

PROJEKT DRVENE KONSTRUKCIJE SPORTSKE HALE KONCIPIRANE OD ZAKRIVLJENIH LAMELIRANIH NOSAČA NA V STUPOVIMA

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Sveučilište u Zagrebu

GRAĐEVINSKI FAKULTET

Nika Dvorščak

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prof.dr.sc. Vlatka Rajčić, dipl.ing.grad.

Zagreb, 2024



University of Zagreb

FACULTY OF CIVIL ENGINEERING

Nika Dvorščak

**DESIGN PROJECT OF SPATIAL TIMBER SPORT
HALL STRUCTURE MADE FROM CURVED
LAMINATED TIMBER GIRDERS ON V SHAPED
COLUMNS**

MASTER THESIS

prof.dr.sc. Vlatka Rajčić

Zagreb, 2024

Ovom prigodom izražavam iskrenu zahvalnost;

svojoj mentorici, prof.dr.sc. Vlatki Rajčić, za njenu stručnost, smjernice i podršku tijekom procesa izrade ovog rada.

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Vaša vjera u mene i nesebična podrška omogućili su mi da ostvarim svoje ciljeve.

Hvala vam od srca.

Nika Dvorščak

SAŽETAK

Tema ovog diplomskog rada je projekt prostorne koncepcije drvene konstrukcije sportske hale. Hala je jednobrodna s mogućnošću poprečnih fleksibilnih prilagođavanja. Nosači su lamelirani, zakrivljenog konveksnog oblika postavljeni na stupove obrnutog V oblika.

Stabilizacija i sekundarni nosivi sustav projektirat će se s upuštenim podrožnicama i stabilizacijskim dijagonalama od čelika.

Drvena sportska hala tlocrtnih je dimenzija 80.00 m x 38.00 m. Visina najviše točke hale iznosi 16.00 m.

Model hale i statički proračun te dimenzioniranje u skladu s graničnim stanjima nosivosti i uporabivosti napravljeni su u software-u RFEM, a analiza vjetra u software-u RWIND, modeliranjem vjetrovnog tunela radi specifičnog oblika konstrukcije.

Vlastite težine elemenata uzete u u obzir u software-u, dok su proračunska opterećenja nanesena ovisno o lokaciji i vremenskim uvjetima.

Proračunski model, analiza opterećenja i dimenzioniranje konstrukcije provedeni su u skladu s Eurocode-om.

Ključne riječi: drvena konstrukcija sportske hale, zakrivljeni nosači, vjetrovni tunel, RFEM, RWIND

SUMMARY

The topic of this thesis is the design of the spatial concept for a timber structure of a sports hall. The hall is single-span with the possibility of transverse flexible adjustments. The main girders are laminated, with a curved convex shape, placed on columns in an inverted V-shape.

The stabilization and secondary load-bearing system will be designed with recessed joists and steel diagonal stabilizers.

The wooden sports hall has a floor plan of 80.00 m x 38.00 m. The height of the highest point of the hall is 16.00 m.

The hall model, static analysis, and design based on ultimate and serviceability limit states were carried out using the RFEM software, while wind analysis was performed using RWIND software through wind tunnel modeling due to the specific shape of the structure.

The self-weight of the elements was considered in the software, while design loads were applied depending on the location and weather conditions.

The calculation model, load analysis, and structural design were conducted in accordance with the Eurocode standards.

Key words: timber structure of a sports hall, curved girders, wind tunnel, RFEM, RWIND

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1. UVOD

1.1. Drvo kroz povijest

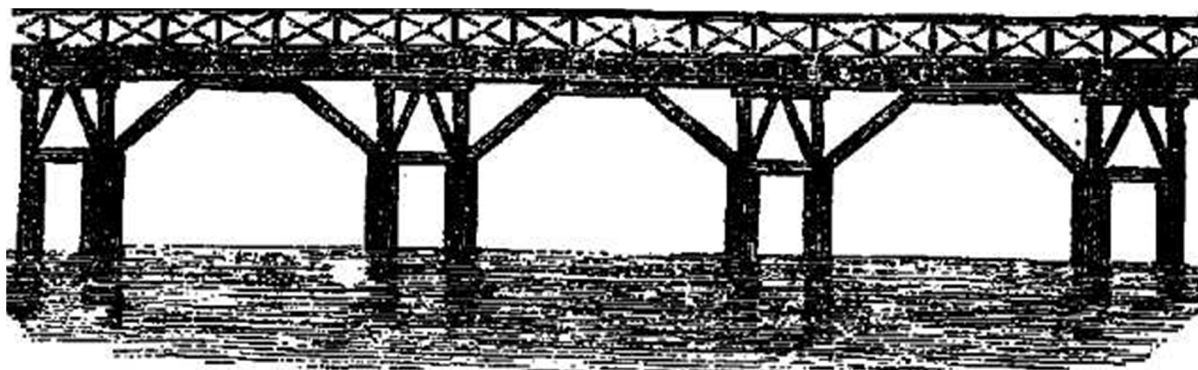
Drvo je jedno od najstarijih građevinskih materijala korišteno kroz povijest, zahvaljujući njegovoj dostupnosti, lakoći obrade i izvanrednim mehaničkim svojstvima. Kroz tisućljeća, drvo je bilo osnovni građevinski materijal za izgradnju domova, mostova, brodova i mnogih drugih struktura. Njegova primjena se razvijala kroz različite epohe, a moderni pristupi omogućuju upotrebu drva u vrlo zahtjevnim i inovativnim konstrukcijama.[4] [5]



Slika 2.1: Sojenice-kuće na vodi, 5000 g.pr.Kr.



