230	-15.7	-11.4	0.052	0.036
25	4.400	9665	-9933	14307	14307	16.3	11.8	0.055	0.039
		-9665	9933	14307	14307	-16.3	-11.8	0.055	0.039
24	4.400	10183	-10371	15384	15384	16.9	12.1	0.058	0.041
		-10183	10371	15384	15384	-16.9	-12.1	0.058	0.041
23	4.400	10683	-10807	16460	16460	17.5	12.4	0.061	0.043
		-10683	10807	16460	16460	-17.5	-12.4	0.061	0.043
22	4.400	11160	-11242	17537	17537	18.0	12.7	0.064	0.045
		-11160	11242	17537	17537	-18.0	-12.7	0.064	0.045
21	4.400	11610	-11676	18614	18614	18.2	12.9	0.066	0.047
		-11610	11676	18614	18614	-18.2	-12.9	0.066	0.047
20	4.400	12035	-12104	19691	19691	17.2	13.0	0.064	0.048
		-12035	12104	19691	19691	-17.2	-13.0	0.064	0.048
19	4.400	12443	-12524	20769	20769	13.0	12.0	0.049	0.045
		-12443	12524	20769	20769	-13.0	-12.0	0.049	0.045

18	8.800	12934	-13017	22079	22079	18.5	18.0	0.036	0.035
		-12934	13017	22079	22079	-18.5	-18.0	0.036	0.035
17	4.400	13353	-13415	23211	23211	13.7	12.5	0.054	0.049
		-13353	13415	23211	23211	-13.7	-12.5	0.054	0.049
16	4.400	13747	-13773	24289	24289	18.9	13.8	0.076	0.055
		-13747	13773	24289	24289	-18.9	-13.8	0.076	0.055
15	4.400	14125	-14106	25366	25366	20.7	14.1	0.085	0.058
		-14125	14106	25366	25366	-20.7	-14.1	0.085	0.058
14	4.400	14480	-14416	26443	26443	21.3	14.3	0.089	0.060
		-14480	14416	26443	26443	-21.3	-14.3	0.089	0.060
13	4.400	14809	-14706	27520	27520	21.6	14.4	0.091	0.061
		-14809	14706	27520	27520	-21.6	-14.4	0.091	0.061
12	4.400	15112	-14984	28597	28597	21.9	14.5	0.094	0.063
		-15112	14984	28597	28597	-21.9	-14.5	0.094	0.063
11	4.400	15389	-15253	29674	29674	22.0	14.5	0.097	0.064
		-15389	15253	29674	29674	-22.0	-14.5	0.097	0.064
10	4.400	15645	-15520	30751	30751	22.1	14.5	0.099	0.065
		-15645	15520	30751	30751	-22.1	-14.5	0.099	0.065
9	4.400	15884	-15787	31828	31828	22.2	14.5	0.101	0.067
		-15884	15787	31828	31828	-22.2	-14.5	0.101	0.067
8	4.400	16114	-16057	32905	32905	22.2	14.5	0.103	0.068
		-16114	16057	32905	32905	-22.2	-14.5	0.103	0.068
7	4.400	16337	-16327	33982	33982	22.2	14.4	0.105	0.068
		-16337	16327	33982	33982	-22.2	-14.4	0.105	0.068
6	4.400	16556	-16592	35058	35058	22.1	14.3	0.106	0.069
		-16556	16592	35058	35058	-22.1	-14.3	0.106	0.069
5	4.400	16768	-16845	36135	36135	22.0	14.2	0.108	0.069
		-16768	16845	36135	36135	-22.0	-14.2	0.108	0.069
4	4.400	16965	-17077	37212	37212	21.8	14.0	0.108	0.070
		-16965	17077	37212	37212	-21.8	-14.0	0.108	0.070
3	4.400	17137	-17277	38289	38289	21.4	13.8	0.109	0.070
		-17137	17277	38289	38289	-21.4	-13.8	0.109	0.070
2	4.400	17273	-17438	39366	39366	20.9	13.6	0.108	0.070
		-17273	17438	39366	39366	-20.9	-13.6	0.108	0.070
1	4.400	17364	-17550	40443	40443	19.3	13.5	0.102	0.071
		-17364	17550	40443	40443	-19.3	-13.5	0.102	0.071
0	4.400	17405	-17607	41521	41521	16.4	14.6	0.089	0.078
		-17405	17607	41521	41521	-16.4	-14.6	0.089	0.078

Prema tablici 21, vidljivo je da vrijednosti  $\ominus$  ne premašuju vrijednosti od 0,1 te nije potrebno u obzir uzeti učinke 2. reda za zgradu kvadratnog tlocrta. Za zgradu okruglog tlocrta,

vrijednosti prelaze vrijednost od 0,1, ali se u radu učinci 2. reda nisu uzeli u obzir zbog toga što potres nije mjerodavno opterećenje kod visokih zgrada.

### Zahtjev ograničenog oštećenja

Konstrukcija se mora moći oduprijeti djelovanju potresa vjerojatnosti pojave  $T_{dlr} = 95$  god, bez pojave oštećenja i ograničenja uporabe nesrazmjernih s jačinom potresa.

Ograničenje pomaka je

$$d_r \cdot v \leq 0,010h$$

Gdje je:

$d_r$  proračunski katni pomak

$v$  faktor smanjenja, prema nacionalnom dodatku iznosi 1,0

Ograničenje za etaže s potpornim rešetkama:

$$0,010h = 0,010 \cdot 880 = 8,8 \text{ cm}$$

Ograničenje za ostale etaže:

$$0,010h = 0,010 \cdot 440 = 4,4 \text{ cm}$$

U tablicama 23 i 24 je vidljivo da svi međukatni pomaci zadovoljavaju zadane uvjete.

**Tablica 23.: Koeficijenti osjetljivosti i međukatni pomaci za potresnu situaciju 95-godišnjeg potresa zgrade kvadratnog tlocrta**

Etaža	Visina etaže $\Delta Z$ [m]	Etažne sile		Kumulativna masa		Međukatni pomak		Koeficijent osjetljivosti	
		FX [kN]	FY [kN]	$M_{x,c}$ [t]	$M_{y,c}$ [t]	$d_r X$ [mm]	$d_r Y$ [mm]	$\Phi X$ [--]	$\Phi Y$ [--]
37	8.800	1136	-981	1407	1407	2.4	2.5	0.003	0.004
		-1136	981	1407	1407	-2.4	-2.5	0.003	0.004
36	4.400	2068	-1802	2648	2648	3.3	3.1	0.010	0.010
		-2068	1802	2648	2648	-3.3	-3.1	0.010	0.010
35	4.400	2841	-2516	3828	3828	3.7	3.5	0.011	0.012
		-2841	2516	3828	3828	-3.7	-3.5	0.011	0.012
34	4.400	3483	-3149	5008	5008	3.9	3.8	0.013	0.014
		-3483	3149	5008	5008	-3.9	-3.8	0.013	0.014
33	4.400	3995	-3697	6187	6187	4.1	4.0	0.014	0.015
		-3995	3697	6187	6187	-4.1	-4.0	0.014	0.015
32	4.400	4386	-4159	7367	7367	4.3	4.1	0.016	0.017
		-4386	4159	7367	7367	-4.3	-4.1	0.016	0.017



Modeliranje konstrukcije i analiza rezultata

31	4.400	4678	-4539	8547	8547	4.4	4.3	0.018	0.018
		-4678	4539	8547	8547	-4.4	-4.3	0.018	0.018
30	4.400	4903	-4847	9726	9726	4.6	4.4	0.021	0.020
		-4903	4847	9726	9726	-4.6	-4.4	0.021	0.020
29	4.400	5094	-5094	10906	10906	4.7	4.6	0.023	0.022
		-5094	5094	10906	10906	-4.7	-4.6	0.023	0.022
28	4.400	5282	-5297	12086	12086	4.8	4.7	0.025	0.024
		-5282	5297	12086	12086	-4.8	-4.7	0.025	0.024
27	4.400	5488	-5473	13266	13266	4.9	4.8	0.027	0.026
		-5488	5473	13266	13266	-4.9	-4.8	0.027	0.026
26	4.400	5721	-5640	14445	14445	5.0	4.9	0.029	0.028
		-5721	5640	14445	14445	-5.0	-4.9	0.029	0.028
25	4.400	5973	-5812	15625	15625	5.1	4.9	0.030	0.030
		-5973	5812	15625	15625	-5.1	-4.9	0.030	0.030
24	4.400	6236	-5999	16805	16805	5.2	5.0	0.032	0.032
		-6236	5999	16805	16805	-5.2	-5.0	0.032	0.032
23	4.400	6489	-6205	17984	17984	5.4	5.0	0.034	0.033
		-6489	6205	17984	17984	-5.4	-5.0	0.034	0.033
22	4.400	6705	-6428	19162	19162	5.3	5.1	0.034	0.034
		-6705	6428	19162	19162	-5.3	-5.1	0.034	0.034
21	4.400	6896	-6662	20342	20342	5.2	5.1	0.035	0.035
		-6896	6662	20342	20342	-5.2	-5.1	0.035	0.035
20	4.400	7066	-6898	21522	21522	5.2	5.0	0.036	0.035
		-7066	6898	21522	21522	-5.2	-5.0	0.036	0.035
19	4.400	7220	-7129	22702	22702	4.7	4.4	0.033	0.032
		-7220	7129	22702	22702	-4.7	-4.4	0.033	0.032
18	8.800	7419	-7405	24167	24167	3.5	3.8	0.013	0.014
		-7419	7405	24167	24167	-3.5	-3.8	0.013	0.014
17	4.400	7615	-7631	25408	25408	4.7	4.4	0.035	0.033
		-7615	7631	25408	25408	-4.7	-4.4	0.035	0.033
16	4.400	7808	-7824	26587	26587	5.3	5.1	0.041	0.039
		-7808	7824	26587	26587	-5.3	-5.1	0.041	0.039
15	4.400	7999	-7990	27767	27767	5.3	5.2	0.042	0.041
		-7999	7990	27767	27767	-5.3	-5.2	0.042	0.041
14	4.400	8180	-8132	28947	28947	5.3	5.2	0.043	0.042
		-8180	8132	28947	28947	-5.3	-5.2	0.043	0.042
13	4.400	8347	-8260	30127	30127	5.3	5.2	0.044	0.043
		-8347	8260	30127	30127	-5.3	-5.2	0.044	0.043
12	4.400	8497	-8383	31306	31306	5.3	5.2	0.045	0.044
		-8497	8383	31306	31306	-5.3	-5.2	0.045	0.044
11	4.400	8633	-8513	32486	32486	5.3	5.1	0.045	0.045
		-8633	8513	32486	32486	-5.3	-5.1	0.045	0.045
10	4.400	8764	-8660	33666	33666	5.2	5.1	0.045	0.045
		-8764	8660	33666	33666	-5.2	-5.1	0.045	0.045
9	4.400	8902	-8830	34846	34846	5.1	5.0	0.045	0.045

		-8902	8830	34846	34846	-5.1	-5.0	0.045	0.045
8	4.400	9058	-9025	36025	36025	4.9	4.9	0.045	0.044
		-9058	9025	36025	36025	-4.9	-4.9	0.045	0.044
7	4.400	9243	-9241	37205	37205	4.8	4.7	0.044	0.043
		-9243	9241	37205	37205	-4.8	-4.7	0.044	0.043
6	4.400	9457	-9470	38385	38385	4.6	4.5	0.042	0.042
		-9457	9470	38385	38385	-4.6	-4.5	0.042	0.042
5	4.400	9693	-9699	39564	39564	4.4	4.3	0.041	0.040
		-9693	9699	39564	39564	-4.4	-4.3	0.041	0.040
4	4.400	9935	-9914	40744	40744	4.1	4.1	0.038	0.038
		-9935	9914	40744	40744	-4.1	-4.1	0.038	0.038
3	4.400	10163	-10101	41924	41924	3.8	3.8	0.036	0.036
		-10163	10101	41924	41924	-3.8	-3.8	0.036	0.036
2	4.400	10355	-10249	43104	43104	3.5	3.5	0.033	0.033
		-10355	10249	43104	43104	-3.5	-3.5	0.033	0.033
1	4.400	10490	-10350	44283	44283	3.1	3.1	0.030	0.030
		-10490	10350	44283	44283	-3.1	-3.1	0.030	0.030
0	4.400	10557	-10399	45469	45469	2.8	2.8	0.028	0.028
		-10557	10399	45469	45469	-2.8	-2.8	0.028	0.028

**Tablica 24.: Koeficijenti osjetljivosti i međukatni pomaci za potresnu situaciju 95-godišnjeg potresa zgrade okruglog tlocrta**

Etaža	Visina etaže $\Delta Z$ [m]	Etažne sile		Kumulativna masa		Međukatni pomak		Koeficijent osjetljivosti	
		FX [kN]	FY [kN]	M <sub>x,c</sub> [t]	M <sub>y,c</sub> [t]	d <sub>x</sub> [mm]	d <sub>y</sub> [mm]	$\phi_X$ [--]	$\phi_Y$ [--]
37	8.800	672	-703	1327	1327	4.2	4.0	0.009	0.009
		-672	703	1327	1327	-4.2	-4.0	0.009	0.009
36	4.400	1219	-1273	2459	2459	3.1	3.1	0.014	0.014
		-1219	1273	2459	2459	-3.1	-3.1	0.014	0.014
35	4.400	1713	-1787	3537	3537	4.2	3.6	0.020	0.016
		-1713	1787	3537	3537	-4.2	-3.6	0.020	0.016
34	4.400	2166	-2266	4614	4614	4.8	3.9	0.023	0.018
		-2166	2266	4614	4614	-4.8	-3.9	0.023	0.018
33	4.400	2575	-2708	5691	5691	5.3	4.2	0.027	0.020
		-2575	2708	5691	5691	-5.3	-4.2	0.027	0.020
32	4.400	2941	-3111	6768	6768	5.7	4.5	0.030	0.022
		-2941	3111	6768	6768	-5.7	-4.5	0.030	0.022
31	4.400	3270	-3475	7845	7845	6.2	4.8	0.034	0.024
		-3270	3475	7845	7845	-6.2	-4.8	0.034	0.024
30	4.400	3572	-3803	8922	8922	6.6	5.0	0.037	0.027
		-3572	3803	8922	8922	-6.6	-5.0	0.037	0.027
29	4.400	3857	-4100	9999	9999	7.0	5.2	0.041	0.029

		-3857	4100	9999	9999	-7.0	-5.2	0.041	0.029
28	4.400	4132	-4370	11076	11076	7.3	5.4	0.045	0.031
		-4132	4370	11076	11076	-7.3	-5.4	0.045	0.031
27	4.400	4404	-4620	12153	12153	7.7	5.6	0.048	0.034
		-4404	4620	12153	12153	-7.7	-5.6	0.048	0.034
26	4.400	4676	-4856	13230	13230	8.0	5.8	0.052	0.036
		-4676	4856	13230	13230	-8.0	-5.8	0.052	0.036
25	4.400	4946	-5083	14307	14307	8.4	6.0	0.055	0.039
		-4946	5083	14307	14307	-8.4	-6.0	0.055	0.039
24	4.400	5211	-5307	15384	15384	8.7	6.2	0.058	0.041
		-5211	5307	15384	15384	-8.7	-6.2	0.058	0.041
23	4.400	5467	-5530	16460	16460	8.9	6.4	0.061	0.043
		-5467	5530	16460	16460	-8.9	-6.4	0.061	0.043
22	4.400	5711	-5753	17537	17537	9.2	6.5	0.064	0.045
		-5711	5753	17537	17537	-9.2	-6.5	0.064	0.045
21	4.400	5941	-5975	18614	18614	9.3	6.6	0.066	0.047
		-5941	5975	18614	18614	-9.3	-6.6	0.066	0.047
20	4.400	6159	-6194	19691	19691	8.8	6.6	0.064	0.048
		-6159	6194	19691	19691	-8.8	-6.6	0.064	0.048
19	4.400	6368	-6409	20769	20769	6.6	6.2	0.049	0.045
		-6368	6409	20769	20769	-6.6	-6.2	0.049	0.045
18	8.800	6619	-6661	22079	22079	9.5	9.2	0.036	0.035
		-6619	6661	22079	22079	-9.5	-9.2	0.036	0.035
17	4.400	6833	-6865	23211	23211	7.0	6.4	0.054	0.049
		-6833	6865	23211	23211	-7.0	-6.4	0.054	0.049
16	4.400	7035	-7048	24289	24289	9.7	7.0	0.076	0.055
		-7035	7048	24289	24289	-9.7	-7.0	0.076	0.055
15	4.400	7228	-7218	25366	25366	10.6	7.2	0.085	0.058
		-7228	7218	25366	25366	-10.6	-7.2	0.085	0.058
14	4.400	7410	-7377	26443	26443	10.9	7.3	0.089	0.060
		-7410	7377	26443	26443	-10.9	-7.3	0.089	0.060
13	4.400	7578	-7526	27520	27520	11.1	7.4	0.091	0.061
		-7578	7526	27520	27520	-11.1	-7.4	0.091	0.061
12	4.400	7733	-7668	28597	28597	11.2	7.4	0.094	0.063
		-7733	7668	28597	28597	-11.2	-7.4	0.094	0.063
11	4.400	7875	-7805	29674	29674	11.3	7.4	0.097	0.064
		-7875	7805	29674	29674	-11.3	-7.4	0.097	0.064
10	4.400	8006	-7942	30751	30751	11.3	7.4	0.099	0.065
		-8006	7942	30751	30751	-11.3	-7.4	0.099	0.065
9	4.400	8129	-8079	31828	31828	11.4	7.4	0.101	0.067
		-8129	8079	31828	31828	-11.4	-7.4	0.101	0.067
8	4.400	8246	-8217	32905	32905	11.4	7.4	0.103	0.068

		-8246	8217	32905	32905	-11.4	-7.4	0.103	0.068
7	4.400	8360	-8355	33982	33982	11.4	7.4	0.105	0.068
		-8360	8355	33982	33982	-11.4	-7.4	0.105	0.068
6	4.400	8472	-8491	35058	35058	11.3	7.3	0.106	0.069
		-8472	8491	35058	35058	-11.3	-7.3	0.106	0.069
5	4.400	8581	-8620	36135	36135	11.2	7.3	0.108	0.069
		-8581	8620	36135	36135	-11.2	-7.3	0.108	0.069
4	4.400	8681	-8739	37212	37212	11.1	7.2	0.108	0.070
		-8681	8739	37212	37212	-11.1	-7.2	0.108	0.070
3	4.400	8770	-8842	38289	38289	11.0	7.1	0.109	0.070
		-8770	8842	38289	38289	-11.0	-7.1	0.109	0.070
2	4.400	8839	-8924	39366	39366	10.7	6.9	0.108	0.070
		-8839	8924	39366	39366	-10.7	-6.9	0.108	0.070
1	4.400	8886	-8981	40443	40443	9.9	6.9	0.102	0.071
		-8886	8981	40443	40443	-9.9	-6.9	0.102	0.071
0	4.400	8907	-9010	41521	41521	8.4	7.5	0.089	0.078
		-8907	9010	41521	41521	-8.4	-7.5	0.089	0.078

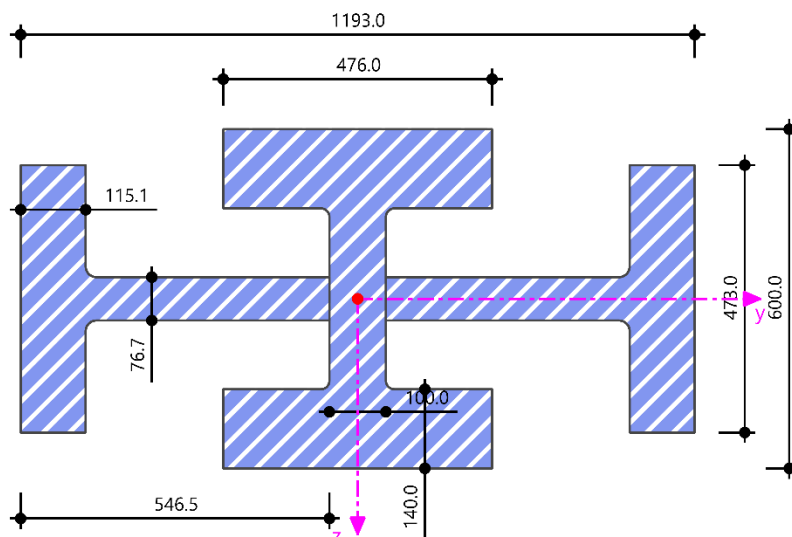
## 5. DIMENZIONIRANJE

Dimenzioniranje se provodi u skladu s normama EN 1993 i EN 1994. Sve vrijednosti učinaka djelovanja dobivene su analizom konstrukcije u softverskom paketu RFEM6.

### 5.1. Zgrada kvadratnog tlocrta

#### 5.1.1. Stup jezgre

Tablica 25.: Karakteristike profila HD 400x1299 & HL 920x1377



A	3408.40	cm <sup>2</sup>
h	1193/600	mm
b	473/476	mm
t <sub>w</sub>	76,7/100	mm
t <sub>f</sub>	115,1/140	mm
r	19/15	mm
I <sub>y</sub>	960900.00	cm <sup>4</sup>
I <sub>z</sub>	4006046.75	cm <sup>4</sup>
W <sub>pl,y</sub>	47402.66	cm <sup>3</sup>
W <sub>pl,z</sub>	93085.93	cm <sup>3</sup>
A <sub>y</sub>	912.86	cm <sup>2</sup>
A <sub>z</sub>	700.74	cm <sup>2</sup>
I <sub>t</sub>	143393.53	cm <sup>4</sup>
I <sub>ω</sub>	7.23e+08	cm <sup>6</sup>

Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

Hrbat profila HL 920x1377

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r - t_{w,HD}}{2 \cdot t_w} = \frac{1193 - 2 \cdot 115,1 - 2 \cdot 19 - 100}{2 \cdot 76,7} = 5,96$$

5,96 < 33 · ε = 33 · 0,75 = 24,75 → hrbat je klase 1

Pojasnica profila HL 920x1377

$$\frac{c}{t} = \frac{\frac{b - t_w - 2 \cdot r}{2}}{t_f} = \frac{\frac{473 - 76,7 - 2 \cdot 19}{2}}{115,1} = 3,11$$

$3,11 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow$  pojasnica je klase 1

Hrbat profila HD 400x1299

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r}{t_w} = \frac{600 - 2 \cdot 140 - 2 \cdot 15}{100} = 2,9$$

$1,06 < 33 \cdot \varepsilon = 33 \cdot 0,75 = 24,75 \rightarrow$  hrbat je klase 1

Pojasnica profila HD 400x1299

$$\frac{c}{t} = \frac{\frac{b - t_w - 2 \cdot r}{2}}{t_f} = \frac{\frac{476 - 100 - 2 \cdot 15}{2}}{140} = 1,24$$

$1,24 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow$  pojasnica je klase 1

Otpornost poprečnog presjeka

Otpornost poprečnog presjeka na tlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{3408,4 \cdot 42,0}{1,0} = 143153 \text{ kN} < N_{Ed} = 84274 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 59%

Otpornost poprečnog presjeka na savijanje

Savijanje oko osi y-y

$$M_{c,y,Rd} = M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}}$$

$$M_{c,y,Rd} = M_{pl,y,Rd} = \frac{47402,66 \cdot 42,0}{1,0} = 19909 \text{ kNm}$$

$$\frac{M_{c,y,Ed}}{M_{c,y,Rd}} = \frac{2216}{19909} = 0,11 < 1,0$$

Presjek zadovoljava uz iskoristivost od 11%

Savijanje oko osi z-z

$$M_{c,z,Rd} = M_{pl,z,Rd} = \frac{W_{pl,z} \cdot f_y}{\gamma_{M0}}$$

$$M_{c,z,Rd} = M_{pl,z,Rd} = \frac{93085.93 \cdot 42,0}{1,0} = 39096 \text{ kNm}$$

$$\frac{M_{c,z,Ed}}{M_{c,z,Rd}} = \frac{3565}{39096} = 0,09 < 1,0$$

Presjek zadovoljava uz iskoristivost od 9%

Posmična otpornost poprečnog presjeka

Posmik u smjeru y-y

Provjera izbočavanja hrpta:

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

$\eta = 1,20$  za valjane profile

$$h_w = \frac{h - 2 \cdot t_f - t_{w,HL}}{2} = \frac{1193 - 2 \cdot 115,1 - 100}{2} = 431,4 \text{ mm}$$

$$\frac{h_w}{t_w} = \frac{431,4}{76,7} = 5,62 < 72 \cdot \frac{0,75}{1,20} = 45$$

Nije potrebna provjera izbočavanja hrpta na posmik

$$V_{pl,y,Rd} = \frac{A_{v,y} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}}$$

$$V_{pl,y,Rd} = \frac{912,86 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 22136 \text{ kN}$$

$$\frac{V_{y,Ed}}{V_{c,y,Rd}} = \frac{764}{22136} = 0,03 < 1,0$$

Presjek zadovoljava uz iskoristivost od 3%

Posmik u smjeru z-z

Provjera izbočavanja hrpta:

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

$\eta = 1,20$  za valjane profile

$$h_w = \frac{h - 2 \cdot t_f - t_{w,HD}}{2} = \frac{600 - 2 \cdot 140 - 76,7}{2} = 121,65 \text{ mm}$$

$$\frac{h_w}{t_w} = \frac{121,65}{100} = 1,22 < 72 \cdot \frac{0,75}{1,20} = 45$$

Nije potrebna provjera izbočavanja hrpta na posmik

$$V_{pl,z,Rd} = \frac{A_{z,y} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}}$$

$$V_{pl,z,Rd} = \frac{700,74 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 16992 \text{ kN}$$

$$\frac{V_{z,Ed}}{V_{c,z,Rd}} = \frac{711}{16992} = 0,04 < 1,0$$

Presjek zadovoljava uz iskoristivost od 4%

M/V/N interakcija

Utjecaj posmične sile:

Nema smanjenja otpornosti poprečnog presjeka ako je zadovoljen uvjet:

$$V_{Ed} \leq 0,5 \cdot V_{z,Rd}$$

$$V_{z,Ed} = 60,29 \text{ kN} < 0,5 \cdot 22136 = 11068 \text{ kN}$$

$$V_{y,Ed} = 132,29 \text{ kN} < 0,5 \cdot 16992 = 8496 \text{ kN}$$

Oba uvjeta su zadovoljena, nema smanjenja otpornosti poprečnog presjeka zbog poprečne sile

Utjecaj uzdužne sile

Oko osi z-z

Uzdužna sila nema utjecaja ako su zadovoljeni uvjeti:

$$N_{Ed} \leq 0,25 \cdot N_{c,Rd}$$

$$N_{Ed} \leq \frac{0,50 \cdot \Sigma(h_w \cdot t_w) \cdot f_y}{\gamma_{M0}}$$

$$N_{Ed} = 73914 > 0,25 \cdot 143154 = 35789 \text{ kN}$$



$$N_{Ed} = 73914 > \frac{0,50 \cdot 982 \cdot 42,0}{1,0} = 20622$$

Kako oba uvjeta ne zadovoljavaju, potrebno je uzdužnu silu uzeti u obzir:

$$\text{za } n < a \quad M_{z,v,N,Rd} = M_{pl,z,Rd}$$

$$\text{za } n > a \quad M_{z,v,N,Rd} = M_{pl,z,Rd} \cdot \left[ 1 - \left( \frac{n-a}{1-a} \right)^2 \right]$$

$$n = \frac{N_{Ed}}{N_{c,Rd}} = \frac{73914}{143154} = 0,52$$

$$a = \frac{A - \Sigma b \cdot t_f}{A} = \frac{3408,4 - 2 \cdot (47,6 \cdot 14,0 + 47,3 \cdot 11,51)}{3408,4} = 0,29 < 0,5$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{z,v,N,Rd}} \leq 1,0$$

$$M_{z,v,N,Rd} = M_{pl,z,Rd} \cdot \left[ 1 - \left( \frac{n-a}{1-a} \right)^2 \right] = 39096 \cdot \left[ 1 - \left( \frac{0,52 - 0,29}{1 - 0,29} \right)^2 \right] = 34993$$

$$\frac{34,64}{34993} = 0,001 < 1,0$$

Presjek zadovoljava

Oko osi y-y

Uzdužna sila nema utjecaja ako su zadovoljeni uvjeti:

$$N_{Ed} \leq 0,25 \cdot N_{c,Rd}$$

$$N_{Ed} \leq \frac{0,50 \cdot \Sigma(h_w \cdot t_w) \cdot f_y}{\gamma_{M0}}$$

$$N_{Ed} = 84254 > 0,25 \cdot 143154 = 35789 \text{ kN}$$

$$N_{Ed} = 84254 > \frac{0,50 \cdot 982 \cdot 42,0}{1,0} = 20622$$

Kako oba uvjeta ne zadovoljavaju, potrebno je uzdužnu silu uzeti u obzir:

$$M_{N,v,y,Rd} = M_{pl,y,Rd} \cdot \frac{1-n}{1-0,5 \cdot a} \leq M_{pl,y,Rd}$$

$$n = \frac{N_{Ed}}{N_{c,Rd}} = \frac{84254}{143154} = 0,59$$

$$a = \frac{A - \Sigma b \cdot t_f}{A} = \frac{3408,4 - 2 \cdot (47,6 \cdot 14,0 + 47,3 \cdot 11,51)}{3408,4} = 0,29 < 0,5$$

$$M_{N,V,y,Rd} = 39096 \cdot \frac{1 - 0,59}{1 - 0,5 \cdot 0,29} = 18748 \text{ kNm} \leq M_{pl,y,Rd}$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{z,V,N,Rd}} \leq 1,0$$

$$\frac{33,8}{18748} = 0,002 < 1,0$$

Presjek zadovoljava

Dvoosno savijanje

$$\left[ \frac{M_{y,Ed}}{M_{y,N,Rd}} \right]^\alpha + \left[ \frac{M_{z,Ed}}{M_{z,N,Rd}} \right]^\beta \leq 1,0$$

$$n = \frac{N_{Ed}}{N_{c,Rd}} = \frac{83281}{143154} = 0,58$$

$$a = \frac{A - \Sigma b \cdot t_f}{A} = \frac{3408,4 - 2 \cdot (47,6 \cdot 14,0 + 47,3 \cdot 11,51)}{3408,4} = 0,29 < 0,5$$

$$M_{z,V,N,Rd} = M_{pl,z,Rd} \cdot \left[ 1 - \left( \frac{n - a}{1 - a} \right)^2 \right] = 39096 \cdot \left[ 1 - \left( \frac{0,58 - 0,29}{1 - 0,29} \right)^2 \right] = 32574 \text{ kNm}$$

$$M_{N,V,y,Rd} = M_{pl,y,Rd} \cdot \frac{1 - n}{1 - 0,5 \cdot a} = 39096 \cdot \frac{1 - 0,58}{1 - 0,5 \cdot 0,29} = 19205 \text{ kNm}$$

$$\alpha = 2,0; \beta = 5 \cdot n = 5 \cdot 0,58 = 2,9$$

$$\left[ \frac{498,51}{19205} \right]^{2,0} + \left[ \frac{124,25}{32574} \right]^{2,9} = 0,0006 < 1,0$$

Presjek zadovoljava

Otpornost elementa na izvijanje

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}}$$

Izvijanje oko slabije osi

Kritična duljina:  $L_{cr} = 5,01 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI_y}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 960900}{501^2} = 793454 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda} = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 3408,4}{793454}} = 0,42$$

Za krivulju izvijanja d:

$$\phi = 0,5 \left[ 1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2 \right] = 0,5[1 + 0,76(0,42 - 0,2) + 0,37^2] = 0,65$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,65 + \sqrt{0,65^2 - 0,42^2}} = 0,87$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,87 \cdot \frac{3408,4 \cdot 42,0}{1,1} = 113221 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{84274}{113221} = 0,74 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 74%

Izvijanje oko jače osi

Kritična duljina:  $L_{cr} = 10,23 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI_z}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 4006047}{1023^2} = 793384 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda} = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 3408,4}{793384}} = 0,47$$

Za krivulju izvijanja d:

$$\phi = 0,5 \left[ 1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2 \right] = 0,5[1 + 0,76(0,47 - 0,2) + 0,47^2] = 0,71$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,71 + \sqrt{0,71^2 - 0,47^2}} = 0,81$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,81 \cdot \frac{3408,4 \cdot 42,0}{1,1} = 105413 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{84274}{105413} = 0,80 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 80%

Otpornost elementa na savijanje

Elastični kritični moment:

$$M_{cr} = C_1 \cdot \frac{\pi^2 \cdot E \cdot I_y}{(k \cdot L_{cr})^2} \cdot \left[ \sqrt{\left(\frac{k}{k_w}\right)^2 \cdot \frac{I_w}{I_y} + \frac{(k \cdot L_{cr})^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_y} + (C_2 \cdot z_g)^2} - C_2 \cdot z_g \right]$$

Prema obliku dijagrama momenta savijanja:

$$C_1 = 1,77$$

$$C_2 = 0$$

$$M_{cr} = 1,77 \cdot \frac{\pi^2 \cdot 21000 \cdot 960900}{440^2} \cdot \left[ \sqrt{\left(\frac{1}{1}\right)^2 \cdot \frac{7,23 \cdot 10^8}{960900} + \frac{440^2 \cdot 8077 \cdot 143393}{\pi^2 \cdot 21000 \cdot 960900}} \right]$$

$$= 16\,758\,621 \text{ kNm}$$

Bezdimenzijska vitkost

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{pl,y} \cdot f_y}{M_{cr}}} = \sqrt{\frac{47403 \cdot 42,0}{16758621}} = 0,34 < 0,4$$

Nije potrebna provjera na bočno-torzijsko izvijanje

$$M_{b,Rd} = \bar{\lambda}_{LT} \cdot \frac{W_{pl,y} \cdot f_y}{\gamma_{M1}} = 1,0 \cdot \frac{47403 \cdot 42,0}{1,1} = 18099 \text{ kNm}$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{b,Rd}} = \frac{2216}{18099} = 0,12 \leq 1,0$$

Uvjet je zadovoljen uz iskoristivost od 12%

Interakcija M/N

Koeficijanti jednolikog ekvivalentnog momenta  $C_m$

Koeficijent  $C_{mz}$ :

$$\psi = 0$$

$$\alpha_s = 0,5$$

$$C_{mz} = 0,6 + 0,4 \cdot \psi = 0,6 > 0,4$$

Koeficijent  $C_{my}$ :

$$\psi = 0$$

$$\alpha_s = 0,5$$

$$C_{my} = 0,6 + 0,4 \cdot \psi = 0,6 > 0,4$$

Interakcijski koeficijenti:

$$k_{yy} = C_{my} \left[ 1 + (\bar{\lambda}_y - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{my} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{yy} = 0,6 \left[ 1 + (0,37 - 0,2) \cdot \frac{83281}{113221} \right] = 0,67 \leq 0,6 \left[ 1 + 0,8 \cdot \frac{83281}{113221} \right] = 0,95$$

$$k_{zz} = C_{mz} \left[ 1 + (\bar{\lambda}_z - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{mz} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{zz} = 0,6 \left[ 1 + (0,06 - 0,2) \cdot \frac{83281}{143153} \right] = 0,55 \leq 0,6 \left[ 1 + 0,8 \cdot \frac{83281}{143153} \right] = 0,88$$

$$k_{zy} = 0,6 \cdot k_{yy} = 0,402$$

$$k_{yz} = 0,6 \cdot k_{zz} = 0,33$$

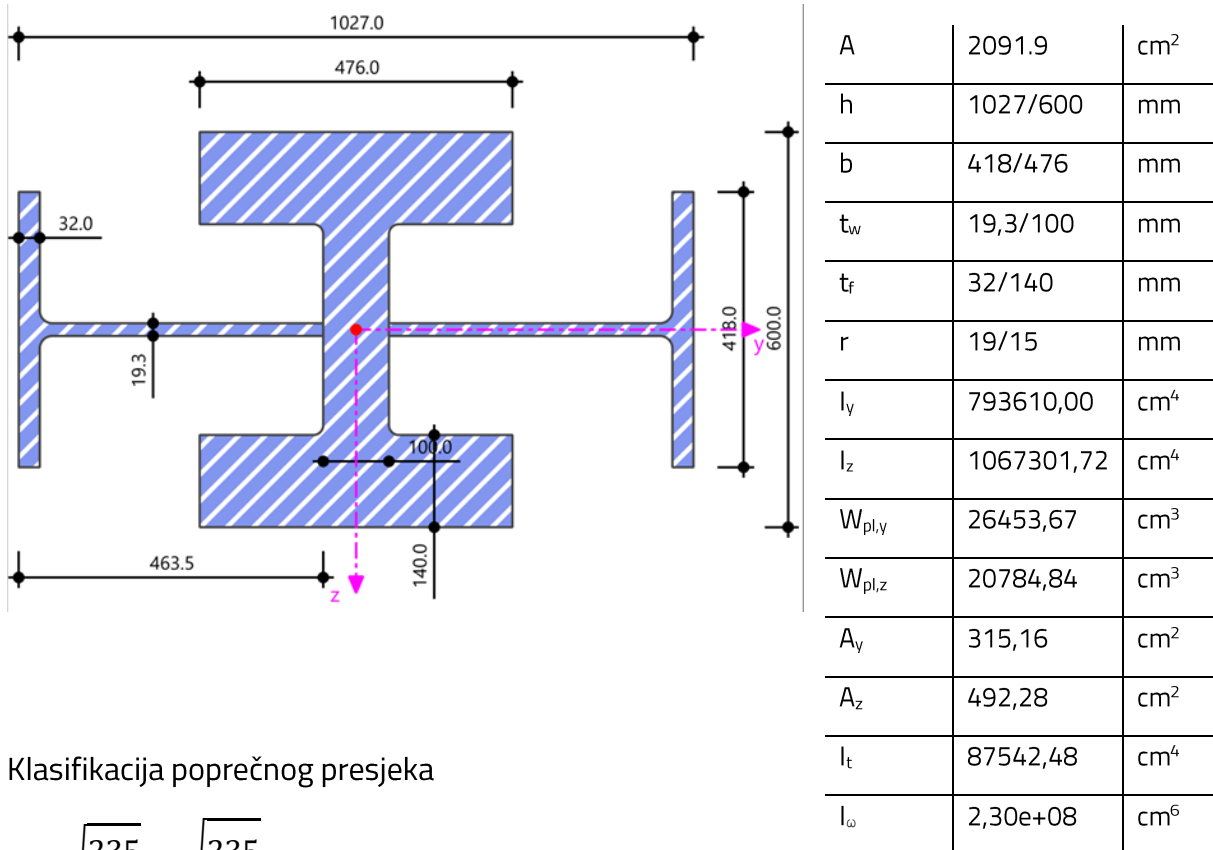
$$\frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} + k_{yy} \cdot \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} + k_{yz} \cdot \frac{M_{y,Ed}}{\frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1$$

$$\frac{83281}{113221} + 0,67 \cdot \frac{124}{35542} + 0,33 \cdot \frac{499}{18099} = 0,75 \leq 1$$

Presjek zadovoljava uz iskoristivost od 75%

5.1.2. Obodni stup

Tablica 26.: Karakteristike profila HD 400x1299 & HL 920x344



Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

Hrbat profila HL 920x1377

$$\frac{c}{t} = \frac{\frac{h - 2 \cdot t_f - 2 \cdot r - t_{w,HD}}{2}}{t_w} = \frac{\frac{1027 - 2 \cdot 32 - 2 \cdot 19 - 100}{2}}{19,3} = 21,37$$

$$21,37 < 33 \cdot \varepsilon = 33 \cdot 0,75 = 24,75 \rightarrow \text{hrbat je klase 1}$$

Pojasnica profila HL 920x1377

$$\frac{c}{t} = \frac{\frac{b - t_w - 2 \cdot r}{2}}{t_f} = \frac{\frac{418 - 19,3 - 2 \cdot 19}{2}}{32} = 5,64$$

$$5,64 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow \text{pojasnica je klase 1}$$

Hrbat profila HD 400x1299

$$\frac{c}{t} = \frac{\frac{h - 2 \cdot t_f - 2 \cdot r - t_{w,HD}}{2}}{t_w} = \frac{\frac{600 - 2 \cdot 140 - 2 \cdot 15 - 19,3}{2}}{100} = 1,35$$

$1,35 < 33 \cdot \varepsilon = 33 \cdot 0,75 = 24,75 \rightarrow$  hrbat je klase 1

Pojasnica profila HD 400x1299

$$\frac{c}{t} = \frac{\frac{b - t_w - 2 \cdot r}{2}}{t_f} = \frac{\frac{476 - 100 - 2 \cdot 15}{2}}{140} = 1,24$$

$1,24 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow$  pojasnica je klase 1

Otpornost poprečnog presjeka

Otpornost poprečnog presjeka na tlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{2091,9 \cdot 42,0}{1,0} = 84836 \text{ kN} < N_{Ed} = 46696 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 55%

Otpornost poprečnog presjeka na savijanje

Savijanje oko osi y-y

$$M_{c,y,Rd} = M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}}$$

$$M_{c,y,Rd} = M_{pl,y,Rd} = \frac{26453,67 \cdot 42,0}{1,0} = 11111 \text{ kNm}$$

$$\frac{M_{c,y,Ed}}{M_{c,y,Rd}} = \frac{2466}{11111} = 0,22 < 1,0$$

Presjek zadovoljava uz iskoristivost od 22%

Savijanje oko osi z-z

$$M_{c,z,Rd} = M_{pl,z,Rd} = \frac{W_{pl,z} \cdot f_y}{\gamma_{M0}}$$

$$M_{c,z,Rd} = M_{pl,z,Rd} = \frac{20784,84 \cdot 42,0}{1,0} = 8729 \text{ kNm}$$

$$\frac{M_{c,z,Ed}}{M_{c,z,Rd}} = \frac{1991}{8729} = 0,23 < 1,0$$

Presjek zadovoljava uz iskoristivost od 23%

Posmična otpornost poprečnog presjeka

Posmik u smjeru y-y

Provjera izbočavanja hrpta:

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

$\eta = 1,20$  za valjane profile

$$h_w = \frac{h - 2 \cdot t_f - t_{w,HL}}{2} = \frac{1027 - 2 \cdot 32 - 100}{2} = 431,5 \text{ mm}$$

$$\frac{h_w}{t_w} = \frac{431,5}{19,3} = 22,36 < 72 \cdot \frac{0,75}{1,20} = 45$$

Nije potrebna provjera izbočavanja hrpta na posmik

$$V_{pl,y,Rd} = \frac{A_{v,y} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}}$$

$$V_{pl,y,Rd} = \frac{315,16 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 7642 \text{ kN}$$

$$\frac{V_{y,Ed}}{V_{c,y,Rd}} = \frac{665}{7642} = 0,09 < 1,0$$

Presjek zadovoljava uz iskoristivost od 9%

Posmik u smjeru z-z

Provjera izbočavanja hrpta:

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

$\eta = 1,20$  za valjane profile

$$h_w = \frac{h - 2 \cdot t_f - t_{w,HD}}{2} = \frac{600 - 2 \cdot 140 - 19,3}{2} = 150,35 \text{ mm}$$

$$\frac{h_w}{t_w} = \frac{150,35}{100} = 1,50 < 72 \cdot \frac{0,75}{1,20} = 45$$



Nije potrebna provjera izbočavanja hrpta na posmik

$$V_{pl,z,Rd} = \frac{A_{z,y} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}}$$

$$V_{pl,z,Rd} = \frac{492,28 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 11937 \text{ kN}$$

$$\frac{V_{z,Ed}}{V_{c,z,Rd}} = \frac{825}{11937} = 0,07 < 1,0$$

Presjek zadovoljava uz iskoristivost od 7%

M/V/N interakcija

Utjecaj posmične sile:

Nema smanjenja otpornosti poprečnog presjeka ako je zadovoljen uvjet:

$$V_{Ed} \leq 0,5 \cdot V_{z,Rd}$$

$$V_{z,Ed} = 825 \text{ kN} < 0,5 \cdot 11937 = 5969 \text{ kN}$$

$$V_{y,Ed} = 665 \text{ kN} < 0,5 \cdot 7642 = 3821 \text{ kN}$$

Oba uvjeta su zadovoljena, nema smanjenja otpornosti poprečnog presjeka zbog poprečne sile

Utjecaj uzdužne sile

Oko osi z-z

Uzdužna sila nema utjecaja ako su zadovoljeni uvjeti:

$$N_{Ed} \leq 0,25 \cdot N_{c,Rd}$$

$$N_{Ed} \leq \frac{0,50 \cdot \Sigma(h_w \cdot t_w) \cdot f_y}{\gamma_{M0}}$$

$$N_{Ed} = 41992 > 0,25 \cdot 84836 = 21209 \text{ kN}$$

$$N_{Ed} = 41992 > \frac{0,50 \cdot 1183 \cdot 42,0}{1,0} = 24843$$

Kako oba uvjeta ne zadovoljavaju, potrebno je uzdužnu silu uzeti u obzir:

$$\text{za } n < a \quad M_{z,v,N,Rd} = M_{pl,z,Rd}$$

$$\text{za } n > a \quad M_{z,v,N,Rd} = M_{pl,z,Rd} \cdot \left[1 - \left(\frac{n-a}{1-a}\right)^2\right]$$

$$n = \frac{N_{Ed}}{N_{c,Rd}} = \frac{41992}{84836} = 0,49$$

$$a = \frac{A - \Sigma b \cdot t_f}{A} = \frac{2091,9 - 2 \cdot (47,6 \cdot 14,0 + 41,8 \cdot 3,2)}{2091,9} = 0,20 < 0,5$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{z,V,N,Rd}} \leq 1,0$$

$$M_{z,V,N,Rd} = M_{pl,z,Rd} \cdot \left[ 1 - \left( \frac{n-a}{1-a} \right)^2 \right] = 9729 \cdot \left[ 1 - \left( \frac{0,49 - 0,20}{1 - 0,20} \right)^2 \right] = 8451 \text{ kNm}$$

$$\frac{18,09}{8451} = 0,002 < 1,0$$

Presjek zadovoljava

Oko osi y-y

Uzdužna sila nema utjecaja ako su zadovoljeni uvjeti:

$$N_{Ed} \leq 0,25 \cdot N_{c,Rd}$$

$$N_{Ed} \leq \frac{0,50 \cdot \Sigma(h_w \cdot t_w) \cdot f_y}{\gamma_{M0}}$$

$$N_{Ed} = 43406 > 0,25 \cdot 84836 = 21209 \text{ kN}$$

$$N_{Ed} = 43406 > \frac{0,50 \cdot 1183 \cdot 42,0}{1,0} = 24843$$

Kako oba uvjeta ne zadovoljavaju, potrebno je uzdužnu silu uzeti u obzir:

$$M_{N,V,y,Rd} = M_{pl,y,Rd} \cdot \frac{1-n}{1-0,5 \cdot a} \leq M_{pl,y,Rd}$$

$$n = \frac{N_{Ed}}{N_{c,Rd}} = \frac{43406}{84836} = 0,51$$

$$a = \frac{A - \Sigma b \cdot t_f}{A} = \frac{2091,9 - 2 \cdot (47,6 \cdot 14,0 + 41,8 \cdot 3,2)}{2091,9} = 0,20 < 0,5$$

$$M_{N,V,y,Rd} = 11111 \cdot \frac{1-0,51}{1-0,5 \cdot 0,20} = 6296 \text{ kNm} \leq M_{pl,y,Rd}$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{z,V,N,Rd}} \leq 1,0$$

$$\frac{32,73}{6296} = 0,005 < 1,0$$

Presjek zadovoljava

Dvoosno savijanje

$$\left[ \frac{M_{y,Ed}}{M_{y,N,Rd}} \right]^\alpha + \left[ \frac{M_{z,Ed}}{M_{z,N,Rd}} \right]^\beta \leq 1,0$$

$$n = \frac{N_{Ed}}{N_{c,Rd}} = \frac{46592}{84836} = 0,55$$

$$a = \frac{A - \Sigma b \cdot t_f}{A} = \frac{2091,9 - 2 \cdot (47,6 \cdot 14,0 + 41,8 \cdot 3,2)}{3408,4} = 0,20 < 0,5$$

$$M_{z,V,N,Rd} = M_{pl,z,Rd} \cdot \left[ 1 - \left( \frac{n-a}{1-a} \right)^2 \right] = 9729 \cdot \left[ 1 - \left( \frac{0,55 - 0,20}{1 - 0,20} \right)^2 \right] = 7867 \text{ kNm}$$

$$M_{N,V,y,Rd} = M_{pl,y,Rd} \cdot \frac{1-n}{1-0,5 \cdot a} = 11111 \cdot \frac{1-0,55}{1-0,5 \cdot 0,20} = 5556 \text{ kNm}$$

$$\alpha = 2,0; \beta = 5 \cdot n = 5 \cdot 0,55 = 2,75$$

$$\left[ \frac{647}{5556} \right]^{2,0} + \left[ \frac{525}{7867} \right]^{2,75} = 0,01 < 1,0$$

Presjek zadovoljava

Otpornost elementa na izvijanje

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}}$$

Izvijanje oko slabije osi

Kritična duljina:  $L_{cr} = 4,4 \text{ m}$

$$N_{cr} = \frac{\pi^2 E I_y}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 793610}{440^2} = 849612 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda} = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 2091,9}{849612}} = 0,32$$

Za krivulju izvijanja d:

$$\phi = 0,5[1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2] = 0,5[1 + 0,76(0,32 - 0,2) + 0,32^2] = 0,597$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,597 + \sqrt{0,597^2 - 0,32^2}} = 0,91$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,91 \cdot \frac{2091,9 \cdot 42,0}{1,1} = 72684 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{46696}{72684} = 0,64 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 64%

Izvijanje oko jače osi

Kritična duljina:  $L_{cr} = 4,4 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI_z}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 1067302}{440^2} = 1142617 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda} = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 2091,9}{1142617}} = 0,28$$

Za krivulju izvijanja d:

$$\phi = 0,5[1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2] = 0,5[1 + 0,76(0,28 - 0,2) + 0,28^2] = 0,57$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,57 + \sqrt{0,57^2 - 0,28^2}} = 0,94$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,94 \cdot \frac{2091,9 \cdot 42,0}{1,1} = 75080 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{46696}{75080} = 0,62 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 62%

Otpornost elementa na savijanje

Elastični kritični moment:

$$M_{cr} = C_1 \cdot \frac{\pi^2 \cdot E \cdot I_y}{(k \cdot L_{cr})^2} \cdot \left[ \sqrt{\left(\frac{k}{k_w}\right)^2 \cdot \frac{I_w}{I_y} + \frac{(k \cdot L_{cr})^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_y} + (C_2 \cdot z_g)^2} - C_2 \cdot z_g \right]$$

Prema obliku dijagrama momenta savijanja:

$$C_1 = 1,77$$

$$C_2 = 0$$

$$M_{cr} = 1,77 \cdot \frac{\pi^2 \cdot 21000 \cdot 793610}{440^2} \cdot \left[ \sqrt{\left(\frac{1}{1}\right)^2 \cdot \frac{2,30 \cdot 10^8}{793610} + \frac{440^2 \cdot 8077 \cdot 87542}{\pi^2 \cdot 21000 \cdot 793610}} \right]$$

$$= 50\,373\,262 \text{ kNm}$$

Bezdimenzijska vitkost

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{pl,y} \cdot f_y}{M_{cr}}} = \sqrt{\frac{26454 \cdot 42,0}{50373262}} = 0,07 < 0,4$$

Nije potrebna provjera na bočno-torzijsko izvijanje

$$M_{b,Rd} = \bar{\lambda}_{LT} \cdot \frac{W_{pl,y} \cdot f_y}{\gamma_{M1}} = 1,0 \cdot \frac{47403 \cdot 42,0}{1,1} = 18099 \text{ kNm}$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{b,Rd}} = \frac{2216}{18099} = 0,12 \leq 1,0$$

Uvjet je zadovoljen uz iskoristivost od 12%

Interakcija M/N

Koeficijanti jednolikog ekvivalentnog momenta  $C_m$

Koeficijent  $C_{mz}$ :

$$\psi = 0$$

$$\alpha_s = 0,5$$

$$C_{mz} = 0,6 + 0,4 \cdot \psi = 0,6 > 0,4$$

Koeficijent  $C_{my}$ :

$$\psi = 0$$

$$\alpha_s = 0,5$$

$$C_{my} = 0,6 + 0,4 \cdot \psi = 0,6 > 0,4$$

Interakcijski koeficijenti:

$$k_{yy} = C_{my} \left[ 1 + (\bar{\lambda}_y - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{my} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{yy} = 0,6 \left[ 1 + (0,32 - 0,2) \cdot \frac{46592}{72684} \right] = 0,65 \leq 0,6 \left[ 1 + 0,8 \cdot \frac{46592}{72684} \right] = 0,91$$

$$k_{zz} = C_{mz} \left[ 1 + (\bar{\lambda}_z - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{mz} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{zz} = 0,6 \left[ 1 + (0,28 - 0,2) \cdot \frac{46592}{75080} \right] = 0,63 \leq 0,6 \left[ 1 + 0,8 \cdot \frac{46592}{75080} \right] = 0,90$$

$$k_{zy} = 0,6 \cdot k_{yy} = 0,39$$

$$k_{yz} = 0,6 \cdot k_{zz} = 0,38$$

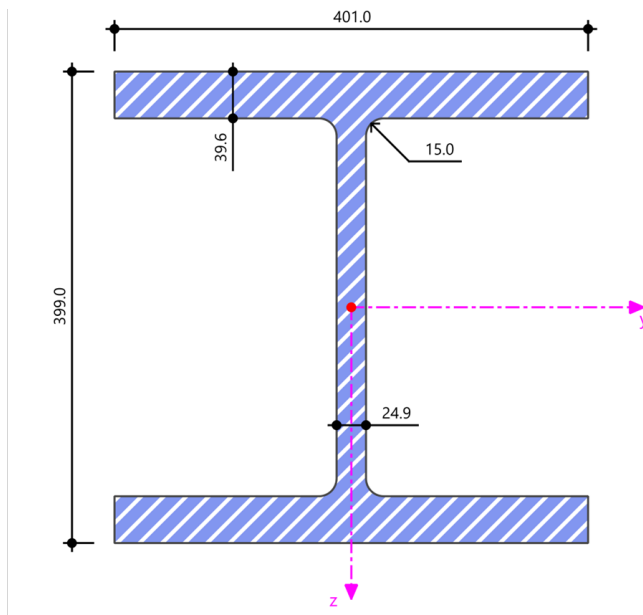
$$\frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} + k_{yy} \cdot \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} + k_{yz} \cdot \frac{M_{y,Ed}}{\frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1$$

$$\frac{46592}{72684} + 0,65 \cdot \frac{525}{8729} + 0,38 \cdot \frac{647}{11111} = 0,70 \leq 1$$

Presjek zadovoljava uz iskoristivost od 70%

## 5.1.3. Glavni nosač

Tablica 27.: Karakteristike profila HD 920x314



A	399,2	cm <sup>2</sup>
h	399	mm
b	401	mm
t <sub>w</sub>	24,9	mm
t <sub>f</sub>	39,6	mm
r	15	mm
I <sub>y</sub>	110230	cm <sup>4</sup>
I <sub>z</sub>	42604	cm <sup>4</sup>
W <sub>pl,y</sub>	6373,18	cm <sup>3</sup>
W <sub>pl,z</sub>	3236,48	cm <sup>3</sup>
A <sub>pl,y</sub>	317,59	cm <sup>2</sup>
A <sub>pl,z</sub>	89,49	cm <sup>2</sup>
I <sub>t</sub>	1848	cm <sup>4</sup>
I <sub>ω</sub>	1,37+07	cm <sup>6</sup>

Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

Hrbat profila

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r}{t_w} = \frac{399,2 - 2 \cdot 39,6 - 2 \cdot 15}{24,9} = 11,65$$

$$11,65 < 33 \cdot \varepsilon = 33 \cdot 0,75 = 24,75 \rightarrow \text{hrbat je klase 1}$$

Pojasnica profila

$$\frac{c}{t} = \frac{b - t_w - 2 \cdot r}{t_f} = \frac{401 - 24,9 - 2 \cdot 15}{2 \cdot 39,6} = 4,37$$

$$4,37 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow \text{pojasnica je klase 1}$$

Otpornost poprečnog presjeka

Otpornost poprečnog presjeka na tlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{399,2 \cdot 42,0}{1,0} = 16766 \text{ kN} > N_{Ed} = 3252 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 19%

Otpornost poprečnog presjeka na vlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{399,2 \cdot 42,0}{1,0} = 16766 \text{ kN} < N_{Ed} = 3310 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 20%

Otpornost poprečnog presjeka na savijanje

Savijanje oko osi y-y

$$M_{c,y,Rd} = M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}}$$

$$M_{c,y,Rd} = M_{el,y,Rd} = \frac{6374,18 \cdot 42,0}{1,0} = 2677 \text{ kNm}$$

$$\frac{M_{c,y,Ed}}{M_{c,y,Rd}} = \frac{2144}{2677} = 0,80 < 1,0$$

Presjek zadovoljava uz iskoristivost od 80%

Savijanje oko osi z-z

$$M_{c,z,Rd} = M_{pl,z,Rd} = \frac{W_{pl,z} \cdot f_y}{\gamma_{M0}}$$

$$M_{c,z,Rd} = M_{pl,z,Rd} = \frac{3236,48 \cdot 42,0}{1,0} = 1359 \text{ kNm}$$

$$\frac{M_{c,z,Ed}}{M_{c,z,Rd}} = \frac{106}{1359} = 0,08 < 1,0$$

Presjek zadovoljava uz iskoristivost od 8%



Posmična otpornost poprečnog presjeka

Posmik u smjeru z-z

Provjera izbočavanja hrpta:

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

$\eta = 1,20$  za valjane profile

$$h_w = 319,8 \text{ mm}$$

$$\frac{h_w}{t_w} = \frac{319,8}{24,9} = 12,84 < 72 \cdot \frac{0,75}{1,20} = 45$$

Nije potrebna provjera izbočavanja hrpta na posmik

$$V_{pl,z,Rd} = \frac{A_{v,z} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}}$$

$$V_{pl,z,Rd} = \frac{89,49 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 2170 \text{ kN}$$

$$\frac{V_{z,Ed}}{V_{c,z,Rd}} = \frac{631}{2170} = 0,29 < 1,0$$

Presjek zadovoljava uz iskoristivost od 29%

M/V/N interakcija

Utjecaj posmične sile:

Nema smanjenja otpornosti poprečnog presjeka ako je zadovoljen uvjet:

$$V_{Ed} \leq 0,5 \cdot V_{z,Rd}$$

$$V_{z,Ed} = 577 \text{ kN} < 0,5 \cdot 2170 = 1085 \text{ kN}$$

Uvjet je zadovoljen, nema smanjenja otpornosti poprečnog presjeka zbog poprečne sile

Utjecaj uzdužne sile

Uvjet:

$$\sigma_{x,Ed} \leq \frac{f_y}{\gamma_{M0}}$$

Naprezanje od uzdužne sile:

$$\sigma_{x,N,Ed} = \frac{N}{A} = \frac{16820}{399200} = 0,04 \text{ Mpa}$$

Naprezanje od momenta savijanja:

$$\sigma_{x,My,Ed} = \frac{M_{y,Ed}}{W_{pl,y}} = \frac{2127000000}{6374000} = 335 \text{ Mpa}$$

$$\sigma_{x,N,Ed} + \sigma_{x,My,Ed} \leq \frac{f_y}{\gamma_{M0}}$$

$$0,04 + 335 = 335,04 \leq \frac{420}{1,0}$$

Presjek zadovoljava

Otpornost elementa na izvijanje

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}}$$

Izvijanje oko osi  $y$ - $y$

Kritična duljina:  $L_{cr} = 12,0 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI_y}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 110230}{1200^2} = 15866 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda} = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 399,2}{15886}} = 1,03$$

Za krivulju izvijanja b:

$$\phi = 0,5[1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2] = 0,5[1 + 0,34(0,32 - 0,2) + 0,34^2] = 1,17$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{1,17 + \sqrt{1,17^2 - 1,03^2}} = 0,58$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,58 \cdot \frac{399,2 \cdot 42,0}{1,1} = 8840 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{3252}{8840} = 0,37 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 37%

Izvijanje oko osi z-z

Kritična duljina:  $L_{cr} = 12,0$  m

$$N_{cr} = \frac{\pi^2 EI_z}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 42604}{1200^2} = 6132 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda} = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 399,2}{6132}} = 1,65$$

Za krivulju izvijanja c:

$$\phi = 0,5[1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2] = 0,5[1 + 0,49(1,65 - 0,2) + 1,65^2] = 2,22$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{2,22 + \sqrt{2,22^2 - 1,65^2}} = 0,27$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,27 \cdot \frac{399,2 \cdot 42,0}{1,1} = 4115 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{3252}{4115} = 0,79 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 79%

Otpornost elementa na savijanje

Oko osi y-y

$$M_{b,Rd} = \lambda_{LT} \cdot \frac{W_{pl,y} \cdot f_y}{\gamma_{M1}} = 1,0 \cdot \frac{6374 \cdot 42,0}{1,1} = 2433 \text{ kNm}$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{b,Rd}} = \frac{2216}{2433} = 0,91 \leq 1,0$$

Uvjet je zadovoljen uz iskoristivost od 91%

Oko osi z-z

$$M_{b,Rd} = \lambda_{LT} \cdot \frac{W_{pl,z} \cdot f_y}{\gamma_{M1}} = 1,0 \cdot \frac{3236 \cdot 42,0}{1,1} = 1236 \text{ kNm}$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{b,Rd}} = \frac{106}{1236} = 0,09 \leq 1,0$$

Uvjet je zadovoljen uz iskoristivost od 9%

Interakcija M/N

Koeficijenti jednolikog ekvivalentnog momenta  $C_m$

Koeficijent  $C_{mz}$ :

$$\psi = 0$$

$$\alpha_s = 0,5$$

$$C_{mz} = 0,6 + 0,4 \cdot (-0,11) = 0,56 > 0,4$$

Koeficijent  $C_{my}$ :

$$\psi = -0,11$$

$$\alpha_s = 0,5$$

$$C_{my} = 0,6 + 0,4 \cdot (-0,02) = 0,59 > 0,4$$

Interakcijski koeficijenti:

$$k_{yy} = C_{my} \left[ 1 + (\bar{\lambda}_y - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{my} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{yy} = 0,59 \left[ 1 + (1,03 - 0,2) \cdot \frac{16,82}{8840} \right] = 0,59 \leq 0,59 \left[ 1 + 0,8 \cdot \frac{16,82}{8840} \right] = 0,59$$

$$k_{zz} = C_{mz} \left[ 1 + (\bar{\lambda}_z - 0,2) \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{mz} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{zz} = 0,56 \left[ 1 + (1,65 - 0,2) \cdot \frac{16,82}{4115} \right] = 0,56 \leq 0,56 \left[ 1 + 0,8 \cdot \frac{16,82}{4115} \right] = 0,56$$

$$k_{zy} = 0,6 \cdot k_{yy} = 0,35$$

$$k_{yz} = 0,6 \cdot k_{zz} = 0,34$$

$$\frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} + k_{yy} \cdot \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} + k_{yz} \cdot \frac{M_{y,Ed}}{\frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1$$

$$\frac{16,82}{8840} + 0,59 \cdot \frac{6,54}{1236} + 0,35 \cdot \frac{2128}{2433} = 0,31 \leq 1$$

Presjek zadovoljava uz iskoristivost od 31%

$$\frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}} + k_{zz} \cdot \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} + k_{zy} \cdot \frac{M_{y,Ed}}{\frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1$$

$$\frac{16,82}{4115} + 0,34 \cdot \frac{6,54}{1236} + 0,56 \cdot \frac{2128}{2433} = 0,50 \leq 1$$

Presjek zadovoljava uz iskoristivost od 50%

Granično stanje uporabljivosti

Za čelični nosač, softverskim putem dobivena je vrijednost progiba:

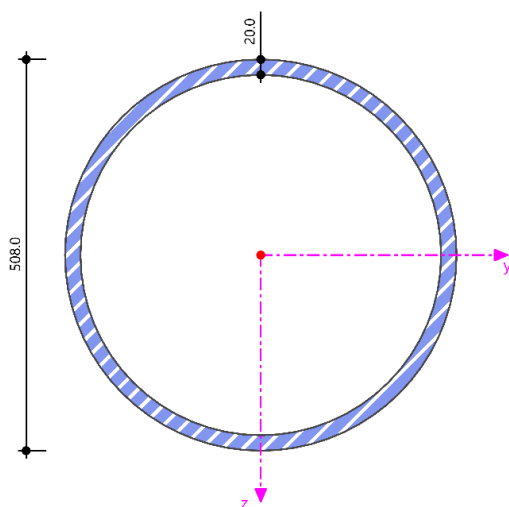
$$\delta = 26,8 \text{ mm} < \delta_{dop} = \frac{L}{250} = 48 \text{ mm}$$

Čelični nosač zadovoljava uz iskoristivost 56%

#### 5.1.4. Dijagonale

Dimenzije dijagonala dobivene preliminarnim dimenzioniranjem nisu zadovoljavale, pa su se povećale dimenzije na CHS 508x20

Tablica 28.: Karakteristike profila CHS 508x20



A	307	cm <sup>2</sup>
D	508	mm
d	468	mm
t	20	mm
I	91428	cm <sup>4</sup>

Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

$$\frac{d}{t} = \frac{468}{16} = 29,25$$

$29,25 < 50 \cdot \varepsilon = 33 \cdot 0,75 = 37,5 \rightarrow$  presjek je klase 1

Otpornost poprečnog presjeka na tlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{307 \cdot 42,0}{1,0} = 12894 \text{ kN} > N_{Ed} = 6334 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 49%

Otpornost poprečnog presjeka na vlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{307 \cdot 42,0}{1,0} = 12894 \text{ kN} < N_{Ed} = 7355 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 57%

Otpornost elementa na izvijanje

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}}$$

Izvijanje oko osi y-y

Kritična duljina:  $L_{cr} = 10,65 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 91428}{1065^2} = 16707 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda} = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 307}{16707}} = 0,88$$

Za krivulju izvijanja a:

$$\phi = 0,5[1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2] = 0,5[1 + 0,21(0,88 - 0,2) + 0,88^2] = 0,96$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,96 + \sqrt{0,96^2 - 0,88^2}} = 0,74$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,74 \cdot \frac{307 \cdot 42,0}{1,1} = 8674 \text{ kN}$$

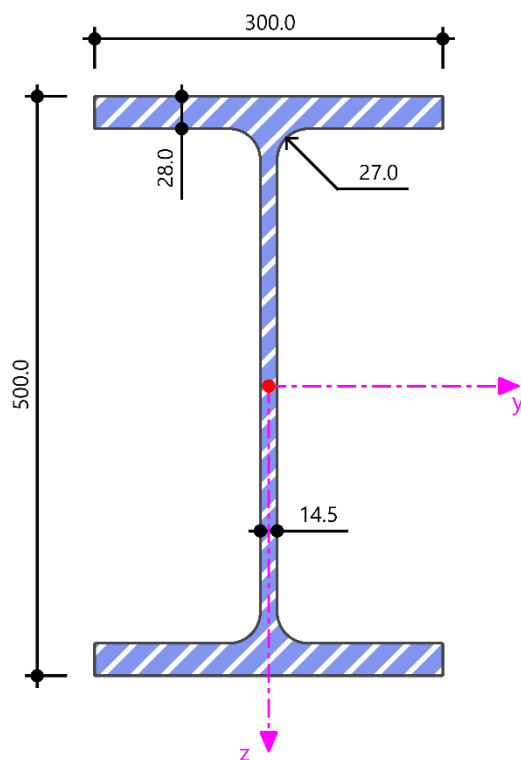
Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{6334}{8674} = 0,73 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 73%

### 5.1.5. Spregnuti nosač

Tablica 29.: Karakteristike profila HEB 500



A	238,6	cm <sup>2</sup>
h	500	mm
b	300	mm
t <sub>w</sub>	14,5	mm
t <sub>f</sub>	28	mm
r	27	mm
I <sub>y</sub>	107200	cm <sup>4</sup>
W <sub>pl,y</sub>	4815,0	cm <sup>3</sup>
I <sub>z</sub>	12620	cm <sup>4</sup>
W <sub>pl,z</sub>	1292,0	cm <sup>3</sup>
I <sub>t</sub>	538,40	cm <sup>4</sup>
I <sub>w</sub>	7018000	cm <sup>6</sup>

Beton kvalitete C25/30

$$f_{ck} = 30 \text{ N/mm}^2$$

$$f_{cd} = \alpha_{cc} \frac{f_{ck}}{\gamma_c} = 1,0 \cdot \frac{25}{1,5} = 16,67 \text{ N/mm}^2$$

$$E_{cm} = 31000 \text{ N/mm}^2$$

Armatura B500B

$$f_{sk} = 500 \text{ N/mm}^2$$

$$f_{sd} = \frac{f_{sk}}{\gamma_s} = \frac{500}{1,15} = 435 \text{ N/mm}^2$$

Konstruktivski čelik S420

$$f_{yk} = 420 \text{ N/mm}^2$$

$$f_{yd} = \frac{f_{yk}}{\gamma_M} = \frac{420}{1,0} = 420 \text{ N/mm}^2$$

$$E_a = 210000 \text{ N/mm}^2$$

Moždanici

$$f_u = 450 \text{ N/mm}^2$$

$$d = 22 \text{ mm}$$

$$h_{sc} = 80 \text{ mm}$$

Djelovanja na nosač

Čelični nosač nije podupiran tijekom izvedbe

Faza izvedbe

Težina svježeg betona	$g_{c,1} = 2,09 \text{ kN/m}^2$
-----------------------	---------------------------------

Profilirani čelični lim	$g_p = 0,19 \text{ kN/m}^2$
-------------------------	-----------------------------

Čelični nosač	$g_n = 0,31 \text{ kN/m}^2$
---------------	-----------------------------

Ukupno	$\Sigma g_{k,1} = 2,59 \text{ kN/m}^2$
--------	--

Servisno opterećenje	$q_{k,1} = 0,75 \text{ kN/m}^2$
----------------------	---------------------------------

Faza uporabe

Spregnuta betonska ploča	$g_{c,2} = 2,01 \text{ kN/m}^2$
--------------------------	---------------------------------

Profilirani čelični lim	$g_p = 0,19 \text{ kN/m}^2$
-------------------------	-----------------------------

Čelični nosač	$g_n = 0,31 \text{ kN/m}^2$
---------------	-----------------------------



Ukupno	$\Sigma g_{k,2} = 2,51 \text{ kN/m}^2$
Slojevi poda	$\Delta g = 1,5 \text{ kN/m}^2$
Pregradni zidovi	$g_{\text{preg}} = 0,70 \text{ kN/m}^2$
Instalacije	$g_{\text{inst}} = 0,50 \text{ kN/m}^2$
Ukupno	$\Sigma g_{k,3} = 2,7 \text{ kN/m}^2$
Korisno opterećenje	$q_{k,2} = 3,0 \text{ kN/m}^2$

Faza izvedbe

Proračunski učinci djelovanja

$$e_d = b \cdot (\gamma_G \cdot g_k + \gamma_Q \cdot q_k) = 3,0 \cdot (1,35 \cdot 2,59 + 1,5 \cdot 0,75) = 13,86 \text{ kN/m}$$

$$M_{\text{Ed}} = \frac{q \cdot l^2}{8} = \frac{13,86 \cdot 12^2}{8} = 249,48 \text{ kNm}$$

$$V_{\text{Ed}} = \frac{e_d \cdot l}{2} = \frac{13,86 \cdot 12}{2} = 83,16 \text{ kN}$$

Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

Hrbat

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r}{t_w} = \frac{500 - 2 \cdot 28 - 2 \cdot 27}{14,5} = 26,9$$

$$13,45 < 72 \cdot \varepsilon = 72 \cdot 0,75 = 54,0 \rightarrow \text{hrbat je klase 1}$$

Pojasnice

$$\frac{c}{t} = \frac{b - t_w - 2 \cdot r}{t_f} = \frac{300 - 14,5 - 2 \cdot 27}{28} = 4,13$$

$$4,13 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow \text{Pojasnica je klase 1}$$

Otpornost poprečnog presjeka na savijanje

$$M_{c,y,Rd} = M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}} = \frac{4815 \cdot 42,0}{1,0} = 2022,3 \text{ kNm}$$

$$M_{Ed} = 249,48 \text{ kNm} < M_{c,y,Rd} = 2022,3 \text{ kNm}$$

Presjek zadovoljava uz iskoristivost od 12%

Posmična otpornost poprečnog presjeka

Provjera izbočavanja hrpta

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

$$h_w = \frac{h - 2 \cdot t_f}{2} = \frac{500 - 2 \cdot 28,0}{2} = 222,0 \text{ mm}$$

$$\frac{h_w}{t_w} = \frac{222,0}{14,5} = 15,31 < 72 \cdot \frac{0,75}{1,20} = 45$$

Nije potrebna provjera izbočavanja hrpta

$$V_{pl,z,Rd} = \frac{A_{v,z} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}}$$

$$V_{pl,z,Rd} = \frac{65,72 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 1594 \text{ kN}$$

$$V_{Ed} = 83,16 \text{ kN} < V_{pl,z,Rd} = 1594 \text{ kN}$$

Uvjet je zadovoljen uz iskoristivost od 5%

Interakcija M/V

Utjecaj posmične sile

$$V_{Ed} \leq 0,5 \cdot V_{z,Rd}$$

$$V_{Ed} = 83,16 \text{ kN} < 0,5 V_{pl,z,Rd} = 797 \text{ kN}$$

Posmična sila ne utječe na otpornost na savijanje

Otpornost elementa na savijanje

Elastični kritični moment:

$$M_{cr} = C_1 \cdot \frac{\pi^2 \cdot E \cdot I_z}{(k \cdot L_{cr})^2} \cdot \left[ \sqrt{\left(\frac{k}{k_w}\right)^2 \cdot \frac{I_w}{I_z} + \frac{(k \cdot L_{cr})^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_z} + (C_2 \cdot z_g)^2} - C_2 \cdot z_g \right]$$

Koeficijenti C1 i C2 određuju se prema obliku momentnog dijagrama, te iznose:

$$C_1 = 1,127 \quad C_2 = 0,454$$

$$M_{cr} = 1,127 \cdot \frac{\pi^2 \cdot 21000 \cdot 12620}{1200^2} \cdot \left[ \sqrt{\left(\frac{1}{1}\right)^2 \cdot \frac{7018000}{12620} + \frac{1200^2 \cdot 8077 \cdot 538,40}{\pi^2 \cdot 21000 \cdot 12620} + (0,454 \cdot 25,0)^2} - 0,454 \cdot 25,0 \right] = 903,57 \text{ kNm}$$

Bezdimenzijska vitkost

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{pl,y} \cdot f_y}{M_{cr}}} = \sqrt{\frac{4815,0 \cdot 42,0}{90356,70}} = 1,49 > 0,4$$

Potrebna je provjera na bočno-torzijsko izvijanje

Linija izvijanja b:

$$\phi_{LT} = 0,5 \left[ 1 + \alpha_{LT}(\bar{\lambda}_{LT} - 0,2) + \bar{\lambda}_{LT}^2 \right] = 0,5 \left[ 1 + 0,34(1,49 - 0,2) + 1,49^2 \right] = 1,83$$

$$\chi_{LT} = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{1,83 + \sqrt{1,83^2 - 1,49^2}} = 0,35 < 1,0$$

$$M_{b,Rd} = \lambda_{LT} \cdot \frac{W_{pl,y} \cdot f_y}{\gamma_{M1}} = 0,35 \cdot \frac{4815,0 \cdot 42,0}{1,1} = 643,46 \text{ kNm}$$

$$M_{Ed} = 249,48 \text{ kNm} < M_{c,y,Rd} = 643,36 \text{ kNm}$$

Element zadovoljava uz iskoristivost od 39%

Faza uporabe

Proračunski učinci djelovanja

$$e_d = b \cdot (\gamma_G \cdot g_k + \gamma_Q \cdot q_k) = 3,0 \cdot (1,35 \cdot 2,51 + 1,5 \cdot 3,0) = 23,67 \text{ kN/m}$$

$$M_{Ed} = \frac{q \cdot l^2}{8} = \frac{23,67 \cdot 12^2}{8} = 426,06 \text{ kNm}$$

$$V_{Ed} = \frac{e_d \cdot l}{2} = \frac{23,67 \cdot 12}{2} = 142,02 \text{ kN}$$

Efektivna širina betonske pojasnice u polju

$$b_{eff} = b_0 + b_{e1} + b_{e2}$$

Za jedan red moždanika:

$$b_0 = 0$$

$$b_{e1} = b_{e2} = \frac{L_e}{8} = \frac{L}{8} = \frac{12,0}{8} = 1,50 \text{ m}$$

$$b_{eff} = 0 + 1,5 + 1,5 = 3,0 = b$$

Položaj neutralne osi

Uvjet za neutralnu os u betonskoj pojasnici:

$$b_{eff} \cdot h_c \cdot 0,85 \cdot f_{cd} > A_a \cdot f_{yd}$$

$$300 \cdot 5,4 \cdot 0,85 \cdot 1,67 = 2300 \text{ kN} < 238,60 \cdot 42,0 = 10021 \text{ kN}$$

Neutralna os ne nalazi se u betonskoj pojasnici

$$x_{pl} = h_c + h_p + t_f + \frac{A_a - 2 \cdot b \cdot t_f}{2 \cdot t_w} - \frac{b_{eff} \cdot h_c \cdot 0,85 \cdot f_{cd}}{2 \cdot t_w \cdot f_{yd}}$$

$$x_{pl} = 5,4 + 5,6 + 2,8 + \frac{238,6 - 2 \cdot 30,0 \cdot 2,8}{2 \cdot 1,45} - \frac{300 \cdot 5,4 \cdot 0,85 \cdot 1,67}{2 \cdot 1,45 \cdot 42,0} = 19,26 \text{ cm}$$

Klasifikacija poprečnog presjeka- za savijanje i tlak

$$c = h - 2 \cdot t_f - 2 \cdot r = 814 - 2 \cdot 40 - 2 \cdot 30 = 674 \text{ mm}$$

$$t = t_w = 21 \text{ mm}$$

Za klasu presjeka 1:

$$\alpha = \frac{z_c}{c} = \frac{192,6}{674} = 0,29$$

$$\frac{c}{t_w} = 32,1 \leq \frac{36 \cdot \varepsilon}{\alpha} = \frac{36 \cdot 0,75}{0,29} = 93,1$$

Pojasnica- klase 1

Poprečni presjek je klase 1

Moment plastične otpornosti

$$M_{pl,Rd} = A_a \cdot f_{yd} \cdot \left( z + h_p \cdot \frac{h_c}{2} \right) - t_w \cdot f_{yd} \cdot (x_{pl} - h_c - h_p - t_f)(x_{pl} + h_p + t_f) - b \cdot t_f \cdot f_{yd} \cdot (h_c + 2h_p + t_f)$$

$$M_{pl,Rd} = 238,6 \cdot 42,0 \cdot \left( 40,7 + 5,6 \cdot \frac{5,4}{2} \right) - 1,45 \cdot 42,0 \cdot (19,26 - 5,4 - 5,6 - 2,8)(19,26 + 5,6 + 2,8) - 30,0 \cdot 2,8 \cdot 42 \cdot (5,4 + 2 \cdot 5,6 + 2,8)$$

$$M_{pl,Rd} = 4817 \text{ kNm}$$

$$M_{Ed} = 426,06 \text{ kNm} < M_{pl,Rd} = 4817 \text{ kNm}$$

Presjek zadovoljava uz iskoristivost od 9%

Otpornost poprečnog presjeka na posmik

Provjera izbočavanja hrpta

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

$$h_w = \frac{h - 2 \cdot t_f}{2} = \frac{500 - 2 \cdot 28,0}{2} = 222,0 \text{ mm}$$

$$\frac{h_w}{t_w} = \frac{222,0}{14,5} = 15,31 < 72 \cdot \frac{0,75}{1,20} = 45$$

Nije potrebna provjera izbočavanja hrpta

$$V_{Ed} = 142 \text{ kN} < V_{pl,z,Rd} = 1594 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 9%

Proračunska otpornost i raspored moždanika

Otkazivanje preko moždanika

$$P_{Rd}^s = \frac{0,8 \cdot f_u \cdot \pi \cdot \frac{d^2}{4}}{\gamma_{Vc}} = \frac{0,8 \cdot 45 \cdot \pi \cdot \frac{2,2^2}{4}}{1,25} = 110 \text{ kN}$$

Otkazivanje preko betona

$$P_{Rd}^c = \frac{0,29 \cdot \alpha \cdot d^2 \sqrt{f_{ck} \cdot E_{cm}}}{\gamma_{Vc}}$$

$\alpha$  – faktor korekcije za vitkost moždanika

$$\frac{h_{sc}}{d} = \frac{80}{22} = 3,64 < 4 \rightarrow \alpha = 0,2 \cdot \left( \frac{h_{sc}}{d} + 1 \right) = 0,2 \cdot \left( \frac{80}{22} + 1 \right) = 0,927$$

$$P_{Rd}^c = \frac{0,29 \cdot 0,927 \cdot 2,2^2 \sqrt{2,5 \cdot 3100}}{1,5} = 76,36 \text{ kN}$$

Potreban broj moždanika

$$n_s = \frac{N_{cf}}{P_{t,Rd}} = \frac{b_{eff} \cdot h_c \cdot 0,85 \cdot f_{cd}}{P_{t,Rd}} = \frac{300 \cdot 5,4 \cdot 0,85 \cdot 1,67}{76,36} = 30,11 \sim 32 \text{ moždanika}$$

Broj rebara uzduž nosača

$$n_r = \frac{L}{b_s} = \frac{12000}{150} = 80$$

Moždanik se postavlja u svako drugo rebro

Betonska ploča se u ovom radu ne proračunava, usvajaju se preporuke proizvođača za debljinu ploče i lima prema slici 23.

Pretpostavke:

Raspon  $L = 3,00 \text{ m}$

Debljina ploče  $d = 11 \text{ cm}$

Beton C25/30

Progib tijekom izgradnje  $L/180$

Progib tijekom korištenja  $L/350$

Granično stanje uporabljivosti

Progib u fazi izvedbe- za čelični nosač

$$e_{d,ukupno} = b \cdot (g_k + q_k) = 3,0 \cdot (2,59 + 0,75) = 8,52 \text{ kN/m}$$

$$\delta_{ukupno} = \frac{5}{384} \cdot \frac{e_{d,ukupno} \cdot L^4}{EI_a} = \frac{5 \cdot 0,0852 \cdot 1200^4}{384 \cdot 21000 \cdot 107200} = 1,02 \text{ cm}$$

$$e_{d,promjenjivo} = b \cdot q_k = 3,0 \cdot 0,75 = 2,25 \text{ kN/m}$$

$$\delta_{promjenjivo} = \frac{5}{384} \cdot \frac{e_d \cdot L^4}{EI_a} = \frac{5 \cdot 0,0225 \cdot 1200^4}{384 \cdot 21000 \cdot 107200} = 0,27 \text{ cm}$$

Ograničenja progiba:

$$\delta_{\text{ukupno}} \leq \frac{L}{250} = \frac{1200}{250} = 4,8 \text{ cm}$$

$$\delta_{\text{promjenjivo}} \leq \frac{L}{360} = \frac{1200}{360} = 3,33 \text{ cm}$$

Oba uvjeta zadovoljavaju

Progib u fazi korištenja- spregnuti nosač

Pojednostavljeni postupak

Skupljanje i pužanje uzeti u obzir pomoću  $E_{cm}/2$

$$E_{c,\text{eff}} = \frac{E_{cm}}{2} = \frac{31000}{2} = 1550 \text{ kN/cm}^2$$

$$EI_L = E_a \cdot I_a + E_{c,\text{eff}} \cdot I_c + \frac{E_a \cdot A_a \cdot E_{c,\text{eff}} \cdot A_c}{E_a \cdot A_a + E_{c,\text{eff}} \cdot A_c} \cdot a^2$$

a Razmak između težišta betonske pojasnice i čeličnog nosača

$$a = \frac{h_a}{2} + h_p + \frac{h_c}{2} = \frac{50}{2} + 5,6 + \frac{5,4}{2} = 33,3 \text{ cm}$$

$$EI_L = 21000 \cdot 107200 + 1550 \cdot 3937 + \frac{21000 \cdot 238,6 \cdot 1550 \cdot 1620}{21000 \cdot 238,6 + 1550 \cdot 1620} \cdot 33,3^2$$

$$EI_P = EI_L = 4112177487 \text{ kNcm}^2 = 411217 \text{ kNm}^2$$

$$e_{d,\text{ukupno}} = b \cdot (g_k + q_k) = 3,0 \cdot (2,51 + 2,7 + 3,0) = 24,63 \text{ kN/m}$$

$$\delta_{\text{ukupno}} = \frac{5}{384} \cdot \frac{e_{d,\text{ukupno}} \cdot L^4}{EI_a} = \frac{5 \cdot 0,2463 \cdot 1200^4}{384 \cdot 4112177487} = 1,52 \text{ cm}$$

$$e_{d,\text{promjenjivo}} = b \cdot q_k = 3,0 \cdot 3,0 = 9 \text{ kN/m}$$

$$\delta_{\text{promjenjivo}} = \frac{5}{384} \cdot \frac{e_d \cdot L^4}{EI_a} = \frac{5 \cdot 0,09 \cdot 1200^4}{384 \cdot 4112177487} = 0,59 \text{ cm}$$

Ograničenja progiba:

$$\delta_{\text{ukupno}} \leq \frac{L}{250} = \frac{1200}{250} = 4,8 \text{ cm}$$

$$\delta_{\text{promjenjivo}} \leq \frac{L}{360} = \frac{1200}{360} = 3,33 \text{ cm}$$

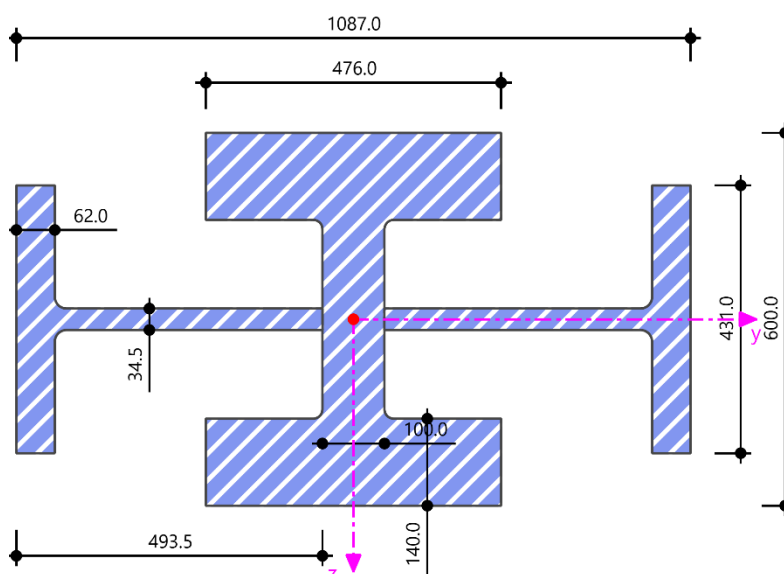
Oba uvjeta zadovoljavaju

## 5.2. Zgrada okruglog tlocrta

Zgrada okruglog tlocrta nije se detaljno proračunavala, već pojednostavljeno, prema očekivanim najvećim djelovanjima.

### 5.2.1. Stup jezgre

Tablica 30.: Karakteristike profila HD 400x1299 & HL 920x656



A	2490.00	cm <sup>2</sup>
h	1087/600	mm
b	431/476	mm
t <sub>w</sub>	34,5/100	mm
t <sub>f</sub>	62/140	mm
r	19/15	mm
I <sub>y</sub>	837640	cm <sup>4</sup>
I <sub>z</sub>	2761031	cm <sup>4</sup>
W <sub>pl,y</sub>	27921	cm <sup>3</sup>
W <sub>pl,z</sub>	35389	cm <sup>3</sup>
A <sub>y</sub>	452,90	cm <sup>2</sup>
A <sub>z</sub>	544,79	cm <sup>2</sup>
I <sub>t</sub>	94066	cm <sup>4</sup>
I <sub>ω</sub>	3,5e+08	cm <sup>6</sup>

Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

Hrbat profila HL 920x656

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r - t_{w,HD}}{2 \cdot t_w} = \frac{1087 - 2 \cdot 62 - 2 \cdot 19 - 100}{2 \cdot 34,5} = 11,96$$

$$11,96 < 33 \cdot \varepsilon = 33 \cdot 0,75 = 24,75 \rightarrow \text{hrbat je klase 1}$$

Pojasnica profila HL 920x656

$$\frac{c}{t} = \frac{b - t_w - 2 \cdot r}{2 \cdot t_f} = \frac{431 - 34,5 - 2 \cdot 19}{2 \cdot 62} = 2,89$$

$$2,89 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow \text{pojasnica je klase 1}$$



Hrbat profila HD 400x1299

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r}{t_w} = \frac{600 - 2 \cdot 140 - 2 \cdot 15}{100} = 2,9$$

$$1,06 < 33 \cdot \varepsilon = 33 \cdot 0,75 = 24,75 \rightarrow \text{hrbat je klase 1}$$

Pojasnica profila HD 400x1299

$$\frac{c}{t} = \frac{\frac{b - t_w - 2 \cdot r}{2}}{t_f} = \frac{\frac{476 - 100 - 2 \cdot 15}{2}}{140} = 1,24$$

$$1,24 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow \text{pojasnica je klase 1}$$

Kako su maksimalni proračunati moment savijanja i poprečna sila male do zanemarive veličine (tablica 25), ovdje se neće posebno računati otpornost na iste. Moment savijanja i poprečna sila uzimaju se u obzir kod M/V/N interakcije.