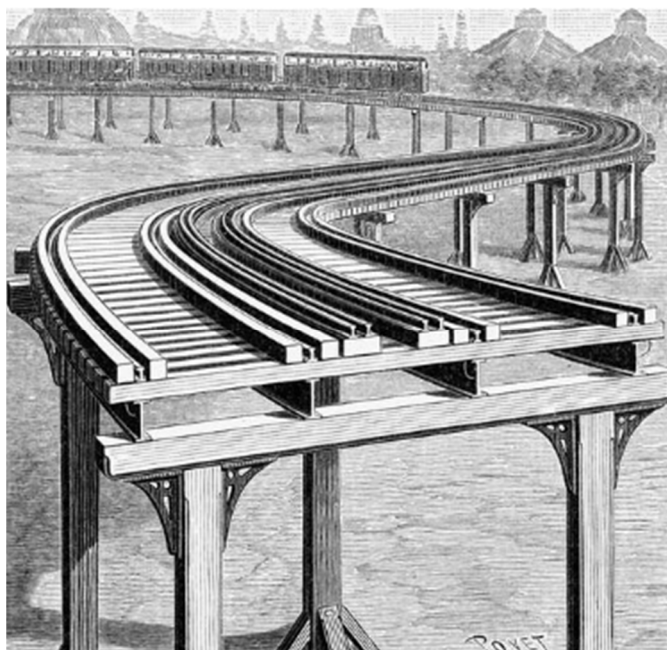
Slika 2.2: The Trireme, master of the seas; Grčki ratni brod [6]



Slika 2.3: Pons Sublicius, drveni most preko rijeke Tiber u Rimu [7]



Slika 2.4: Stavkirke; drvene crkve u Norveškoj, 12.st.



Slika 2.5: Industrijska revolucija i izgradnja drvenih željezničkih mostova, Engleska, 19.st.



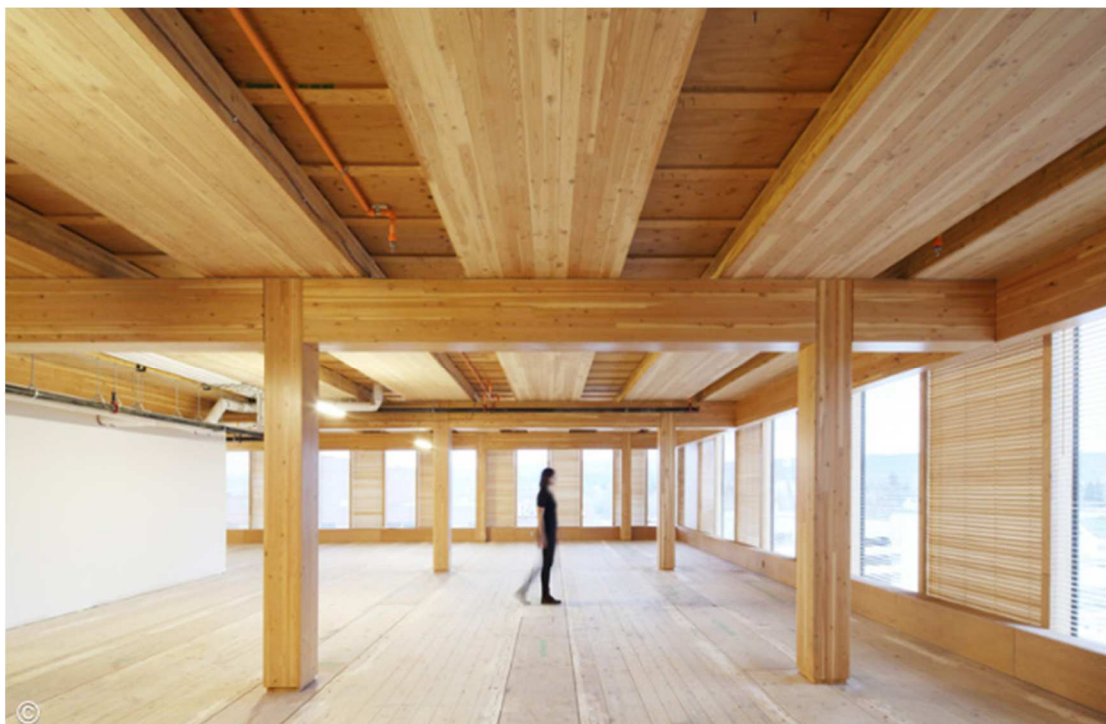
Slika 2.6: Mjøstårnet ,drveni neboder (najviša drvena zgrada na svijetu, 85.40 m), Norveška, 21.st.