**Tablica 31.: Veličine proračunskih momenata savijanja, uzdužne i poprečne sile**

Max $N_{Ed}$ [kN]	61653
Max $V_{z,Ed}$ [kN]	481
Max $V_{y,Ed}$ [kN]	352
Max $M_{z,Ed}$ [kNm]	1282
Max $M_{y,Ed}$ [kNm]	1469

Otpornost poprečnog presjeka

Otpornost poprečnog presjeka na tlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{2490,0 \cdot 42,0}{1,0} = 104580 \text{ kN} > N_{Ed} = 61653 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 59%

M/V/N interakcija

Utjecaj posmične sile:

Nema smanjenja otpornosti poprečnog presjeka ako je zadovoljen uvjet:

$$V_{Ed} \leq 0,5 \cdot V_{z,Rd}$$

$$V_{pl,z,Rd} = \frac{A_{v,z} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}} = \frac{544,79 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 13210 \text{ kN}$$

$$V_{pl,y,Rd} = \frac{A_{v,y} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}} = \frac{452,90 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 10982 \text{ kN}$$

$$V_{z,Ed} = 481 \text{ kN} < 0,5 \cdot 13210 = 6605 \text{ kN}$$

$$V_{y,Ed} = 352 \text{ kN} < 0,5 \cdot 10982 = 5491 \text{ kN}$$

Oba uvjeta su zadovoljena, nema smanjenja otpornosti poprečnog presjeka zbog poprečne sile

Utjecaj uzdužne sile

Okolo osi z-z

Uzdužna sila nema utjecaja ako su zadovoljeni uvjeti:

$$N_{Ed} \leq 0,25 \cdot N_{c,Rd}$$

$$N_{Ed} \leq \frac{0,50 \cdot \Sigma(h_w \cdot t_w) \cdot f_y}{\gamma_{M0}}$$

$$N_{Ed} = 62380 > 0,25 \cdot 104580 = 26145 \text{ kN}$$

$$N_{Ed} = 62380 > \frac{0,50 \cdot 469 \cdot 42,0}{1,0} = 9849 \text{ kN}$$

Kako oba uvjeta ne zadovoljavaju, potrebno je uzdužnu silu uzeti u obzir:

$$\text{za } n < a \quad M_{z,v,N,Rd} = M_{pl,z,Rd}$$

$$\text{za } n > a \quad M_{z,v,N,Rd} = M_{pl,z,Rd} \cdot \left[1 - \left(\frac{n-a}{1-a}\right)^2\right]$$

$$n = \frac{N_{Ed}}{N_{c,Rd}} = \frac{61653}{104580} = 0,59$$

$$a = \frac{A - \Sigma b \cdot t_f}{A} = \frac{2490 - 2 \cdot (47,6 \cdot 14,0 + 4,31 \cdot 6,2)}{2490} = 0,44 < 0,5$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{z,V,N,Rd}} \leq 1,0$$

$$M_{z,V,N,Rd} = M_{pl,z,Rd} \cdot \left[ 1 - \left( \frac{n-a}{1-a} \right)^2 \right] = 17721 \cdot \left[ 1 - \left( \frac{0,59-0,44}{1-0,44} \right)^2 \right] = 16274$$

$$\frac{1282}{16274} = 0,08 < 1,0$$

Presjek zadovoljava

Oko osi y-y

Uzdužna sila nema utjecaja ako su zadovoljeni uvjeti:

$$N_{Ed} \leq 0,25 \cdot N_{c,Rd}$$

$$N_{Ed} \leq \frac{0,50 \cdot \Sigma(h_w \cdot t_w) \cdot f_y}{\gamma_{M0}}$$

$$N_{Ed} = 62380 > 0,25 \cdot 104580 = 26145 \text{ kN}$$

$$N_{Ed} = 62380 > \frac{0,50 \cdot 469 \cdot 42,0}{1,0} = 9849 \text{ kN}$$

Kako oba uvjeta ne zadovoljavaju, potrebno je uzdužnu silu uzeti u obzir:

$$M_{N,V,y,Rd} = M_{pl,y,Rd} \cdot \frac{1-n}{1-0,5 \cdot a} \leq M_{pl,y,Rd}$$

$$n = \frac{N_{Ed}}{N_{c,Rd}} = \frac{61653}{104580} = 0,59$$

$$a = \frac{A - \Sigma b \cdot t_f}{A} = \frac{2490 - 2 \cdot (47,6 \cdot 14,0 + 4,31 \cdot 6,2)}{2490} = 0,44 < 0,5$$

$$M_{N,V,y,Rd} = 13351 \cdot \frac{1-0,60}{1-0,5 \cdot 0,44} = 6847 \text{ kNm} \leq M_{pl,y,Rd}$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{y,V,N,Rd}} \leq 1,0$$

$$\frac{1469}{6847} = 0,21 < 1,0$$

Presjek zadovoljava

Otpornost elementa na izvijanje

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}}$$

Izvijanje oko slabije osi

Kritična duljina:  $L_{cr} = 8,8 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI_y}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 837640}{880^2} = 224187 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda}_y = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 2490}{224187}} = 0,68$$

Za krivulju izvijanja d:

$$\phi = 0,5 \left[ 1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2 \right] = 0,5[1 + 0,76(0,68 - 0,2) + 0,68^2] = 0,91$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,91 + \sqrt{0,91^2 - 0,68^2}} = 0,66$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,66 \cdot \frac{2490 \cdot 42,0}{1,1} = 62748 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{61653}{62748} = 0,98 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 87%

Izvijanje oko jače osi

Kritična duljina:  $L_{cr} = 8.8 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI_z}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 1923391}{880^2} = 514780 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda}_z = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 2490}{514780}} = 0,45$$

Za krivulju izvijanja d:

$$\phi = 0,5 \left[ 1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2 \right] = 0,5 \left[ 1 + 0,76(0,45 - 0,2) + 0,45^2 \right] = 0,7$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,7 + \sqrt{0,7^2 - 0,45^2}} = 0,81$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,81 \cdot \frac{2490 \cdot 42,0}{1,1} = 77009 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{61653}{77009} = 0,80 \leq 1,0$$

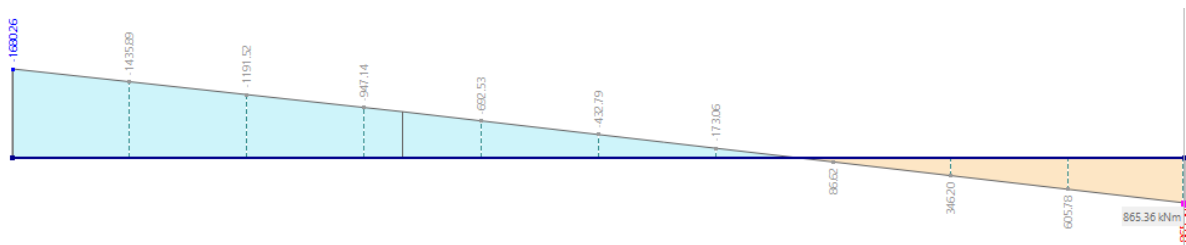
Presjek zadovoljava uz iskoristivost od 80%

Otpornost elementa na savijanje

Elastični kritični moment:

$$M_{cr} = C_1 \cdot \frac{\pi^2 \cdot E \cdot I_y}{(k \cdot L_{cr})^2} \cdot \left[ \sqrt{\left( \frac{k}{k_w} \right)^2 \cdot \frac{I_w}{I_y} + \frac{(k \cdot L_{cr})^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_y} + (C_2 \cdot z_g)^2} - C_2 \cdot z_g \right]$$

Prema obliku dijagrama momenta savijanja sa slike 37:



Slika 37. Momentni dijagram za stup Jezgre

$$C_1 = 2,26$$

$$C_2 = 0$$

$$M_{cr} = 2,26 \cdot \frac{\pi^2 \cdot 21000 \cdot 837640}{880^2} \cdot \left[ \sqrt{\left( \frac{1}{1} \right)^2 \cdot \frac{3,5 \cdot 10^8}{837640} + \frac{880^2 \cdot 8077 \cdot 94065}{\pi^2 \cdot 21000 \cdot 1923391}} \right]$$

$$= 21463177 \text{ kNcm}$$

Bezdimenzijska vitkost

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{pl,y} \cdot f_y}{M_{cr}}} = \sqrt{\frac{39267 \cdot 42,0}{21463177}} = 0,27 < 0,4$$

Nije potrebna provjera na bočno-torzijsko izvijanje

Interakcija M/N

Koeficijenti jednolikog ekvivalentnog momenta  $C_m$

Koeficijent  $C_{mz}$ :

$$\psi = 0$$

$$\alpha_s = 0,5$$

$$C_{mz} = 0,6 > 0,4$$

Koeficijent  $C_{my}$ :

$$\psi = 0$$

$$\alpha_s = 0,5$$

$$C_{my} = 0,6 + 0,4 \cdot \psi = 0,6 > 0,4$$

Interakcijski koeficijenti:

$$k_{yy} = C_{my} \left[ 1 + (\bar{\lambda}_y - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{my} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{yy} = 0,6 \left[ 1 + (0,68 - 0,2) \cdot \frac{61537}{62748} \right] = 0,88 \leq 0,6 \left[ 1 + 0,8 \cdot \frac{61537}{62748} \right] = 1,07$$

$$k_{zz} = C_{mz} \left[ 1 + (\bar{\lambda}_z - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{mz} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{zz} = 0,6 \left[ 1 + (0,45 - 0,2) \cdot \frac{61537}{77009} \right] = 0,72 \leq 0,6 \left[ 1 + 0,8 \cdot \frac{61537}{77009} \right] = 0,98$$

$$k_{zy} = 0,6 \cdot k_{yy} = 0,53$$

$$k_{yz} = 0,6 \cdot k_{zz} = 0,43$$

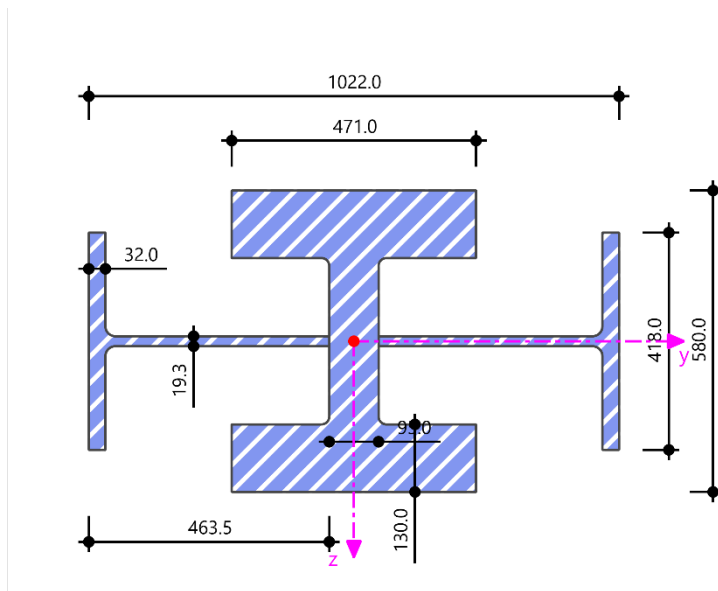
$$\frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} + k_{yy} \cdot \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} + k_{yz} \cdot \frac{M_{y,Ed}}{\frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1$$

$$\frac{61537}{62748} + 0,88 \cdot \frac{24}{16110} + 0,43 \cdot \frac{498}{12137} = 1,0 \leq 1$$

Presjek zadovoljava uz iskoristivost od 100 %

## 5.2.2. Stup oboda

Tablica 32.: Karakteristike profila HD 400x1202 &amp; HL 920x344



A	1967,7	cm <sup>2</sup>
h	1022/580	mm
b	418/471	mm
t <sub>w</sub>	19,3/95	mm
t <sub>f</sub>	32/130	mm
r	19/15	mm
I <sub>y</sub>	702610	cm <sup>4</sup>
I <sub>z</sub>	1032740	cm <sup>4</sup>
W <sub>pl,y</sub>	32896	cm <sup>3</sup>
W <sub>pl,z</sub>	32926	cm <sup>3</sup>
A <sub>y</sub>	300,58	cm <sup>2</sup>
A <sub>z</sub>	458,02	cm <sup>2</sup>
I <sub>t</sub>	71049	cm <sup>4</sup>
I <sub>ω</sub>	2,1e+08	cm <sup>6</sup>

Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

Hrnat profila HL 920x344

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r - t_{w,HD}}{2 \cdot t_w} = \frac{1022 - 2 \cdot 32 - 2 \cdot 19 - 95}{2 \cdot 19,3} = 21,37$$

$$21,37 < 33 \cdot \varepsilon = 33 \cdot 0,75 = 24,75 \rightarrow \text{hrnat je klase 1}$$

Pojasnica profila HL 920x344

$$\frac{c}{t} = \frac{b - t_w - 2 \cdot r}{2 \cdot t_f} = \frac{418 - 19,3 - 2 \cdot 19}{2 \cdot 32} = 5,64$$

$$5,64 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow \text{pojasnica je klase 1}$$

Hrnat profila HD 400x1202

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r}{2 \cdot t_w} = \frac{580 - 2 \cdot 130 - 2 \cdot 15}{2 \cdot 95} = 3,05$$

$$3,05 < 33 \cdot \varepsilon = 33 \cdot 0,75 = 24,75 \rightarrow \text{hrnat je klase 1}$$

Pojasnica profila HD 400x1299

$$\frac{c}{t} = \frac{\frac{b - t_w - 2 \cdot r}{2}}{t_f} = \frac{471 - 95 - 2 \cdot 15}{130} = 1,33$$

$1,33 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow$  pojasnica je klase 1

Kako su maksimalni proračunati moment savijanja i poprečna sila male do zanemarive veličine (tablica 26), ovdje se neće posebno računati otpornost na iste. Moment savijanja i poprečna sila uzimaju se u obzir kod M/V/N interakcije.

**Tablica 33.: Veličine proračunskih momenata savijanja, uzdužne i poprečne sile**

Max $N_{Ed}$ [kN]	43264
Max $V_{z,Ed}$ [kN]	564
Max $V_{y,Ed}$ [kN]	465
Max $M_{z,Ed}$ [kNm]	1475
Max $M_{y,Ed}$ [kNm]	1277

Otpornost poprečnog presjeka

Otpornost poprečnog presjeka na tlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{1968 \cdot 42,0}{1,0} = 82656 \text{ kN} > N_{Ed} = 43264 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 52%

M/V/N interakcija

Utjecaj posmične sile:

Nema smanjenja otpornosti poprečnog presjeka ako je zadovoljen uvjet:

$$V_{Ed} \leq 0,5 \cdot V_{z,Rd}$$

$$V_{pl,z,Rd} = \frac{A_{v,z} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}} = \frac{458,02 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 11106 \text{ kN}$$



$$V_{pl,y,Rd} = \frac{A_{v,y} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}} = \frac{300,58 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 7289 \text{ kN}$$

$$V_{z,Ed} = 564 \text{ kN} < 0,5 \cdot 11106 = 5553 \text{ kN}$$

$$V_{y,Ed} = 465 \text{ kN} < 0,5 \cdot 7289 = 3915 \text{ kN}$$

Oba uvjeta su zadovoljena, nema smanjenja otpornosti poprečnog presjeka zbog poprečne sile

Utjecaj uzdužne sile

Oko osi z-z

Uzdužna sila nema utjecaja ako su zadovoljeni uvjeti:

$$N_{Ed} \leq 0,25 \cdot N_{c,Rd}$$

$$N_{Ed} \leq \frac{0,50 \cdot \Sigma(h_w \cdot t_w) \cdot f_y}{\gamma_{M0}}$$

$$N_{Ed} = 43264 > 0,25 \cdot 82656 = 41328 \text{ kN}$$

$$N_{Ed} = 43264 > \frac{0,50 \cdot 489 \cdot 42,0}{1,0} = 10269 \text{ kN}$$

Kako oba uvjeta ne zadovoljavaju, potrebno je uzdužnu silu uzeti u obzir:

$$\text{za } n < a \quad M_{z,v,N,Rd} = M_{pl,z,Rd}$$

$$\text{za } n > a \quad M_{z,v,N,Rd} = M_{pl,z,Rd} \cdot \left[1 - \left(\frac{n-a}{1-a}\right)^2\right]$$

$$n = \frac{N_{Ed}}{N_{c,Rd}} = \frac{43264}{82656} = 0,52$$

$$a = \frac{A - \Sigma b \cdot t_f}{A} = \frac{1968 - 2 \cdot (41,8 \cdot 3,2 + 47,1 \cdot 13,0)}{1968} = 0,24 < 0,5$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{z,v,N,Rd}} \leq 1,0$$

$$M_{z,v,N,Rd} = M_{pl,z,Rd} \cdot \left[1 - \left(\frac{n-a}{1-a}\right)^2\right] = 11195 \cdot \left[1 - \left(\frac{0,52 - 0,24}{1 - 0,24}\right)^2\right] = 9675$$

$$\frac{1277}{9675} = 0,13 < 1,0$$

Presjek zadovoljava

Oko osi  $y$ - $y$

$$M_{N,V,y,Rd} = M_{pl,y,Rd} \cdot \frac{1 - n}{1 - 0,5 \cdot a} \leq M_{pl,y,Rd}$$

$$M_{N,V,y,Rd} = 11188 \cdot \frac{1 - 0,52}{1 - 0,5 \cdot 0,24} = 6102 \text{ kNm} \leq M_{pl,y,Rd}$$

Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{y,V,N,Rd}} \leq 1,0$$

$$\frac{1475}{6102} = 0,24 < 1,0$$

Presjek zadovoljava

Otpornost elementa na izvijanje

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}}$$

Izvijanje oko slabije osi

Kritična duljina:  $L_{cr} = 8,8 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI_y}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 702610}{880^2} = 188048 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda}_y = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 1968}{188048}} = 0,66$$

Za krivulju izvijanja d:

$$\phi = 0,5 \left[ 1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2 \right] = 0,5[1 + 0,76(0,66 - 0,2) + 0,53^2] = 0,82$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,82 + \sqrt{0,82^2 - 0,66^2}} = 0,77$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,77 \cdot \frac{1968 \cdot 42,0}{1,1} = 57859 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{43264}{57859} = 0,75 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 75%

Izvijanje oko jače osi

Kritična duljina:  $L_{cr} = 8.8 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI_z}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 1032740}{880^2} = 276404 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda}_z = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 1968}{276404}} = 0,55$$

Za krivulju izvijanja d:

$$\phi = 0,5 \left[ 1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2 \right] = 0,5 \left[ 1 + 0,76(0,55 - 0,2) + 0,45^2 \right] = 0,73$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,73 + \sqrt{0,73^2 - 0,55^2}} = 0,83$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,83 \cdot \frac{1968 \cdot 42,0}{1,1} = 62368 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{43264}{62368} = 0,69 \leq 1,0$$

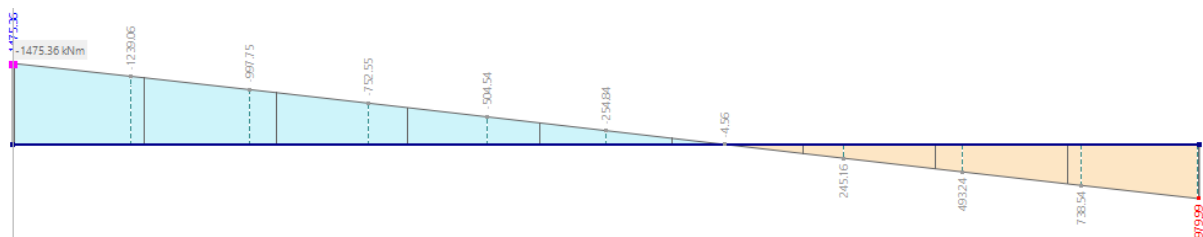
Presjek zadovoljava uz iskoristivost od 69%

Otpornost elementa na savijanje

Elastični kritični moment:

$$M_{cr} = C_1 \cdot \frac{\pi^2 \cdot E \cdot I_y}{(k \cdot L_{cr})^2} \cdot \left[ \sqrt{\left( \frac{k}{k_w} \right)^2 \cdot \frac{I_w}{I_y} + \frac{(k \cdot L_{cr})^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_y}} + (C_2 \cdot z_g)^2 - C_2 \cdot z_g \right]$$

Prema obliku dijagrama momenta savijanja sa slike 38:



Slika 38. Momentni dijagram za stup oboda

$$C_1 = 2,4 \quad C_2 = 0$$

$$M_{cr} = 2,4 \cdot \frac{\pi^2 \cdot 21000 \cdot 702610}{880^2} \cdot \left[ \sqrt{\left(\frac{1}{1}\right)^2 \cdot \frac{2,1 \cdot 10^8}{702610} + \frac{880^2 \cdot 8077 \cdot 71049}{\pi^2 \cdot 21000 \cdot 1032740}} \right]$$

$$= 21994614 \text{ kNcm}$$

Bezdimenzijska vitkost

$$\lambda_{LT}^- = \sqrt{\frac{W_{pl,y} \cdot f_y}{M_{cr}}} = \sqrt{\frac{32896 \cdot 42,0}{21994614}} = 0,25 < 0,4$$

Nije potrebna provjera na bočno-torzijsko izvijanje

Interakcija M/N

Koeficijenti jednolikog ekvivalentnog momenta  $C_m$

Koeficijent  $C_{mz}$ :

$$\psi = -0,64$$

$$\alpha_s = 0,5$$

$$C_{mz} = 0,6 + 0,4 \cdot \psi = 0,34 > 0,4$$

Koeficijent  $C_{my}$ :

$$\psi = -0,23$$

$$\alpha_s = 0,5$$

$$C_{my} = 0,6 + 0,4 \cdot \psi = 0,51 > 0,4$$

Interakcijski koeficijenti:

$$k_{yy} = C_{my} \left[ 1 + (\bar{\lambda}_y - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{my} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{yy} = 0,34 \left[ 1 + (0,66 - 0,2) \cdot \frac{41176}{57859} \right] = 0,45 \leq 0,6 \left[ 1 + 0,8 \cdot \frac{41176}{57859} \right] = 0,94$$

$$k_{zz} = C_{mz} \left[ 1 + (\bar{\lambda}_z - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{mz} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{zz} = 0,51 \left[ 1 + (0,65 - 0,2) \cdot \frac{41176}{62368} \right] = 0,65 \leq 0,6 \left[ 1 + 0,8 \cdot \frac{41176}{62368} \right] = 0,92$$

$$k_{zy} = 0,6 \cdot k_{yy} = 0,27$$

$$k_{yz} = 0,6 \cdot k_{zz} = 0,39$$

$$\frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} + k_{yy} \cdot \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} + k_{yz} \cdot \frac{M_{y,Ed}}{\frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1$$

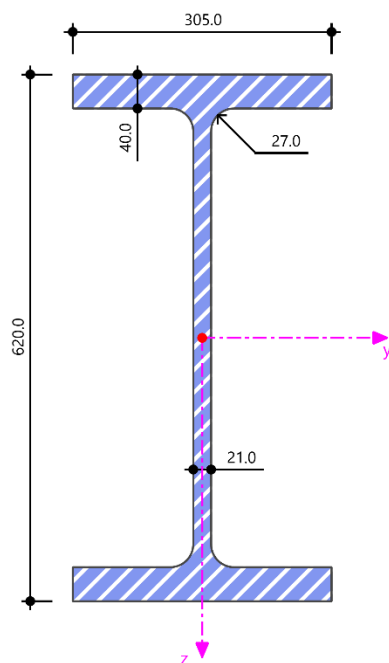
$$\frac{41176}{57859} + 0,45 \cdot \frac{126}{10177} + 0,43 \cdot \frac{942}{10167} = 0,76 \leq 1$$

Presjek zadovoljava uz iskoristivost od 76%

### 5.2.3. Glavni nosač

Kod glavnih nosača vladajuće djelovanje je moment savijanja pa se neće posebno proračunavati otpornost na uzdužnu i poprečne sile. Navedene se uzimaju u obzir kod proračuna interakcije.

Tablica 34.: Karakteristike profila HEM 600



A	364	cm <sup>2</sup>
h	620	mm
b	305	mm
t <sub>w</sub>	21	mm
t <sub>f</sub>	40	mm
r	27	mm
I <sub>y</sub>	237400	cm <sup>4</sup>
I <sub>z</sub>	18980	cm <sup>4</sup>
W <sub>pl,y</sub>	8780	cm <sup>3</sup>
W <sub>pl,z</sub>	1930	cm <sup>3</sup>
A <sub>pl,y</sub>	205,32	cm <sup>2</sup>
A <sub>pl,z</sub>	118	cm <sup>2</sup>
I <sub>t</sub>	1570	cm <sup>4</sup>
I <sub>ω</sub>	1,59+07	cm <sup>6</sup>

Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

Hrbat profila

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r}{t_w} = \frac{620 - 2 \cdot 40 - 2 \cdot 27}{21} = 23,14$$

$23,14 < 33 \cdot \varepsilon = 33 \cdot 0,75 = 24,75 \rightarrow$  hrbat je klase 1

Pojasnica profila

$$\frac{c}{t} = \frac{b - t_w - 2 \cdot r}{t_f} = \frac{305 - 21 - 2 \cdot 27}{2 \cdot 40} = 2,88$$

$2,88 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow$  pojasnica je klase 1

Otpornost poprečnog presjeka

Otpornost poprečnog presjeka na savijanje

Savijanje oko osi y-y

$$M_{c,y,Rd} = M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}}$$

$$M_{c,y,Rd} = M_{el,y,Rd} = \frac{8780 \cdot 42,0}{1,0} = 3688 \text{ kNm}$$

$$\frac{M_{c,y,Ed}}{M_{c,y,Rd}} = \frac{2104}{3688} = 0,57 < 1,0$$

Presjek zadovoljava uz iskoristivost od 57%

M/V/N interakcija

Utjecaj posmične sile:

Nema smanjenja otpornosti poprečnog presjeka ako je zadovoljen uvjet:

$$V_{Ed} \leq 0,5 \cdot V_{z,Rd}$$

$$V_{z,Ed} = 895 \text{ kN} < 0,5 \cdot 3457 = 1729 \text{ kN}$$

Uvjet je zadovoljen, nema smanjenja otpornosti poprečnog presjeka zbog poprečne sile

Utjecaj uzdužne sile

Uvjet:

$$\sigma_{x,Ed} \leq \frac{f_y}{\gamma_{M0}}$$

Naprezanje od uzdužne sile:

$$\sigma_{x,N,Ed} = \frac{N}{A} = \frac{2101000}{36400} = 57,72 \text{ Mpa}$$

Naprezanje od momenta savijanja:

$$\sigma_{x,My,Ed} = \frac{M_{y,Ed}}{W_{pl,y}} = \frac{2104000000}{8780000} = 240 \text{ Mpa}$$

$$\sigma_{x,N,Ed} + \sigma_{x,My,Ed} \leq \frac{f_y}{\gamma_{M0}}$$

$$57,72 + 240 = 297,72 \leq \frac{420}{1,0}$$

Presjek zadovoljava

Izvijanje oko osi z-z

Kritična duljina:  $L_{cr} = 12 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI_z}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 18980}{1200^2} = 2731 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda}_z = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 364}{18980}} = 2,37$$

Za krivulju izvijanja b:

$$\phi = 0,5 \left[ 1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2 \right] = 0,5[1 + 0,34(2,37 - 0,2) + 2,37^2] = 3,67$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{3,67 + \sqrt{3,67^2 - 2,37^2}} = 0,16$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,16 \cdot \frac{364 \cdot 42,0}{1,1} = 2223 \text{ kN}$$

Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{2102}{2223} = 0,95 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 95%

Otpornost elementa na savijanje

Elastični kritični moment:

$$M_{cr} = C_1 \cdot \frac{\pi^2 \cdot E \cdot I_y}{(k \cdot L_{cr})^2} \cdot \left[ \sqrt{\left(\frac{k}{k_w}\right)^2 \cdot \frac{I_w}{I_y} + \frac{(k \cdot L_{cr})^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_y}} + (C_2 \cdot z_g)^2 - C_2 \cdot z_g \right]$$

Prema obliku dijagrama momenta savijanja:

$$C_1 = 2,061$$

$$C_2 = 0$$

$$M_{cr} = 2,061 \cdot \frac{\pi^2 \cdot 21000 \cdot 18980}{1200^2} \cdot \left[ \sqrt{\left(\frac{1}{1}\right)^2 \cdot \frac{1,57 \cdot 10^7}{18980} + \frac{1200^2 \cdot 8077 \cdot 1574}{\pi^2 \cdot 21000 \cdot 18980}} \right]$$

$$= 416800 \text{ kNm}$$

Bezdimenzijska vitkost

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{pl,y} \cdot f_y}{M_{cr}}} = \sqrt{\frac{8772 \cdot 42,0}{416800}} = 0,94 > 0,4$$

Potrebna je provjera na bočno-torzijsko izvijanje

$$\Phi_{LT} = 0,5 \cdot [1 + \alpha_{LT}(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}) + \beta \cdot \bar{\lambda}_{LT}^2]$$

$$= 0,5 \cdot [1 + 0,49 \cdot (0,940 - 0,400) + 0,750 \cdot 0,940^2] = 0,964$$

$$\chi_{LT} = \min\left[1,0, \frac{1}{\bar{\lambda}_{LT}^2}, 1/(\Phi_{LT} + [\Phi_{LT}^2 - \beta \bar{\lambda}_{LT}^2]^{0,5})\right]$$

$$= \min\left[1,0, \frac{1}{0,940^2}, 1/(0,964 + [0,964^2 - 0,750 \cdot 0,940^2]^{0,5})\right] = 0,676$$

$$f = \min(1,0, 1 - 0,5 \cdot (1 - k_c) \cdot [1 - 2,0 \cdot (\bar{\lambda}_{LT} - 0,8)^2])$$

$$= \min(1,0, 1 - 0,5 \cdot (1 - 0,706) \cdot [1 - 2,0 \cdot (0,940 - 0,8)^2]) = 0,859$$

$$\chi_{LT,mod} = \min\left(1, \frac{1}{\bar{\lambda}_{LT}^2}, \frac{\chi_{LT}}{f}\right) = \min\left(1, \frac{1}{0,940^2}, \frac{0,676}{0,859}\right) = 0,787$$

$$M_{b,Rd} = \chi_{LT,mod} \cdot \frac{W_y \cdot f_y}{\gamma_{M1}} = 0,787 \cdot \frac{8780 \cdot 42,0}{1,10} = 2638 \text{ kNm}$$



Dokaz pouzdanosti:

$$\frac{M_{Ed}}{M_{b,Rd}} = \frac{2104}{2638} = 0,80 \leq 1,0$$

Uvjet je zadovoljen uz iskoristivost od 80%

Interakcija M/N

Koeficijanti jednolikog ekvivalentnog momenta  $C_m$

Koeficijent  $C_{mz}$ :

$$\psi = 0,5$$

$$\alpha_s = 0,5$$

$$C_{mz} = 0,6 + 0,4 \cdot (0,5) = 0,8 > 0,4$$

Koeficijent  $C_{my}$ :

$$\psi = 0,5$$

$$\alpha_s = 0,5$$

$$C_{my} = 0,6 + 0,4 \cdot (0,5) = 0,8 > 0,4$$

Interakcijski koeficijenti:

$$k_{yy} = C_{my} \left[ 1 + (\bar{\lambda}_y - 0,2) \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{my} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{yy} = 0,8 \left[ 1 + (0,669 - 0,2) \cdot \frac{41}{13166} \right] = 0,8 \leq 0,80 \left[ 1 + 0,8 \cdot \frac{41}{13166} \right] = 0,80$$

$$k_{zz} = C_{mz} \left[ 1 + (\bar{\lambda}_z - 0,2) \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right] \leq C_{mz} \left[ 1 + 0,8 \cdot \frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}} \right]$$

$$k_{zz} = 0,8 \left[ 1 + (2,37 - 0,2) \cdot \frac{41}{2444} \right] = 0,83 > 0,8 \left[ 1 + 0,8 \cdot \frac{41}{2444} \right] = 0,81$$

$$k_{zy} = 1 - \frac{0,1\bar{\lambda}_z n_z}{C_{mLT} - 0,25} k_{yz} = 0,992$$

$$\frac{N_{Ed}}{\chi_y \cdot \frac{N_{Rk}}{\gamma_{M1}}} + k_{yy} \cdot \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} + k_{yz} \cdot \frac{M_{y,Ed}}{\frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1$$

$$\frac{16,82}{8840} + 0,59 \cdot \frac{6,54}{1236} + 0,35 \cdot \frac{2128}{2433} = 0,31 \leq 1$$

Presjek zadovoljava uz iskoristivost od 31%

$$\frac{N_{Ed}}{\chi_z \cdot \frac{N_{Rk}}{\gamma_{M1}}} + k_{zz} \cdot \frac{M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} + k_{zy} \cdot \frac{M_{y,Ed}}{\chi_{LT} \cdot \frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1$$

$$\frac{41}{2444} + 0,83 \cdot \frac{1,22}{736} + 0,992 \cdot \frac{2128}{2638} = 0,82 \leq 1$$

Presjek zadovoljava uz iskoristivost od 82%

Granično stanje uporabljivosti

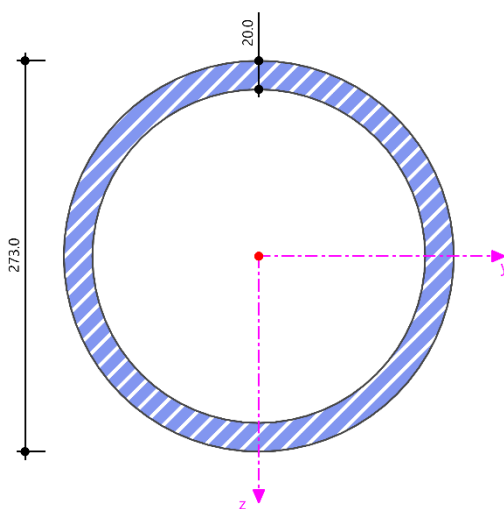
Za čelični nosač, softverskim putem dobivena je vrijednost progiba:

$$\delta = 7,3 \text{ mm} < \delta_{dop} = \frac{L}{250} = 48 \text{ mm}$$

Čelični nosač zadovoljava uz iskoristivost 15%

#### 5.2.4. Dijagonale

Tablica 35.: Karakteristike profila CHS 355.6x16



A	171	cm <sup>2</sup>
D	355,6	mm
d	323,6	mm
t	16	mm
I	24660	cm <sup>4</sup>

Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

$$\frac{d}{t} = \frac{323,6}{16} = 20,23$$

$14,56 < 50 \cdot \varepsilon = 33 \cdot 0,75 = 37,5 \rightarrow$  presjek je klase 1

Otpornost poprečnog presjeka na tlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{171 \cdot 42,0}{1,0} = 7182 \text{ kN} > N_{Ed} = 3401 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 47%

Otpornost poprečnog presjeka na vlak

$$N_{c,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{171 \cdot 42,0}{1,0} = 7182 \text{ kN} < N_{Ed} = 2793 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 39%

Otpornost elementa na izvijanje

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}}$$

Izvijanje oko osi y-y

Kritična duljina:  $L_{cr} = 10,38 \text{ m}$

$$N_{cr} = \frac{\pi^2 EI}{L_{cr}^2} = \frac{\pi^2 \cdot 21000 \cdot 24660}{1038^2} = 4745 \text{ kN}$$

Svedena vitkost

$$\bar{\lambda} = \sqrt{\frac{f_y \cdot A}{N_{cr}}} = \sqrt{\frac{42,0 \cdot 171}{24660}} = 0,54$$

Za krivulju izvijanja a:

$$\phi = 0,5[1 + \alpha(\bar{\lambda} - 0,2) + \bar{\lambda}^2] = 0,5[1 + 0,21(0,54 - 0,2) + 0,54^2] = 0,68$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{0,68 + \sqrt{0,68^2 - 0,54^2}} = 0,91$$

$$N_{b,Rd} = \chi \cdot \frac{A \cdot f_y}{\gamma_{M1}} = 0,91 \cdot \frac{171 \cdot 42,0}{1,1} = 5942 \text{ kN}$$

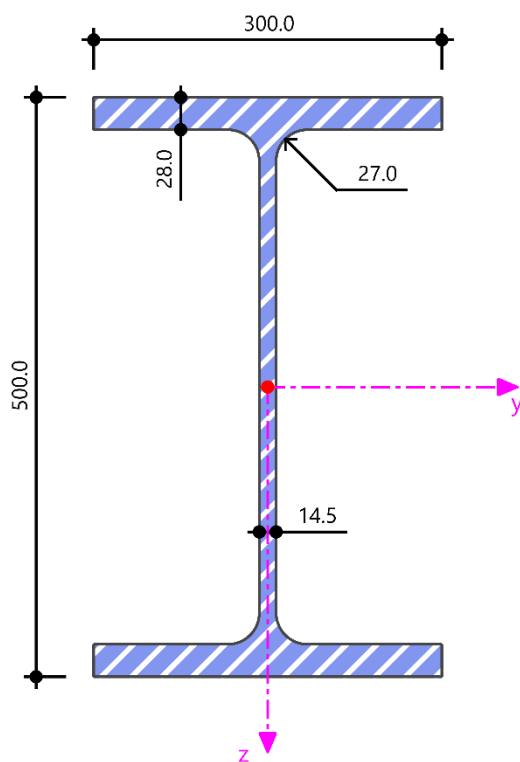
Dokaz pouzdanosti

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{3401}{5941} = 0,57 \leq 1,0$$

Presjek zadovoljava uz iskoristivost od 57%

### 5.2.5. Spregnuti nosač

Tablica 36.: Karakteristike profila HE 500 B



A	238,6	cm <sup>2</sup>
h	500	mm
b	300	mm
t <sub>w</sub>	14,5	mm
t <sub>f</sub>	28	mm
r	27	mm
I <sub>y</sub>	107200	cm <sup>4</sup>
W <sub>pl,y</sub>	4815,0	cm <sup>3</sup>
I <sub>z</sub>	12620	cm <sup>4</sup>
W <sub>pl,z</sub>	1292,0	cm <sup>3</sup>
I <sub>t</sub>	538,40	cm <sup>4</sup>
I <sub>w</sub>	7018000	cm <sup>6</sup>

Beton kvalitete C25/30

$$f_{ck} = 30 \text{ N/mm}^2$$

$$f_{cd} = \alpha_{cc} \frac{f_{ck}}{\gamma_c} = 1,0 \cdot \frac{25}{1,5} = 16,67 \text{ N/mm}^2$$

$$E_{cm} = 31000 \text{ N/mm}^2$$

Armatura B500B

$$f_{sk} = 500 \text{ N/mm}^2$$

$$f_{sd} = \frac{f_{sk}}{\gamma_s} = \frac{500}{1,15} = 435 \text{ N/mm}^2$$

Konstruktivski čelik S420

$$f_{yk} = 420 \text{ N/mm}^2$$

$$f_{yd} = \frac{f_{yk}}{\gamma_M} = \frac{420}{1,0} = 420 \text{ N/mm}^2$$

$$E_a = 210000 \text{ N/mm}^2$$

Moždanici

$$f_u = 450 \text{ N/mm}^2$$

$$d = 22 \text{ mm}$$

$$h_{sc} = 80 \text{ mm}$$

Djelovanja na nosač

Čelični nosač nije podupiran tijekom izvedbe

Faza izvedbe

Težina svježeg betona  $g_{c,1} = 2,09 \text{ kN/m}^2$

Profilirani čelični lim  $g_p = 0,19 \text{ kN/m}^2$

Čelični nosač  $g_n = 0,31 \text{ kN/m}^2$

Ukupno  $\Sigma g_{k,1} = 2,59 \text{ kN/m}^2$

Servisno opterećenje  $q_{k,1} = 0,75 \text{ kN/m}^2$

Faza uporabe

Spregnuta betonska ploča  $g_{c,2} = 2,01 \text{ kN/m}^2$

Profilirani čelični lim  $g_p = 0,19 \text{ kN/m}^2$

Čelični nosač  $g_n = 0,31 \text{ kN/m}^2$

Ukupno	$\Sigma g_{k,2} = 2,51 \text{ kN/m}^2$
Slojevi poda	$\Delta g = 1,5 \text{ kN/m}^2$
Pregradni zidovi	$g_{\text{preg}} = 0,70 \text{ kN/m}^2$
Instalacije	$g_{\text{inst}} = 0,50 \text{ kN/m}^2$
Ukupno	$\Sigma g_{k,3} = 2,7 \text{ kN/m}^2$
Korisno opterećenje	$q_{k,2} = 3,0 \text{ kN/m}^2$

Faza izvedbe

Proračunski učinci djelovanja

$$e_d = b \cdot (\gamma_G \cdot g_k + \gamma_Q \cdot q_k) = 3,11 \cdot (1,35 \cdot 2,59 + 1,5 \cdot 0,75) = 14,37 \text{ kN/m}$$

$$M_{\text{Ed}} = \frac{e_d \cdot l^2}{8} = \frac{14,37 \cdot 15,54^2}{8} = 433,78 \text{ kNm}$$

$$V_{\text{Ed}} = \frac{e_d \cdot l}{2} = \frac{14,37 \cdot 15,54}{2} = 111,65 \text{ kN}$$

Klasifikacija poprečnog presjeka

$$\varepsilon = \sqrt{\frac{235}{f_y}} = \sqrt{\frac{235}{420}} = 0,75$$

Hrbat

$$\frac{c}{t} = \frac{h - 2 \cdot t_f - 2 \cdot r}{t_w} = \frac{500 - 2 \cdot 28 - 2 \cdot 27}{14,5} = 26,9$$

$$13,45 < 72 \cdot \varepsilon = 72 \cdot 0,75 = 54,0 \rightarrow \text{hrbat je klase 1}$$

Pojasnice

$$\frac{c}{t} = \frac{b - t_w - 2 \cdot r}{t_f} = \frac{300 - 14,5 - 2 \cdot 27}{28} = 4,13$$

$$4,13 < 9 \cdot \varepsilon = 9 \cdot 0,75 = 6,75 \rightarrow \text{Pojasnica je klase 1}$$

Otpornost poprečnog presjeka na savijanje

$$M_{c,y,Rd} = M_{pl,y,Rd} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}} = \frac{4815 \cdot 42,0}{1,0} = 2022,3 \text{ kNm}$$

$$M_{Ed} = 433,78 \text{ kNm} < M_{c,y,Rd} = 2022,3 \text{ kNm}$$

Presjek zadovoljava uz iskoristivost od 21%

Posmična otpornost poprečnog presjeka

Provjera izbočavanja hrpta

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

$$h_w = \frac{h - 2 \cdot t_f}{2} = \frac{500 - 2 \cdot 28,0}{2} = 222,0 \text{ mm}$$

$$\frac{h_w}{t_w} = \frac{222,0}{14,5} = 15,31 < 72 \cdot \frac{0,75}{1,20} = 45$$

Nije potrebna provjera izbočavanja hrpta

$$V_{pl,z,Rd} = \frac{A_{v,z} \cdot \left(\frac{f_y}{\sqrt{3}}\right)}{\gamma_{M0}}$$

$$V_{pl,z,Rd} = \frac{65,72 \cdot \left(\frac{42,0}{\sqrt{3}}\right)}{1,0} = 1594 \text{ kN}$$

$$V_{Ed} = 111,65 \text{ kN} < V_{pl,z,Rd} = 1594 \text{ kN}$$

Uvjet je zadovoljen uz iskoristivost od 7%

Interakcija M/V

Utjecaj posmične sile

$$V_{Ed} \leq 0,5 \cdot V_{z,Rd}$$

$$V_{Ed} = 111,65 \text{ kN} < 0,5 V_{pl,z,Rd} = 797 \text{ kN}$$

Posmična sila ne utječe na otpornost na savijanje

Otpornost elementa na savijanje

Elastični kritični moment:

$$M_{cr} = C_1 \cdot \frac{\pi^2 \cdot E \cdot I_z}{(k \cdot L_{cr})^2} \cdot \left[ \sqrt{\left(\frac{k}{k_w}\right)^2 \cdot \frac{I_w}{I_z} + \frac{(k \cdot L_{cr})^2 \cdot G \cdot I_t}{\pi^2 \cdot E \cdot I_z}} + (C_2 \cdot z_g)^2 - C_2 \cdot z_g \right]$$

Koeficijenti C1 i C2 određuju se prema obliku momentnog dijagrama, te iznose:

$$C_1 = 1,127 \quad C_2 = 0,454$$

$$M_{cr} = 1,127 \cdot \frac{\pi^2 \cdot 21000 \cdot 12620}{1554^2} \cdot \left[ \sqrt{\left(\frac{1}{1}\right)^2 \cdot \frac{7018000}{12620} + \frac{1554^2 \cdot 8077 \cdot 538,40}{\pi^2 \cdot 21000 \cdot 12620}} + (0,454 \cdot 25,0)^2 - 0,454 \cdot 25,0 \right] = 836,72 \text{ kNm}$$

Bezdimenzijska vitkost

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{pl,y} \cdot f_y}{M_{cr}}} = \sqrt{\frac{4815,0 \cdot 42,0}{83672,72}} = 1,55 > 0,4$$

Potrebna je provjera na bočno-torzijsko izvijanje

Linija izvijanja b:

$$\phi_{LT} = 0,5 \left[ 1 + \alpha_{LT}(\bar{\lambda}_{LT} - 0,2) + \bar{\lambda}_{LT}^2 \right] = 0,5 \left[ 1 + 0,34(1,55 - 0,2) + 1,55^2 \right] = 1,93$$

$$\chi_{LT} = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} = \frac{1}{1,93 + \sqrt{1,93^2 - 1,55^2}} = 0,32 < 1,0$$

$$M_{b,Rd} = \lambda_{LT} \cdot \frac{W_{pl,y} \cdot f_y}{\gamma_{M1}} = 0,32 \cdot \frac{4815,0 \cdot 42,0}{1,1} = 588,30 \text{ kNm}$$

$$M_{Ed} = 433,78 \text{ kNm} < M_{c,y,Rd} = 588,30 \text{ kNm}$$

Element zadovoljava uz iskoristivost od 74%

Faza uporabe

Proračunski učinci djelovanja

$$e_d = b \cdot (\gamma_G \cdot g_k + \gamma_Q \cdot q_k) = 3,11 \cdot (1,35 \cdot 2,51 + 1,5 \cdot 3,0) = 24,53 \text{ kN/m}$$

$$M_{Ed} = \frac{q \cdot l^2}{8} = \frac{24,53 \cdot 15,54^2}{8} = 740,47 \text{ kNm}$$



$$V_{Ed} = \frac{e_d \cdot l}{2} = \frac{24,53 \cdot 15,54}{2} = 190,60 \text{ kN}$$

Efektivna širina betonske pojasnice u polju

$$b_{eff} = b_0 + b_{e1} + b_{e2}$$

Za jedan red moždanika:

$$b_0 = 0$$

$$b_{e1} = b_{e2} = \frac{L_e}{8} = \frac{L}{8} = \frac{15,54}{8} = 1,94 \text{ m}$$

$$b_{eff} = 0 + 1,94 + 1,94 = 3,88 \text{ m} > b = 3,00 \text{ m}$$

Položaj neutralne osi

Uvjet za neutralnu os u betonskoj pojasnici:

$$b_{eff} \cdot h_c \cdot 0,85 \cdot f_{cd} > A_a \cdot f_{yd}$$

$$300 \cdot 5,4 \cdot 0,85 \cdot 1,67 = 2300 \text{ kN} < 238,60 \cdot 42,0 = 10021 \text{ kN}$$

Neutralna os ne nalazi se u betonskoj pojasnici

$$x_{pl} = h_c + h_p + t_f + \frac{A_a - 2 \cdot b \cdot t_f}{2 \cdot t_w} - \frac{b_{eff} \cdot h_c \cdot 0,85 \cdot f_{cd}}{2 \cdot t_w \cdot f_{yd}}$$

$$x_{pl} = 5,4 + 5,6 + 2,8 + \frac{238,6 - 2 \cdot 30,0 \cdot 2,8}{2 \cdot 1,45} - \frac{300 \cdot 5,4 \cdot 0,85 \cdot 1,67}{2 \cdot 1,45 \cdot 42,0} = 19,26 \text{ cm}$$

Klasifikacija poprečnog presjeka- za savijanje i tlak

$$c = h - 2 \cdot t_f - 2 \cdot r = 814 - 2 \cdot 40 - 2 \cdot 30 = 674 \text{ mm}$$

$$t = t_w = 21 \text{ mm}$$

Za klasu presjeka 1:

$$\alpha = \frac{z_c}{c} = \frac{192,6}{674} = 0,29$$

$$\frac{c}{t_w} = 32,1 \leq \frac{36 \cdot \varepsilon}{\alpha} = \frac{36 \cdot 0,75}{0,29} = 93,1$$

Pojasnica- klase 1

Poprečni presjek je klase 1

Moment plastične otpornosti

$$M_{pl,Rd} = A_a \cdot f_{yd} \cdot \left( z + h_p \cdot \frac{h_c}{2} \right) - t_w \cdot f_{yd} \cdot (x_{pl} - h_c - h_p - t_f)(x_{pl} + h_p + t_f) - b \cdot t_f \cdot f_{yd} \cdot (h_c + 2h_p + t_f)$$

$$M_{pl,Rd} = 238,6 \cdot 42,0 \cdot \left( 40,7 + 5,6 \cdot \frac{5,4}{2} \right) - 1,45 \cdot 42,0 \cdot (19,26 - 5,4 - 5,6 - 2,8)(19,26 + 5,6 + 2,8) - 30,0 \cdot 2,8 \cdot 42 \cdot (5,4 + 2 \cdot 5,6 + 2,8)$$

$$M_{pl,Rd} = 4817 \text{ kNm}$$

$$M_{Ed} = 740,47 \text{ kNm} < M_{pl,Rd} = 4817 \text{ kNm}$$

Presjek zadovoljava uz iskoristivost od 15%

Otpornost poprečnog presjeka na posmik

Provjera izbočavanja hrpta

$$\frac{h_w}{t_w} > 72 \cdot \frac{\varepsilon}{\eta}$$

$$h_w = \frac{h - 2 \cdot t_f}{2} = \frac{500 - 2 \cdot 28,0}{2} = 222,0 \text{ mm}$$

$$\frac{h_w}{t_w} = \frac{222,0}{14,5} = 15,31 < 72 \cdot \frac{0,75}{1,20} = 45$$

Nije potrebna provjera izbočavanja hrpta

$$V_{Ed} = 190,60 \text{ kN} < V_{pl,z,Rd} = 1594 \text{ kN}$$

Presjek zadovoljava uz iskoristivost od 12%

Proračunska otpornost i raspored moždanika

Otkazivanje preko moždanika

$$P_{Rd}^s = \frac{0,8 \cdot f_u \cdot \pi \cdot \frac{d^2}{4}}{\gamma_{Vc}} = \frac{0,8 \cdot 45 \cdot \pi \cdot \frac{2,2^2}{4}}{1,25} = 110 \text{ kN}$$

Otkazivanje preko betona

$$P_{Rd}^c = \frac{0,29 \cdot \alpha \cdot d^2 \sqrt{f_{ck} \cdot E_{cm}}}{\gamma_{Vc}}$$

$\alpha$  – faktor korekcije za vitkost moždanika

$$\frac{h_{sc}}{d} = \frac{80}{22} = 3,64 < 4 \rightarrow \alpha = 0,2 \cdot \left( \frac{h_{sc}}{d} + 1 \right) = 0,2 \cdot \left( \frac{80}{22} + 1 \right) = 0,927$$

$$P_{Rd}^c = \frac{0,29 \cdot 0,927 \cdot 2,2^2 \sqrt{2,5 \cdot 3100}}{1,5} = 76,36 \text{ kN}$$

Potreban broj moždanika

$$n_s = \frac{N_{cf}}{P_{t,Rd}} = \frac{b_{eff} \cdot h_c \cdot 0,85 \cdot f_{cd}}{P_{t,Rd}} = \frac{300 \cdot 5,4 \cdot 0,85 \cdot 1,67}{76,36} = 30,12 \sim 31 \text{ moždanika}$$

Broj rebara uzduž nosača

$$n_r = \frac{L}{b_s} = \frac{15540}{150} = 103,6$$

Moždanik se postavlja na svako treće rebro.

Betonska ploča se u ovom radu ne proračunava, usvajaju se preporuke proizvođača za debljinu ploče i lima prema slici 23.

Pretpostavke:

Raspon  $L = 3,00 \text{ m}$

Debljina ploče  $d = 11 \text{ cm}$

Beton C25/30

Progib tijekom izgradnje  $L/180$

Progib tijekom korištenja  $L/350$

Granično stanje uporabljivosti

Progib u fazi izvedbe- za čelični nosač

$$e_{d,ukupno} = b \cdot (g_k + q_k) = 3,11 \cdot (2,59 + 0,75) = 10,38 \text{ kN/m}$$

$$\delta_{ukupno} = \frac{5}{384} \cdot \frac{e_{d,ukupno} \cdot L^4}{EI_a} = \frac{5 \cdot 0,1038 \cdot 1554^4}{384 \cdot 21000 \cdot 107200} = 3,50 \text{ cm}$$

$$e_{d,promjenjivo} = b \cdot q_k = 3,11 \cdot 0,75 = 2,33 \text{ kN/m}$$

$$\delta_{promjenjivo} = \frac{5}{384} \cdot \frac{e_d \cdot L^4}{EI_a} = \frac{5 \cdot 0,0233 \cdot 1554^4}{384 \cdot 21000 \cdot 107200} = 0,79 \text{ cm}$$

Ograničenja progiba:

$$\delta_{\text{ukupno}} \leq \frac{L}{250} = \frac{1554}{250} = 6,21 \text{ cm}$$

$$\delta_{\text{promjenjivo}} \leq \frac{L}{360} = \frac{1554}{360} = 4,32 \text{ cm}$$

Oba uvjeta zadovoljavaju

Progib u fazi korištenja- spregnuti nosač

Pojednostavljeni postupak

Skupljanje i puzanje uzeti u obzir pomoću  $E_{cm}/2$

$$E_{c,\text{eff}} = \frac{E_{cm}}{2} = \frac{31000}{2} = 1550 \text{ kN/cm}^2$$

$$EI_L = E_a \cdot I_a + E_{c,\text{eff}} \cdot I_c + \frac{E_a \cdot A_a \cdot E_{c,\text{eff}} \cdot A_c}{E_a \cdot A_a + E_{c,\text{eff}} \cdot A_c} \cdot a^2$$

a Razmak između težišta betonske pojasnice i čeličnog nosača

$$a = \frac{h_a}{2} + h_p + \frac{h_c}{2} = \frac{50}{2} + 5,6 + \frac{5,4}{2} = 33,3 \text{ cm}$$

$$EI_L = 21000 \cdot 107200 + 1550 \cdot 3937 + \frac{21000 \cdot 238,6 \cdot 1550 \cdot 1620}{21000 \cdot 238,6 + 1550 \cdot 1620} \cdot 33,3^2$$

$$EI_p = EI_L = 4112177487 \text{ kNcm}^2 = 411217 \text{ kNm}^2$$

$$e_{d,\text{ukupno}} = b \cdot (g_k + q_k) = 3,11 \cdot (2,51 + 2,7 + 3,0) = 25,53 \text{ kN/m}$$

$$e_{d,\text{promjenjivo}} = b \cdot q_k = 3,11 \cdot 3,0 = 9,33 \text{ kN/m}$$

$$\delta_{\text{ukupno}} = \frac{5}{384} \cdot \frac{e_{d,\text{ukupno}} \cdot L^4}{EI_a} = \frac{5 \cdot 0,2553 \cdot 1554^4}{384 \cdot 4112177487} = 4,71 \text{ cm}$$

$$\delta_{\text{promjenjivo}} = \frac{5}{384} \cdot \frac{e_d \cdot L^4}{EI_a} = \frac{5 \cdot 0,0933 \cdot 1554^4}{384 \cdot 4112177487} = 1,72 \text{ cm}$$

Ograničenja progiba:

$$\delta_{\text{ukupno}} \leq \frac{L}{250} = \frac{1554}{250} = 6,21 \text{ cm}$$

$$\delta_{\text{promjenjivo}} \leq \frac{L}{360} = \frac{1554}{360} = 4,32 \text{ cm}$$

Oba uvjeta zadovoljavaju

### 5.3. Dimenzioniranje priključaka

#### 5.3.1. Priključak sekundarnog nosača na glavni nosač

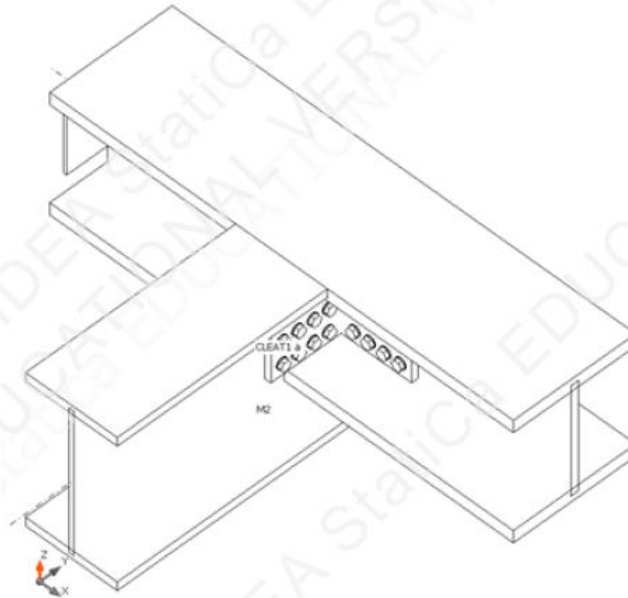
##### Members

##### Geometry

Name	Cross-section	$\beta$ - Direction [°]	$\gamma$ - Pitch [°]	$\alpha$ - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]
M1	1 - CON1(HD400/314)	0.0	0.0	0.0	0	0	0
M2	2 - CON1(HEB500)	-90.0	0.0	0.0	0	0	-50

##### Supports and forces

Name	Support	Forces in	X [mm]
M1 / begin	N-Vy-Vz-Mx-My-Mz	Node	0
M1 / end		Node	0
M2 / end		Bolts	152



**Cross-sections**

Name	Material
1 - CON1(HD400/314)	S 420 N/NL
2 - CON1(HEB500)	S 420 N/NL
4 - L250X20	S 420 N/NL

**Bolts**

Name	Diameter [mm]	$f_y$ [MPa]	$f_u$ [MPa]	Gross area [mm <sup>2</sup> ]
M20 10.9	20	900.0	1000.0	314

**Load effects (forces in equilibrium)**

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	M1 / Begin	85.0	0.0	0.0	0.0	513.0	0.0
	M1 / End	-85.0	0.0	0.0	0.0	-513.0	0.0
	M2 / End	160.0	83.0	-751.0	0.0	0.0	0.0

**Unbalanced forces**

Name	X [kN]	Y [kN]	Z [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	83.0	-160.0	-751.0	106.3	-4.1	12.6

**Check**

**Summary**

Name	Value	Check status
Analysis	100.0%	OK
Plates	2.1 < 5.0%	OK
Bolts	98.3 < 100%	OK
Buckling	15.87	



**Plates**

Name	$t_p$ [mm]	Loads	$\sigma_{Ed}$ [MPa]	$\epsilon_{p1}$ [%]	$\sigma_{c,Ed}$ [MPa]	Status
M1-bfl 1	40.0	LE1	228.9	0.0	0.0	OK
M1-tfl 1	40.0	LE1	261.1	0.0	0.0	OK
M1-w 1	24.5	LE1	420.5	0.3	190.5	OK
M2-bfl 1	28.0	LE1	203.3	0.0	0.0	OK
M2-tfl 1	28.0	LE1	207.6	0.0	0.0	OK
M2-w 1	14.5	LE1	422.2	1.0	62.4	OK
CLEAT1 a-bfl 1	20.0	LE1	420.9	0.4	487.2	OK
CLEAT1 a-w 1	20.0	LE1	422.0	0.9	487.2	OK
CLEAT1 b-bfl 1	20.0	LE1	424.4	2.1	381.1	OK
CLEAT1 b-w 1	20.0	LE1	423.1	1.5	381.1	OK

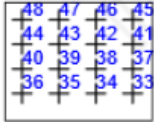
**Design data**

Material	$f_y$ [MPa]	$\epsilon_{lim}$ [%]
S 420 N/NL	420.0	5.0

Bolts

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_{t_t}$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	B1	M20 10.9 - 1	LE1	49.2	38.7	178.8	27.9	39.5	59.4	OK	OK
	B2	M20 10.9 - 1	LE1	38.7	32.4	178.8	22.0	33.0	48.7	OK	OK
	B3	M20 10.9 - 1	LE1	46.7	27.7	158.5	26.5	30.7	47.2	OK	OK
	B4	M20 10.9 - 1	LE1	54.4	24.7	121.9	30.8	37.3	47.2	OK	OK
	B5	M20 10.9 - 1	LE1	6.6	39.7	178.8	3.8	40.5	43.2	OK	OK
	B6	M20 10.9 - 1	LE1	1.9	30.5	158.5	1.1	31.1	31.9	OK	OK
	B7	M20 10.9 - 1	LE1	6.9	22.8	158.5	3.9	27.5	26.1	OK	OK
	B8	M20 10.9 - 1	LE1	12.2	23.8	121.9	6.9	34.1	29.3	OK	OK
	B9	M20 10.9 - 1	LE1	21.9	42.1	178.8	12.4	43.0	51.8	OK	OK
	B10	M20 10.9 - 1	LE1	0.0	30.6	158.5	0.0	31.3	31.3	OK	OK
	B11	M20 10.9 - 1	LE1	0.0	23.7	158.5	0.0	28.2	24.2	OK	OK
	B12	M20 10.9 - 1	LE1	11.3	30.6	121.9	6.4	37.7	35.8	OK	OK
	B13	M20 10.9 - 1	LE1	49.0	46.5	178.8	27.8	47.4	67.3	OK	OK
	B14	M20 10.9 - 1	LE1	7.9	32.3	158.5	4.5	33.8	36.2	OK	OK
	B15	M20 10.9 - 1	LE1	11.6	27.4	158.5	6.6	31.5	32.6	OK	OK
	B16	M20 10.9 - 1	LE1	35.0	34.5	178.8	19.9	35.2	49.4	OK	OK
	B17	M20 10.9 - 1	LE1	14.5	47.8	375.1	8.2	48.8	54.6	OK	OK
	B18	M20 10.9 - 1	LE1	20.8	32.6	218.6	11.8	33.2	41.7	OK	OK
	B19	M20 10.9 - 1	LE1	94.3	43.5	246.6	53.5	44.4	82.6	OK	OK
	B20	M20 10.9 - 1	LE1	158.5	32.1	220.8	89.8	32.8	96.9	OK	OK
	B21	M20 10.9 - 1	LE1	7.7	34.3	416.0	4.4	35.0	38.1	OK	OK
	B22	M20 10.9 - 1	LE1	0.0	21.8	246.6	0.0	22.2	22.2	OK	OK
	B23	M20 10.9 - 1	LE1	0.0	29.3	218.6	0.0	29.9	29.9	OK	OK
	B24	M20 10.9 - 1	LE1	52.4	44.7	130.8	29.7	45.6	66.8	OK	OK
	B25	M20 10.9 - 1	LE1	5.8	25.4	416.0	3.3	25.9	28.2	OK	OK
	B26	M20 10.9 - 1	LE1	1.0	13.1	416.0	0.6	13.3	13.7	OK	OK
	B27	M20 10.9 - 1	LE1	0.0	16.1	218.6	0.0	16.4	16.4	OK	OK
	B28	M20 10.9 - 1	LE1	8.7	27.1	130.8	4.9	27.6	31.2	OK	OK
	B29	M20 10.9 - 1	LE1	4.6	21.1	211.2	2.6	21.6	23.5	OK	OK
	B30	M20 10.9 - 1	LE1	1.9	9.6	211.2	1.1	9.8	10.5	OK	OK
	B31	M20 10.9 - 1	LE1	1.1	4.7	218.6	0.6	4.8	5.2	OK	OK
	B32	M20 10.9 - 1	LE1	4.0	13.6	130.8	2.3	13.8	15.5	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_{t_t}$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	B33	M20 10.9 - 1	LE1	39.2	51.0	348.4	22.2	52.0	67.9	OK	OK
	B34	M20 10.9 - 1	LE1	61.8	26.2	218.6	35.1	26.7	51.7	OK	OK
	B35	M20 10.9 - 1	LE1	129.2	41.2	416.0	73.2	42.0	94.3	OK	OK
	B36	M20 10.9 - 1	LE1	156.0	34.4	235.3	88.4	35.1	98.3	OK	OK
	B37	M20 10.9 - 1	LE1	10.2	42.2	416.0	5.8	43.1	47.2	OK	OK
	B38	M20 10.9 - 1	LE1	0.0	21.9	218.6	0.0	22.4	22.4	OK	OK
	B39	M20 10.9 - 1	LE1	0.0	37.4	416.0	0.0	38.2	38.2	OK	OK
	B40	M20 10.9 - 1	LE1	59.3	62.4	226.3	33.6	63.6	87.6	OK	OK
	B41	M20 10.9 - 1	LE1	6.5	38.3	416.0	3.7	39.1	41.7	OK	OK
	B42	M20 10.9 - 1	LE1	0.5	19.3	246.6	0.3	19.7	19.9	OK	OK
	B43	M20 10.9 - 1	LE1	0.0	30.4	416.0	0.0	31.0	31.0	OK	OK
	B44	M20 10.9 - 1	LE1	12.0	49.4	225.7	6.8	50.4	55.3	OK	OK
	B45	M20 10.9 - 1	LE1	5.0	37.0	416.0	2.8	37.7	39.8	OK	OK
	B46	M20 10.9 - 1	LE1	2.0	18.7	246.6	1.1	19.1	19.9	OK	OK
	B47	M20 10.9 - 1	LE1	0.3	25.7	262.8	0.2	26.3	26.4	OK	OK
	B48	M20 10.9 - 1	LE1	20.8	41.9	227.1	11.8	42.7	51.1	OK	OK



Design data

Grade	$F_{t,Rd}$ [kN]	$E_{p,Rd}$ [kN]	$F_{v,Rd}$ [kN]
M20 10.9 - 1	176.4	498.2	98.0

Buckling

Loads	Shape	Factor [-]
LE1	1	15.87
	2	17.93
	3	26.06
	4	31.56
	5	44.01
	6	46.58

5.3.2. Priključak stupa i dijagonale na temelj

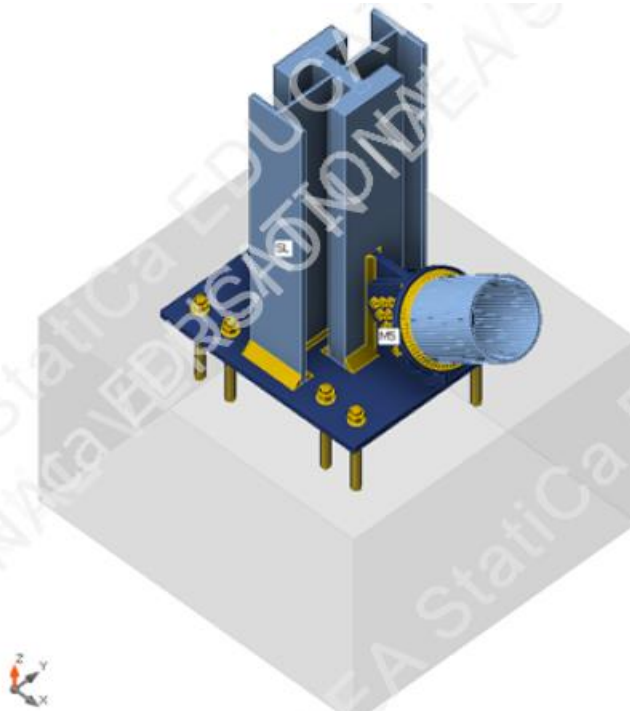
Geometry

Name	Cross-section	$\beta$ - Direction [°]	$\gamma$ - Pitch [°]	$\alpha$ - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]
SL	4 - General	0.0	90.0	0.0	0	0	0
M5	6 - CHS508.0/20.0	0.0	36.0	0.0	0	0	0

Supports and forces

Name	Support	Forces in	X [mm]
SL / end		Node	0
M5 / end		Node	0





**Cross-sections**

Name	Material
4 - General	S 420 N/NL, S 420 N/NL, S 420 N/NL
6 - CHS508.0/20.0	S 420 N/NL

**Anchors / Bolts**

Name	Diameter [mm]	$f_y$ [MPa]	$f_u$ [MPa]	Gross area [mm <sup>2</sup> ]
M60 10.9	60	900.0	1000.0	2827
M33 10.9	33	900.0	1000.0	855

**Load effects (forces in equilibrium)**

Name	Member	N [kN]	V <sub>y</sub> [kN]	V <sub>z</sub> [kN]	M <sub>x</sub> [kNm]	M <sub>y</sub> [kNm]	M <sub>z</sub> [kNm]
LE2	SL / End	-46458.0	0.0	90.6	0.0	0.0	0.0
	M5 / End	7351.0	0.0	0.0	0.0	0.0	0.0

**Unbalanced forces**

Name	X [kN]	Y [kN]	Z [kN]	M <sub>x</sub> [kNm]	M <sub>y</sub> [kNm]	M <sub>z</sub> [kNm]
LE2	5856.5	0.0	-42137.2	0.0	0.0	0.0

## Foundation block

Item	Value	Unit
<b>CB 1</b>		
Dimensions	2322 x 2580	mm
Depth	1500	mm
Anchor	M60 10.9	
Anchoring length	500	mm
Shear force transfer	Friction	

## Check

## Summary

Name	Value	Check status
Analysis	100.0%	OK
Plates	3.4 < 5.0%	OK
Loc. deformation	0.3 < 3%	OK
Bolts	93.9 < 100%	OK
Anchors	49.3 < 100%	OK
Welds	98.7 < 100%	OK
Concrete block	77.2 < 100%	OK
Shear	54.7 < 100%	OK
Buckling	Not calculated	

## Plates

Name	Material	$t_p$ [mm]	Loads	$\sigma_{Ed}$ [MPa]	$\epsilon_{pI}$ [%]	$\sigma_{c,Ed}$ [MPa]	Status
SL-bfl 1	S 420 N/NL	130.0	LE2	352.7	0.0	0.0	OK
SL-tfl 1	S 420 N/NL	130.0	LE2	328.0	0.0	0.0	OK
SL-w 1	S 420 N/NL	95.0	LE2	224.3	0.0	0.0	OK
SL-tfl 2	S 420 N/NL - 1	32.0	LE2	420.8	0.4	0.0	OK
SL-w 2	S 420 N/NL - 1	19.3	LE2	420.6	0.3	0.0	OK
SL-tfl 3	S 420 N/NL - 1	32.0	LE2	420.7	0.4	0.0	OK
SL-w 3	S 420 N/NL - 1	19.3	LE2	420.6	0.3	0.0	OK
M5	S 420 N/NL *	20.0	LE2	385.0	3.4	0.0	OK
BP1	S 460 M/ML	50.0	LE2	430.1	0.0	0.0	OK
CPL1a	S 460 M/ML	50.0	LE2	430.7	0.4	12.3	OK
CPL1b	S 460 M/ML	50.0	LE2	431.4	0.7	0.0	OK
CPL1c	S 460 M/ML	50.0	LE2	375.4	0.0	12.4	OK
CPL1d	S 460 M/ML	50.0	LE2	375.2	0.0	12.4	OK


## Design data

Material	$C_f$ [-]	$f_y$ [MPa]	$\epsilon_{lim}$ [%]
S 420 N/NL	-	390.0	5.0
S 420 N/NL - 1	-	420.0	5.0
S 420 N/NL *	0.90	378.0	5.0
S 460 M/ML	-	430.0	5.0

Loc. deformation

Name	$d_0$ [mm]	Loads	$\delta$ [mm]	$\delta_{lim}$ [mm]	$\delta/d_0$ [%]	Check status
M5	508	LE2	2	15	0.3	OK

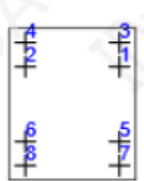
Bolts

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_{t_t}$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	B9	M33 10.9 - 1	LE2	61.4	231.9	493.6	12.3	93.9	92.3	OK	OK
	B10	M33 10.9 - 1	LE2	4.6	214.6	493.6	0.9	87.0	78.0	OK	OK
	B11	M33 10.9 - 1	LE2	0.0	209.0	493.6	0.0	84.7	75.3	OK	OK
	B12	M33 10.9 - 1	LE2	21.0	220.5	493.6	4.2	79.4	82.4	OK	OK
	B13	M33 10.9 - 1	LE2	70.3	194.4	493.6	14.1	78.8	80.1	OK	OK
	B14	M33 10.9 - 1	LE2	6.0	176.7	493.6	1.2	71.6	64.5	OK	OK
	B15	M33 10.9 - 1	LE2	0.0	170.0	493.6	0.0	68.9	61.2	OK	OK
	B16	M33 10.9 - 1	LE2	9.5	180.5	493.6	1.9	65.0	66.4	OK	OK
	B17	M33 10.9 - 1	LE2	71.8	177.7	493.6	14.4	72.0	74.3	OK	OK
	B18	M33 10.9 - 1	LE2	6.3	161.1	493.6	1.3	65.3	58.9	OK	OK
	B19	M33 10.9 - 1	LE2	0.0	154.1	493.6	0.0	62.5	55.5	OK	OK
	B20	M33 10.9 - 1	LE2	7.7	162.1	493.6	1.5	58.4	59.5	OK	OK
	B21	M33 10.9 - 1	LE2	69.6	180.6	493.6	13.9	73.2	75.0	OK	OK
	B22	M33 10.9 - 1	LE2	6.0	164.9	493.6	1.2	66.8	60.2	OK	OK
	B23	M33 10.9 - 1	LE2	0.0	157.9	493.6	0.0	64.0	56.9	OK	OK
	B24	M33 10.9 - 1	LE2	10.9	165.9	493.6	2.2	59.7	61.3	OK	OK
	B25	M33 10.9 - 1	LE2	62.3	204.1	493.6	12.5	82.7	82.4	OK	OK
	B26	M33 10.9 - 1	LE2	5.0	190.3	493.6	1.0	77.1	69.3	OK	OK
	B27	M33 10.9 - 1	LE2	0.0	184.0	493.6	0.0	74.5	66.3	OK	OK
	B28	M33 10.9 - 1	LE2	20.5	192.5	493.6	4.1	69.4	72.3	OK	OK

Design data

Grade	$F_{t,Rd}$ [kN]	$F_{p,Rd}$ [kN]	$F_{v,Rd}$ [kN]
M33 10.9 - 1	499.7	2145.1	277.6

Anchors

Shape	Item	Loads	$N_{Ed}$ [kN]	$V_{Ed}$ [kN]	$N_{Rd,c}$ [kN]	$V_{Rd,cp}$ [kN]	$U_{t_t}$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	A1	LE2	0.0	0.5	0.0	2866.3	0.0	0.1	0.0	OK	OK
	A2	LE2	0.0	0.5	0.0	2866.3	0.0	0.1	0.0	OK	OK
	A3	LE2	147.4	0.5	1184.9	2866.3	49.3	0.1	34.6	OK	OK
	A4	LE2	147.0	0.5	1184.9	2866.3	49.3	0.1	34.6	OK	OK
	A5	LE2	0.0	0.6	0.0	2866.3	0.0	0.1	0.0	OK	OK
	A6	LE2	0.0	0.6	0.0	2866.3	0.0	0.1	0.0	OK	OK
	A7	LE2	144.5	0.6	1184.9	2866.3	49.3	0.1	34.6	OK	OK
	A8	LE2	145.0	0.6	1184.9	2866.3	49.3	0.1	34.6	OK	OK

Design data

Grade	$N_{Rd,s}$ [kN]	$V_{Rd,s}$ [kN]
M60 10.9 - 2	1434.1	787.3

Welds

Item	Edge	T <sub>w</sub> [mm]	L [mm]	Loads	σ <sub>w,Ed</sub> [MPa]	ε <sub>pl</sub> [%]	σ <sub>⊥</sub> [MPa]	τ <sub>⊥</sub> [MPa]	τ <sub>  </sub> [MPa]	U <sub>t</sub> [%]	U <sub>t,c</sub> [%]	Detailing	Status
BP1	SL-bfil 1	▲ 48.0 ▼	471	LE2	463.8	0.3	-141.7	-236.6	-95.0	98.1	91.5	OK	OK
		▲ 48.0 ▼	470	LE2	464.6	0.7	-257.8	204.3	89.7	98.3	92.6	OK	OK
BP1	SL-tfil 1	▲ 48.0 ▼	470	LE2	464.8	0.8	-212.6	-216.7	-100.0	98.3	95.5	OK	OK
		▲ 48.0 ▼	471	LE2	464.0	0.4	-221.0	213.9	98.6	98.1	92.2	OK	OK
BP1	SL-w 1	▲ 15.0 ▼	449	LE2	466.4	1.7	-210.6	-212.2	-112.7	98.7	97.3	OK	OK
		▲ 15.0 ▼	449	LE2	466.4	1.7	-212.8	211.3	113.1	98.7	97.1	OK	OK
BP1	SL-tfil 2	▲ 48.0 ▼	418	LE2	250.0	0.0	-107.0	-113.5	-64.2	52.9	49.5	OK	OK
		▲ 48.0 ▼	418	LE2	241.5	0.0	-110.3	103.8	68.0	51.1	48.0	OK	OK
BP1	SL-w 2	▲ 15.0 ▼	447	LE2	463.9	0.3	-344.2	-168.7	-61.4	98.1	70.1	OK	OK
		▲ 15.0 ▼	447	LE2	464.6	0.7	-140.6	248.9	-58.5	98.3	76.8	OK	OK
BP1	SL-tfil 3	▲ 48.0 ▼	418	LE2	252.5	0.0	-108.5	-113.9	65.9	53.4	49.8	OK	OK
		▲ 48.0 ▼	418	LE2	244.9	0.0	-111.0	105.5	-69.0	51.8	48.5	OK	OK
BP1	SL-w 3	▲ 15.0 ▼	447	LE2	464.5	0.7	-140.8	-250.1	52.8	98.3	74.5	OK	OK
		▲ 15.0 ▼	447	LE2	463.9	0.3	-341.9	166.9	70.1	98.1	68.0	OK	OK
SL-bfil 1	CPL1a	▲ 26.0 ▼	780	LE2	464.3	0.6	232.2	-232.1	-2.3	98.2	83.8	OK	OK
		▲ 26.0 ▼	780	LE2	464.3	0.6	232.2	232.2	2.2	98.2	83.8	OK	OK
CPL1b	CPL1c	▲ 34.0 ▼	578	LE2	463.5	0.1	236.7	228.8	23.8	98.0	95.9	OK	OK
CPL1b	CPL1d	▲ 34.0 ▼	578	LE2	463.5	0.1	233.5	-226.8	-44.7	98.0	96.2	OK	OK
CPL1b	M5	▲ 25.0 ▼	1532	LE2	465.8	1.3	247.1	-228.0	1.2	98.5	57.9	OK	OK

Design data

Material	f <sub>u</sub> [MPa]	β <sub>w</sub> [-]	σ <sub>w,Rd</sub> [MPa]	0.9 σ [MPa]
S 420	520.0	0.88	472.7	374.4

Concrete block

Item	Loads	c [mm]	A <sub>eff</sub> [mm <sup>2</sup> ]	σ [MPa]	k <sub>j</sub> [-]	f <sub>jd</sub> [MPa]	U <sub>t</sub> [%]	Status
CB 1	LE2	63	610772	70.1	2.54	90.8	77.2	OK

Shear in contact plane

Name	Loads	V <sub>y</sub> [kN]	V <sub>z</sub> [kN]	V <sub>Rd,y</sub> [kN]	V <sub>Rd,z</sub> [kN]	U <sub>t</sub> [%]	Status
BP1	LE2	0.0	-5851.9	10703.9	10703.9	54.7	OK

## 5.3.3. Priključak dijagonala na glavni nosač

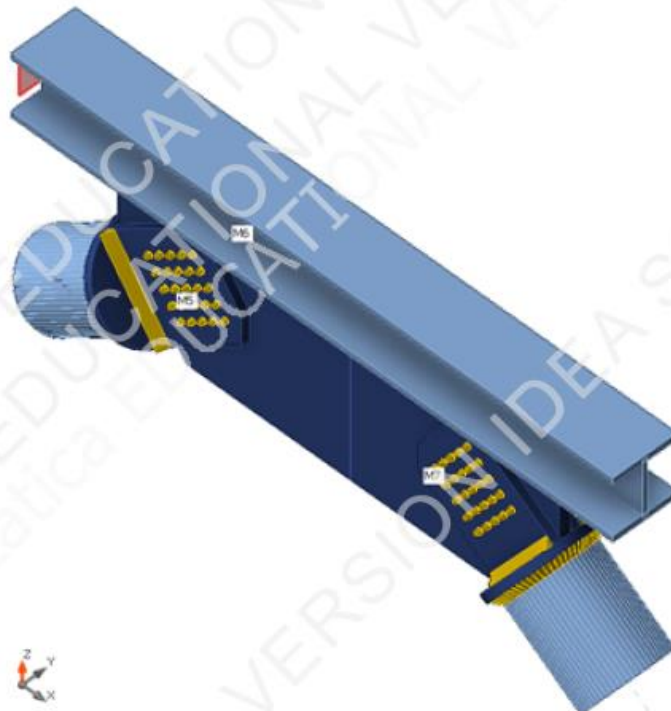
## Members

## Geometry

Name	Cross-section	$\beta$ - Direction [°]	$\gamma$ - Pitch [°]	$\alpha$ - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]
M5	6 - CHS508.0/20.0	180.0	-36.0	0.0	0	0	0
M6	2 - HD400/314	0.0	0.0	0.0	0	0	0
M7	6 - CHS508.0/20.0	0.0	-36.0	0.0	0	0	0

## Supports and forces

Name	Support	Forces in	X [mm]
M5 / end		Node	0
M6 / begin	N-Vy-Vz-Mx-My-Mz	Node	0
M6 / end		Node	0
M7 / end		Node	0



## Cross-sections

Name	Material
6 - CHS508.0/20.0	S 420 N/NL
2 - HD400/314	S 420 N/NL

## Bolts

Name	Diameter [mm]	$f_y$ [MPa]	$f_u$ [MPa]	Gross area [mm <sup>2</sup> ]
M20 10.9	20	900.0	1000.0	314

Load effects (forces in equilibrium)

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE2	M5 / End	3945.0	0.0	0.0	0.0	0.0	0.0
	M6 / End	-2377.0	0.0	0.0	0.0	-256.0	0.0
	M6 / Begin	2377.0	0.0	0.0	0.0	256.0	0.0
	M7 / End	-4745.0	0.0	0.0	0.0	0.0	0.0

Unbalanced forces

Name	X [kN]	Y [kN]	Z [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE2	-7030.4	0.0	470.2	0.0	0.0	0.0

Check

Summary

Name	Value	Check status
Analysis	100.0%	OK
Plates	0.1 < 5.0%	OK
Loc. deformation	0.2 < 3%	OK
Bolts	100.0 < 100%	OK
Welds	98.0 < 100%	OK
Buckling	Not calculated	

Plates

Name	Material	$t_p$ [mm]	Loads	$\sigma_{Ed}$ [MPa]	$\epsilon_{pl}$ [%]	$\sigma_{c,Ed}$ [MPa]	Status
M5	S 420 N/NL *	20.0	LE2	359.5	0.0	0.0	OK
M6-bfl 1	S 420 N/NL	40.0	LE2	373.7	0.0	0.0	OK
M6-tfl 1	S 420 N/NL	40.0	LE2	420.0	0.0	0.0	OK
M6-w 1	S 420 N/NL	24.5	LE2	420.3	0.1	0.0	OK
M7	S 420 N/NL *	20.0	LE2	378.1	0.1	0.0	OK
CPL2a	S 460 M/ML	70.0	LE2	311.9	0.0	33.9	OK
CPL2b	S 460 M/ML	50.0	LE2	190.4	0.0	0.0	OK
CPL2c	S 460 M/ML	50.0	LE2	162.3	0.0	22.5	OK
CPL2d	S 460 M/ML	50.0	LE2	162.6	0.0	22.5	OK
CPL3a	S 460 M/ML	70.0	LE2	318.2	0.0	8.1	OK
CPL3b	S 460 M/ML	50.0	LE2	188.8	0.0	0.0	OK
CPL3c	S 460 M/ML	50.0	LE2	149.4	0.0	8.4	OK
CPL3d	S 460 M/ML	50.0	LE2	149.7	0.0	9.1	OK

Design data

Material	$C_f$ [-]	$f_y$ [MPa]	$\epsilon_{lim}$ [%]
S 420 N/NL *	0.90	378.0	5.0
S 420 N/NL	-	420.0	5.0
S 460 M/ML	-	430.0	5.0

Loc. deformation

Name	$d_0$ [mm]	Loads	$\delta$ [mm]	$\delta_{lim}$ [mm]	$\delta/d_0$ [%]	Check status
M5	508	LE2	1	15	0.2	OK
M7	508	LE2	1	15	0.2	OK

Bolts

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B1	M20 10.9 - 1	LE2	0.0	97.9	1512.0	0.0	99.9	99.9	OK	OK
	B2	M20 10.9 - 1	LE2	2.1	97.0	1512.0	1.2	99.0	99.8	OK	OK
	B3	M20 10.9 - 1	LE2	6.4	95.1	1512.0	3.6	97.1	99.7	OK	OK
	B4	M20 10.9 - 1	LE2	12.1	92.7	1512.0	6.9	94.6	99.5	OK	OK
	B5	M20 10.9 - 1	LE2	16.5	90.8	1512.0	9.3	92.6	99.3	OK	OK
	B6	M20 10.9 - 1	LE2	0.0	97.9	1512.0	0.0	99.9	99.9	OK	OK
	B7	M20 10.9 - 1	LE2	1.4	97.3	1512.0	0.8	99.3	99.9	OK	OK
	B8	M20 10.9 - 1	LE2	5.0	95.7	1512.0	2.8	97.7	99.7	OK	OK
	B9	M20 10.9 - 1	LE2	10.6	93.3	1512.0	6.0	95.2	99.5	OK	OK
	B10	M20 10.9 - 1	LE2	15.7	91.1	1512.0	8.9	93.0	99.4	OK	OK
	B11	M20 10.9 - 1	LE2	0.0	97.9	1512.0	0.0	99.9	99.9	OK	OK
	B12	M20 10.9 - 1	LE2	1.2	97.4	1512.0	0.7	99.4	99.9	OK	OK
	B13	M20 10.9 - 1	LE2	4.6	95.9	1512.0	2.6	97.9	99.8	OK	OK
	B14	M20 10.9 - 1	LE2	9.8	93.7	1512.0	5.6	95.6	99.6	OK	OK
	B15	M20 10.9 - 1	LE2	14.8	91.6	1512.0	8.4	93.4	99.4	OK	OK
	B16	M20 10.9 - 1	LE2	0.0	98.0	1512.0	0.0	100.0	100.0	OK	OK
	B17	M20 10.9 - 1	LE2	1.5	97.3	1512.0	0.9	99.3	99.9	OK	OK
	B18	M20 10.9 - 1	LE2	4.7	95.9	1512.0	2.7	97.9	99.8	OK	OK
	B19	M20 10.9 - 1	LE2	9.3	93.9	1512.0	5.3	95.8	99.6	OK	OK
	B20	M20 10.9 - 1	LE2	13.6	92.1	1512.0	7.7	94.0	99.5	OK	OK
	B21	M20 10.9 - 1	LE2	0.1	97.9	1512.0	0.1	99.9	100.0	OK	OK
	B22	M20 10.9 - 1	LE2	2.4	97.0	1512.0	1.3	98.9	99.9	OK	OK
	B23	M20 10.9 - 1	LE2	5.3	95.7	1512.0	3.0	97.6	99.8	OK	OK
	B24	M20 10.9 - 1	LE2	9.0	94.1	1512.0	5.1	96.0	99.7	OK	OK
	B25	M20 10.9 - 1	LE2	12.0	92.9	1512.0	6.8	94.8	99.6	OK	OK



Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_{t_t}$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	B26	M20 10.9 - 1	LE2	26.1	82.4	1512.0	14.8	84.1	94.7	OK	OK
	B27	M20 10.9 - 1	LE2	8.4	81.9	1512.0	4.7	83.6	87.0	OK	OK
	B28	M20 10.9 - 1	LE2	1.5	82.5	1512.0	0.8	84.2	84.8	OK	OK
	B29	M20 10.9 - 1	LE2	0.0	83.9	1512.0	0.0	85.7	85.7	OK	OK
	B30	M20 10.9 - 1	LE2	0.0	86.7	1512.0	0.0	88.4	88.4	OK	OK
	B31	M20 10.9 - 1	LE2	26.9	76.5	1512.0	15.3	78.1	89.0	OK	OK
	B32	M20 10.9 - 1	LE2	8.1	76.0	1512.0	4.6	77.5	80.8	OK	OK
	B33	M20 10.9 - 1	LE2	1.2	76.6	1512.0	0.7	78.1	78.6	OK	OK
	B34	M20 10.9 - 1	LE2	0.0	78.0	1512.0	0.0	79.6	79.6	OK	OK
	B35	M20 10.9 - 1	LE2	0.0	80.7	1512.0	0.0	82.4	82.4	OK	OK
	B36	M20 10.9 - 1	LE2	27.0	74.0	1512.0	15.3	75.5	86.4	OK	OK
	B37	M20 10.9 - 1	LE2	8.0	73.6	1512.0	4.5	75.1	78.4	OK	OK
	B38	M20 10.9 - 1	LE2	1.1	74.3	1512.0	0.6	75.8	76.3	OK	OK
	B39	M20 10.9 - 1	LE2	0.0	75.8	1512.0	0.0	77.4	77.4	OK	OK
	B40	M20 10.9 - 1	LE2	0.0	78.6	1512.0	0.0	80.2	80.2	OK	OK
	B41	M20 10.9 - 1	LE2	26.5	74.8	1512.0	15.0	76.3	87.1	OK	OK
	B42	M20 10.9 - 1	LE2	8.0	74.7	1512.0	4.5	76.2	79.5	OK	OK
	B43	M20 10.9 - 1	LE2	1.2	75.6	1512.0	0.7	77.2	77.7	OK	OK
	B44	M20 10.9 - 1	LE2	0.0	77.4	1512.0	0.0	78.9	78.9	OK	OK
	B45	M20 10.9 - 1	LE2	0.0	80.5	1512.0	0.0	82.1	82.1	OK	OK
	B46	M20 10.9 - 1	LE2	25.3	79.5	1512.0	14.3	81.1	91.3	OK	OK
	B47	M20 10.9 - 1	LE2	8.0	79.7	1512.0	4.5	81.3	84.6	OK	OK
	B48	M20 10.9 - 1	LE2	1.3	80.9	1512.0	0.7	82.5	83.0	OK	OK
	B49	M20 10.9 - 1	LE2	0.0	82.9	1512.0	0.0	84.6	84.6	OK	OK
	B50	M20 10.9 - 1	LE2	0.0	86.4	1512.0	0.0	88.2	88.2	OK	OK