1.2. Moderna gradnja drvom

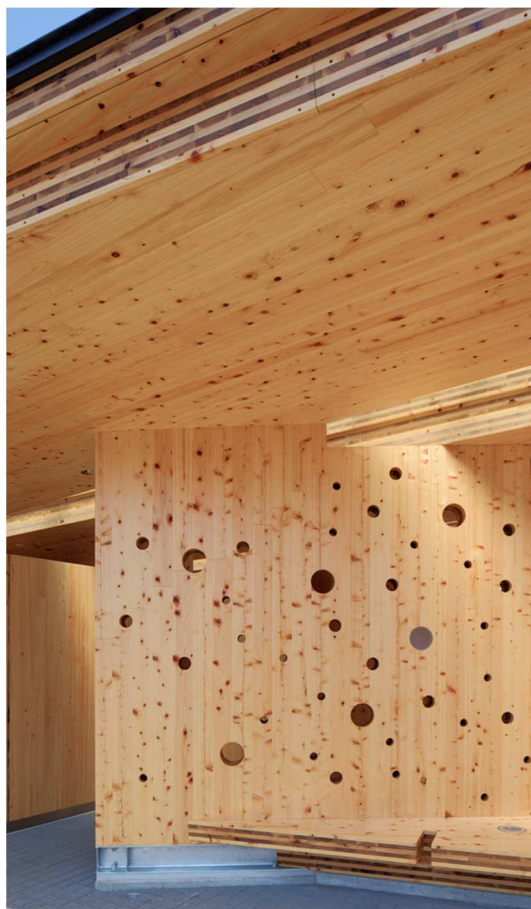
Suvremena gradnja drvom postiže brojna konstrukcijska dostignuća u suvremenoj arhitekturi i inženjerstvu, zahvaljujući napretku tehnologije i rastućoj svijesti o održivosti[9] [10] [11].

Tradicionalni materijal, koji se stoljećima koristio za izgradnju manjih objekata, danas se sve češće pojavljuje kao ključni element u modernim, ekološki osviještenim građevinama. Tehnička dostignuća, poput križno lameliranog (CLT) i ljepljeno lameliranog drva (GLT), omogućuju drvetu da bude ozbiljan konkurent materijalima poput čelika i betona, i to ne samo u niskogradnji, već i u visokim zgradama i složenim konstrukcijama.

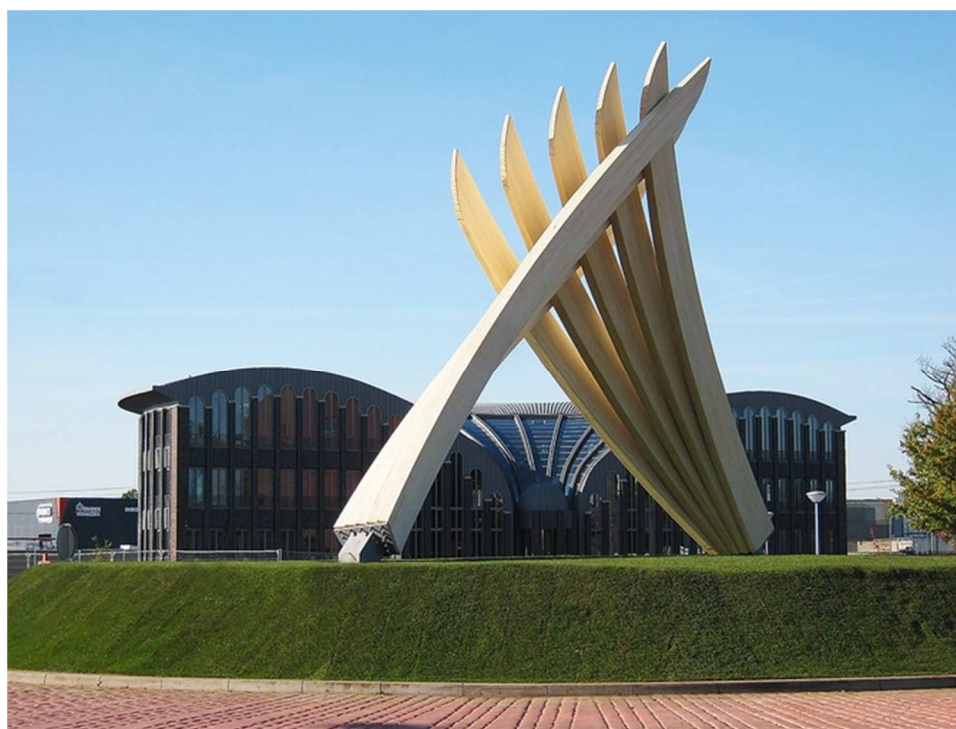
Jedno od najvažnijih dostignuća u drvenoj gradnji je uvođenje križno lameliranog drva (CLT), koje se sastoji od slojeva drvenih ploča postavljenih pod pravim kutom, čime se postiže izvanredna stabilnost i nosivost. CLT ploče su **otporne na vatru**, jer drvo gori kontrolirano i polako, formirajući zaštitni sloj ugljena koji usporava daljnje sagorijevanje. Ova svojstva osiguravaju dugovječnost i sigurnost objekta, čak i u ekstremnim uvjetima. Zahvaljujući ovoj tehnologiji, drveni neboderi – poput zgrade Mjøstårnet u Norveškoj, najvišeg drvenog nebodera na svijetu – postaju stvarnost. Slično tome, ljepljeno lamelirano drvo (GLT) nudi visoku otpornost i fleksibilnost, osobito u izgradnji velikih raspona bez oslonaca, što je korisno u konstrukcijama poput mostova ili velikih komercijalnih objekata.

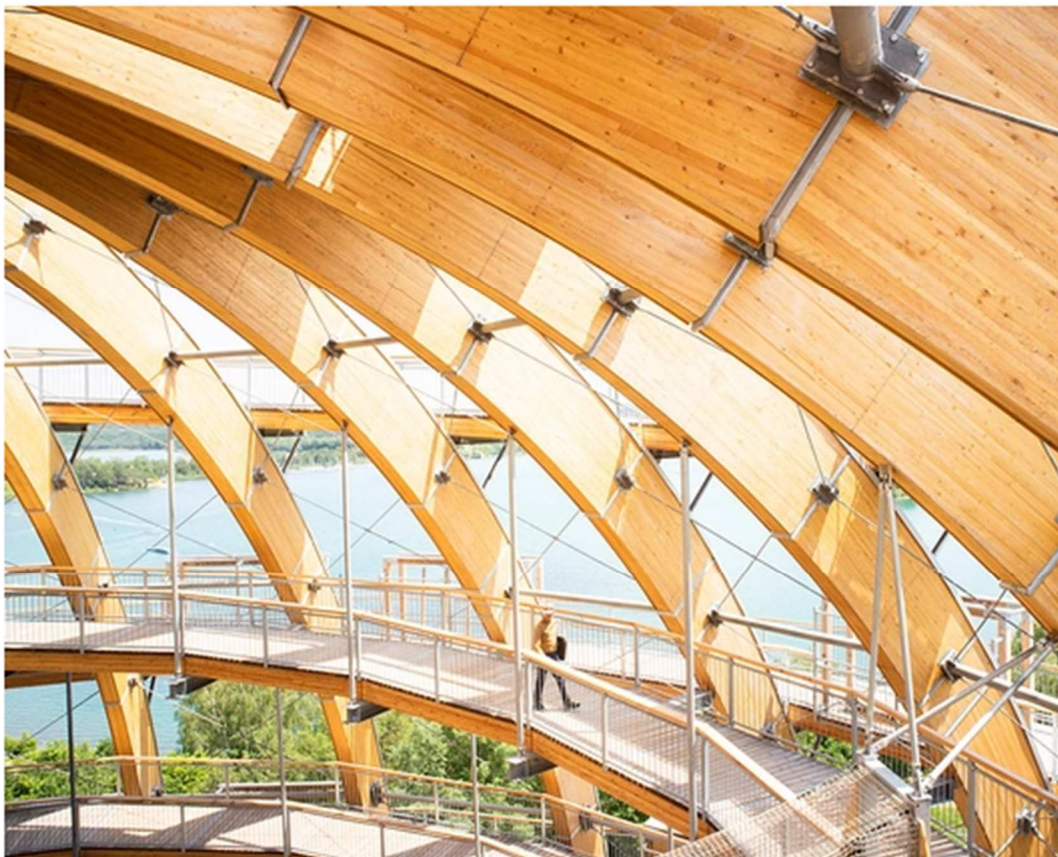


Slika 2.7: Wood Innovation Design Centre, CLT [12]



Slika 2.8: Ki-Terasu, modelna CLT zgrada [12]



Slika 2.9: GLT 'Fingers' [12]**Slika 2.10:** GLT Steinberg Kugelturm [12]

Osim tehničkih inovacija, drvena gradnja postaje sve popularnija zbog svojih održivih svojstava. Drvo je obnovljiv materijal s malim ugljičnim otiskom, što ga čini idealnim izborom za arhitekte i inženjere koji se bave održivim razvojem. Za razliku od betona i čelika, čija proizvodnja zahtijeva velike količine energije, drvo pohranjuje ugljik tijekom svog životnog ciklusa, smanjujući ukupne emisije stakleničkih plinova.

Jedna od ključnih prednosti drvene gradnje je energetska učinkovitost. Drvo je prirodni izolator, što omogućuje bolje zadržavanje topline i smanjenje energetske potrebe zgrada. Ova značajka, u kombinaciji s modernim metodama izolacije i ventilacije, može rezultirati znatno nižim troškovima grijanja i hlađenja. Dodatno, drvo prirodno regulira vlažnost, što poboljšava kvalitetu zraka u unutarnjim prostorima i pridonosi ugodnijem životnom okruženju.