Design data

Grade	$F_{t,Rd}$ [kN]	$B_{p,Rd}$ [kN]	$F_{v,Rd}$ [kN]
M20 10.9 - 1	176.4	1293.3	98.0



## Welds

Item	Edge	$T_w$ [mm]	L [mm]	Loads	$\sigma_{w,Ed}$ [MPa]	$\epsilon_{pl}$ [%]	$\sigma_{\perp}$ [MPa]	$\tau_{\perp}$ [MPa]	$\tau_{\parallel}$ [MPa]	Ut [%]	Ut <sub>c</sub> [%]	Detailing	Status
M6-bfl 1	CPL2a	▲ 42.0 ▼	1298	LE2	463.4	0.1	-145.5	-145.5	-208.3	98.0	72.5	OK	OK
		▲ 42.0 ▼	1298	LE2	463.4	0.1	-145.5	145.5	208.3	98.0	72.5	OK	OK
CPL2b	CPL2c	▲ 35.0 ▼	598	LE2	300.2	0.0	-167.9	-143.7	1.6	63.5	45.8	OK	OK
CPL2b	CPL2d	▲ 35.0 ▼	598	LE2	301.0	0.0	-168.3	144.1	-0.3	63.7	46.3	OK	OK
M6-bfl 1	CPL3a	▲ 42.0 ▼	1448	LE2	379.0	0.0	166.2	166.2	-105.2	80.2	55.1	OK	OK
		▲ 42.0 ▼	1448	LE2	379.0	0.0	166.2	-166.2	105.2	80.2	55.1	OK	OK
CPL3b	CPL3c	▲ 35.0 ▼	598	LE2	265.1	0.0	133.4	132.3	-0.8	56.1	41.7	OK	OK
CPL3b	CPL3d	▲ 35.0 ▼	598	LE2	264.7	0.0	133.1	-132.1	0.8	56.0	42.0	OK	OK
CPL2b	M7	▲ 35.0 ▼	1532	LE2	305.1	0.0	-147.4	154.2	-1.5	64.5	22.2	OK	OK
CPL3b	M5	▲ 35.0 ▼	1532	LE2	266.2	0.0	126.7	-134.4	-13.9	56.3	19.3	OK	OK

## Design data

Material	$f_u$ [MPa]	$\beta_w$ [-]	$\sigma_{w,Rd}$ [MPa]	$0.9 \sigma$ [MPa]
S 420	520.0	0.88	472.7	374.4

### 5.3.4. Nastavak stupa

#### Members

##### Geometry

Name	Cross-section	$\beta$ - Direction [°]	$\gamma$ - Pitch [°]	$\alpha$ - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]
B1	4 - General	0.0	90.0	0.0	0	0	0
B2	4 - General	0.0	-90.0	0.0	0	0	0

##### Supports and forces

Name	Support	Forces in	X [mm]
B1 / end		Node	0
B2 / end	N-Vy-Vz-Mx-My-Mz	Node	0



##### Cross-sections

Name	Material
4 - General	S 420 N/NL, S 420 N/NL, S 420 N/NL

##### Bolts

Name	Diameter [mm]	$f_y$ [MPa]	$f_u$ [MPa]	Gross area [mm <sup>2</sup> ]
M20 10.9	20	900.0	1000.0	314

##### Load effects (forces in equilibrium)

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	B1 / End	-16435.0	107.0	802.0	0.0	2453.0	0.0
	B2 / End	-16435.0	107.0	802.0	0.0	-2435.0	0.0

## Unbalanced forces

Name	X [kN]	Y [kN]	Z [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	0.0	214.0	0.0	0.0	18.0	0.0

## Check

## Summary


Name	Value	Check status
Analysis	100.0%	OK
Plates	2.8 < 5.0%	OK
Bolts	99.9 < 100%	OK
Buckling	Not calculated	

## Plates

Name	Material	$t_p$ [mm]	Loads	$\sigma_{Ed}$ [MPa]	$\epsilon_{pl}$ [%]	$\sigma_{c,Ed}$ [MPa]	Status
B1-bfl 1	S 420 N/NL	130.0	LE1	228.6	0.0	48.2	OK
B1-tfl 1	S 420 N/NL	130.0	LE1	101.3	0.0	95.7	OK
B1-w 1	S 420 N/NL	95.0	LE1	183.0	0.0	0.0	OK
B1-tfl 2	S 420 N/NL - 1	32.0	LE1	325.2	0.0	11.4	OK
B1-w 2	S 420 N/NL - 1	19.3	LE1	357.7	0.0	0.0	OK
B1-tfl 3	S 420 N/NL - 1	32.0	LE1	319.8	0.0	21.8	OK
B1-w 3	S 420 N/NL - 1	19.3	LE1	367.8	0.0	0.0	OK
B2-bfl 1	S 420 N/NL	130.0	LE1	59.7	0.0	29.0	OK
B2-tfl 1	S 420 N/NL	130.0	LE1	170.5	0.0	46.9	OK
B2-w 1	S 420 N/NL	95.0	LE1	111.6	0.0	0.0	OK
B2-tfl 2	S 420 N/NL - 1	32.0	LE1	285.6	0.0	21.3	OK
B2-w 2	S 420 N/NL - 1	19.3	LE1	321.3	0.0	0.0	OK
B2-tfl 3	S 420 N/NL - 1	32.0	LE1	293.1	0.0	11.7	OK
B2-w 3	S 420 N/NL - 1	19.3	LE1	311.0	0.0	0.0	OK
SPL1a	S 420 N/NL - 1	25.0	LE1	381.8	0.0	119.4	OK
SPL1b	S 420 N/NL - 1	25.0	LE1	410.4	0.0	40.0	OK
SPL1c	S 420 N/NL - 1	25.0	LE1	407.7	0.0	36.1	OK
SPL2a	S 420 N/NL - 1	25.0	LE1	300.9	0.0	13.0	OK
SPL2b	S 420 N/NL - 1	25.0	LE1	226.2	0.0	8.1	OK
SPL2c	S 420 N/NL - 1	25.0	LE1	319.5	0.0	14.2	OK
SPL3a	S 420 N/NL - 1	25.0	LE1	297.9	0.0	18.3	OK
SPL3b	S 420 N/NL - 1	25.0	LE1	236.8	0.0	5.7	OK
SPL3c	S 420 N/NL - 1	25.0	LE1	321.1	0.0	12.6	OK
SPL4a	S 420 N/NL - 1	25.0	LE1	426.0	2.8	52.7	OK
SPL4b	S 420 N/NL - 1	25.0	LE1	424.0	1.9	34.4	OK
SPL4c	S 420 N/NL - 1	25.0	LE1	424.0	1.9	33.3	OK

Design data

Material	$f_y$ [MPa]	$\epsilon_{lim}$ [%]
S 420 N/NL	390.0	5.0
S 420 N/NL - 1	420.0	5.0


Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	B1	M20 10.9 - 1	LE1	53.4	11.1	227.2	30.3	11.3	32.9	OK	OK
	B2	M20 10.9 - 1	LE1	15.0	23.3	203.1	8.5	23.8	29.8	OK	OK
	B3	M20 10.9 - 1	LE1	2.3	30.4	203.1	1.3	31.1	32.0	OK	OK
	B4	M20 10.9 - 1	LE1	0.5	29.4	203.1	0.3	30.0	30.2	OK	OK
	B5	M20 10.9 - 1	LE1	0.1	27.0	203.1	0.1	27.6	27.6	OK	OK
	B6	M20 10.9 - 1	LE1	0.1	25.1	203.1	0.1	25.6	25.7	OK	OK
	B7	M20 10.9 - 1	LE1	0.1	23.6	203.1	0.1	24.1	24.2	OK	OK
	B8	M20 10.9 - 1	LE1	0.5	22.6	203.1	0.3	23.0	23.2	OK	OK
	B9	M20 10.9 - 1	LE1	2.9	21.8	203.1	1.6	22.2	23.4	OK	OK
	B10	M20 10.9 - 1	LE1	9.3	21.0	203.1	5.3	21.4	25.2	OK	OK
	B11	M20 10.9 - 1	LE1	45.8	7.9	485.4	26.0	8.1	26.6	OK	OK
	B12	M20 10.9 - 1	LE1	11.1	22.7	203.1	6.3	23.2	27.7	OK	OK
	B13	M20 10.9 - 1	LE1	1.2	29.2	203.1	0.7	29.8	30.2	OK	OK
	B14	M20 10.9 - 1	LE1	0.3	28.0	203.1	0.2	28.6	28.7	OK	OK
	B15	M20 10.9 - 1	LE1	0.2	25.8	203.1	0.1	26.3	26.4	OK	OK
	B16	M20 10.9 - 1	LE1	0.2	24.0	203.1	0.1	24.5	24.6	OK	OK
	B17	M20 10.9 - 1	LE1	0.2	22.7	203.1	0.1	23.1	23.2	OK	OK
	B18	M20 10.9 - 1	LE1	0.3	21.6	203.1	0.2	22.1	22.2	OK	OK
	B19	M20 10.9 - 1	LE1	2.0	20.9	203.1	1.1	21.4	22.2	OK	OK
	B20	M20 10.9 - 1	LE1	8.2	20.2	203.1	4.6	20.6	24.0	OK	OK
	B21	M20 10.9 - 1	LE1	45.3	8.9	203.1	25.7	9.1	27.5	OK	OK
	B22	M20 10.9 - 1	LE1	12.1	22.6	203.1	6.8	23.1	28.0	OK	OK
	B23	M20 10.9 - 1	LE1	2.1	28.9	203.1	1.2	29.5	30.4	OK	OK
	B24	M20 10.9 - 1	LE1	0.9	27.6	203.1	0.5	28.1	28.5	OK	OK
	B25	M20 10.9 - 1	LE1	0.4	25.4	203.1	0.2	25.9	26.1	OK	OK
	B26	M20 10.9 - 1	LE1	0.2	23.8	203.1	0.1	24.2	24.3	OK	OK
	B27	M20 10.9 - 1	LE1	0.3	22.5	203.1	0.1	22.9	23.0	OK	OK
	B28	M20 10.9 - 1	LE1	0.3	21.6	203.1	0.2	22.0	22.1	OK	OK
	B29	M20 10.9 - 1	LE1	1.6	21.0	203.1	0.9	21.4	22.0	OK	OK
	B30	M20 10.9 - 1	LE1	7.5	20.5	203.1	4.3	20.9	23.9	OK	OK
	B31	M20 10.9 - 1	LE1	53.2	12.9	520.0	30.1	13.1	34.7	OK	OK
	B32	M20 10.9 - 1	LE1	14.1	24.0	203.1	8.0	24.5	30.2	OK	OK
	B33	M20 10.9 - 1	LE1	1.7	31.3	203.1	1.0	32.0	32.7	OK	OK
	B34	M20 10.9 - 1	LE1	0.2	30.2	203.1	0.1	30.8	30.9	OK	OK
	B35	M20 10.9 - 1	LE1	0.0	27.6	203.1	0.0	28.2	28.2	OK	OK
	B36	M20 10.9 - 1	LE1	0.0	25.5	203.1	0.0	26.0	26.0	OK	OK
	B37	M20 10.9 - 1	LE1	0.1	23.9	203.1	0.0	24.4	24.4	OK	OK

B38	M20 10.9 - 1	LE1	0.5	22.8	203.1	0.3	23.2	23.4	OK	OK
B39	M20 10.9 - 1	LE1	3.0	21.9	203.1	1.7	22.4	23.6	OK	OK
B40	M20 10.9 - 1	LE1	9.6	21.1	203.1	5.4	21.5	25.4	OK	OK
B41	M20 10.9 - 1	LE1	47.0	9.9	308.2	26.6	10.1	29.1	OK	OK
B42	M20 10.9 - 1	LE1	11.3	22.5	203.1	6.4	22.9	27.5	OK	OK
B43	M20 10.9 - 1	LE1	1.2	29.2	203.1	0.7	29.8	30.3	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B44	M20 10.9 - 1	LE1	0.3	28.2	203.1	0.2	28.7	28.9	OK	OK
	B45	M20 10.9 - 1	LE1	0.3	25.9	203.1	0.1	26.4	26.5	OK	OK
	B46	M20 10.9 - 1	LE1	0.2	24.1	203.1	0.1	24.6	24.7	OK	OK
	B47	M20 10.9 - 1	LE1	0.2	22.7	203.1	0.1	23.2	23.3	OK	OK
	B48	M20 10.9 - 1	LE1	0.3	21.6	203.1	0.1	22.1	22.2	OK	OK
	B49	M20 10.9 - 1	LE1	2.1	20.9	203.1	1.2	21.3	22.1	OK	OK
	B50	M20 10.9 - 1	LE1	8.5	20.0	203.1	4.8	20.4	23.9	OK	OK
	B51	M20 10.9 - 1	LE1	48.0	6.5	423.8	27.2	6.6	26.0	OK	OK
	B52	M20 10.9 - 1	LE1	13.5	21.4	203.1	7.6	21.8	27.3	OK	OK
	B53	M20 10.9 - 1	LE1	2.9	28.3	203.1	1.6	28.9	30.0	OK	OK
	B54	M20 10.9 - 1	LE1	1.4	27.2	203.1	0.8	27.7	28.3	OK	OK
	B55	M20 10.9 - 1	LE1	0.7	25.1	203.1	0.4	25.7	25.9	OK	OK
	B56	M20 10.9 - 1	LE1	0.3	23.6	203.1	0.2	24.0	24.2	OK	OK
	B57	M20 10.9 - 1	LE1	0.2	22.3	203.1	0.1	22.8	22.9	OK	OK
	B58	M20 10.9 - 1	LE1	0.2	21.4	203.1	0.1	21.8	21.9	OK	OK
	B59	M20 10.9 - 1	LE1	1.6	20.8	203.1	0.9	21.2	21.9	OK	OK
	B60	M20 10.9 - 1	LE1	7.9	20.1	203.1	4.5	20.6	23.7	OK	OK
	B61	M20 10.9 - 1	LE1	60.5	35.5	203.1	34.3	36.2	60.7	OK	OK
	B62	M20 10.9 - 1	LE1	25.7	30.9	203.1	14.6	31.6	42.0	OK	OK
	B63	M20 10.9 - 1	LE1	7.7	27.1	203.1	4.4	27.7	30.8	OK	OK
	B64	M20 10.9 - 1	LE1	1.4	23.7	203.1	0.8	24.2	24.8	OK	OK
	B65	M20 10.9 - 1	LE1	0.1	21.0	203.1	0.0	21.5	21.5	OK	OK
	B66	M20 10.9 - 1	LE1	0.1	19.1	203.1	0.0	19.5	19.5	OK	OK
	B67	M20 10.9 - 1	LE1	0.2	17.8	203.1	0.1	18.2	18.3	OK	OK
	B68	M20 10.9 - 1	LE1	0.5	17.1	203.1	0.3	17.5	17.7	OK	OK
	B69	M20 10.9 - 1	LE1	1.6	16.9	203.1	0.9	17.2	17.9	OK	OK
	B70	M20 10.9 - 1	LE1	4.0	16.7	203.1	2.3	17.0	18.7	OK	OK
	B71	M20 10.9 - 1	LE1	47.9	33.8	203.1	27.1	34.5	53.9	OK	OK
	B72	M20 10.9 - 1	LE1	17.1	30.2	203.1	9.7	30.8	37.8	OK	OK
	B73	M20 10.9 - 1	LE1	3.7	26.7	203.1	2.1	27.2	28.7	OK	OK
	B74	M20 10.9 - 1	LE1	0.2	23.4	203.1	0.1	23.9	24.0	OK	OK
	B75	M20 10.9 - 1	LE1	0.0	20.9	203.1	0.0	21.3	21.3	OK	OK
	B76	M20 10.9 - 1	LE1	0.1	19.1	203.1	0.1	19.5	19.5	OK	OK
	B77	M20 10.9 - 1	LE1	0.2	17.8	203.1	0.1	18.2	18.3	OK	OK
	B78	M20 10.9 - 1	LE1	0.3	17.1	203.1	0.2	17.5	17.6	OK	OK
	B79	M20 10.9 - 1	LE1	1.1	16.8	203.1	0.7	17.2	17.6	OK	OK
	B80	M20 10.9 - 1	LE1	3.5	16.6	203.1	2.0	17.0	18.4	OK	OK

B81	M20 10.9 - 1	LE1	46.7	33.8	203.1	26.5	34.5	53.4	OK	OK
B82	M20 10.9 - 1	LE1	15.7	30.0	203.1	8.9	30.6	37.0	OK	OK
B83	M20 10.9 - 1	LE1	2.5	26.7	203.1	1.4	27.2	28.2	OK	OK
B84	M20 10.9 - 1	LE1	0.0	23.7	203.1	0.0	24.2	24.2	OK	OK
B85	M20 10.9 - 1	LE1	0.0	21.3	203.1	0.0	21.7	21.7	OK	OK
B86	M20 10.9 - 1	LE1	0.1	19.5	203.1	0.0	19.9	19.9	OK	OK


Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B87	M20 10.9 - 1	LE1	0.1	18.3	203.1	0.1	18.6	18.7	OK	OK
	B88	M20 10.9 - 1	LE1	0.2	17.6	203.1	0.1	18.0	18.0	OK	OK
	B89	M20 10.9 - 1	LE1	1.0	17.4	203.1	0.6	17.7	18.1	OK	OK
	B90	M20 10.9 - 1	LE1	3.3	17.2	203.1	1.9	17.5	18.9	OK	OK
	B91	M20 10.9 - 1	LE1	61.1	34.3	203.1	34.7	35.0	59.8	OK	OK
	B92	M20 10.9 - 1	LE1	26.1	29.9	203.1	14.8	30.6	41.1	OK	OK
	B93	M20 10.9 - 1	LE1	8.0	26.4	203.1	4.6	26.9	30.2	OK	OK
	B94	M20 10.9 - 1	LE1	1.7	23.1	203.1	0.9	23.6	24.3	OK	OK
	B95	M20 10.9 - 1	LE1	0.2	20.6	203.1	0.1	21.1	21.1	OK	OK
	B96	M20 10.9 - 1	LE1	0.1	18.8	203.1	0.1	19.2	19.3	OK	OK
	B97	M20 10.9 - 1	LE1	0.2	17.7	203.1	0.1	18.0	18.1	OK	OK
	B98	M20 10.9 - 1	LE1	0.5	17.0	203.1	0.3	17.4	17.6	OK	OK
	B99	M20 10.9 - 1	LE1	1.5	16.8	203.1	0.9	17.2	17.8	OK	OK
	B100	M20 10.9 - 1	LE1	3.7	16.7	203.1	2.1	17.0	18.6	OK	OK
	B101	M20 10.9 - 1	LE1	49.4	33.7	203.1	28.0	34.4	54.4	OK	OK
	B102	M20 10.9 - 1	LE1	17.4	30.1	203.1	9.9	30.7	37.8	OK	OK
	B103	M20 10.9 - 1	LE1	3.8	26.6	203.1	2.1	27.2	28.7	OK	OK
	B104	M20 10.9 - 1	LE1	0.3	23.4	203.1	0.1	23.8	23.9	OK	OK
	B105	M20 10.9 - 1	LE1	0.0	20.8	203.1	0.0	21.2	21.2	OK	OK
	B106	M20 10.9 - 1	LE1	0.1	19.0	203.1	0.1	19.4	19.5	OK	OK
	B107	M20 10.9 - 1	LE1	0.2	17.8	203.1	0.1	18.2	18.3	OK	OK
	B108	M20 10.9 - 1	LE1	0.3	17.1	203.1	0.2	17.5	17.6	OK	OK
	B109	M20 10.9 - 1	LE1	1.1	16.9	203.1	0.6	17.3	17.7	OK	OK
	B110	M20 10.9 - 1	LE1	3.1	16.7	203.1	1.8	17.0	18.3	OK	OK
	B111	M20 10.9 - 1	LE1	48.5	34.8	203.1	27.5	35.5	55.1	OK	OK
	B112	M20 10.9 - 1	LE1	15.9	30.8	203.1	9.0	31.4	37.8	OK	OK
	B113	M20 10.9 - 1	LE1	2.2	27.3	203.1	1.3	27.9	28.8	OK	OK
	B114	M20 10.9 - 1	LE1	0.0	24.1	203.1	0.0	24.6	24.6	OK	OK
	B115	M20 10.9 - 1	LE1	0.0	21.5	203.1	0.0	22.0	22.0	OK	OK
	B116	M20 10.9 - 1	LE1	0.1	19.7	203.1	0.0	20.1	20.1	OK	OK
	B117	M20 10.9 - 1	LE1	0.1	18.5	203.1	0.1	18.8	18.9	OK	OK
	B118	M20 10.9 - 1	LE1	0.3	17.8	203.1	0.2	18.2	18.3	OK	OK
	B119	M20 10.9 - 1	LE1	1.0	17.6	203.1	0.6	17.9	18.3	OK	OK
	B120	M20 10.9 - 1	LE1	3.0	17.4	203.1	1.7	17.8	19.0	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B121	M20 10.9 - 1	LE1	14.3	41.2	260.0	8.1	42.0	47.8	OK	OK
	B122	M20 10.9 - 1	LE1	3.8	37.0	260.0	2.2	37.8	39.3	OK	OK
	B123	M20 10.9 - 1	LE1	1.6	33.7	260.0	0.9	34.4	35.0	OK	OK
	B124	M20 10.9 - 1	LE1	1.2	31.2	260.0	0.7	31.9	32.4	OK	OK
	B125	M20 10.9 - 1	LE1	1.2	30.0	260.0	0.7	30.6	31.1	OK	OK
	B126	M20 10.9 - 1	LE1	1.2	30.1	260.0	0.7	30.7	31.2	OK	OK
	B127	M20 10.9 - 1	LE1	1.3	31.5	260.0	0.8	32.1	32.6	OK	OK
	B128	M20 10.9 - 1	LE1	1.6	34.1	260.0	0.9	34.8	35.5	OK	OK
	B129	M20 10.9 - 1	LE1	2.0	38.1	260.0	1.1	38.9	39.7	OK	OK
	B130	M20 10.9 - 1	LE1	0.4	43.7	394.5	0.2	44.6	44.8	OK	OK
	B131	M20 10.9 - 1	LE1	10.9	41.3	260.0	6.2	42.2	46.6	OK	OK
	B132	M20 10.9 - 1	LE1	1.2	36.2	260.0	0.7	36.9	37.4	OK	OK
	B133	M20 10.9 - 1	LE1	0.3	32.0	260.0	0.2	32.7	32.8	OK	OK
	B134	M20 10.9 - 1	LE1	0.5	29.1	260.0	0.3	29.7	29.9	OK	OK
	B135	M20 10.9 - 1	LE1	0.6	27.6	260.0	0.3	28.1	28.3	OK	OK
	B136	M20 10.9 - 1	LE1	0.6	28.2	260.0	0.3	28.8	29.1	OK	OK
	B137	M20 10.9 - 1	LE1	0.7	30.3	260.0	0.4	31.0	31.2	OK	OK
	B138	M20 10.9 - 1	LE1	1.0	33.9	260.0	0.6	34.6	35.0	OK	OK
	B139	M20 10.9 - 1	LE1	1.7	39.1	260.0	1.0	39.9	40.6	OK	OK
	B140	M20 10.9 - 1	LE1	0.2	46.2	203.1	0.1	47.2	47.3	OK	OK
	B141	M20 10.9 - 1	LE1	8.8	43.8	260.0	5.0	44.6	48.2	OK	OK
	B142	M20 10.9 - 1	LE1	0.5	37.4	260.0	0.3	38.2	38.3	OK	OK
	B143	M20 10.9 - 1	LE1	0.1	32.3	260.0	0.0	33.0	33.0	OK	OK
	B144	M20 10.9 - 1	LE1	0.5	29.1	260.0	0.3	29.7	29.9	OK	OK
	B145	M20 10.9 - 1	LE1	0.5	28.6	260.0	0.3	29.2	29.4	OK	OK
	B146	M20 10.9 - 1	LE1	0.7	29.6	260.0	0.4	30.2	30.5	OK	OK
	B147	M20 10.9 - 1	LE1	1.1	32.2	260.0	0.6	32.8	33.2	OK	OK
	B148	M20 10.9 - 1	LE1	2.0	36.4	260.0	1.2	37.1	37.9	OK	OK
	B149	M20 10.9 - 1	LE1	3.4	42.4	260.0	1.9	43.3	44.7	OK	OK
	B150	M20 10.9 - 1	LE1	1.4	50.7	203.1	0.8	51.7	52.3	OK	OK
	B151	M20 10.9 - 1	LE1	10.1	35.1	260.0	5.7	35.8	39.9	OK	OK
	B152	M20 10.9 - 1	LE1	2.0	30.9	260.0	1.1	31.5	32.3	OK	OK
	B153	M20 10.9 - 1	LE1	0.7	27.2	260.0	0.4	27.7	28.0	OK	OK
B154	M20 10.9 - 1	LE1	0.6	24.4	260.0	0.3	24.9	25.1	OK	OK	
B155	M20 10.9 - 1	LE1	0.5	22.8	260.0	0.3	23.3	23.5	OK	OK	
B156	M20 10.9 - 1	LE1	0.4	23.1	260.0	0.3	23.5	23.7	OK	OK	
B157	M20 10.9 - 1	LE1	0.5	23.9	260.0	0.3	24.4	24.6	OK	OK	
B158	M20 10.9 - 1	LE1	0.9	25.4	260.0	0.5	26.0	26.3	OK	OK	
B159	M20 10.9 - 1	LE1	1.6	27.6	260.0	0.9	28.2	28.8	OK	OK	
B160	M20 10.9 - 1	LE1	1.0	30.8	203.1	0.6	31.4	31.8	OK	OK	
B161	M20 10.9 - 1	LE1	8.0	28.6	260.0	4.5	29.2	32.5	OK	OK	
B162	M20 10.9 - 1	LE1	0.7	25.6	260.0	0.4	26.1	26.4	OK	OK	
B163	M20 10.9 - 1	LE1	0.1	22.9	260.0	0.1	23.3	23.4	OK	OK	

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B164	M20 10.9 - 1	LE1	0.4	20.8	260.0	0.2	21.2	21.4	OK	OK
	B165	M20 10.9 - 1	LE1	0.4	19.4	260.0	0.2	19.8	20.0	OK	OK
	B166	M20 10.9 - 1	LE1	0.4	18.8	260.0	0.3	19.2	19.3	OK	OK
	B167	M20 10.9 - 1	LE1	0.4	19.3	260.0	0.3	19.7	19.9	OK	OK
	B168	M20 10.9 - 1	LE1	0.5	20.2	260.0	0.3	20.7	20.9	OK	OK
	B169	M20 10.9 - 1	LE1	0.7	21.7	260.0	0.4	22.1	22.4	OK	OK
	B170	M20 10.9 - 1	LE1	0.0	24.0	394.5	0.0	24.5	24.5	OK	OK
	B171	M20 10.9 - 1	LE1	7.5	24.1	260.0	4.2	24.6	27.7	OK	OK
	B172	M20 10.9 - 1	LE1	0.9	22.1	260.0	0.5	22.6	23.0	OK	OK
	B173	M20 10.9 - 1	LE1	0.2	20.5	260.0	0.1	20.9	21.0	OK	OK
	B174	M20 10.9 - 1	LE1	0.4	19.1	260.0	0.2	19.4	19.6	OK	OK
	B175	M20 10.9 - 1	LE1	0.4	18.0	260.0	0.2	18.4	18.6	OK	OK
	B176	M20 10.9 - 1	LE1	0.4	17.4	260.0	0.3	17.7	17.9	OK	OK
	B177	M20 10.9 - 1	LE1	0.4	17.1	260.0	0.2	17.5	17.7	OK	OK
	B178	M20 10.9 - 1	LE1	0.4	17.3	260.0	0.2	17.7	17.8	OK	OK
	B179	M20 10.9 - 1	LE1	0.5	18.0	260.0	0.3	18.4	18.6	OK	OK
	B180	M20 10.9 - 1	LE1	0.0	19.7	357.8	0.0	20.1	20.1	OK	OK
	B181	M20 10.9 - 1	LE1	13.6	42.2	260.0	7.7	43.0	48.6	OK	OK
	B182	M20 10.9 - 1	LE1	2.4	38.5	260.0	1.3	39.3	40.3	OK	OK
	B183	M20 10.9 - 1	LE1	0.8	35.4	260.0	0.4	36.2	36.5	OK	OK
	B184	M20 10.9 - 1	LE1	0.9	33.0	260.0	0.5	33.7	34.1	OK	OK
	B185	M20 10.9 - 1	LE1	0.9	31.7	260.0	0.5	32.3	32.7	OK	OK
	B186	M20 10.9 - 1	LE1	1.0	31.6	260.0	0.5	32.2	32.6	OK	OK
	B187	M20 10.9 - 1	LE1	1.1	32.6	260.0	0.6	33.3	33.7	OK	OK
	B188	M20 10.9 - 1	LE1	1.3	35.0	260.0	0.7	35.7	36.2	OK	OK
	B189	M20 10.9 - 1	LE1	1.7	38.6	260.0	1.0	39.3	40.0	OK	OK
	B190	M20 10.9 - 1	LE1	0.4	43.5	394.5	0.2	44.4	44.5	OK	OK
	B191	M20 10.9 - 1	LE1	10.8	40.9	260.0	6.1	41.7	46.1	OK	OK
	B192	M20 10.9 - 1	LE1	1.0	36.2	260.0	0.6	37.0	37.4	OK	OK
	B193	M20 10.9 - 1	LE1	0.3	32.4	260.0	0.2	33.1	33.2	OK	OK
	B194	M20 10.9 - 1	LE1	0.6	29.6	260.0	0.3	30.2	30.4	OK	OK
	B195	M20 10.9 - 1	LE1	0.6	28.1	260.0	0.3	28.7	28.9	OK	OK
	B196	M20 10.9 - 1	LE1	0.6	27.9	260.0	0.4	28.5	28.7	OK	OK
	B197	M20 10.9 - 1	LE1	0.7	29.7	260.0	0.4	30.3	30.5	OK	OK
	B198	M20 10.9 - 1	LE1	1.0	32.8	260.0	0.6	33.4	33.8	OK	OK
	B199	M20 10.9 - 1	LE1	1.6	37.4	260.0	0.9	38.1	38.8	OK	OK
	B200	M20 10.9 - 1	LE1	0.2	43.8	394.5	0.1	44.6	44.7	OK	OK
	B201	M20 10.9 - 1	LE1	9.0	42.2	260.0	5.1	43.1	46.7	OK	OK
	B202	M20 10.9 - 1	LE1	0.5	36.2	260.0	0.3	37.0	37.2	OK	OK
	B203	M20 10.9 - 1	LE1	0.1	32.1	260.0	0.1	32.7	32.8	OK	OK
	B204	M20 10.9 - 1	LE1	0.5	29.6	260.0	0.3	30.2	30.4	OK	OK
	B205	M20 10.9 - 1	LE1	0.6	28.8	260.0	0.3	29.4	29.6	OK	OK
	B206	M20 10.9 - 1	LE1	0.8	29.4	260.0	0.4	30.0	30.3	OK	OK




Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B207	M20 10.9 - 1	LE1	1.0	31.5	260.0	0.6	32.1	32.6	OK	OK
	B208	M20 10.9 - 1	LE1	1.9	35.1	260.0	1.1	35.8	36.6	OK	OK
	B209	M20 10.9 - 1	LE1	3.0	40.4	260.0	1.7	41.2	42.4	OK	OK
	B210	M20 10.9 - 1	LE1	1.2	47.6	203.1	0.7	48.5	49.0	OK	OK
	B211	M20 10.9 - 1	LE1	9.8	32.6	260.0	5.5	33.2	37.2	OK	OK
	B212	M20 10.9 - 1	LE1	1.5	29.1	260.0	0.8	29.7	30.3	OK	OK
	B213	M20 10.9 - 1	LE1	0.5	25.9	260.0	0.3	26.4	26.6	OK	OK
	B214	M20 10.9 - 1	LE1	0.7	23.4	260.0	0.4	23.8	24.1	OK	OK
	B215	M20 10.9 - 1	LE1	0.6	22.8	260.0	0.3	23.3	23.5	OK	OK
	B216	M20 10.9 - 1	LE1	0.6	23.1	260.0	0.3	23.6	23.8	OK	OK
	B217	M20 10.9 - 1	LE1	0.7	24.0	260.0	0.4	24.5	24.8	OK	OK
	B218	M20 10.9 - 1	LE1	1.1	25.6	260.0	0.6	26.1	26.6	OK	OK
	B219	M20 10.9 - 1	LE1	1.8	27.9	260.0	1.0	28.5	29.2	OK	OK
	B220	M20 10.9 - 1	LE1	1.1	31.2	203.1	0.6	31.8	32.2	OK	OK
	B221	M20 10.9 - 1	LE1	7.9	27.6	260.0	4.5	28.2	31.4	OK	OK
	B222	M20 10.9 - 1	LE1	0.7	25.0	260.0	0.4	25.5	25.8	OK	OK
	B223	M20 10.9 - 1	LE1	0.2	22.6	260.0	0.1	23.1	23.1	OK	OK
	B224	M20 10.9 - 1	LE1	0.4	20.7	260.0	0.2	21.1	21.3	OK	OK
	B225	M20 10.9 - 1	LE1	0.4	19.4	260.0	0.2	19.8	19.9	OK	OK
	B226	M20 10.9 - 1	LE1	0.4	18.7	260.0	0.2	19.1	19.3	OK	OK
	B227	M20 10.9 - 1	LE1	0.4	19.4	260.0	0.2	19.8	20.0	OK	OK
	B228	M20 10.9 - 1	LE1	0.5	20.6	260.0	0.3	21.0	21.2	OK	OK
	B229	M20 10.9 - 1	LE1	0.7	22.4	260.0	0.4	22.8	23.1	OK	OK
	B230	M20 10.9 - 1	LE1	0.0	24.9	394.5	0.0	25.5	25.5	OK	OK
	B231	M20 10.9 - 1	LE1	7.2	24.5	260.0	4.1	25.0	27.9	OK	OK
	B232	M20 10.9 - 1	LE1	0.8	22.8	260.0	0.5	23.2	23.6	OK	OK
	B233	M20 10.9 - 1	LE1	0.1	21.2	260.0	0.1	21.7	21.7	OK	OK
	B234	M20 10.9 - 1	LE1	0.3	19.8	260.0	0.2	20.2	20.3	OK	OK
	B235	M20 10.9 - 1	LE1	0.4	18.8	260.0	0.2	19.2	19.3	OK	OK
	B236	M20 10.9 - 1	LE1	0.4	18.2	260.0	0.2	18.5	18.7	OK	OK
	B237	M20 10.9 - 1	LE1	0.4	18.0	260.0	0.2	18.4	18.5	OK	OK
	B238	M20 10.9 - 1	LE1	0.5	18.4	260.0	0.3	18.8	18.9	OK	OK
	B239	M20 10.9 - 1	LE1	0.6	19.4	260.0	0.3	19.8	20.0	OK	OK
	B240	M20 10.9 - 1	LE1	0.0	21.4	380.2	0.0	21.8	21.8	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_{t_t}$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	B241	M20 10.9 - 1	LE1	9.7	34.4	260.0	5.5	35.1	39.1	OK	OK
	B242	M20 10.9 - 1	LE1	1.3	30.7	260.0	0.7	31.3	31.8	OK	OK
	B243	M20 10.9 - 1	LE1	0.4	27.2	260.0	0.2	27.8	27.9	OK	OK
	B244	M20 10.9 - 1	LE1	0.6	24.4	260.0	0.3	24.9	25.2	OK	OK
	B245	M20 10.9 - 1	LE1	0.5	22.9	260.0	0.3	23.4	23.6	OK	OK
	B246	M20 10.9 - 1	LE1	0.5	23.1	260.0	0.3	23.5	23.7	OK	OK
	B247	M20 10.9 - 1	LE1	0.5	23.8	260.0	0.3	24.3	24.5	OK	OK
	B248	M20 10.9 - 1	LE1	0.8	25.2	260.0	0.5	25.7	26.1	OK	OK
	B249	M20 10.9 - 1	LE1	1.5	27.3	260.0	0.8	27.8	28.4	OK	OK
	B250	M20 10.9 - 1	LE1	0.8	30.3	203.1	0.5	30.9	31.3	OK	OK
	B251	M20 10.9 - 1	LE1	8.0	28.1	260.0	4.6	28.6	31.9	OK	OK
	B252	M20 10.9 - 1	LE1	0.7	25.3	260.0	0.4	25.8	26.1	OK	OK
	B253	M20 10.9 - 1	LE1	0.2	22.8	260.0	0.1	23.3	23.4	OK	OK
	B254	M20 10.9 - 1	LE1	0.4	20.8	260.0	0.2	21.3	21.4	OK	OK
	B255	M20 10.9 - 1	LE1	0.4	19.5	260.0	0.2	19.9	20.0	OK	OK
	B256	M20 10.9 - 1	LE1	0.4	18.7	260.0	0.2	19.1	19.2	OK	OK
	B257	M20 10.9 - 1	LE1	0.5	19.1	260.0	0.3	19.5	19.7	OK	OK
	B258	M20 10.9 - 1	LE1	0.5	19.9	260.0	0.3	20.3	20.5	OK	OK
	B259	M20 10.9 - 1	LE1	0.7	21.3	260.0	0.4	21.7	22.0	OK	OK
	B260	M20 10.9 - 1	LE1	0.0	23.4	394.5	0.0	23.9	23.9	OK	OK
	B261	M20 10.9 - 1	LE1	7.5	23.6	260.0	4.2	24.1	27.1	OK	OK
	B262	M20 10.9 - 1	LE1	1.0	21.9	260.0	0.6	22.3	22.7	OK	OK
	B263	M20 10.9 - 1	LE1	0.2	20.5	260.0	0.1	20.9	21.0	OK	OK
	B264	M20 10.9 - 1	LE1	0.4	19.1	260.0	0.2	19.5	19.7	OK	OK
	B265	M20 10.9 - 1	LE1	0.4	18.2	260.0	0.2	18.5	18.7	OK	OK
	B266	M20 10.9 - 1	LE1	0.4	17.5	260.0	0.2	17.9	18.0	OK	OK
	B267	M20 10.9 - 1	LE1	0.4	17.2	260.0	0.2	17.5	17.7	OK	OK
	B268	M20 10.9 - 1	LE1	0.4	17.2	260.0	0.2	17.6	17.8	OK	OK
	B269	M20 10.9 - 1	LE1	0.5	17.8	260.0	0.3	18.1	18.3	OK	OK
	B270	M20 10.9 - 1	LE1	0.0	19.1	361.1	0.0	19.5	19.5	OK	OK
	B271	M20 10.9 - 1	LE1	14.0	40.8	260.0	7.9	41.7	47.3	OK	OK
	B272	M20 10.9 - 1	LE1	2.9	37.0	260.0	1.6	37.7	38.9	OK	OK
	B273	M20 10.9 - 1	LE1	1.1	33.8	260.0	0.6	34.5	35.0	OK	OK
	B274	M20 10.9 - 1	LE1	1.2	31.4	260.0	0.7	32.1	32.5	OK	OK
	B275	M20 10.9 - 1	LE1	1.2	30.2	260.0	0.7	30.8	31.3	OK	OK
	B276	M20 10.9 - 1	LE1	1.2	30.1	260.0	0.7	30.8	31.2	OK	OK
	B277	M20 10.9 - 1	LE1	1.3	31.4	260.0	0.7	32.0	32.5	OK	OK
	B278	M20 10.9 - 1	LE1	1.5	33.9	260.0	0.9	34.6	35.2	OK	OK
	B279	M20 10.9 - 1	LE1	1.9	37.7	260.0	1.1	38.4	39.2	OK	OK
	B280	M20 10.9 - 1	LE1	0.4	43.2	394.5	0.2	44.1	44.3	OK	OK
	B281	M20 10.9 - 1	LE1	10.6	41.0	260.0	6.0	41.9	46.2	OK	OK
	B282	M20 10.9 - 1	LE1	1.0	36.1	260.0	0.5	36.8	37.2	OK	OK
	B283	M20 10.9 - 1	LE1	0.3	32.1	260.0	0.2	32.7	32.9	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_{t_t}$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	B284	M20 10.9 - 1	LE1	0.6	29.2	260.0	0.3	29.8	30.0	OK	OK
	B285	M20 10.9 - 1	LE1	0.6	27.7	260.0	0.3	28.2	28.5	OK	OK
	B286	M20 10.9 - 1	LE1	0.6	28.2	260.0	0.4	28.7	29.0	OK	OK
	B287	M20 10.9 - 1	LE1	0.7	30.2	260.0	0.4	30.8	31.1	OK	OK
	B288	M20 10.9 - 1	LE1	1.0	33.6	260.0	0.6	34.3	34.7	OK	OK
	B289	M20 10.9 - 1	LE1	1.7	38.7	260.0	0.9	39.5	40.1	OK	OK
	B290	M20 10.9 - 1	LE1	0.2	45.7	203.1	0.1	46.6	46.7	OK	OK
	B291	M20 10.9 - 1	LE1	8.4	43.5	260.0	4.8	44.4	47.8	OK	OK
	B292	M20 10.9 - 1	LE1	0.3	37.3	260.0	0.2	38.0	38.1	OK	OK
	B293	M20 10.9 - 1	LE1	0.1	32.3	260.0	0.1	33.0	33.0	OK	OK
	B294	M20 10.9 - 1	LE1	0.5	29.3	260.0	0.3	29.9	30.1	OK	OK
	B295	M20 10.9 - 1	LE1	0.5	28.7	260.0	0.3	29.3	29.5	OK	OK
	B296	M20 10.9 - 1	LE1	0.7	29.5	260.0	0.4	30.1	30.4	OK	OK
	B297	M20 10.9 - 1	LE1	1.1	31.9	260.0	0.6	32.6	33.0	OK	OK
	B298	M20 10.9 - 1	LE1	2.0	36.0	260.0	1.2	36.8	37.6	OK	OK
	B299	M20 10.9 - 1	LE1	3.3	42.0	260.0	1.9	42.8	44.2	OK	OK
	B300	M20 10.9 - 1	LE1	1.4	50.1	203.1	0.8	51.1	51.7	OK	OK
	B301	M20 10.9 - 1	LE1	10.3	33.2	260.0	5.8	33.9	38.0	OK	OK
	B302	M20 10.9 - 1	LE1	2.5	29.1	260.0	1.4	29.6	30.6	OK	OK
	B303	M20 10.9 - 1	LE1	1.0	25.4	260.0	0.6	25.9	26.3	OK	OK
	B304	M20 10.9 - 1	LE1	0.7	23.2	260.0	0.4	23.7	24.0	OK	OK
	B305	M20 10.9 - 1	LE1	0.6	23.0	260.0	0.3	23.5	23.7	OK	OK
	B306	M20 10.9 - 1	LE1	0.5	23.4	260.0	0.3	23.9	24.1	OK	OK
	B307	M20 10.9 - 1	LE1	0.7	24.4	260.0	0.4	24.9	25.1	OK	OK
	B308	M20 10.9 - 1	LE1	1.0	26.1	260.0	0.6	26.6	27.0	OK	OK
	B309	M20 10.9 - 1	LE1	1.7	28.5	260.0	1.0	29.1	29.8	OK	OK
	B310	M20 10.9 - 1	LE1	1.1	31.9	203.1	0.6	32.6	33.0	OK	OK
	B311	M20 10.9 - 1	LE1	8.0	28.3	260.0	4.5	28.9	32.1	OK	OK
	B312	M20 10.9 - 1	LE1	0.8	25.2	260.0	0.5	25.7	26.1	OK	OK
	B313	M20 10.9 - 1	LE1	0.2	22.5	260.0	0.1	22.9	23.0	OK	OK
	B314	M20 10.9 - 1	LE1	0.4	20.4	260.0	0.2	20.8	20.9	OK	OK
	B315	M20 10.9 - 1	LE1	0.4	18.9	260.0	0.2	19.3	19.5	OK	OK
	B316	M20 10.9 - 1	LE1	0.4	19.0	260.0	0.2	19.4	19.6	OK	OK
	B317	M20 10.9 - 1	LE1	0.4	19.8	260.0	0.2	20.2	20.4	OK	OK
	B318	M20 10.9 - 1	LE1	0.5	21.1	260.0	0.3	21.5	21.7	OK	OK
	B319	M20 10.9 - 1	LE1	0.7	23.0	260.0	0.4	23.5	23.8	OK	OK
	B320	M20 10.9 - 1	LE1	0.0	25.8	203.1	0.0	26.3	26.3	OK	OK
	B321	M20 10.9 - 1	LE1	7.1	25.2	260.0	4.0	25.7	28.6	OK	OK
	B322	M20 10.9 - 1	LE1	0.7	23.2	260.0	0.4	23.7	23.9	OK	OK
	B323	M20 10.9 - 1	LE1	0.0	21.3	260.0	0.0	21.8	21.8	OK	OK
	B324	M20 10.9 - 1	LE1	0.3	19.7	260.0	0.2	20.1	20.3	OK	OK
	B325	M20 10.9 - 1	LE1	0.3	18.6	260.0	0.2	19.0	19.1	OK	OK
	B326	M20 10.9 - 1	LE1	0.4	18.0	260.0	0.2	18.3	18.5	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B327	M20 10.9 - 1	LE1	0.4	17.9	260.0	0.2	18.2	18.4	OK	OK
	B328	M20 10.9 - 1	LE1	0.5	18.3	260.0	0.3	18.7	18.9	OK	OK
	B329	M20 10.9 - 1	LE1	0.6	19.5	260.0	0.3	19.9	20.1	OK	OK
	B330	M20 10.9 - 1	LE1	0.0	21.5	391.9	0.0	21.9	21.9	OK	OK
	B331	M20 10.9 - 1	LE1	13.9	42.8	260.0	7.9	43.7	49.3	OK	OK
	B332	M20 10.9 - 1	LE1	3.3	38.6	260.0	1.8	39.4	40.7	OK	OK
	B333	M20 10.9 - 1	LE1	1.3	35.1	260.0	0.8	35.8	36.3	OK	OK
	B334	M20 10.9 - 1	LE1	1.0	32.5	260.0	0.6	33.1	33.5	OK	OK
	B335	M20 10.9 - 1	LE1	0.9	31.0	260.0	0.5	31.7	32.1	OK	OK
	B336	M20 10.9 - 1	LE1	1.0	30.9	260.0	0.5	31.5	31.9	OK	OK
	B337	M20 10.9 - 1	LE1	1.1	32.0	260.0	0.6	32.7	33.1	OK	OK
	B338	M20 10.9 - 1	LE1	1.3	34.4	260.0	0.7	35.1	35.7	OK	OK
	B339	M20 10.9 - 1	LE1	1.7	38.1	260.0	1.0	38.9	39.6	OK	OK
	B340	M20 10.9 - 1	LE1	0.3	43.2	394.5	0.2	44.1	44.2	OK	OK
	B341	M20 10.9 - 1	LE1	10.6	41.6	260.0	6.0	42.4	46.7	OK	OK
	B342	M20 10.9 - 1	LE1	1.0	36.5	260.0	0.6	37.3	37.7	OK	OK
	B343	M20 10.9 - 1	LE1	0.3	32.3	260.0	0.2	33.0	33.1	OK	OK
	B344	M20 10.9 - 1	LE1	0.5	29.3	260.0	0.3	29.9	30.1	OK	OK
	B345	M20 10.9 - 1	LE1	0.6	27.7	260.0	0.3	28.3	28.5	OK	OK
	B346	M20 10.9 - 1	LE1	0.6	28.2	260.0	0.4	28.8	29.0	OK	OK
	B347	M20 10.9 - 1	LE1	0.7	30.1	260.0	0.4	30.7	31.0	OK	OK
	B348	M20 10.9 - 1	LE1	1.0	33.3	260.0	0.6	33.9	34.3	OK	OK
	B349	M20 10.9 - 1	LE1	1.6	38.0	260.0	0.9	38.8	39.5	OK	OK
	B350	M20 10.9 - 1	LE1	0.2	44.6	203.1	0.1	45.5	45.6	OK	OK
	B351	M20 10.9 - 1	LE1	8.6	42.7	260.0	4.9	43.6	47.1	OK	OK
	B352	M20 10.9 - 1	LE1	0.4	36.5	260.0	0.2	37.3	37.4	OK	OK
	B353	M20 10.9 - 1	LE1	0.1	31.9	260.0	0.1	32.5	32.6	OK	OK
	B354	M20 10.9 - 1	LE1	0.5	29.6	260.0	0.3	30.2	30.4	OK	OK
	B355	M20 10.9 - 1	LE1	0.6	29.0	260.0	0.3	29.6	29.8	OK	OK
	B356	M20 10.9 - 1	LE1	0.8	29.7	260.0	0.4	30.3	30.6	OK	OK
	B357	M20 10.9 - 1	LE1	1.1	31.9	260.0	0.6	32.5	33.0	OK	OK
	B358	M20 10.9 - 1	LE1	2.0	35.6	260.0	1.1	36.3	37.1	OK	OK
	B359	M20 10.9 - 1	LE1	3.2	41.1	260.0	1.8	41.9	43.2	OK	OK
	B360	M20 10.9 - 1	LE1	1.3	48.4	203.1	0.7	49.4	49.9	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B361	M20 10.9 - 1	LE1	75.9	65.1	308.2	43.0	66.4	97.2	OK	OK
	B362	M20 10.9 - 1	LE1	15.0	91.3	203.1	8.5	93.2	99.3	OK	OK
	B363	M20 10.9 - 1	LE1	5.0	95.7	203.1	2.8	97.7	99.7	OK	OK
	B364	M20 10.9 - 1	LE1	3.0	96.6	203.1	1.7	98.6	99.8	OK	OK
	B365	M20 10.9 - 1	LE1	1.9	93.7	203.1	1.1	95.6	96.3	OK	OK
	B366	M20 10.9 - 1	LE1	1.6	89.7	203.1	0.9	91.6	92.2	OK	OK
	B367	M20 10.9 - 1	LE1	2.0	87.8	203.1	1.1	89.6	90.3	OK	OK
	B368	M20 10.9 - 1	LE1	2.6	87.7	203.1	1.5	89.5	90.5	OK	OK
	B369	M20 10.9 - 1	LE1	2.8	88.8	203.1	1.6	90.6	91.7	OK	OK
	B370	M20 10.9 - 1	LE1	0.0	88.9	203.1	0.0	90.7	90.7	OK	OK
	B371	M20 10.9 - 1	LE1	73.0	66.0	308.2	41.4	67.3	96.9	OK	OK
	B372	M20 10.9 - 1	LE1	8.7	94.1	203.1	4.9	96.0	99.5	OK	OK
	B373	M20 10.9 - 1	LE1	2.8	96.7	203.1	1.6	98.7	99.8	OK	OK
	B374	M20 10.9 - 1	LE1	2.2	97.0	203.1	1.2	98.9	99.8	OK	OK
	B375	M20 10.9 - 1	LE1	1.6	92.2	203.1	0.9	94.1	94.8	OK	OK
	B376	M20 10.9 - 1	LE1	1.6	87.9	203.1	0.9	89.7	90.4	OK	OK
	B377	M20 10.9 - 1	LE1	2.0	85.7	203.1	1.1	87.4	88.2	OK	OK
	B378	M20 10.9 - 1	LE1	2.7	85.4	203.1	1.5	87.1	88.2	OK	OK
	B379	M20 10.9 - 1	LE1	2.6	86.2	203.1	1.5	87.9	89.0	OK	OK
	B380	M20 10.9 - 1	LE1	0.0	85.6	203.1	0.0	87.3	87.3	OK	OK
	B381	M20 10.9 - 1	LE1	52.0	75.4	308.2	29.5	76.9	97.9	OK	OK
	B382	M20 10.9 - 1	LE1	2.5	96.8	203.1	1.4	98.8	99.8	OK	OK
	B383	M20 10.9 - 1	LE1	0.8	97.6	203.1	0.5	99.5	99.9	OK	OK
	B384	M20 10.9 - 1	LE1	0.9	97.5	203.1	0.5	99.5	99.9	OK	OK
	B385	M20 10.9 - 1	LE1	0.7	94.5	203.1	0.4	96.4	96.7	OK	OK
	B386	M20 10.9 - 1	LE1	1.0	89.5	203.1	0.6	91.4	91.8	OK	OK
	B387	M20 10.9 - 1	LE1	2.1	86.9	203.1	1.2	88.7	89.6	OK	OK
	B388	M20 10.9 - 1	LE1	3.5	86.7	203.1	2.0	88.5	89.9	OK	OK
	B389	M20 10.9 - 1	LE1	4.1	87.3	203.1	2.3	89.1	90.7	OK	OK
	B390	M20 10.9 - 1	LE1	0.0	86.7	203.1	0.0	88.4	88.4	OK	OK
	B391	M20 10.9 - 1	LE1	74.6	65.7	308.2	42.3	67.0	97.2	OK	OK
	B392	M20 10.9 - 1	LE1	14.7	91.5	203.1	8.3	93.3	99.3	OK	OK
	B393	M20 10.9 - 1	LE1	4.7	95.8	203.1	2.7	97.8	99.7	OK	OK
	B394	M20 10.9 - 1	LE1	2.8	96.7	203.1	1.6	98.6	99.8	OK	OK
	B395	M20 10.9 - 1	LE1	1.8	93.3	203.1	1.0	95.2	96.0	OK	OK
	B396	M20 10.9 - 1	LE1	1.6	89.4	203.1	0.9	91.2	91.8	OK	OK
	B397	M20 10.9 - 1	LE1	2.0	87.4	203.1	1.1	89.2	90.0	OK	OK
	B398	M20 10.9 - 1	LE1	2.7	87.4	203.1	1.5	89.2	90.3	OK	OK
	B399	M20 10.9 - 1	LE1	3.0	88.4	203.1	1.7	90.2	91.4	OK	OK
	B400	M20 10.9 - 1	LE1	0.0	88.2	203.1	0.0	90.0	90.0	OK	OK
	B401	M20 10.9 - 1	LE1	74.4	65.4	308.2	42.2	66.8	96.9	OK	OK
	B402	M20 10.9 - 1	LE1	8.6	94.2	203.1	4.9	96.1	99.6	OK	OK
	B403	M20 10.9 - 1	LE1	2.7	96.7	203.1	1.5	98.7	99.8	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_{t_t}$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	B404	M20 10.9 - 1	LE1	2.1	97.0	203.1	1.2	99.0	99.8	OK	OK
	B405	M20 10.9 - 1	LE1	1.6	91.6	203.1	0.9	93.5	94.1	OK	OK
	B406	M20 10.9 - 1	LE1	1.6	87.4	203.1	0.9	89.1	89.8	OK	OK
	B407	M20 10.9 - 1	LE1	1.9	85.1	203.1	1.1	86.8	87.6	OK	OK
	B408	M20 10.9 - 1	LE1	2.7	84.9	203.1	1.5	86.6	87.7	OK	OK
	B409	M20 10.9 - 1	LE1	2.6	85.6	203.1	1.5	87.3	88.4	OK	OK
	B410	M20 10.9 - 1	LE1	0.0	84.4	203.1	0.0	86.1	86.1	OK	OK
	B411	M20 10.9 - 1	LE1	54.0	74.4	308.2	30.6	75.9	97.8	OK	OK
	B412	M20 10.9 - 1	LE1	2.6	96.8	203.1	1.5	98.8	99.8	OK	OK
	B413	M20 10.9 - 1	LE1	0.7	97.6	203.1	0.4	99.6	99.9	OK	OK
	B414	M20 10.9 - 1	LE1	0.8	97.6	203.1	0.5	99.5	99.9	OK	OK
	B415	M20 10.9 - 1	LE1	0.8	93.7	203.1	0.4	95.6	95.9	OK	OK
	B416	M20 10.9 - 1	LE1	0.9	88.8	203.1	0.5	90.6	91.0	OK	OK
	B417	M20 10.9 - 1	LE1	2.0	86.2	203.1	1.2	88.0	88.8	OK	OK
	B418	M20 10.9 - 1	LE1	3.7	85.9	203.1	2.1	87.6	89.1	OK	OK
	B419	M20 10.9 - 1	LE1	4.1	86.4	203.1	2.3	88.1	89.8	OK	OK
	B420	M20 10.9 - 1	LE1	0.0	85.5	203.1	0.0	87.3	87.3	OK	OK
	B421	M20 10.9 - 1	LE1	70.0	67.6	308.2	39.7	69.0	97.4	OK	OK
	B422	M20 10.9 - 1	LE1	9.3	93.9	203.1	5.3	95.8	99.5	OK	OK
	B423	M20 10.9 - 1	LE1	3.6	96.4	203.1	2.0	98.3	99.8	OK	OK
	B424	M20 10.9 - 1	LE1	2.8	96.7	203.1	1.6	98.6	99.8	OK	OK
	B425	M20 10.9 - 1	LE1	1.9	94.1	203.1	1.1	96.0	96.8	OK	OK
	B426	M20 10.9 - 1	LE1	1.7	89.9	203.1	1.0	91.7	92.4	OK	OK
	B427	M20 10.9 - 1	LE1	1.9	87.4	203.1	1.1	89.1	89.9	OK	OK
	B428	M20 10.9 - 1	LE1	2.5	86.6	203.1	1.4	88.4	89.4	OK	OK
	B429	M20 10.9 - 1	LE1	2.7	86.7	203.1	1.5	88.5	89.6	OK	OK
	B430	M20 10.9 - 1	LE1	0.0	85.9	203.1	0.0	87.6	87.6	OK	OK
	B431	M20 10.9 - 1	LE1	65.9	69.5	308.2	37.3	70.9	97.6	OK	OK
	B432	M20 10.9 - 1	LE1	9.0	94.0	203.1	5.1	95.9	99.6	OK	OK
	B433	M20 10.9 - 1	LE1	2.8	96.7	203.1	1.6	98.7	99.8	OK	OK
	B434	M20 10.9 - 1	LE1	2.2	96.9	203.1	1.2	98.9	99.8	OK	OK
	B435	M20 10.9 - 1	LE1	1.6	91.9	203.1	0.9	93.8	94.5	OK	OK
	B436	M20 10.9 - 1	LE1	1.6	87.3	203.1	0.9	89.1	89.8	OK	OK
	B437	M20 10.9 - 1	LE1	1.9	84.6	203.1	1.1	86.3	87.0	OK	OK
	B438	M20 10.9 - 1	LE1	2.5	83.7	203.1	1.4	85.4	86.4	OK	OK
	B439	M20 10.9 - 1	LE1	2.4	83.5	203.1	1.4	85.2	86.2	OK	OK
	B440	M20 10.9 - 1	LE1	0.0	82.0	203.1	0.0	83.7	83.7	OK	OK
	B441	M20 10.9 - 1	LE1	49.9	76.7	308.2	28.3	78.3	98.5	OK	OK
	B442	M20 10.9 - 1	LE1	6.5	95.1	203.1	3.7	97.1	99.7	OK	OK
	B443	M20 10.9 - 1	LE1	1.1	97.4	203.1	0.6	99.4	99.9	OK	OK
	B444	M20 10.9 - 1	LE1	0.8	97.6	203.1	0.5	99.5	99.9	OK	OK
	B445	M20 10.9 - 1	LE1	0.7	93.6	203.1	0.4	95.5	95.8	OK	OK
	B446	M20 10.9 - 1	LE1	1.0	88.4	203.1	0.5	90.2	90.5	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B447	M20 10.9 - 1	LE1	1.8	85.3	203.1	1.0	87.0	87.7	OK	OK
	B448	M20 10.9 - 1	LE1	3.2	84.2	203.1	1.8	86.0	87.2	OK	OK
	B449	M20 10.9 - 1	LE1	3.6	83.9	203.1	2.0	85.6	87.1	OK	OK
	B450	M20 10.9 - 1	LE1	0.0	82.7	203.1	0.0	84.4	84.4	OK	OK
	B451	M20 10.9 - 1	LE1	71.1	67.2	308.2	40.3	68.6	97.4	OK	OK
	B452	M20 10.9 - 1	LE1	9.9	93.6	203.1	5.6	95.5	99.5	OK	OK
	B453	M20 10.9 - 1	LE1	3.7	96.3	203.1	2.1	98.2	99.8	OK	OK
	B454	M20 10.9 - 1	LE1	3.0	96.6	203.1	1.7	98.5	99.8	OK	OK
	B455	M20 10.9 - 1	LE1	2.1	94.5	203.1	1.2	96.4	97.3	OK	OK
	B456	M20 10.9 - 1	LE1	1.7	90.3	203.1	1.0	92.1	92.8	OK	OK
	B457	M20 10.9 - 1	LE1	1.8	87.8	203.1	1.0	89.6	90.3	OK	OK
	B458	M20 10.9 - 1	LE1	2.5	87.0	203.1	1.4	88.8	89.8	OK	OK
	B459	M20 10.9 - 1	LE1	2.8	87.2	203.1	1.6	88.9	90.1	OK	OK
	B460	M20 10.9 - 1	LE1	0.0	86.1	203.1	0.0	87.8	87.8	OK	OK
	B461	M20 10.9 - 1	LE1	65.1	69.8	308.2	36.9	71.3	97.7	OK	OK
	B462	M20 10.9 - 1	LE1	9.3	93.9	203.1	5.3	95.8	99.6	OK	OK
	B463	M20 10.9 - 1	LE1	2.9	96.7	203.1	1.6	98.6	99.8	OK	OK
	B464	M20 10.9 - 1	LE1	2.3	96.9	203.1	1.3	98.9	99.8	OK	OK
	B465	M20 10.9 - 1	LE1	1.7	92.6	203.1	1.0	94.5	95.2	OK	OK
	B466	M20 10.9 - 1	LE1	1.6	88.0	203.1	0.9	89.8	90.5	OK	OK
	B467	M20 10.9 - 1	LE1	1.8	85.2	203.1	1.0	87.0	87.7	OK	OK
	B468	M20 10.9 - 1	LE1	2.5	84.3	203.1	1.4	86.0	87.1	OK	OK
	B469	M20 10.9 - 1	LE1	2.5	84.2	203.1	1.4	85.9	86.9	OK	OK
	B470	M20 10.9 - 1	LE1	0.0	82.1	203.1	0.0	83.8	83.8	OK	OK
	B471	M20 10.9 - 1	LE1	48.5	77.4	308.2	27.5	78.9	98.6	OK	OK
	B472	M20 10.9 - 1	LE1	6.5	95.1	203.1	3.7	97.0	99.7	OK	OK
	B473	M20 10.9 - 1	LE1	1.0	97.5	203.1	0.6	99.5	99.9	OK	OK
	B474	M20 10.9 - 1	LE1	0.9	97.5	203.1	0.5	99.5	99.9	OK	OK
	B475	M20 10.9 - 1	LE1	0.7	94.8	203.1	0.4	96.7	97.0	OK	OK
	B476	M20 10.9 - 1	LE1	1.0	89.4	203.1	0.5	91.2	91.6	OK	OK
	B477	M20 10.9 - 1	LE1	1.9	86.3	203.1	1.1	88.0	88.8	OK	OK
	B478	M20 10.9 - 1	LE1	3.2	85.3	203.1	1.8	87.0	88.3	OK	OK
	B479	M20 10.9 - 1	LE1	3.9	84.7	203.1	2.2	86.5	88.1	OK	OK
	B480	M20 10.9 - 1	LE1	0.0	83.2	203.1	0.0	84.9	84.9	OK	OK

## Design data

Grade	$F_{t,Rd}$ [kN]	$B_{p,Rd}$ [kN]	$F_{v,Rd}$ [kN]
M20 10.9 - 1	176.4	622.7	98.0

## 5.3.5. Nastavak nosača

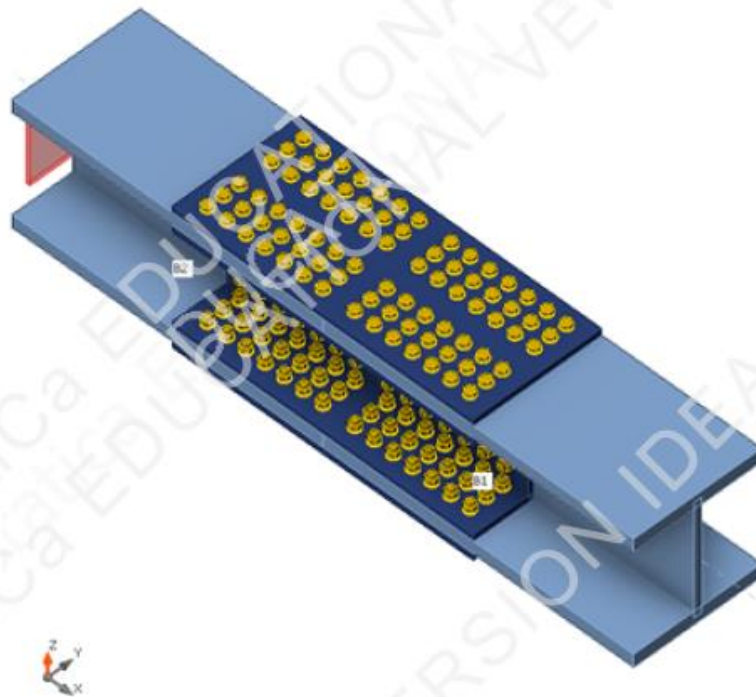
## Members

## Geometry

Name	Cross-section	$\beta$ - Direction [°]	$\gamma$ - Pitch [°]	$\alpha$ - Rotation [°]	Offset ex [mm]	Offset ey [mm]	Offset ez [mm]
B1	2 - HD400/314	0.0	0.0	0.0	0	0	0
B2	2 - HD400/314	180.0	0.0	0.0	0	0	0

## Supports and forces

Name	Support	Forces in	X [mm]
B1 / end		Node	0
B2 / end	N-Vy-Vz-Mx-My-Mz	Node	0



## Cross-sections

Name	Material
2 - HD400/314	S 420 N/NL

## Bolts

Name	Diameter [mm]	$f_y$ [MPa]	$f_u$ [MPa]	Gross area [mm <sup>2</sup> ]
M20 10.9	20	900.0	1000.0	314



Load effects (forces in equilibrium)

Name	Member	N [kN]	Vy [kN]	Vz [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	B1 / End	3389.0	0.0	0.0	0.0	-220.0	0.0
	B2 / End	33890.0	0.0	0.0	0.0	-2220.0	0.0
LE2	B1 / End	0.0	0.0	-610.0	0.0	-2042.0	0.0
	B2 / End	0.0	0.0	610.0	0.0	-2042.0	0.0

Unbalanced forces

Name	X [kN]	Y [kN]	Z [kN]	Mx [kNm]	My [kNm]	Mz [kNm]
LE1	-30501.0	0.0	0.0	0.0	2000.0	0.0
LE2	0.0	0.0	0.0	0.0	0.0	0.0

Check

Summary

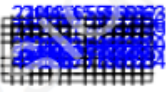
Name	Value	Check status
Analysis	100.0%	OK
Plates	2.2 < 5.0%	OK
Bolts	97.9 < 100%	OK
Buckling	Not calculated	

Plates


Name	$t_p$ [mm]	Loads	$\sigma_{Ed}$ [MPa]	$\epsilon_{pl}$ [%]	$\sigma_{c,Ed}$ [MPa]	Status
B1-bfl 1	40.0	LE2	424.3	2.0	96.4	OK
B1-tfl 1	40.0	LE2	420.1	0.1	81.8	OK
B1-w 1	24.5	LE2	420.7	0.3	96.4	OK
B2-bfl 1	40.0	LE2	420.6	0.3	32.8	OK
B2-tfl 1	40.0	LE2	367.1	0.0	29.0	OK
B2-w 1	24.5	LE2	316.6	0.0	7.9	OK
SPL1a	20.0	LE2	420.9	0.4	29.0	OK
SPL1b	20.0	LE2	420.4	0.2	43.5	OK
SPL1c	20.0	LE2	420.4	0.2	46.5	OK
SPL2a	20.0	LE2	424.7	2.2	66.9	OK
SPL2b	20.0	LE2	422.7	1.3	57.2	OK
SPL2c	20.0	LE2	422.7	1.3	56.7	OK
SPL3a	15.0	LE2	420.2	0.1	13.9	OK
SPL3b	15.0	LE2	420.2	0.1	13.9	OK

Design data

Material	$f_y$ [MPa]	$\epsilon_{lim}$ [%]
S 420 N/NL	420.0	5.0

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B1	M20 10.9 - 1	LE2	37.7	70.2	325.0	21.4	71.6	86.9	OK	OK
	B2	M20 10.9 - 1	LE2	2.8	70.0	162.5	1.6	71.4	72.5	OK	OK
	B3	M20 10.9 - 1	LE2	1.8	66.4	162.5	1.0	67.7	68.5	OK	OK
	B4	M20 10.9 - 1	LE2	2.2	65.3	162.5	1.2	66.7	67.6	OK	OK
	B5	M20 10.9 - 1	LE2	2.2	68.1	162.5	1.3	69.5	70.4	OK	OK
	B6	M20 10.9 - 1	LE2	2.7	74.8	162.5	1.5	76.4	77.5	OK	OK
	B7	M20 10.9 - 1	LE2	1.1	85.5	162.5	0.6	87.2	87.7	OK	OK
	B8	M20 10.9 - 1	LE2	24.8	70.3	325.0	14.1	71.7	81.8	OK	OK
	B9	M20 10.9 - 1	LE2	0.1	69.8	162.5	0.0	71.2	71.2	OK	OK
	B10	M20 10.9 - 1	LE2	1.4	66.4	162.5	0.8	67.7	68.3	OK	OK
	B11	M20 10.9 - 1	LE2	2.0	65.8	162.5	1.1	67.2	68.0	OK	OK
	B12	M20 10.9 - 1	LE2	2.2	68.7	162.5	1.2	70.1	71.0	OK	OK
	B13	M20 10.9 - 1	LE2	2.8	75.3	162.5	1.6	76.8	77.9	OK	OK
	B14	M20 10.9 - 1	LE2	1.1	86.0	162.5	0.6	87.8	88.2	OK	OK
	B15	M20 10.9 - 1	LE2	22.9	74.1	325.0	13.0	75.6	84.9	OK	OK
	B16	M20 10.9 - 1	LE2	1.5	72.1	162.5	0.8	73.6	74.2	OK	OK
	B17	M20 10.9 - 1	LE2	1.5	68.9	162.5	0.8	70.3	70.9	OK	OK
	B18	M20 10.9 - 1	LE2	2.2	68.6	162.5	1.2	70.0	70.9	OK	OK
	B19	M20 10.9 - 1	LE2	3.1	71.7	162.5	1.8	73.2	74.5	OK	OK
	B20	M20 10.9 - 1	LE2	4.4	78.4	162.5	2.5	80.0	81.8	OK	OK
	B21	M20 10.9 - 1	LE2	2.2	89.1	162.5	1.2	90.9	91.8	OK	OK
	B22	M20 10.9 - 1	LE2	37.6	70.2	325.0	21.3	71.7	86.9	OK	OK
	B23	M20 10.9 - 1	LE2	2.7	70.0	162.5	1.5	71.4	72.5	OK	OK
	B24	M20 10.9 - 1	LE2	1.8	66.4	162.5	1.0	67.7	68.5	OK	OK
	B25	M20 10.9 - 1	LE2	2.3	65.3	162.5	1.3	66.7	67.6	OK	OK
	B26	M20 10.9 - 1	LE2	2.2	68.1	162.5	1.3	69.5	70.4	OK	OK
	B27	M20 10.9 - 1	LE2	2.7	74.8	162.5	1.5	76.4	77.5	OK	OK
	B28	M20 10.9 - 1	LE2	1.1	85.5	162.5	0.6	87.2	87.7	OK	OK
	B29	M20 10.9 - 1	LE2	24.9	70.3	325.0	14.1	71.7	81.8	OK	OK
	B30	M20 10.9 - 1	LE2	0.0	69.8	162.5	0.0	71.2	71.2	OK	OK
	B31	M20 10.9 - 1	LE2	1.4	66.4	162.5	0.8	67.7	68.3	OK	OK
	B32	M20 10.9 - 1	LE2	2.0	65.8	162.5	1.1	67.2	68.0	OK	OK
	B33	M20 10.9 - 1	LE2	2.2	68.7	162.5	1.2	70.1	71.0	OK	OK
	B34	M20 10.9 - 1	LE2	2.8	75.3	162.5	1.6	76.8	78.0	OK	OK
	B35	M20 10.9 - 1	LE2	1.1	86.0	162.5	0.6	87.8	88.2	OK	OK
	B36	M20 10.9 - 1	LE2	22.6	74.1	325.0	12.8	75.6	84.8	OK	OK
	B37	M20 10.9 - 1	LE2	1.4	72.1	162.5	0.8	73.6	74.2	OK	OK
	B38	M20 10.9 - 1	LE2	1.6	68.9	162.5	0.9	70.3	70.9	OK	OK
	B39	M20 10.9 - 1	LE2	2.2	68.6	162.5	1.2	70.0	70.8	OK	OK
	B40	M20 10.9 - 1	LE2	3.1	71.7	162.5	1.8	73.2	74.5	OK	OK
	B41	M20 10.9 - 1	LE2	4.4	78.4	162.5	2.5	80.0	81.8	OK	OK
	B42	M20 10.9 - 1	LE2	2.3	89.1	162.5	1.3	90.9	91.8	OK	OK
	B43	M20 10.9 - 1	LE2	44.1	78.5	325.0	25.0	80.1	97.9	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B44	M20 10.9 - 1	LE2	5.0	74.2	162.5	2.8	75.7	77.8	OK	OK
	B45	M20 10.9 - 1	LE2	1.2	68.9	162.5	0.7	70.3	70.8	OK	OK
	B46	M20 10.9 - 1	LE2	1.9	66.7	162.5	1.1	68.1	68.8	OK	OK
	B47	M20 10.9 - 1	LE2	2.0	67.9	162.5	1.1	69.3	70.1	OK	OK
	B48	M20 10.9 - 1	LE2	2.5	72.3	162.5	1.4	73.8	74.8	OK	OK
	B49	M20 10.9 - 1	LE2	1.0	79.7	162.5	0.6	81.3	81.7	OK	OK
	B50	M20 10.9 - 1	LE2	31.8	78.8	325.0	18.1	80.4	93.3	OK	OK
	B51	M20 10.9 - 1	LE2	2.2	72.9	162.5	1.3	74.4	75.3	OK	OK
	B52	M20 10.9 - 1	LE2	1.5	67.6	162.5	0.9	69.0	69.6	OK	OK
	B53	M20 10.9 - 1	LE2	2.2	65.5	162.5	1.2	66.8	67.7	OK	OK
	B54	M20 10.9 - 1	LE2	2.2	66.6	162.5	1.3	68.0	68.9	OK	OK
	B55	M20 10.9 - 1	LE2	2.7	70.9	162.5	1.5	72.3	73.4	OK	OK
	B56	M20 10.9 - 1	LE2	1.1	78.4	162.5	0.6	80.0	80.4	OK	OK
	B57	M20 10.9 - 1	LE2	26.1	80.3	325.0	14.8	81.9	92.5	OK	OK
	B58	M20 10.9 - 1	LE2	1.5	74.7	162.5	0.9	76.2	76.8	OK	OK
	B59	M20 10.9 - 1	LE2	1.2	69.7	162.5	0.7	71.1	71.6	OK	OK
	B60	M20 10.9 - 1	LE2	2.1	67.5	162.5	1.2	68.8	69.7	OK	OK
	B61	M20 10.9 - 1	LE2	2.8	68.5	162.5	1.6	69.9	71.0	OK	OK
	B62	M20 10.9 - 1	LE2	3.8	72.7	162.5	2.2	74.2	75.8	OK	OK
	B63	M20 10.9 - 1	LE2	2.1	80.1	162.5	1.2	81.8	82.6	OK	OK
	B64	M20 10.9 - 1	LE2	44.4	78.4	325.0	25.2	80.0	97.9	OK	OK
	B65	M20 10.9 - 1	LE2	5.0	74.2	162.5	2.8	75.7	77.8	OK	OK
	B66	M20 10.9 - 1	LE2	1.2	68.9	162.5	0.7	70.3	70.8	OK	OK
	B67	M20 10.9 - 1	LE2	1.9	66.7	162.5	1.1	68.1	68.8	OK	OK
	B68	M20 10.9 - 1	LE2	2.0	67.9	162.5	1.1	69.3	70.1	OK	OK
	B69	M20 10.9 - 1	LE2	2.5	72.3	162.5	1.4	73.8	74.8	OK	OK
	B70	M20 10.9 - 1	LE2	1.1	79.7	162.5	0.7	81.4	81.8	OK	OK
	B71	M20 10.9 - 1	LE2	32.0	78.9	325.0	18.1	80.5	93.4	OK	OK
	B72	M20 10.9 - 1	LE2	2.3	72.9	162.5	1.3	74.4	75.3	OK	OK
	B73	M20 10.9 - 1	LE2	1.5	67.7	162.5	0.9	69.0	69.7	OK	OK
	B74	M20 10.9 - 1	LE2	2.2	65.5	162.5	1.2	66.9	67.7	OK	OK
	B75	M20 10.9 - 1	LE2	2.2	66.6	162.5	1.3	68.0	68.9	OK	OK
	B76	M20 10.9 - 1	LE2	2.7	70.9	162.5	1.5	72.3	73.4	OK	OK
	B77	M20 10.9 - 1	LE2	1.1	78.4	162.5	0.6	80.0	80.5	OK	OK
	B78	M20 10.9 - 1	LE2	25.9	80.4	325.0	14.7	82.0	92.5	OK	OK
	B79	M20 10.9 - 1	LE2	1.5	74.7	162.5	0.8	76.2	76.8	OK	OK
	B80	M20 10.9 - 1	LE2	1.2	69.7	162.5	0.7	71.1	71.6	OK	OK
	B81	M20 10.9 - 1	LE2	2.1	67.5	162.5	1.2	68.9	69.7	OK	OK
	B82	M20 10.9 - 1	LE2	2.8	68.6	162.5	1.6	70.0	71.1	OK	OK
	B83	M20 10.9 - 1	LE2	3.7	72.7	162.5	2.1	74.2	75.7	OK	OK
	B84	M20 10.9 - 1	LE2	1.9	80.2	162.5	1.1	81.8	82.5	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_{t_t}$ [%]	$U_{t_s}$ [%]	$U_{t_{ts}}$ [%]	Detailing	Status
	B85	M20 10.9 - 1	LE2	19.8	66.4	162.5	11.2	67.7	75.7	OK	OK
	B86	M20 10.9 - 1	LE2	3.0	62.3	162.5	1.7	63.6	64.8	OK	OK
	B87	M20 10.9 - 1	LE2	1.5	57.8	162.5	0.9	59.0	59.6	OK	OK
	B88	M20 10.9 - 1	LE2	1.7	57.3	162.5	1.0	58.4	59.2	OK	OK
	B89	M20 10.9 - 1	LE2	1.3	59.8	162.5	0.8	61.0	61.6	OK	OK
	B90	M20 10.9 - 1	LE2	0.2	65.2	162.5	0.1	66.5	66.6	OK	OK
	B91	M20 10.9 - 1	LE2	28.4	72.9	325.0	16.1	74.4	85.9	OK	OK
	B92	M20 10.9 - 1	LE2	14.0	64.9	162.5	7.9	66.2	71.9	OK	OK
	B93	M20 10.9 - 1	LE2	4.1	61.5	162.5	2.3	62.8	64.5	OK	OK
	B94	M20 10.9 - 1	LE2	1.9	57.7	162.5	1.1	58.9	59.7	OK	OK
	B95	M20 10.9 - 1	LE2	2.0	57.4	162.5	1.1	58.6	59.4	OK	OK
	B96	M20 10.9 - 1	LE2	1.6	59.8	162.5	0.9	61.0	61.7	OK	OK
	B97	M20 10.9 - 1	LE2	0.0	65.0	162.5	0.0	66.4	66.4	OK	OK
	B98	M20 10.9 - 1	LE2	24.8	71.3	325.0	14.1	72.7	82.8	OK	OK
	B99	M20 10.9 - 1	LE2	16.0	71.2	162.5	9.0	72.6	79.1	OK	OK
	B100	M20 10.9 - 1	LE2	7.4	65.4	162.5	4.2	66.7	69.7	OK	OK
	B101	M20 10.9 - 1	LE2	2.3	61.1	162.5	1.3	62.4	63.3	OK	OK
	B102	M20 10.9 - 1	LE2	2.0	60.6	162.5	1.1	61.9	62.7	OK	OK
	B103	M20 10.9 - 1	LE2	1.5	63.0	162.5	0.8	64.3	64.9	OK	OK
	B104	M20 10.9 - 1	LE2	0.0	68.8	162.5	0.0	70.2	70.2	OK	OK
	B105	M20 10.9 - 1	LE2	23.1	76.7	325.0	13.1	78.3	87.6	OK	OK
	B106	M20 10.9 - 1	LE2	19.4	66.3	162.5	11.0	67.6	75.5	OK	OK
	B107	M20 10.9 - 1	LE2	2.9	62.4	162.5	1.7	63.7	64.8	OK	OK
	B108	M20 10.9 - 1	LE2	1.6	57.9	162.5	0.9	59.1	59.7	OK	OK
	B109	M20 10.9 - 1	LE2	1.7	57.3	162.5	1.0	58.5	59.2	OK	OK
	B110	M20 10.9 - 1	LE2	1.4	59.9	162.5	0.8	61.1	61.6	OK	OK
	B111	M20 10.9 - 1	LE2	0.2	65.3	162.5	0.1	66.6	66.7	OK	OK
B112	M20 10.9 - 1	LE2	28.4	72.9	325.0	16.1	74.3	85.8	OK	OK	
B113	M20 10.9 - 1	LE2	14.1	64.9	162.5	8.0	66.3	72.0	OK	OK	
B114	M20 10.9 - 1	LE2	4.0	61.6	162.5	2.3	62.9	64.5	OK	OK	
B115	M20 10.9 - 1	LE2	1.9	57.8	162.5	1.1	59.0	59.8	OK	OK	
B116	M20 10.9 - 1	LE2	2.0	57.5	162.5	1.1	58.7	59.5	OK	OK	
B117	M20 10.9 - 1	LE2	1.6	59.9	162.5	0.9	61.1	61.8	OK	OK	
B118	M20 10.9 - 1	LE2	0.0	65.1	162.5	0.0	66.4	66.4	OK	OK	
B119	M20 10.9 - 1	LE2	24.8	71.3	325.0	14.1	72.8	82.9	OK	OK	
B120	M20 10.9 - 1	LE2	16.3	71.1	162.5	9.2	72.6	79.2	OK	OK	
B121	M20 10.9 - 1	LE2	7.4	65.4	162.5	4.2	66.8	69.8	OK	OK	
B122	M20 10.9 - 1	LE2	2.3	61.2	162.5	1.3	62.5	63.4	OK	OK	
B123	M20 10.9 - 1	LE2	2.0	60.7	162.5	1.1	61.9	62.7	OK	OK	
B124	M20 10.9 - 1	LE2	1.4	63.1	162.5	0.8	64.4	65.0	OK	OK	
B125	M20 10.9 - 1	LE2	0.0	68.9	162.5	0.0	70.3	70.3	OK	OK	
B126	M20 10.9 - 1	LE2	23.2	76.8	325.0	13.1	78.4	87.7	OK	OK	
B127	M20 10.9 - 1	LE2	23.9	74.9	162.5	13.5	76.5	86.1	OK	OK	

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_{ts}$ [%]	$U_{ts}$ [%]	Detailing	Status
	B169	M20 10.9 - 2	LE2	3.0	47.9	219.2	1.7	48.9	50.1	OK	OK
	B170	M20 10.9 - 2	LE2	1.0	25.9	219.2	0.6	26.4	26.8	OK	OK
	B171	M20 10.9 - 2	LE2	0.7	12.9	258.7	0.4	13.1	13.4	OK	OK
	B172	M20 10.9 - 2	LE1	0.6	10.3	199.1	0.3	10.5	10.7	OK	OK
	B173	M20 10.9 - 2	LE1	0.6	10.8	199.1	0.4	11.0	11.2	OK	OK
	B174	M20 10.9 - 2	LE2	0.0	14.9	219.2	0.0	15.2	15.2	OK	OK
	B175	M20 10.9 - 2	LE2	0.8	30.2	219.2	0.4	30.8	31.1	OK	OK
	B176	M20 10.9 - 2	LE2	3.3	59.5	509.6	1.9	60.8	62.1	OK	OK
	B177	M20 10.9 - 2	LE2	1.0	40.5	509.6	0.5	41.3	41.7	OK	OK
	B178	M20 10.9 - 2	LE2	0.9	30.0	302.1	0.5	30.6	31.0	OK	OK
	B179	M20 10.9 - 2	LE2	1.0	25.5	199.1	0.6	26.0	26.4	OK	OK
	B180	M20 10.9 - 2	LE2	2.6	25.3	199.1	1.5	25.8	26.9	OK	OK
	B181	M20 10.9 - 2	LE2	5.5	30.1	475.6	3.1	30.7	32.9	OK	OK
	B182	M20 10.9 - 2	LE2	5.8	42.5	509.6	3.3	43.3	45.7	OK	OK
	B183	M20 10.9 - 2	LE2	0.8	50.0	219.2	0.5	51.0	51.3	OK	OK
	B184	M20 10.9 - 2	LE2	0.3	28.9	509.6	0.2	29.5	29.6	OK	OK
	B185	M20 10.9 - 2	LE2	0.3	17.9	475.6	0.2	18.3	18.4	OK	OK
	B186	M20 10.9 - 2	LE2	0.6	13.6	199.1	0.3	13.9	14.1	OK	OK
	B187	M20 10.9 - 2	LE2	0.8	15.2	199.1	0.5	15.5	15.8	OK	OK
	B188	M20 10.9 - 2	LE2	0.5	22.3	475.6	0.3	22.8	23.0	OK	OK
	B189	M20 10.9 - 2	LE2	5.5	36.0	509.6	3.1	36.8	39.0	OK	OK
	B190	M20 10.9 - 2	LE2	9.5	64.2	405.5	5.4	65.5	69.4	OK	OK
	B191	M20 10.9 - 2	LE2	8.9	45.6	475.6	5.1	46.5	50.1	OK	OK
	B192	M20 10.9 - 2	LE2	5.0	36.2	199.1	2.9	37.0	39.0	OK	OK
	B193	M20 10.9 - 2	LE2	2.3	33.0	199.1	1.3	33.7	34.7	OK	OK
	B194	M20 10.9 - 2	LE2	1.3	34.8	199.1	0.8	35.5	36.0	OK	OK
	B195	M20 10.9 - 2	LE2	0.7	41.0	302.1	0.4	41.9	42.1	OK	OK
	B196	M20 10.9 - 2	LE2	6.9	52.8	509.6	3.9	53.9	56.7	OK	OK
	B197	M20 10.9 - 2	LE1	0.8	13.1	228.8	0.4	13.4	13.7	OK	OK
	B198	M20 10.9 - 2	LE1	0.7	11.4	199.1	0.4	11.6	11.9	OK	OK
	B199	M20 10.9 - 2	LE1	0.6	10.5	199.1	0.3	10.7	10.9	OK	OK
	B200	M20 10.9 - 2	LE1	0.6	10.3	199.1	0.3	10.5	10.7	OK	OK
	B201	M20 10.9 - 2	LE1	0.6	10.8	199.1	0.4	11.0	11.2	OK	OK
	B202	M20 10.9 - 2	LE2	0.0	14.5	219.2	0.0	14.8	14.8	OK	OK
	B203	M20 10.9 - 2	LE2	0.3	25.4	219.2	0.2	25.9	26.1	OK	OK
	B204	M20 10.9 - 2	LE2	1.6	15.0	509.6	0.9	15.3	15.9	OK	OK
	B205	M20 10.9 - 2	LE1	0.5	10.8	199.1	0.3	11.0	11.2	OK	OK
	B206	M20 10.9 - 2	LE1	0.5	10.1	199.1	0.3	10.4	10.6	OK	OK
	B207	M20 10.9 - 2	LE1	0.5	10.0	199.1	0.3	10.3	10.5	OK	OK
	B208	M20 10.9 - 2	LE1	0.6	10.5	199.1	0.3	10.7	10.9	OK	OK
	B209	M20 10.9 - 2	LE2	5.0	16.0	258.7	2.8	16.3	18.3	OK	OK
	B210	M20 10.9 - 2	LE2	6.0	27.0	219.2	3.4	27.5	30.0	OK	OK
	B211	M20 10.9 - 2	LE2	0.3	16.5	401.4	0.2	16.9	17.0	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B128	M20 10.9 - 1	LE2	5.8	65.2	162.5	3.3	66.5	68.9	OK	OK
	B129	M20 10.9 - 1	LE2	2.1	59.1	162.5	1.2	60.3	61.1	OK	OK
	B130	M20 10.9 - 1	LE2	2.1	57.3	162.5	1.2	58.5	59.3	OK	OK
	B131	M20 10.9 - 1	LE2	1.8	59.0	162.5	1.0	60.2	60.9	OK	OK
	B132	M20 10.9 - 1	LE2	0.3	63.5	162.5	0.2	64.8	65.0	OK	OK
	B133	M20 10.9 - 1	LE2	25.6	68.2	325.0	14.5	69.6	80.0	OK	OK
	B134	M20 10.9 - 1	LE2	9.5	69.1	162.5	5.4	70.6	74.4	OK	OK
	B135	M20 10.9 - 1	LE2	3.4	63.9	162.5	1.9	65.2	66.6	OK	OK
	B136	M20 10.9 - 1	LE2	1.7	58.3	162.5	1.0	59.5	60.2	OK	OK
	B137	M20 10.9 - 1	LE2	1.9	56.5	162.5	1.1	57.7	58.4	OK	OK
	B138	M20 10.9 - 1	LE2	1.6	57.9	162.5	0.9	59.1	59.7	OK	OK
	B139	M20 10.9 - 1	LE2	0.0	62.3	162.5	0.0	63.6	63.6	OK	OK
	B140	M20 10.9 - 1	LE2	23.4	66.8	325.0	13.2	68.1	77.6	OK	OK
	B141	M20 10.9 - 1	LE2	8.1	73.6	162.5	4.6	75.1	78.3	OK	OK
	B142	M20 10.9 - 1	LE2	5.2	67.4	162.5	2.9	68.8	70.9	OK	OK
	B143	M20 10.9 - 1	LE2	2.3	61.4	162.5	1.3	62.6	63.6	OK	OK
	B144	M20 10.9 - 1	LE2	2.0	59.1	162.5	1.1	60.3	61.1	OK	OK
	B145	M20 10.9 - 1	LE2	1.4	60.2	162.5	0.8	61.4	62.0	OK	OK
	B146	M20 10.9 - 1	LE2	0.0	64.6	162.5	0.0	65.9	65.9	OK	OK
	B147	M20 10.9 - 1	LE2	21.9	69.4	325.0	12.4	70.8	79.7	OK	OK
	B148	M20 10.9 - 1	LE2	23.8	74.7	162.5	13.5	76.2	85.9	OK	OK
	B149	M20 10.9 - 1	LE2	5.9	65.3	162.5	3.3	66.6	69.0	OK	OK
	B150	M20 10.9 - 1	LE2	2.1	59.1	162.5	1.2	60.3	61.1	OK	OK
	B151	M20 10.9 - 1	LE2	2.1	57.3	162.5	1.2	58.5	59.3	OK	OK
	B152	M20 10.9 - 1	LE2	1.7	58.9	162.5	1.0	60.1	60.8	OK	OK
	B153	M20 10.9 - 1	LE2	0.3	63.5	162.5	0.2	64.8	64.9	OK	OK
	B154	M20 10.9 - 1	LE2	25.7	68.2	325.0	14.6	69.6	80.0	OK	OK
	B155	M20 10.9 - 1	LE2	9.9	68.8	162.5	5.6	70.2	74.2	OK	OK
	B156	M20 10.9 - 1	LE2	3.7	63.9	162.5	2.1	65.3	66.7	OK	OK
	B157	M20 10.9 - 1	LE2	1.7	58.3	162.5	1.0	59.5	60.2	OK	OK
	B158	M20 10.9 - 1	LE2	1.9	56.5	162.5	1.1	57.6	58.4	OK	OK
	B159	M20 10.9 - 1	LE2	1.6	57.9	162.5	0.9	59.0	59.7	OK	OK
	B160	M20 10.9 - 1	LE2	0.0	62.3	162.5	0.0	63.5	63.5	OK	OK
	B161	M20 10.9 - 1	LE2	23.4	66.7	325.0	13.2	68.1	77.5	OK	OK
	B162	M20 10.9 - 1	LE2	8.1	73.2	162.5	4.6	74.7	78.0	OK	OK
	B163	M20 10.9 - 1	LE2	5.3	67.5	162.5	3.0	68.9	71.0	OK	OK
	B164	M20 10.9 - 1	LE2	2.3	61.3	162.5	1.3	62.6	63.5	OK	OK
	B165	M20 10.9 - 1	LE2	2.0	59.0	162.5	1.1	60.2	61.0	OK	OK
	B166	M20 10.9 - 1	LE2	1.4	60.2	162.5	0.8	61.4	62.0	OK	OK
	B167	M20 10.9 - 1	LE2	0.0	64.6	162.5	0.0	65.9	65.9	OK	OK
	B168	M20 10.9 - 1	LE2	21.8	69.3	325.0	12.4	70.8	79.6	OK	OK