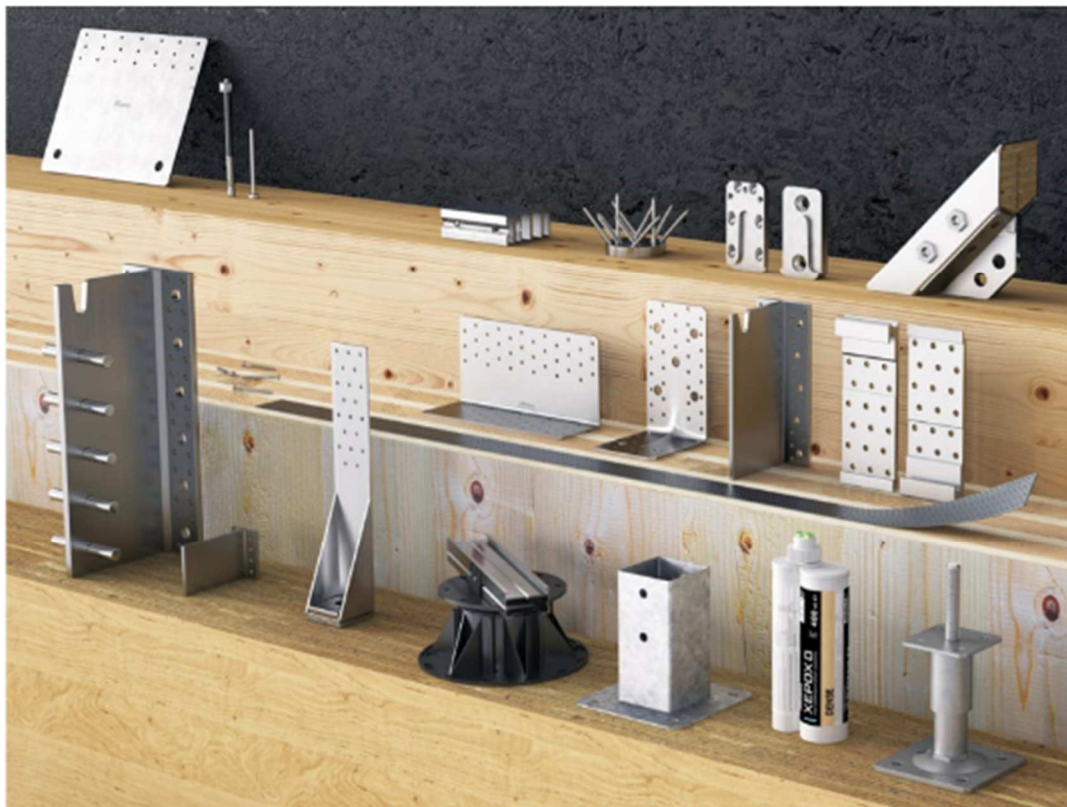
Estetika drvene gradnje još je jedan aspekt koji privlači mnoge arhitekte i dizajnere. Drvo unosi toplinu i prirodnost u interijere, pružajući osjećaj ugone i povezanosti s prirodom. Njegova prilagodljivost i fleksibilnost omogućuju inženjerima stvaranje jedinstvenih, inovativnih oblika i struktura, čime se otvaraju nove kreativne mogućnosti u dizajnu.

Tehnologije poput prefabrikacije, koja omogućuje modularnu gradnju drvenih panela, dodatno smanjuju troškove i vrijeme izgradnje. Drveni moduli se izrađuju u kontroliranim uvjetima tvornica, a na gradilištu se brzo sastavljaju, čime se značajno smanjuju rizici i nepredviđeni troškovi. Ovo rješenje omogućuje i bolju kontrolu kvalitete te smanjenje otpada na gradilištu, čineći gradnju drvom ekološki prihvatljivom i ekonomičnom.



Slika 2.11: Modularna gradnja drvom

Još jedno važno tehničko dostignuće u gradnji drvom su napredni spojevi, poput čeličnih ploča koje omogućuju čvrsto i sigurno povezivanje drvenih elemenata.



Slika 2.12: Rothoblaas spojevi

Spojevi poput onih koje proizvodi Rothoblaas, omogućuju izgradnju drvenih konstrukcija u seizmičkim područjima, čime se dodatno povećava sigurnost i otpornost građevina. Zahvaljujući prirodnim svojstvima drva, koje je elastično i lako apsorbira energiju potresa, drvene konstrukcije mogu učinkovito podnijeti seizmičke sile, smanjujući rizik od oštećenja. Moderni proračuni prema Eurocode 8 standardima pokazuju da drvene zgrade mogu pružiti visoku otpornost na potrese.

Kada se uzmu u obzir sve ove prednosti – od održivosti i energetske učinkovitosti do fleksibilnosti dizajna, požarne otpornosti i otpornosti na potrese – jasno je da drvena gradnja predstavlja značajan korak naprijed u građevinskoj industriji. Osim što odgovara na globalne izazove smanjenja emisija i održivosti, drvo nudi izvanrednu funkcionalnost, estetiku i brzinu gradnje. U tom smislu, gradnja drvom ne samo da nas vraća prirodi, već i oblikuje budućnost arhitekture i inženjeringa na održiv, inovativan i ekološki prihvatljiv način.

2. METODE I TEHNIKE RADA

2.1. Tehnički opis

Predmet ovog diplomskog rada je projektni proračun sportske hale s fokusom na konstrukcijski sustav od drvenih lameliranih nosača. Hala je planirana na području Grada Zagreba (Hrvatska), a karakteristična je po varijabilnoj visini stropa u uzdužnom i poprečnom smjeru.

Glavni konstrukcijski sustav čine zakrivljeni ljepljeni lamelirani drveni nosači, koji se protežu u dva ortogonalna smjera. Glavna nosiva struktura sastoji se od dva uzdužna zakrivljena nosača dimenzija 20x80 cm, klase drva GL32h, te 17 poprečnih zakrivljenih nosača dimenzija 20x60 cm, također klase GL32h. Ovi nosači formiraju osnovu nosive strukture.

Sekundarni nosivi sustav sastavljen je od grednih nosača raspona od 5 metara, koji su postavljeni paralelno glavnim poprečnim nosačima, s poprečnim presjekom od 16x20 cm, izrađeni od drva klase GL24h. Ovi nosači dodatno stabiliziraju cijelu konstrukciju i ravnomjerno raspoređuju opterećenja.

Za ukrućivanje krovne konstrukcije koriste se čelični spregovi od čelika kvalitete S355. Vjetrovni spregovi postavljeni su između glavnih poprečnih nosača, ispod sekundarnih nosača, pri čemu je ukupno pet vjetrovnih spregova, raspoređenih na udaljenosti od 15 do 20,05 metara, što omogućava stabilizaciju do četiri glavna nosača. Spregovi su kružnog poprečnog presjeka promjera 20 mm i pričvršćeni su za glavne nosače pomoću čeličnih ploča.

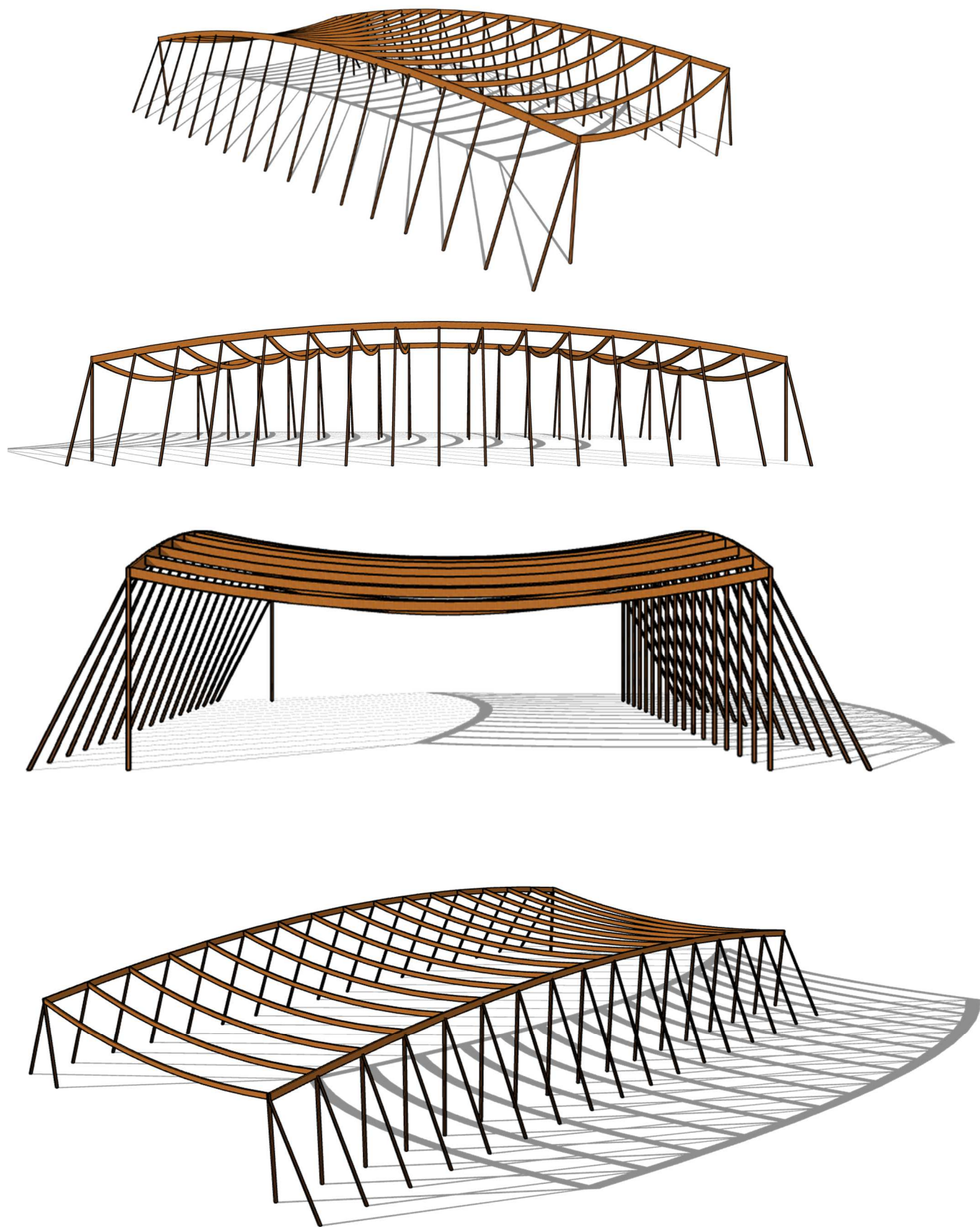
Glavna nosiva poprečna konstrukcija oslanja se na drvene stupove obrnutog V oblika, dimenzija poprečnog presjeka 20x20 cm, također klase drva GL32h. Ovi stupovi osiguravaju stabilnost i otpornost na vertikalna opterećenja.

Dodatno, projekt uključuje korištenje pokrova od trevire, materijala koji je odabran zbog svoje izdržljivosti, fleksibilnosti i otpornosti na vremenske uvjete. Trevira kao krovni pokrov nudi lagano i čvrsto rješenje, koje smanjuje opterećenje na nosivu konstrukciju, a istovremeno pruža zaštitu od vanjskih utjecaja.