Shape	Item	Grade	Loads	$F_{t,Ed}$ [kN]	$F_{v,Ed}$ [kN]	$F_{b,Rd}$ [kN]	$U_t$ [%]	$U_s$ [%]	$U_{ts}$ [%]	Detailing	Status
	B212	M20 10.9 - 2	LE1	0.7	12.9	199.1	0.4	13.2	13.5	OK	OK
	B213	M20 10.9 - 2	LE1	0.6	11.8	199.1	0.4	12.1	12.3	OK	OK
	B214	M20 10.9 - 2	LE1	0.6	11.6	199.1	0.4	11.8	12.1	OK	OK
	B215	M20 10.9 - 2	LE1	0.7	12.1	199.1	0.4	12.3	12.6	OK	OK
	B216	M20 10.9 - 2	LE2	0.5	16.5	509.6	0.3	16.8	17.1	OK	OK
	B217	M20 10.9 - 2	LE2	2.6	27.1	219.2	1.5	27.6	28.7	OK	OK
	B218	M20 10.9 - 2	LE2	3.4	26.0	386.3	1.9	26.5	27.9	OK	OK
	B219	M20 10.9 - 2	LE2	2.5	18.4	199.1	1.4	18.7	19.8	OK	OK
	B220	M20 10.9 - 2	LE2	1.1	14.8	199.1	0.6	15.1	15.6	OK	OK
	B221	M20 10.9 - 2	LE2	0.5	14.3	199.1	0.3	14.6	14.8	OK	OK
	B222	M20 10.9 - 2	LE2	0.5	16.5	509.6	0.3	16.9	17.1	OK	OK
	B223	M20 10.9 - 2	LE2	0.4	22.1	509.6	0.2	22.5	22.7	OK	OK
	B224	M20 10.9 - 2	LE2	2.6	32.3	509.6	1.5	33.0	34.1	OK	OK

Design data

Grade	$F_{t,Rd}$ [kN]	$B_{p,Rd}$ [kN]	$F_{v,Rd}$ [kN]
M20 10.9 - 1	176.4	498.2	98.0
M20 10.9 - 2	176.4	373.6	98.0

## 6. USPOREDBA DOBIVENIH REZULTATA

Tablica 37 prikazuje usporedbu veličine sila po etažama za obje zgrade. Vidljivo je da se zaobljenjem oblika sila proračunata prema [15] smanjuje za 60% u odnosu na zgradu kvadratnog tlocrta.

**Tablica 37.: Dobivene sile  $F_w$  za obje zgrade**

Etaža	Okrugla- $F_w$ [kN]	Kvadratna- $F_w$ [kN]	Omjer okrugle/kvadratne
7	112.20	262.96	0.43
8	116.64	282.95	0.41
9	120.70	292.64	0.41
10	124.47	301.59	0.41
11	127.97	309.93	0.41
12	131.25	317.72	0.41
13	134.33	325.04	0.41
14	137.24	331.95	0.41
15	139.99	338.50	0.41
16	142.61	344.71	0.41
17	145.10	350.64	0.41
18	147.49	356.29	0.41
19	149.77	361.71	0.41
20	151.96	366.90	0.41
21	154.06	371.89	0.41
22	156.09	376.69	0.41
23	158.04	381.32	0.41
24	159.93	385.79	0.41
25	161.75	390.11	0.41
26	163.52	394.30	0.41
27	165.23	398.35	0.41
28	166.89	402.28	0.41
29	168.50	406.10	0.41
38	181.26	436.30	0.42



Usporedbom unutarnjih sila može se vidjeti da se kod odabranih zgrada sila u stupovima i dijagonalama smanjila zaobljenjem tlocrta. Bitno je naglasiti kako su se vlačne sile drastično smanjile (tablica 39), što je posljedica smanjenih sila vjetra i boljih aerodinamičkih svojstava zgrade okruglog tlocrta.

Sile su se više smanjile u stupovima jezgre nego u obodnim stupovima. Jezgre su obično su najkrući dio zgrade i preuzimaju najveće sile, dok su obodni stupovi kod sustava potpornih rešetki elementi koji preuzimaju dio te sile i rasterećuju jezgru. Kako jezgra preuzima najveći dio opterećenja, smanjenjem opterećenja najveće smanjenje sile u elementima biti će vidljivo upravo u jezgri.

Sile u dijagonalama također su se značajno smanjile. Dijagonale su stabilizacijski elementi u zgradi te je smanjenjem opterećenja potrebna manja sila stabilizacije, što dovodi do smanjenih sila u dijagonalama.

Iz poglavlja 4., sa slika 33 i 34, usporedbom horizontalnih pomaka konstrukcije možemo vidjeti da se pomak zgrade okruglog tlocrta smanjio za 30% u odnosu na zgradu kvadratnog tlocrta.

Dobiveni rezultati u skladu su s rezultatima Rajmani i Guha, gdje su se dobila približno ista smanjenja momenata [17]. Međutim u radu [17] se deformacija zgrade smanjila za 60%, što je više nego u predmetu ovog rada.

U istraživanju Manohar i Babu [18], pokazalo se da su se deformacije okrugle zgrade smanjile za 46% u odnosu na kvadratnu zgradu, što je u skladu s deformacijama dobivenim ovim radom. Međutim, moment se smanjio za 70%, te je u radu zaključeno da su uzdužne sile veće u zgradi okruglog tlocrta [18].

Razlog različitih rezultata može biti različit konstrukcijski sustav, drukčiji način zadavanja opterećenja te je bitno i gleda li se pojedini element, ili cijela konstrukcija, što sve treba uzeti u obzir pri interpretaciji rezultata i usporedbi s nalazima drugih istraživanja.

Sile na glavnim i sekundarnim nosačima nisu u skladu sa smanjenjem sila na stupove. Razlog tome je što su nosači horizontalni elementi i na njih više djeluju vertikalna, a ne horizontalna opterećenja. Sekundarni nosači su kod okrugle zgrade bili na nešto većem razmaku, te to objašnjava nešto veće poprečne sile i momente savijanja. Posljedično, veće sile na sekundarne nosače uzrokuju i nešto veće sile na glavne nosače.

Tablice 38, 39, 40 i 41 prikazuju dobivene maksimalne sile u zgradama te njihov omjer.

Tablica 38.: Usporedba tlačnih sila

Maksimalna tlačna sila [kN]	Okrugli tlocrt	Kvadratni tlocrt	Omjer okrugla/kvadratna
Stup jezgre	61557	76901	0,80
Stup oboda	43454	46458	0,95
Glavni nosač	2126	3342	0,64
Sekundarni nosač	353	416	0,85
Dijagonale	3401	6318	0,54

Tablica 39.: Usporedba vlačnih sila

Maksimalna vlačna sila [kN]	Okrugli tlocrt	Kvadratni tlocrt	Omjer okrugla/kvadratna
Stup jezgre	1618	5572	0,29
Stup oboda	173	2966	0,06
Glavni nosač	2452	3387	0,72
Sekundarni nosač	546	307	1,78
Dijagonale	2793	7351	0,37

Tablica 40.: Usporedba poprečnih sila

Maksimalna poprečna sila [kN]	Okrugli tlocrt	Kvadratni tlocrt	Omjer okrugla/kvadratna
Stup jezgre	472	671	0,70
Stup oboda	556	839	0,66
Glavni nosač	900	615	1,46
Sekundarni nosač	1075	1632	0,66
Dijagonale	/	/	/

Tablica 41.: Usporedba momenata savijanja

Maksimalni moment savijanja	Okrugli tlocrt	Kvadratni tlocrt	Omjer okrugla/kvadratna
Stup jezgre	1445	3621	0,40
Stup oboda	1456	1950	0,75
Glavni nosač	2084	2041	1,02
Sekundarni nosač	751	508	1,48
Dijagonale	/	/	/

Usporedbom mase konstrukcija iz tablice 42, vidljivo je da se masa konstrukcije smanjila za 26% promjenom oblika, što sugerira i jeftiniju konstrukciju. Međutim, masa konstrukcije nije jedini parametar koji uvjetuje cijenu te i to treba uzeti u obzir. Okrugli tlocrti kompliciraniji su za izvedbu te time mogu biti i skuplji. U svakom slučaju potrebna je detaljna analiza cjelokupne konstrukcije i cijene kako bi se dobili konačni zaključci.

**Tablica 42.: Usporedba masa konstrukcija**

	Okrugli tlocrt	Kvadratni tlocrt	Omjer okrugla/kvadratna
Ukupna masa konstrukcije [t]	11567	15587	0,74
Masa po tlocrtnom m <sup>2</sup> [t/m <sup>2</sup> ]	0,23	0,32	0,74

Oplošje okrugle zgrade :  $40,62 \cdot \pi \cdot 176 = 22460 \text{ m}^2$

Oplošje kvadratne zgrade:  $4 \cdot 36 \cdot 176 = 25344 \text{ m}^2$

Uspoređujući površine fasade, površina fasade okrugle zgrade 12% je manja od površine fasade kvadratne zgrade. Fasade su jedan od skupljih dijelova zgrade, te se zaobljenjem tlocrta dobiva na uštedi materijala. Dobiva se i na uštedi energije, jer smanjeno oplošje znači smanjenju površinu kroz koju se može gubiti toplina.

## 7. ZAKLJUČAK

Provedenom analizom različitih oblika tlocrta zgrade mogu se izvući sljedeći zaključci za okrugli tlocrt u odnosu na kvadratni tlocrt:

- Sile vjetra smanjile su se za 60%
- Opterećenja na stupove i stabilizaciju također su se smanjila
- Vršni pomaci smanjili su se za 30%
- Masa se smanjila za 25%
- Površina fasade smanjila se za 12%
- Opterećenja na sekundarne i glavne nosače nisu se značajno smanjila, a negdje su se čak i povećala, što je posljedica većih raspona i većeg razmaka između nosača

Provedeno istraživanje sugerira da se zaobljenjem tlocrta dobivaju povoljniji uvjeti opterećenja te potencijalno manja cijena i bolja energetska učinkovitost.

Međutim, izabran je samo jedan položaj elemenata u tlocrtu za svaku zgradu, te izabrani položaji i veličine presjeka nisu ekvivalentni. Potrebna su dodatna istraživanja sa više vrsta položaja elemenata i veličina presjeka kako bi se dobili pouzdaniji rezultati.

Cijena zgrada također ovisi i o tipu i načinu izrade detalja te jednostavnosti izvedbe, te nije moguće bez detaljne analize utvrditi koji tip tlocrta bi bio cjenovno povoljniji.

Preporučuje se detaljna analiza više vrsta željenih oblika zgrada kako bi se dobili pouzdaniji rezultati za izabrane konstrukcije.

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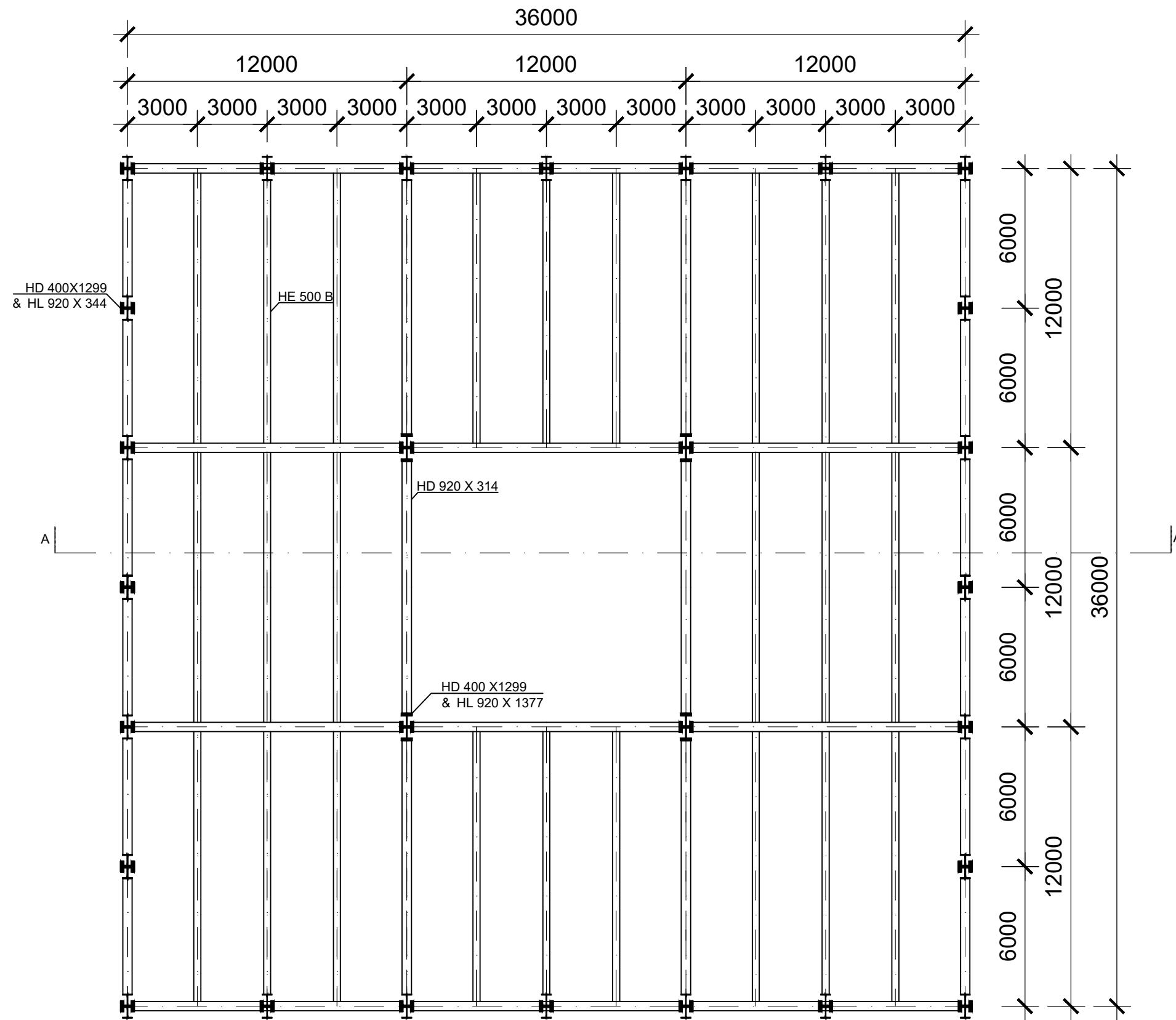
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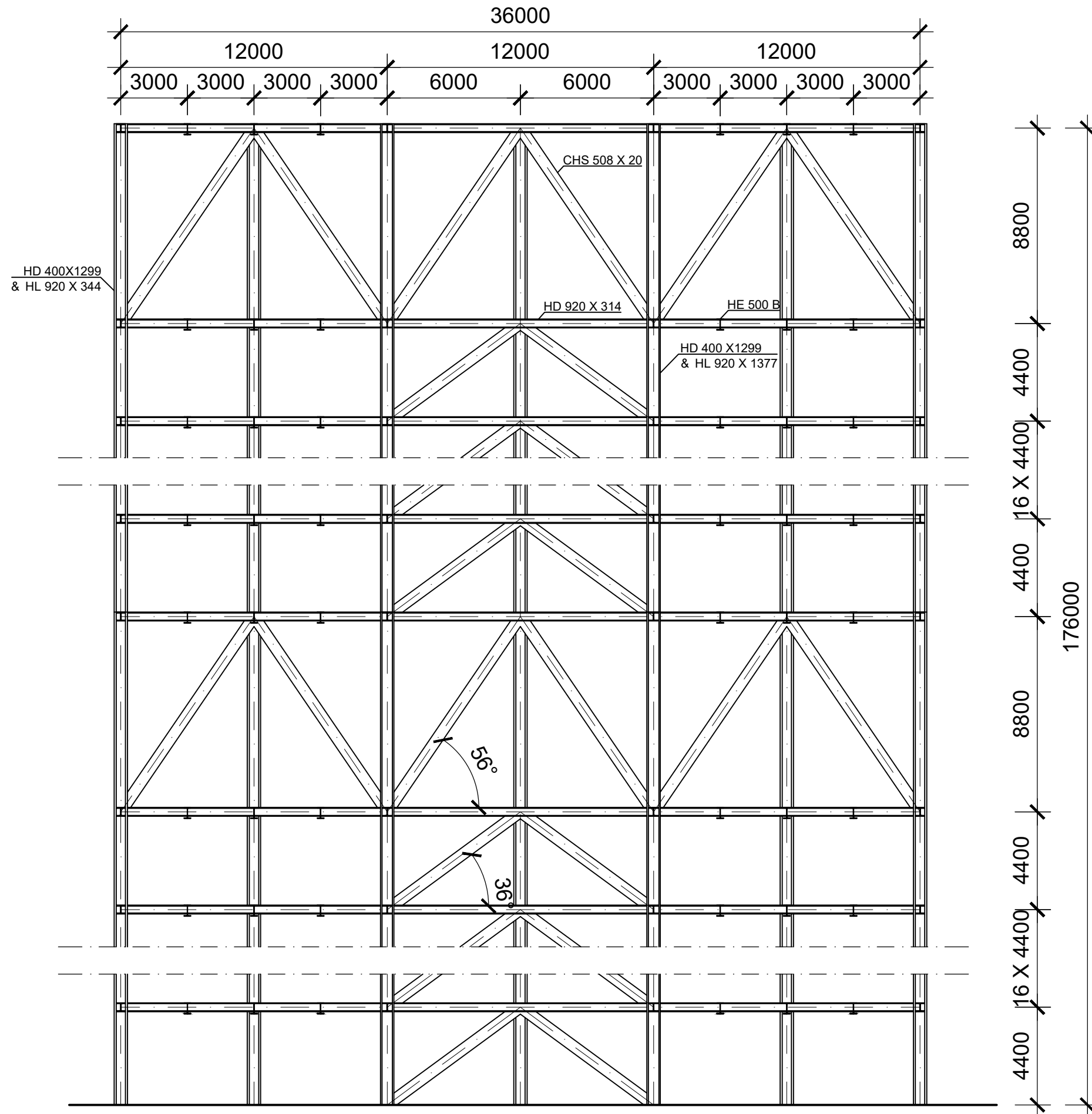
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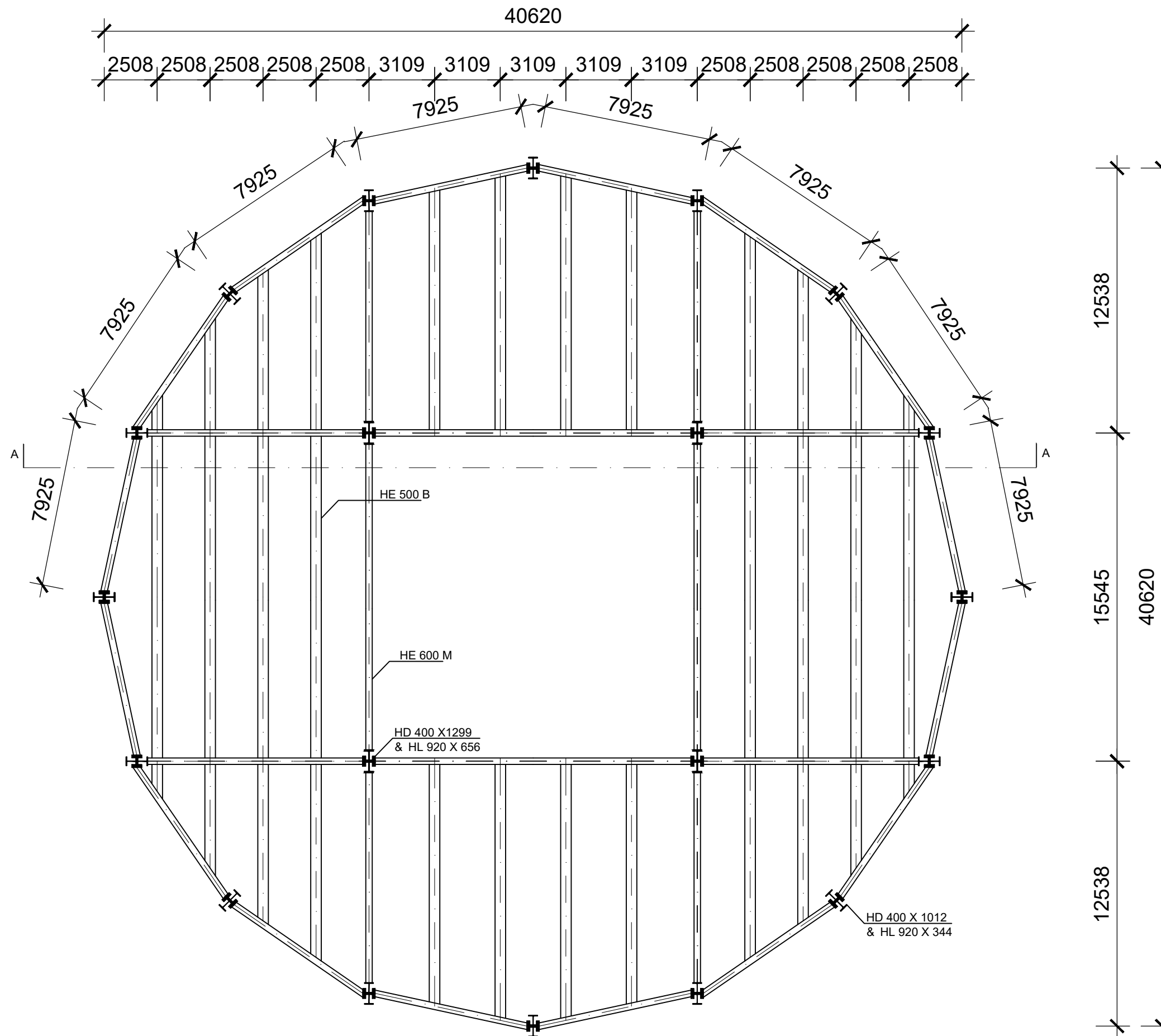
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PRESJEK A-A  
MJ 1:200



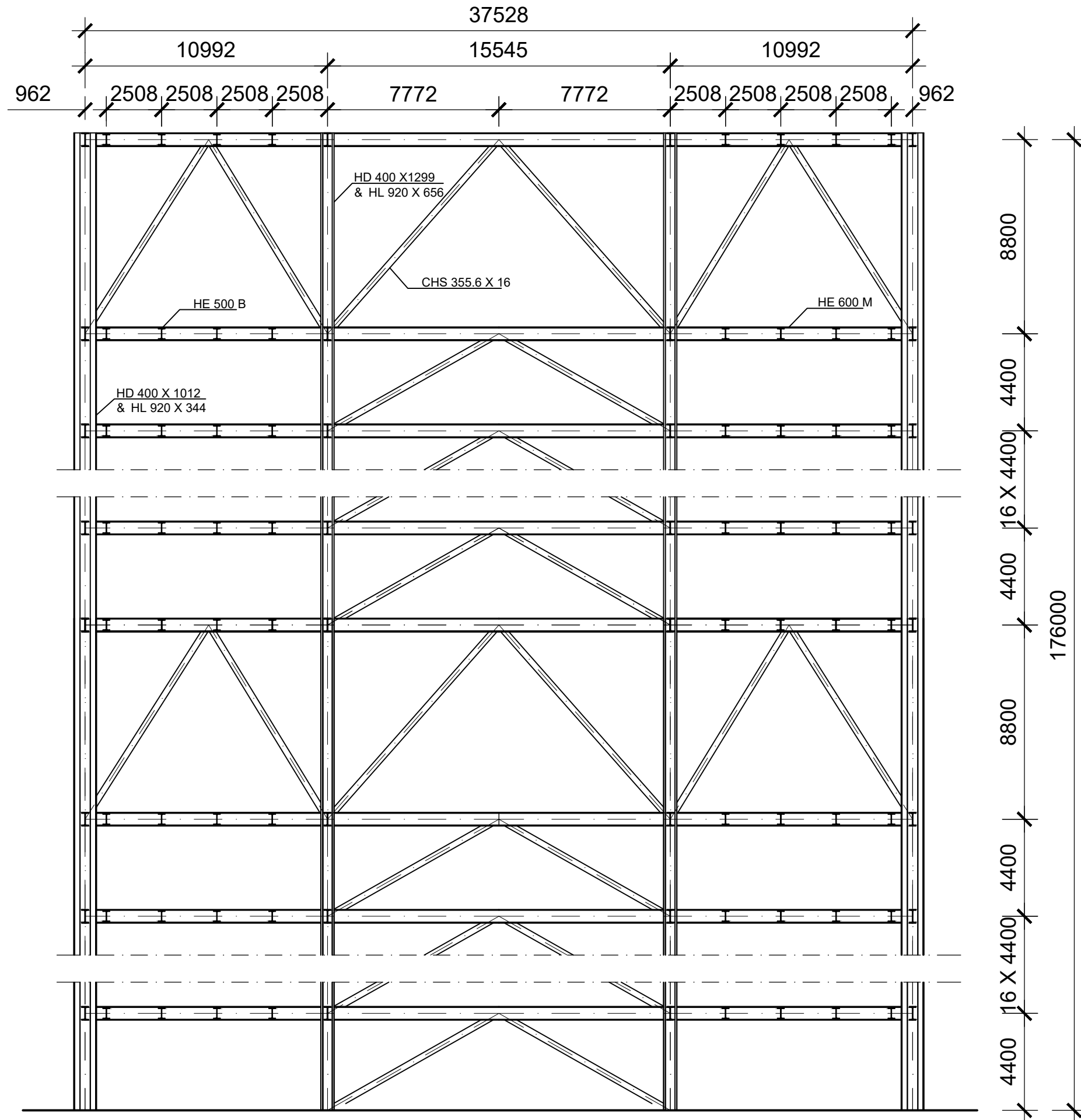
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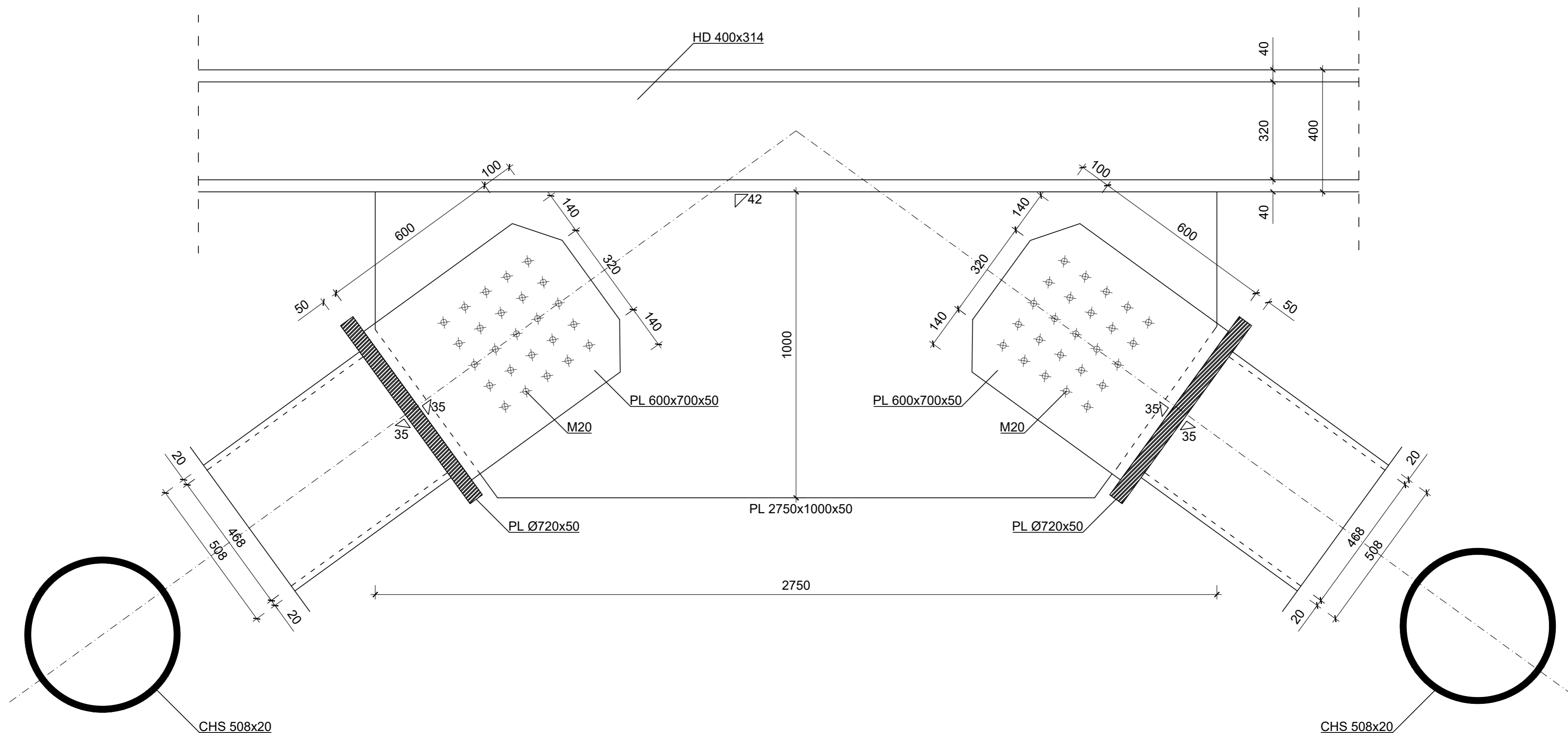
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Sadržaj	Tlocrt zgrade okruglog tlocrta		
Mentor	izv. prof. dr. sc. Ivan Lukačević		
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PRESJEK A-A  
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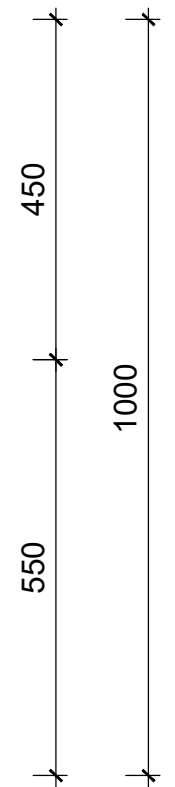
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PRIKLJUČAK DIJAGONALA NA GLAVNI NOSAČ  
UZDUŽNI PRESJEK  
MJ 1:10

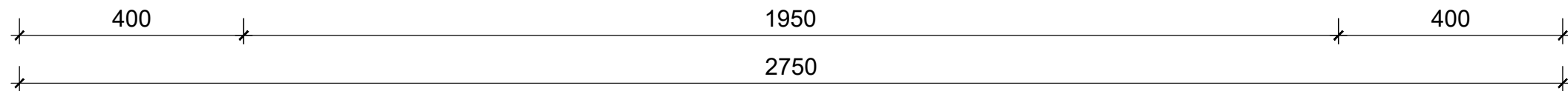


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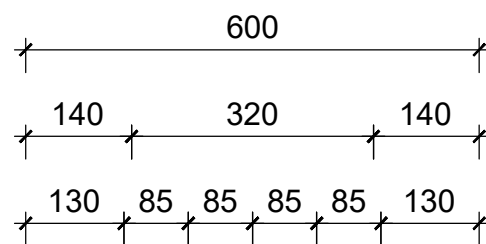
PRIKLJUČAK DIJAGONALA NA GLAVNI NOSAČ  
 ČELIČNI LIMOVI  
 MJ 1:10



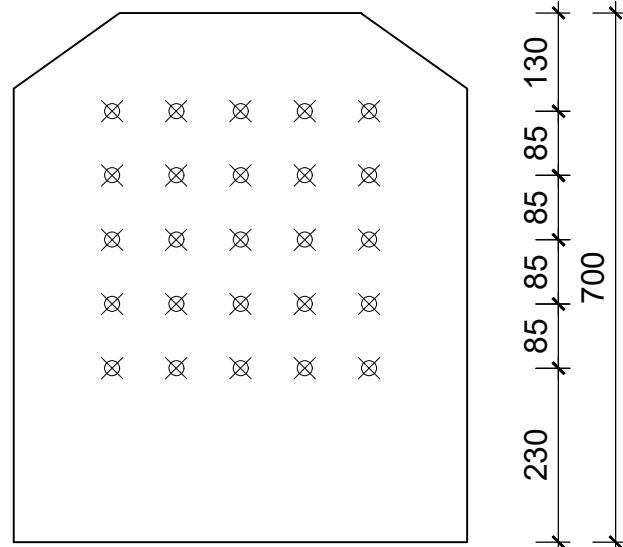
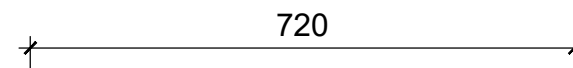
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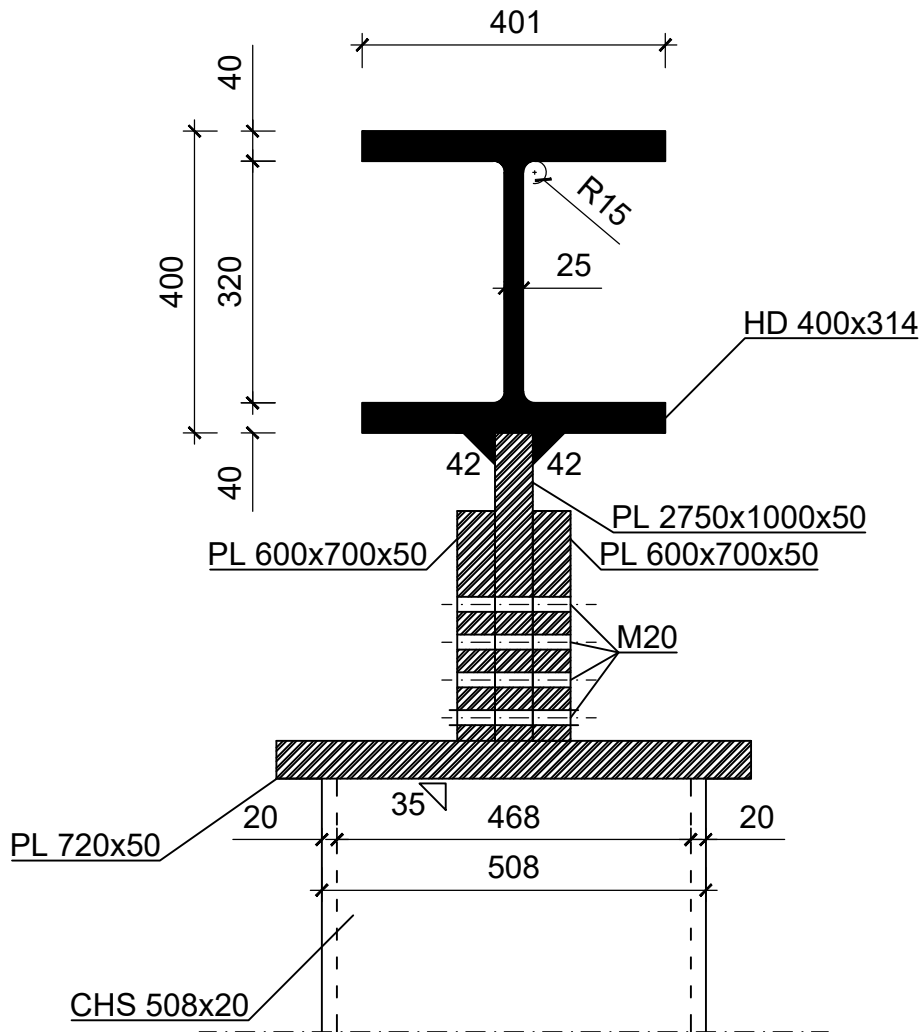
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# PRIKLJUČAK DIJAGONALA NA GLAVNI NOSAČ POPREČNI PRESJEK MJ 1:10

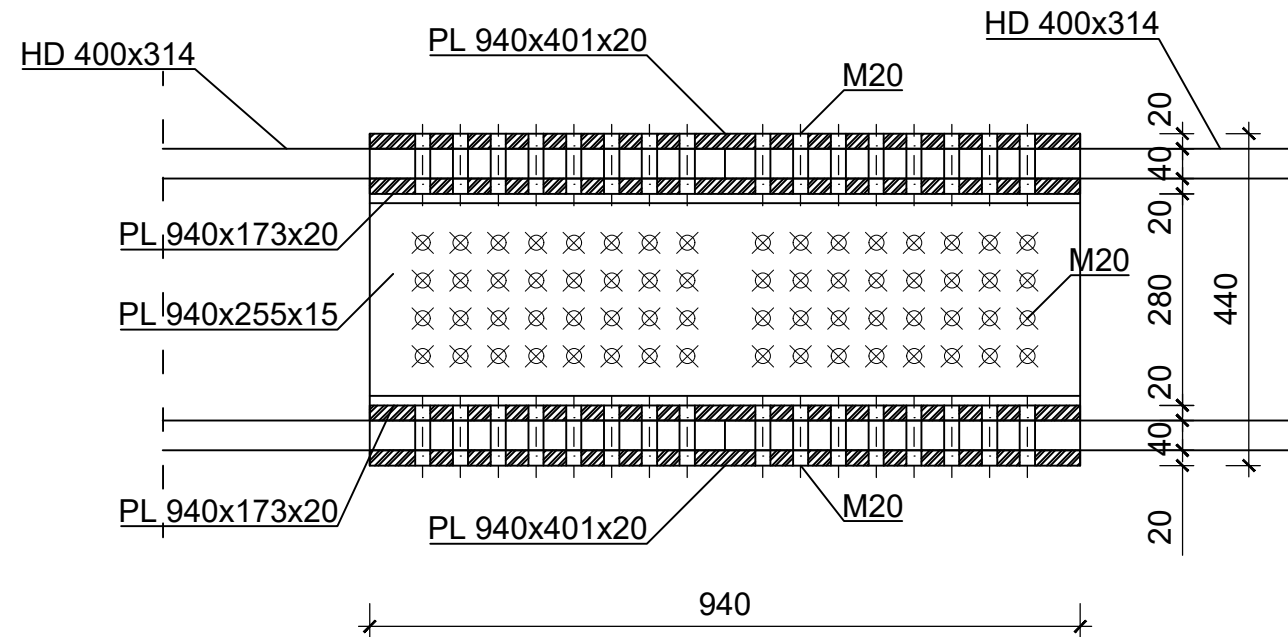


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Sadržaj	Priključak dijagonala na glavni nosač- poprečni presjek	
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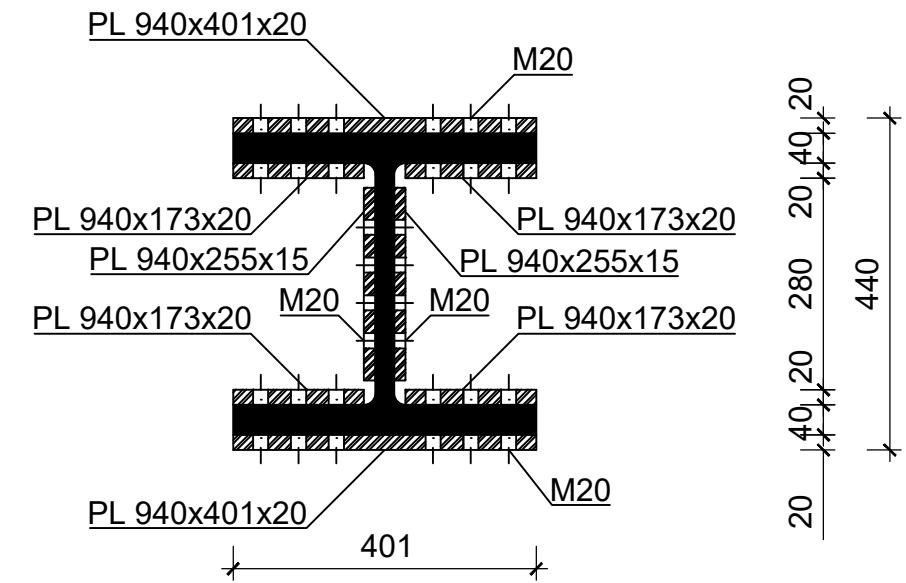
# NASTAVAK GLAVNOG NOSAČA