Kao bočni pokrov, koriste se klizne stijene izrađene od leksana koje dodatno doprinose energetske učinkovitosti hale, omogućujući ulazak prirodne svjetlosti te kompletno otvaranje prostora. Leksan je odabran zbog svoje visoke otpornosti na udarce, UV zaštite i male težine, što ga čini pogodnim materijalom za klizne stijene u velikim sportskim objektima.

Analiza opterećenja vjetrom provedena je pomoću softverskog alata RWIND 3.0, dok je statički proračun nosivosti i stabilnosti cijele konstrukcije izvršen u softveru Dlubal RFEM 6, što omogućava preciznu evaluaciju svih relevantnih parametara u skladu s važećim normama i standardima.

Navedeni podaci predstavljaju početne polazne parametre projekta koji će biti predmet daljnje detaljne analize i optimizacije u okviru konačnog rješenja konstrukcije.



Slika 2.1: Pogledi na model

3. ANALIZA OPTEREĆENJA

3.1. Stalno opterećenje

3.1.1. Vlastita težina

Svim će elementima prilikom statičkog proračuna u računalnom programu biti zadana pripadna vlastita težina.

Vlastita težina pokrova sastoji se od horizontalnog krovnog pokrova (trevera) i fleksibilnog bočnog pokrova kliznih stijena od leksana.

Trevira je debljine 20mm karakteristične gustoće $\gamma = 1350\text{kg}/\text{m}^3$, pri čemu opterećenje na nosače iznosi;

$$g_{pokrov,k} = 0,02 \cdot 1350 \cdot \frac{9,81}{1000} = 0,26 \text{ kN}/\text{m}^2$$

Nosači su na razmaku od 5m, te linijsko opterećenje na unutarnje nosače od pokrova iznosi;

$$g_{pokrov,k} = 0,26 \cdot 5,00 = 1,3 \text{ kN}/\text{m}'$$

dok opterećenje na rubne nosače iznosi 50% opterećenja unutarnjih, odnosno;

$$g_{pokrov,k} = 0,26 \cdot \frac{5,00}{2} = 0,65 \text{ kN}/\text{m}'$$

Leksana (LTC SC) je debljine 20mm i karakteristične gustoće $\gamma = 1200\text{kg}/\text{m}^3$, pri čemu opterećenje na nosače iznosi;

$$g_{ltc,k} = 0,02 \cdot 1200 \cdot \frac{9,81}{1000} = 0,24 \text{ kN}/\text{m}^2$$

Nosači su najveće visine 16m, te se ova visina uzima u obzir za sve nosače radi sigurnosti.

$$g_{ltc,k} = 0,24 \cdot 16 = 3,84 \text{ kN}/\text{m}'$$

3.1.2. Dodatno stalno opterećenje

Dodatno stalno opterećenje krova raspodjeljuje se na poprečne krovne nosače, a sastoji se od težine instalacija $g_{inst,k} = 0.1 kN/m^2$.

Nosači su na razmaku od 5m, te linijsko opterećenje na unutarnje nosače od instalacija iznosi;

$$g_{inst,k} = 0.1 \cdot 5,00 = 0,50 kN/m'$$

dok opterećenje na rubne nosače iznosi 50% opterećenja unutarnjih, odnosno;

$$g_{inst,k} = 0.1 \cdot \frac{5,00}{2} = 0,25 kN/m'$$

3.2. Opterećenje snijegom

Opterećenje snijegom promjenjivo je djelovanje koje ovisi o geografskom području konstrukcije.

Opterećenje snijegom na krov određuje se izrazom:

$$S = S_k \cdot \mu_i \cdot C_e \cdot C_t$$

Pri čemu je:

S_k - karakteristično opterećenje snijegom, očitano iz karte snježnih područja (Slika 3.1), te tablice opterećenja snijega za snježna područja uz pripadajuće nadmorske visine (Tablica 1), a ovisno o lokaciji u kojoj se objekt nalazi

Za Grad Zagreb, 158 m.n.v. S_k iznosi $1,25 kN/m^2$.



Slika 3.1: Karta snježnih područja (Izvor: [1])

Tablica 1.: Opterećenje snijegom za snježna područja i pripadajuće nadmorske visine
(Izvor: [1])

Nadmorska visina do [m]	1. područje-priobalja i otoci [kN/m ²]	2. područje-zaleđe Dalmacije, Primorja i Istre [kN/m ²]	3. područje-kontinentalna Hrvatska [kN/m ²]	4. područje-gorska Hrvatska [kN/m ²]
100	0,50	0,75	1,00	1,25
200	0,50	0,75	1,25	1,50
300	0,50	0,75	1,50	1,75
400	0,50	1,00	1,75	2,00
500	0,50	1,25	2,00	2,50
600	0,50	1,50	2,25	3,00
700	0,50	2,00	2,50	3,50
800	0,50	2,50	2,75	4,00
900	1,00	3,00	3,00	4,50
1000	2,00	4,00	3,50	5,00
1100	3,00	5,00	4,00	5,50
1200	4,00	6,00	4,50	6,00
1300	5,00	7,00		7,00
1400	6,00	8,00		8,00
1500		9,00		9,00
1600		10,00		10,00
1700		11,00		11,00
1800		12,00		