## MJ 1:10

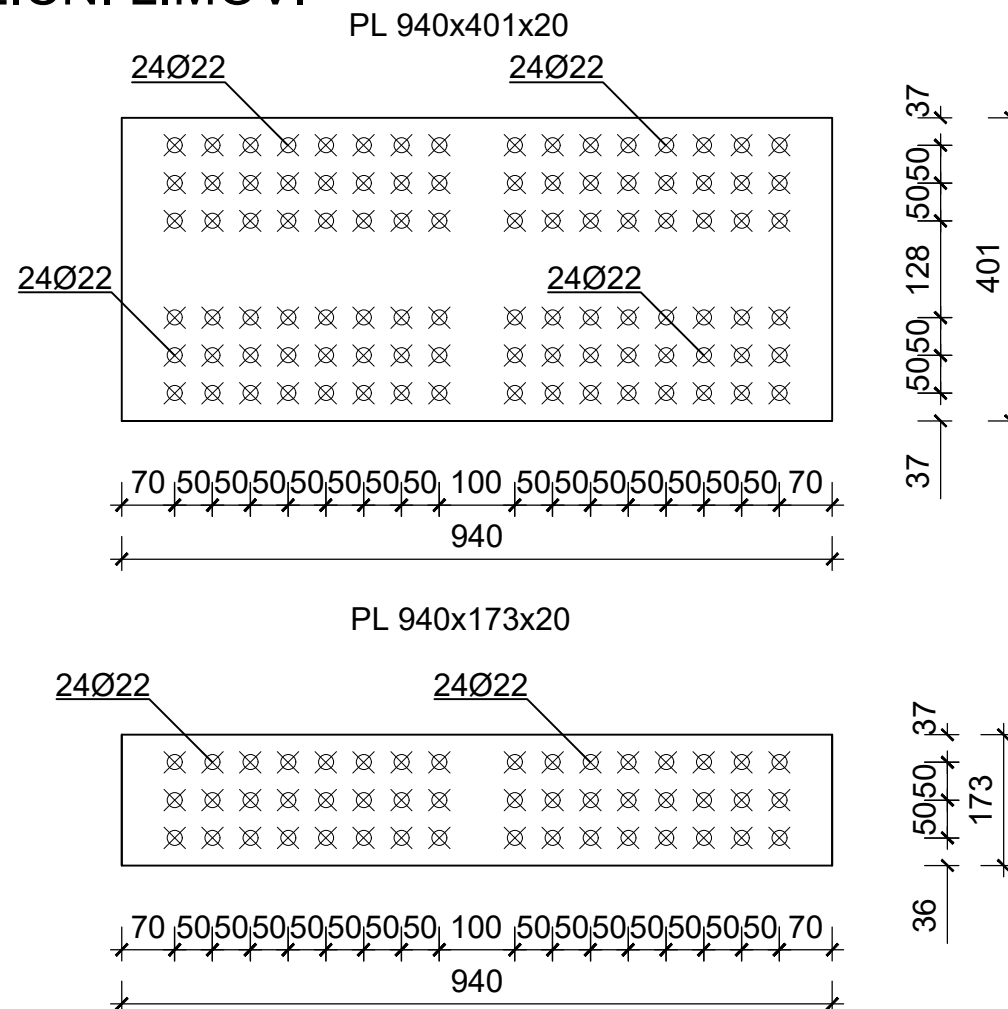
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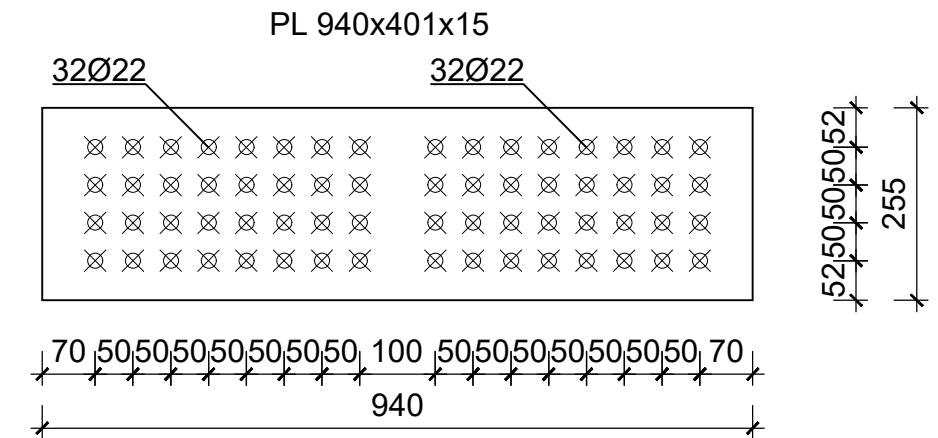
### POPREČNI PRESJEK



### ČELIČNI LIMOVI



### ČELIČNI LIM

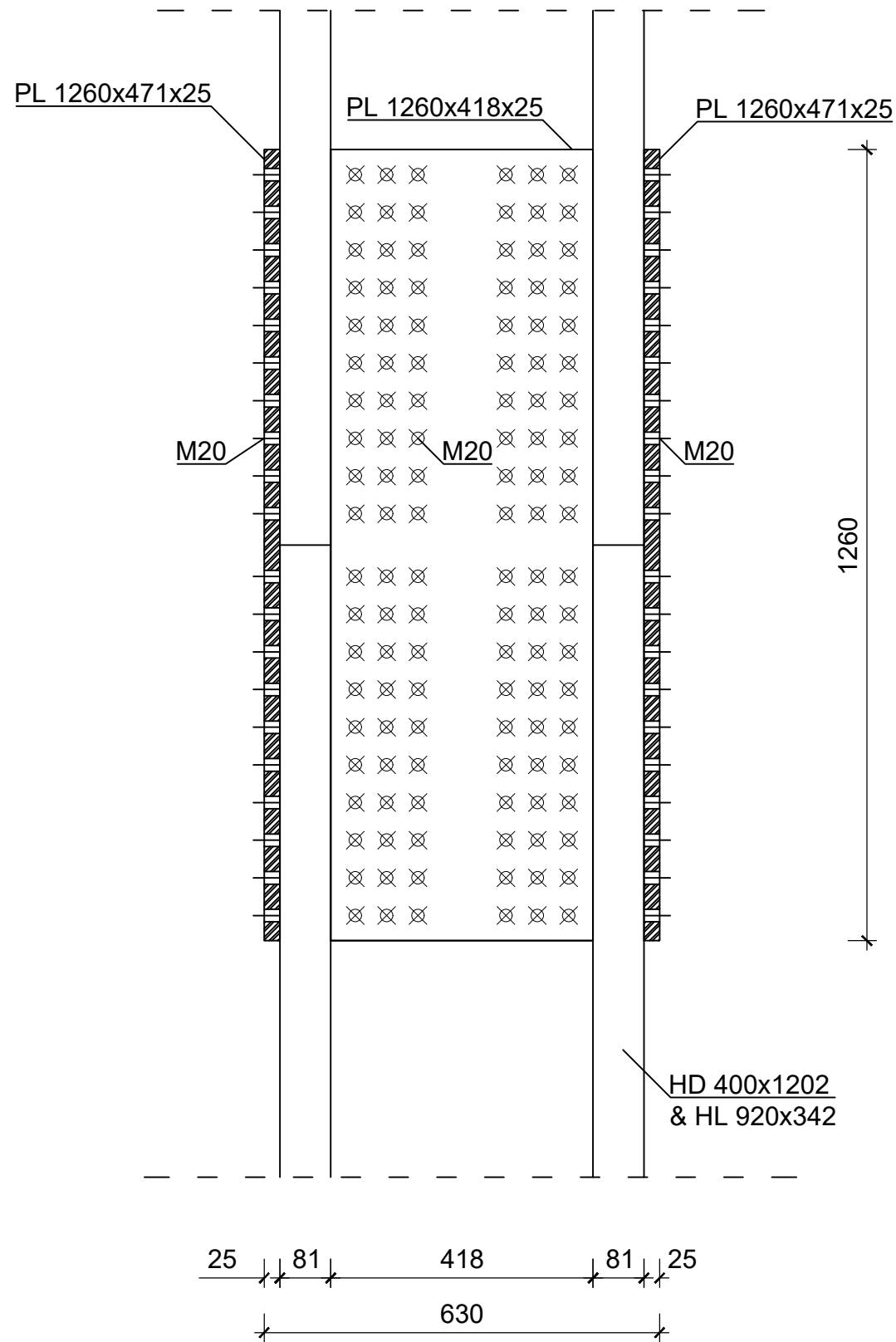


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Sadržaj	Nastavak glavnog nosača		
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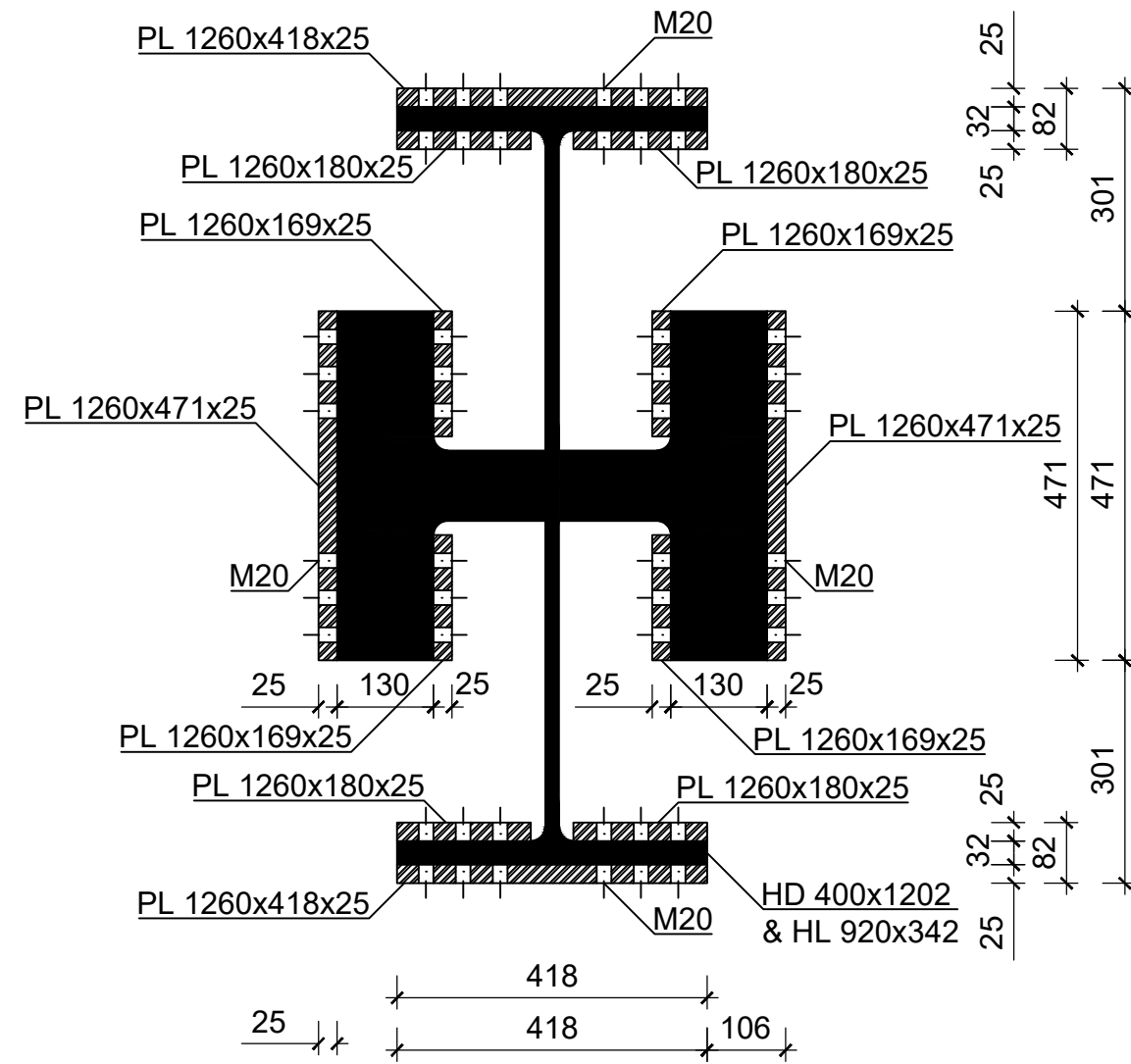
# NASTAVAK OBODNOG STUPA

## MJ 1:10

### POPREČNI PRESJEK



### TLOCRT

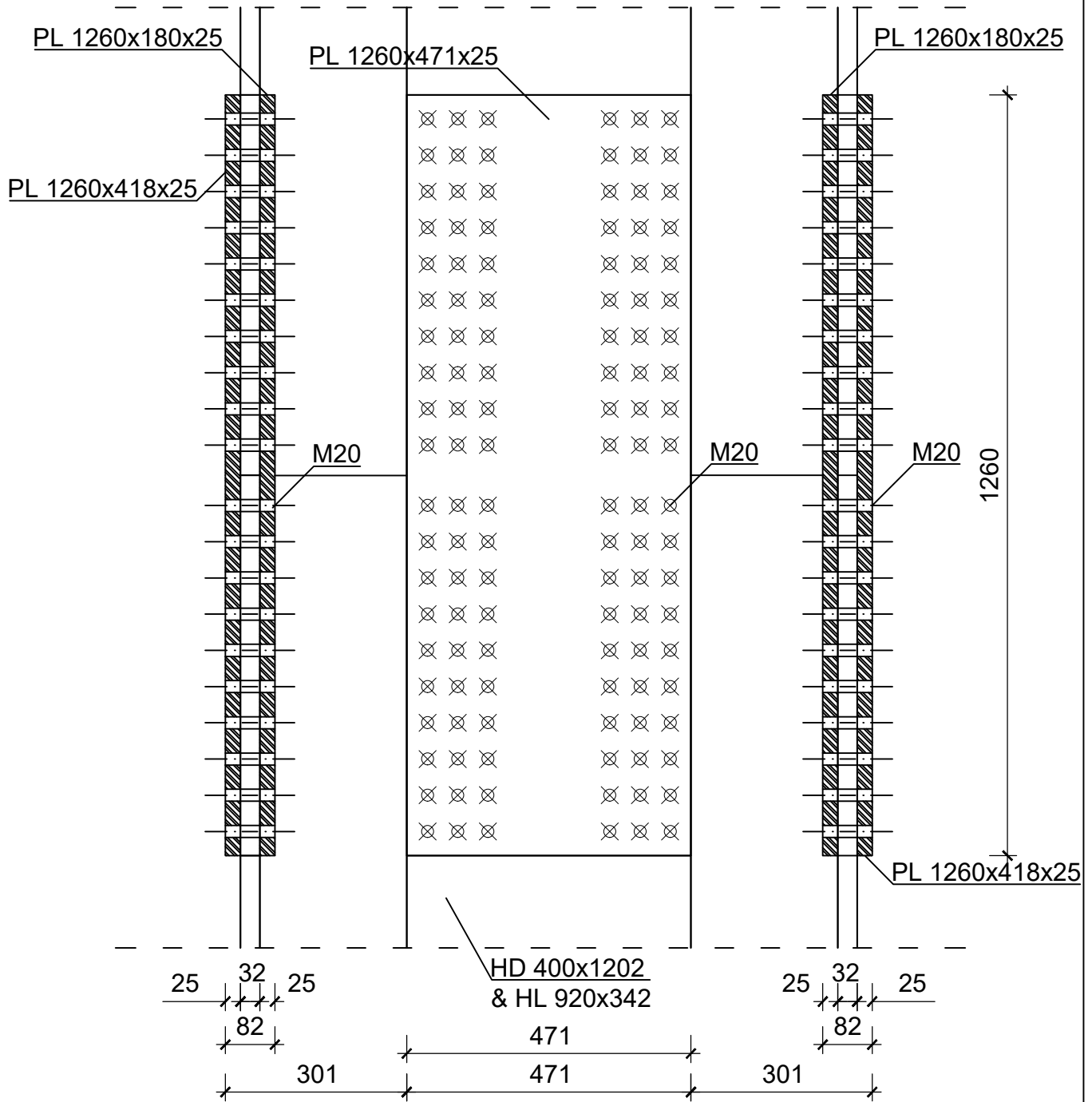


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# NASTAVAK STUPA

## UZDUŽNI PRESJEK

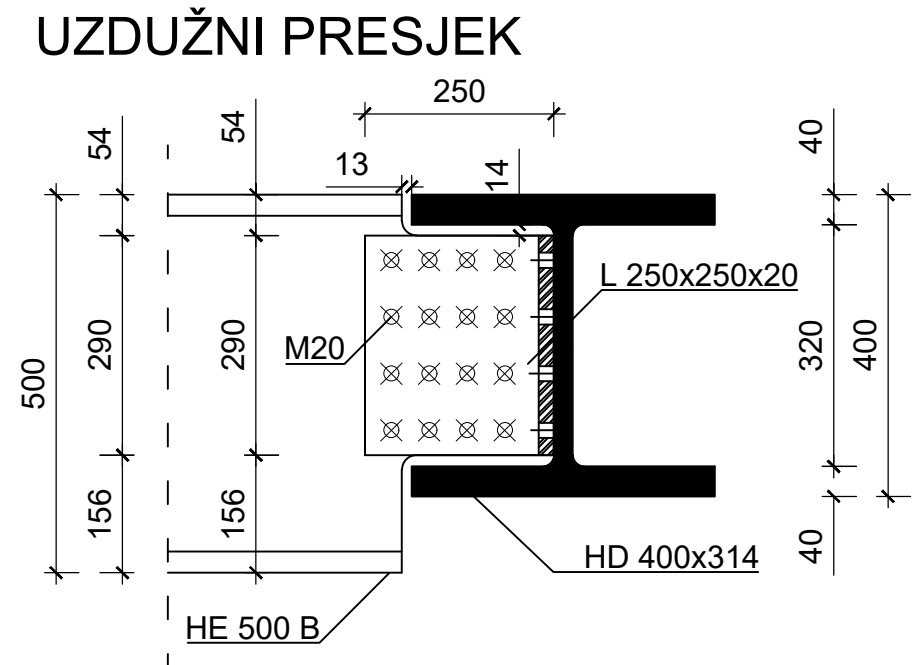
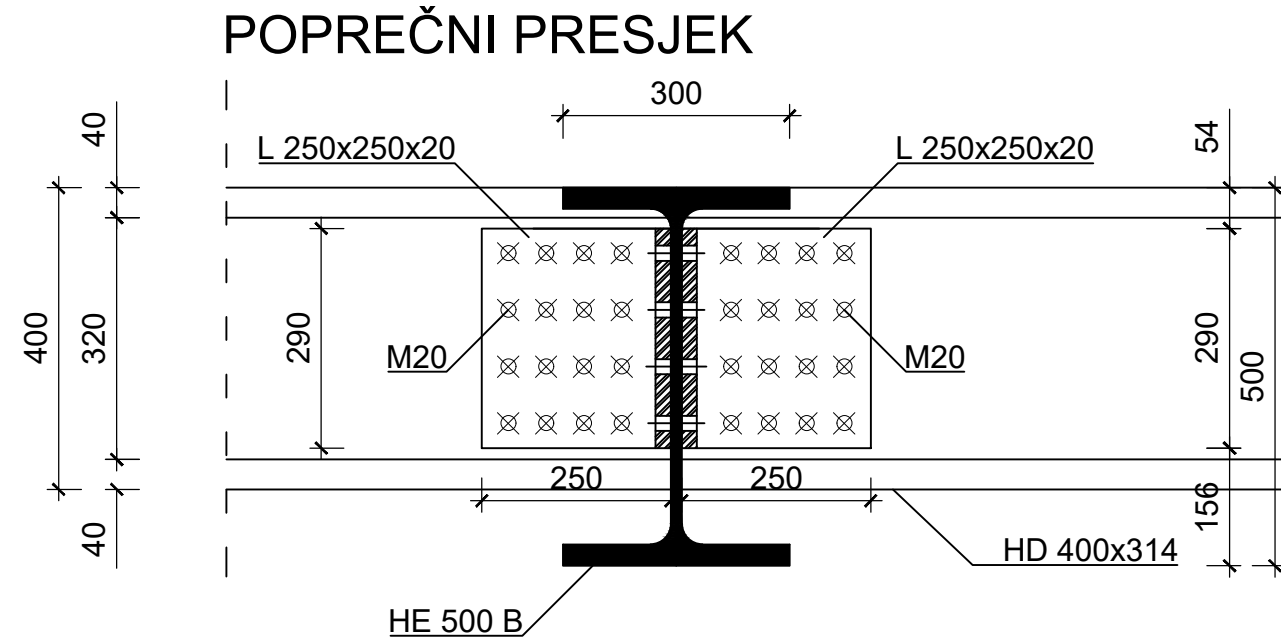
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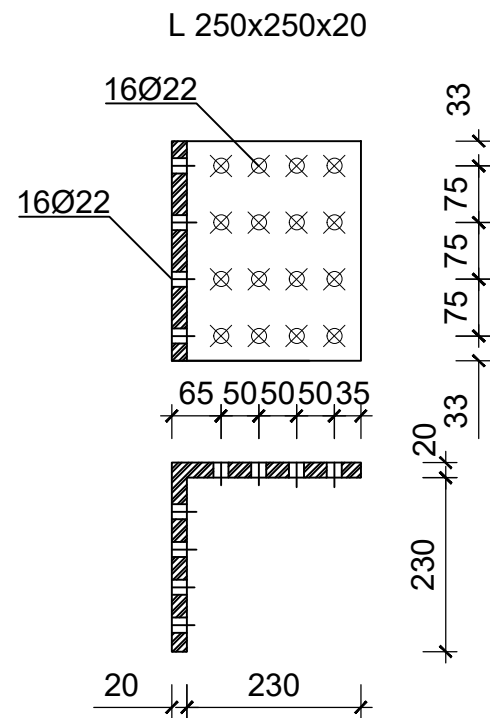
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# PRIKLJUČAK SEKUNDARNOG NOSAČA NA GLAVNI NOSAČ

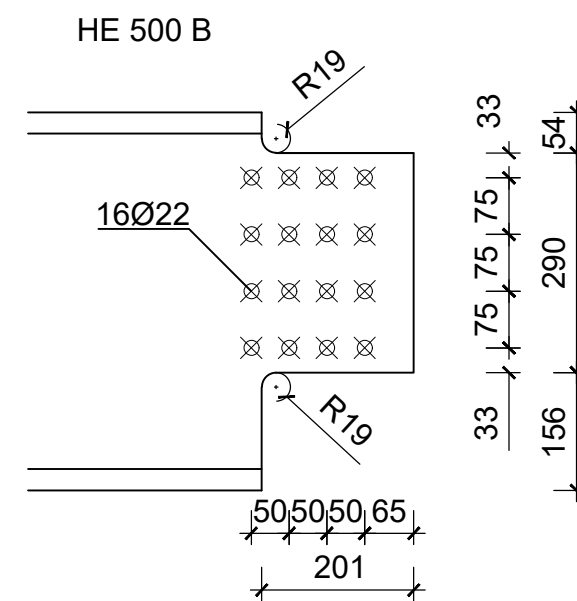
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### ČELIČNI KUTNIK

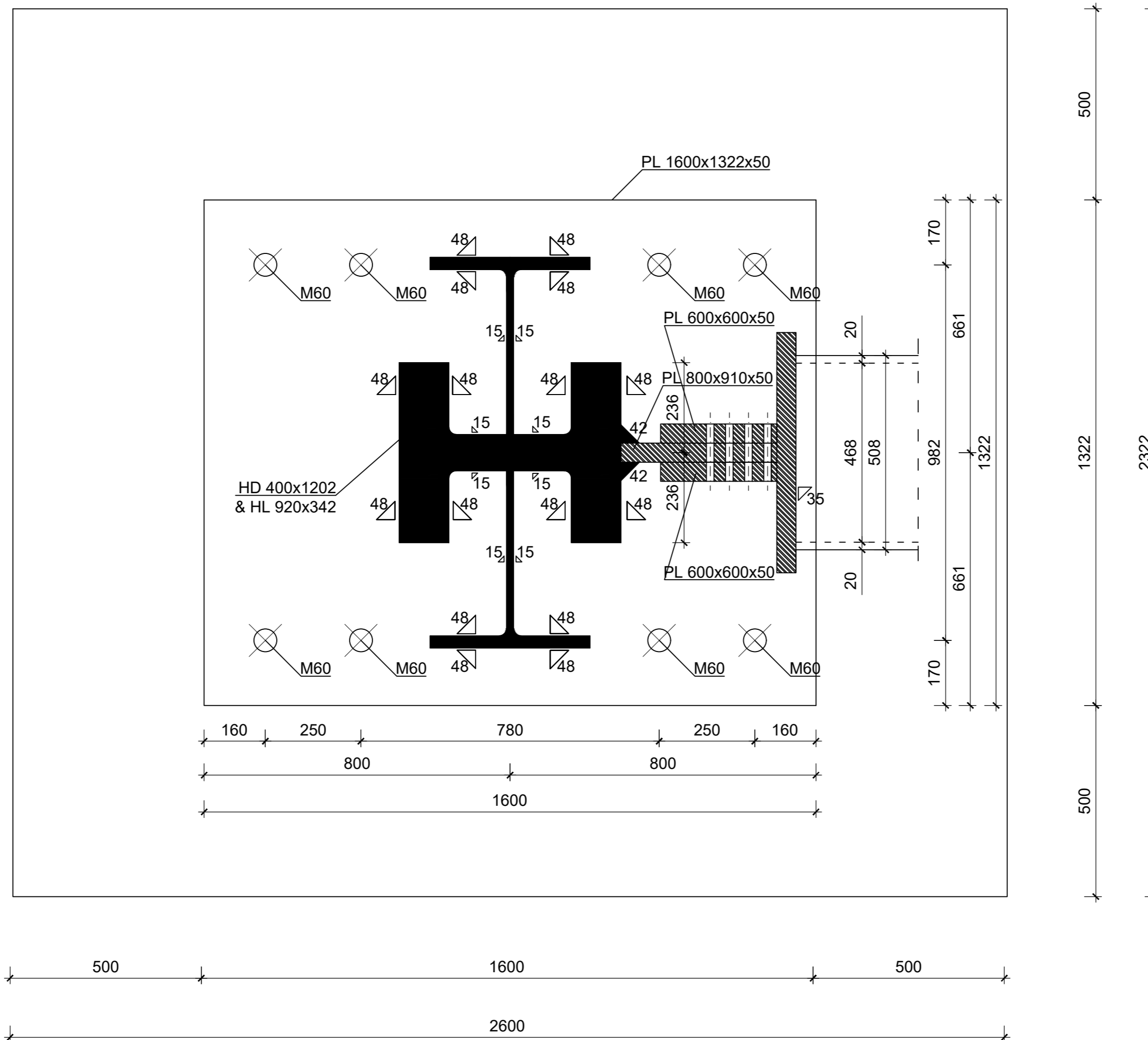


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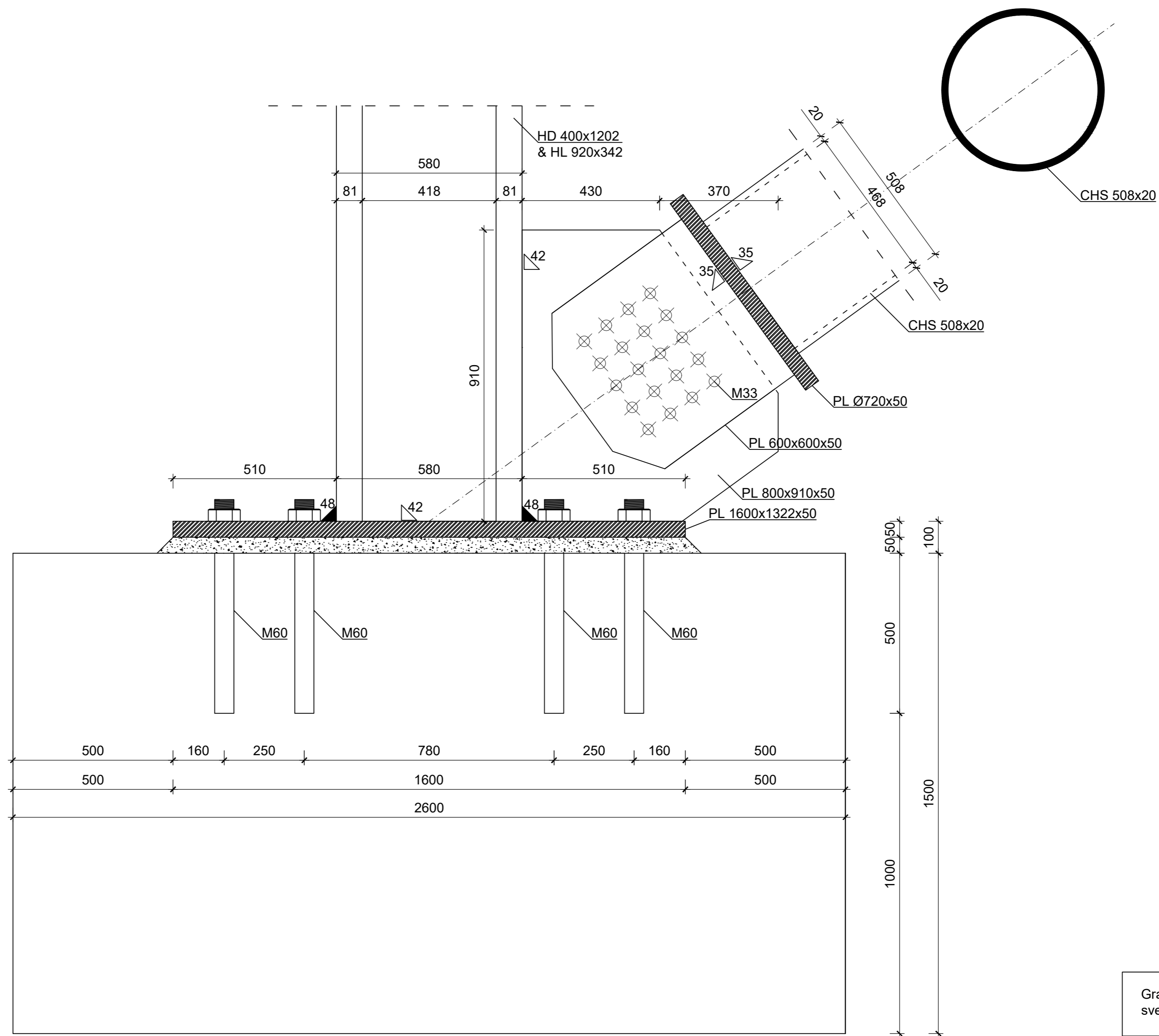
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PRIKLJUČAK OBODNOG STUPA NA TEMELJ  
TLOCRT  
MJ 1:10



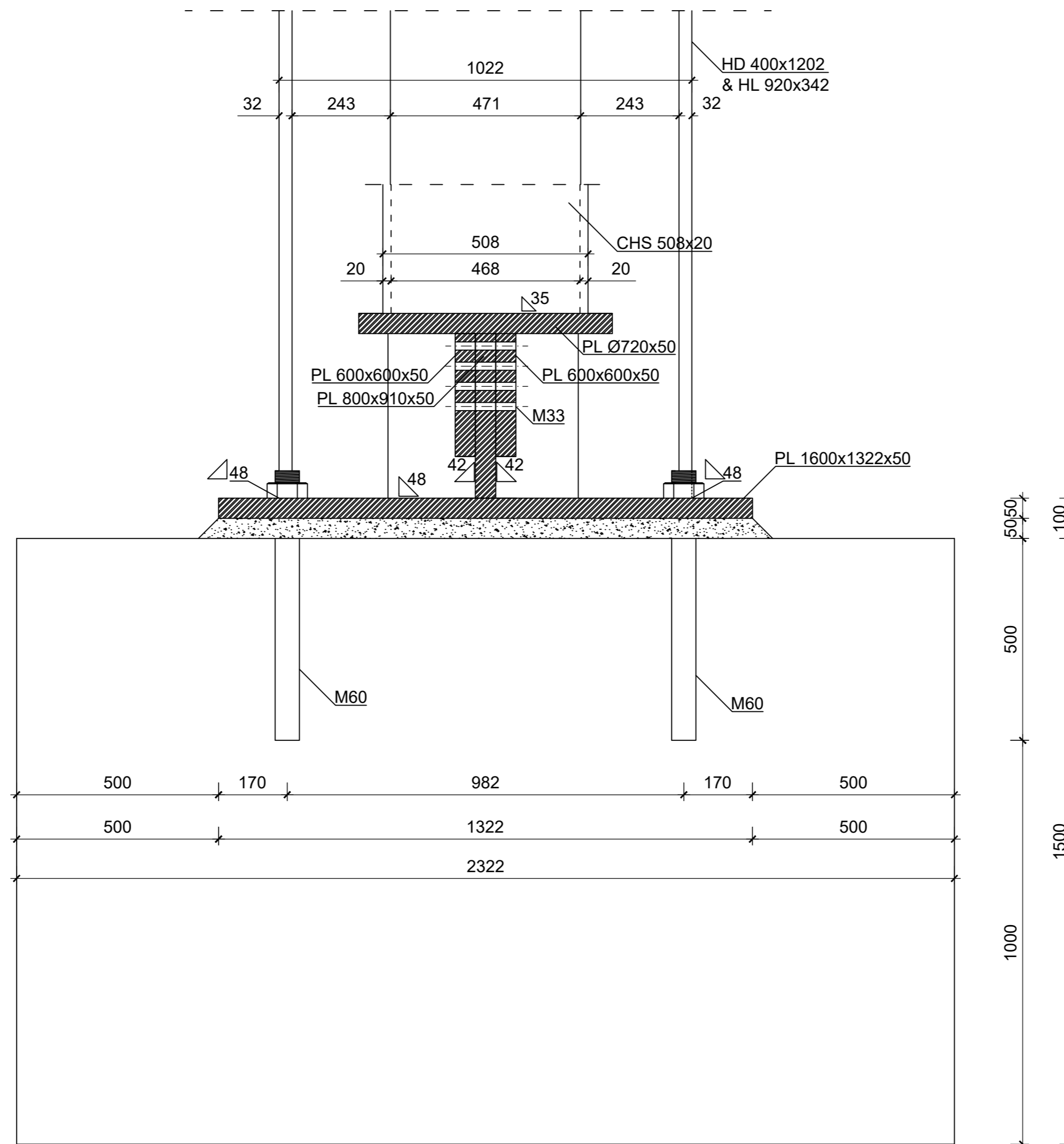
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PRIKLJUČAK OBODNOG STUPA NA TEMELJ  
 POPREČNI PRESJEK  
 MJ 1:10



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 UZDUŽNI PRESJEK  
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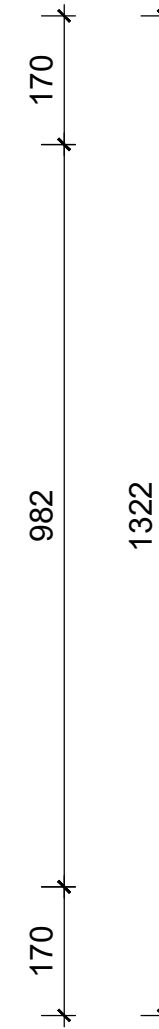
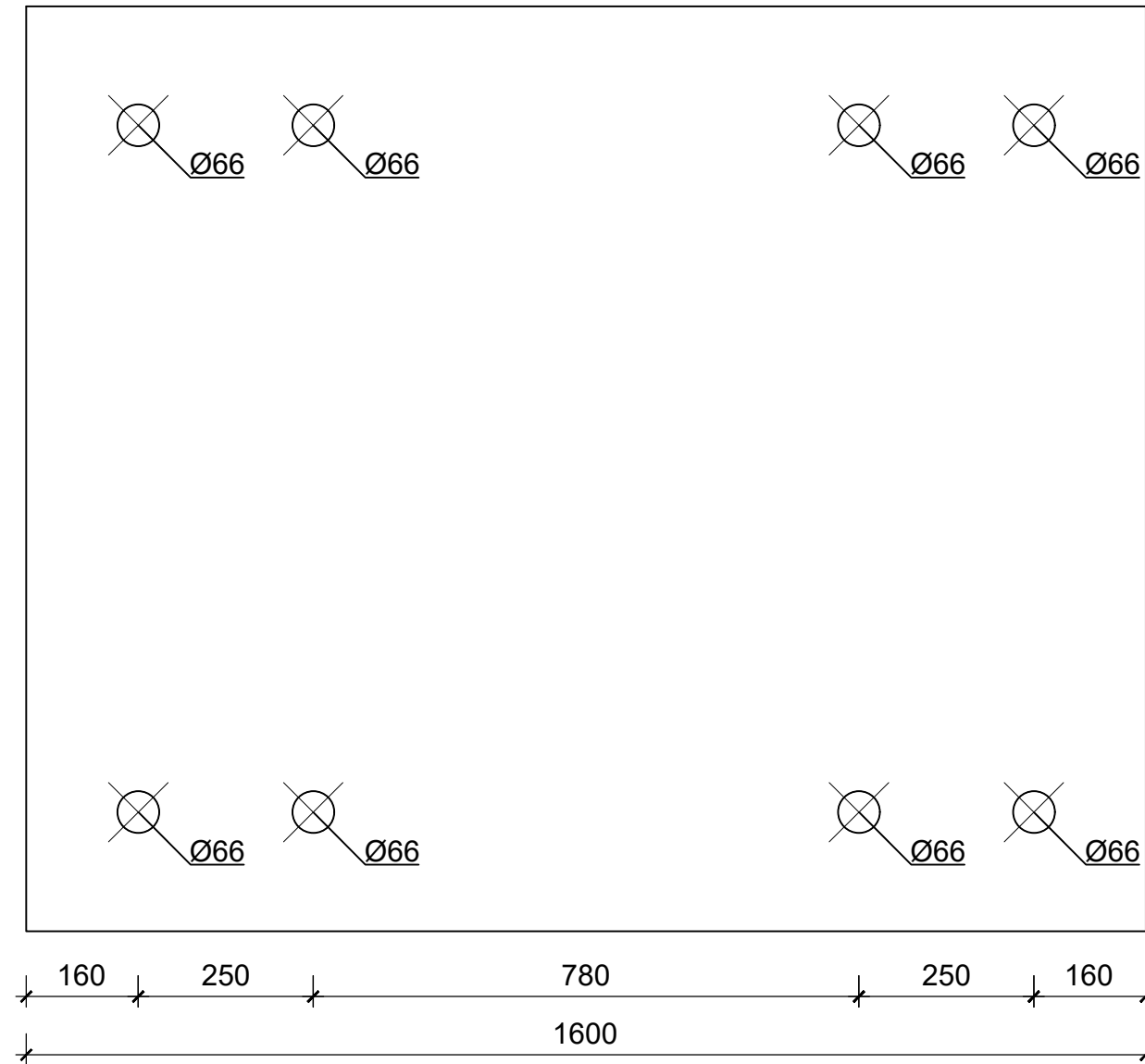


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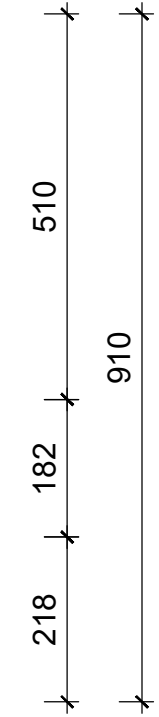
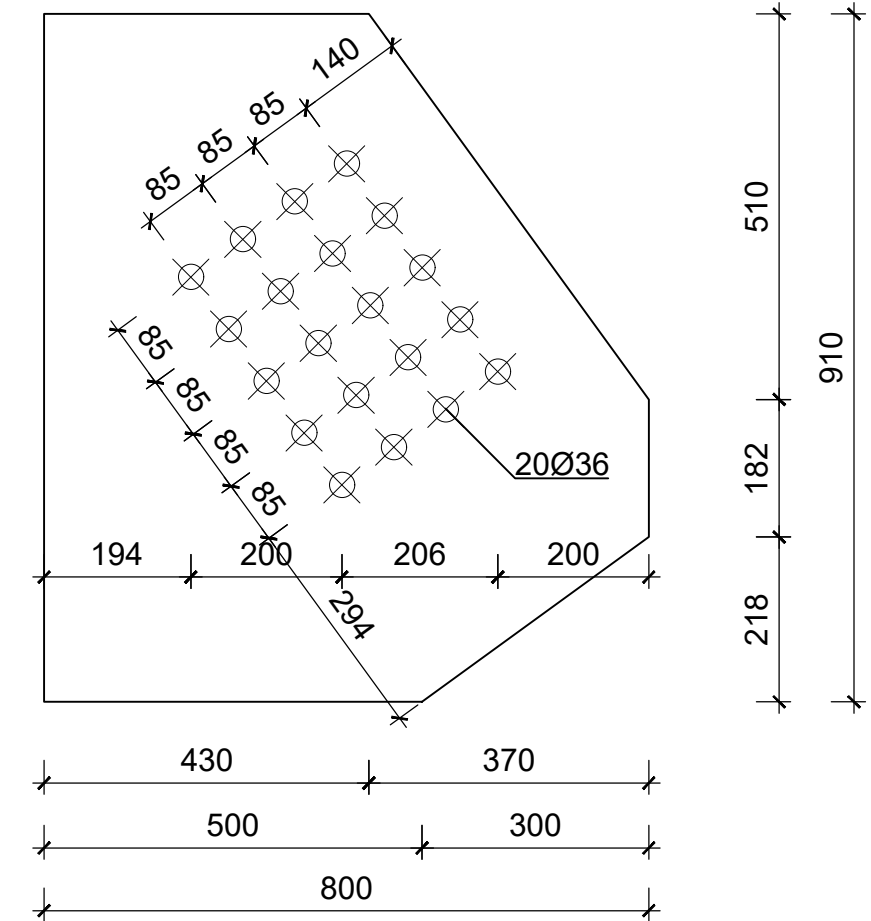


PRIKLJUČAK OBODNOG STUPA NA TEMELJ  
 ČELIČNI LIMOVI  
 MJ 1:10

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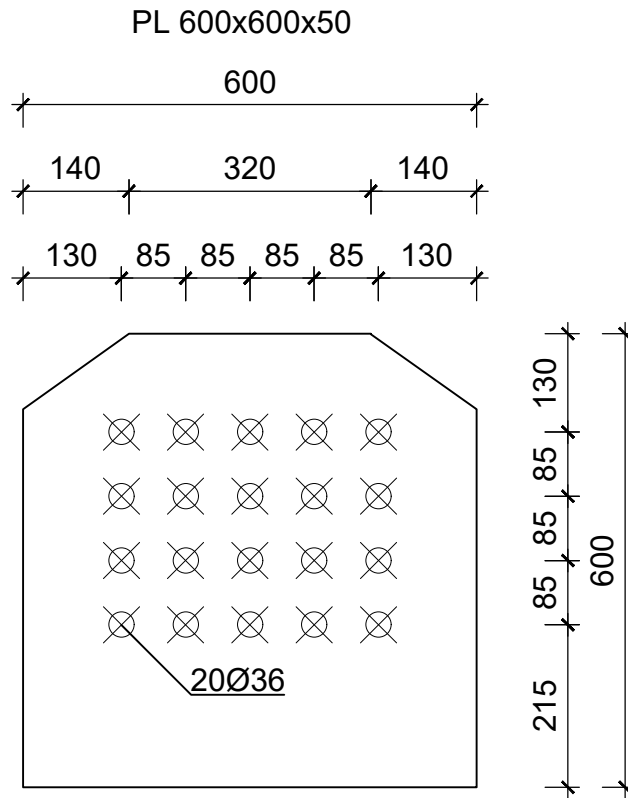


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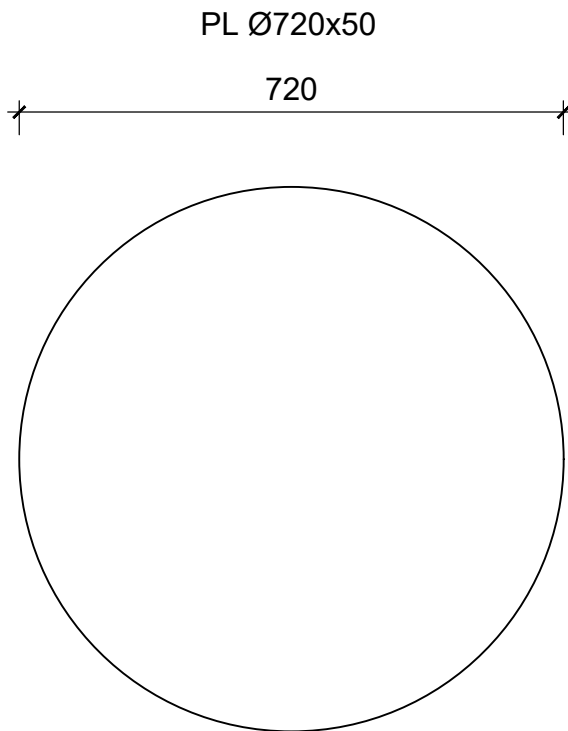
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PRIKLJUČAK OBODNOG STUPA NA TEMELJ  
ČELIČNI LIM  
MJ 1:10



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