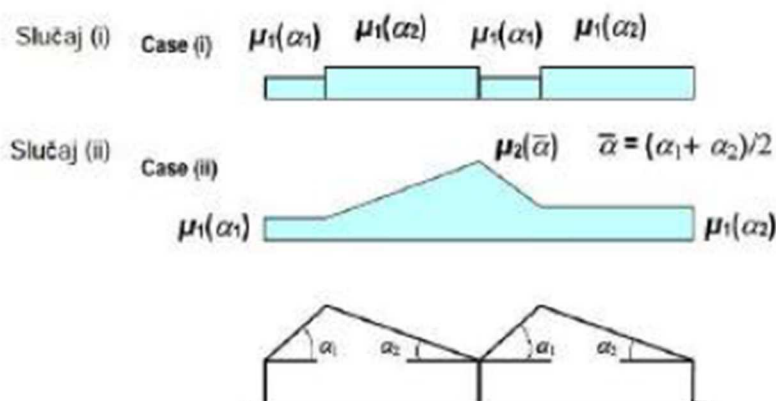
μ_i - koeficijent oblika opterećenja krova ovisno o geometriji krova očitano za varijantu opterećenja za višeraspanske krovove (Slika 3.2), te dijagrama za određivanje parametra μ_1 i μ_2 (Slika 3.3).

Lučni nosač aproksimiran je kao dvostrešni s negativnim nagibom, te ima dva slučaja opterećenja.

Za slučaj opterećenja 1, koeficijent μ_1 je konstantan i iznosi $\mu_1 = 0,8$ za nagib krova od 7° .

Za slučaj opterećenja 2, koeficijent oblika opterećenja krova linearno raste od μ_1 na najvišoj rubnoj točki nosača do μ_2 na dnu uvale.

Tada koeficijent μ_1 iznosi 0,8 za nagib krova od 7° u najvišoj točki, a koeficijent μ_2 određen je za kut $\bar{\alpha} = (\alpha_1 + \alpha_2) = 7^\circ$ i iznosi: $\mu_2 = 0,8$



Slika 3.2.: Koeficijenti oblika opterećenja snijegom za višeraspanske krovove (Izvor: [1])

Tablica 2.: Koeficijenti oblika opterećenja snijegom

Kut nagib krova α	$0^\circ \leq \alpha \leq 30^\circ$	$30^\circ \leq \alpha \leq 60^\circ$	$\alpha \geq 60^\circ$
$\mu_1(\alpha)$	0,8	$0,8 \cdot \frac{(60^\circ - \alpha)}{30^\circ}$	0,0
$\mu_2(\alpha)$	0,8	$0,8 \cdot \frac{(60^\circ - \alpha)}{30^\circ}$	0,0
$\mu_3(\alpha)$	$0,8 + 0,8 \cdot \frac{\alpha}{30^\circ}$	1,6	-

C_e – koeficijent izloženosti, za uobičajen oblik terena preporučena vrijednost iznosi $C_e = 1,0$

C_t – toplinski koeficijent, preporučena vrijednost iznosi $C_t = 1,0$

Ukupno opterećenje snijegom, prema izrazu $S = S_k \cdot \mu_3 \cdot C_e \cdot C_t$ iznosi

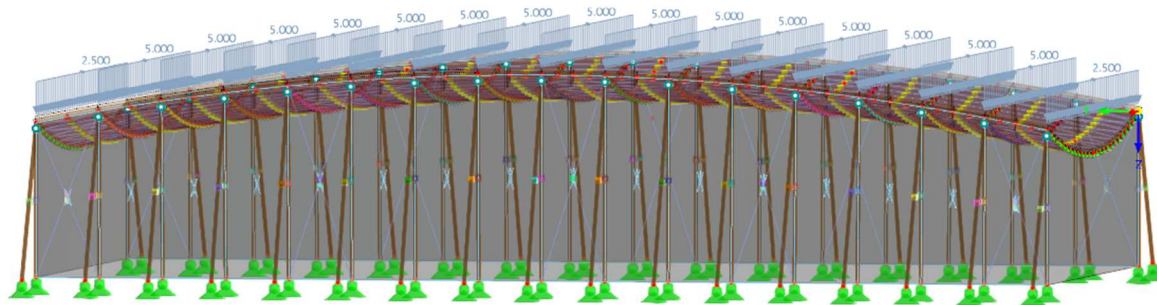
$$S = 1,25 \cdot 0,8 \cdot 1,0 \cdot 1,0 = 1,0 \text{ kN/m}^2$$

Nosači su na razmaku od 5m, te linijsko opterećenje na unutarnje nosače od snijega iznosi;

$$g_{pokr, k} = 1,0 \cdot 5,00 = 5 \text{ kN/m'}$$

dok opterećenje na rubne nosače iznosi 50% opterećenja unutarnjih, odnosno;

$$g_{pokr, k} = 1,0 \cdot 2,50 = 2,5 \text{ kN/m'}$$



Slika 3.3.: Opterećenje snijegom

3.3. Opterećenje vjetrom

Opterećenje vjetrom promjenjivo je djelovanje koje ovisi o geografskom području konstrukcije, lokalnom položaju građevine i zaštićenosti od vjetra te visini građevine.

Sportska dvorana se nalazi u gradu Zagrebu. Područje na kojem se nalazi je površina redovito pokrivena vegetacijom, zgradama ili izoliranim preprekama sa maksimalnim razmakom od 20 visina prepreke (kao što su sela, predgrađa, stalne šume). Stoga je svrstan u kategoriju terena III.

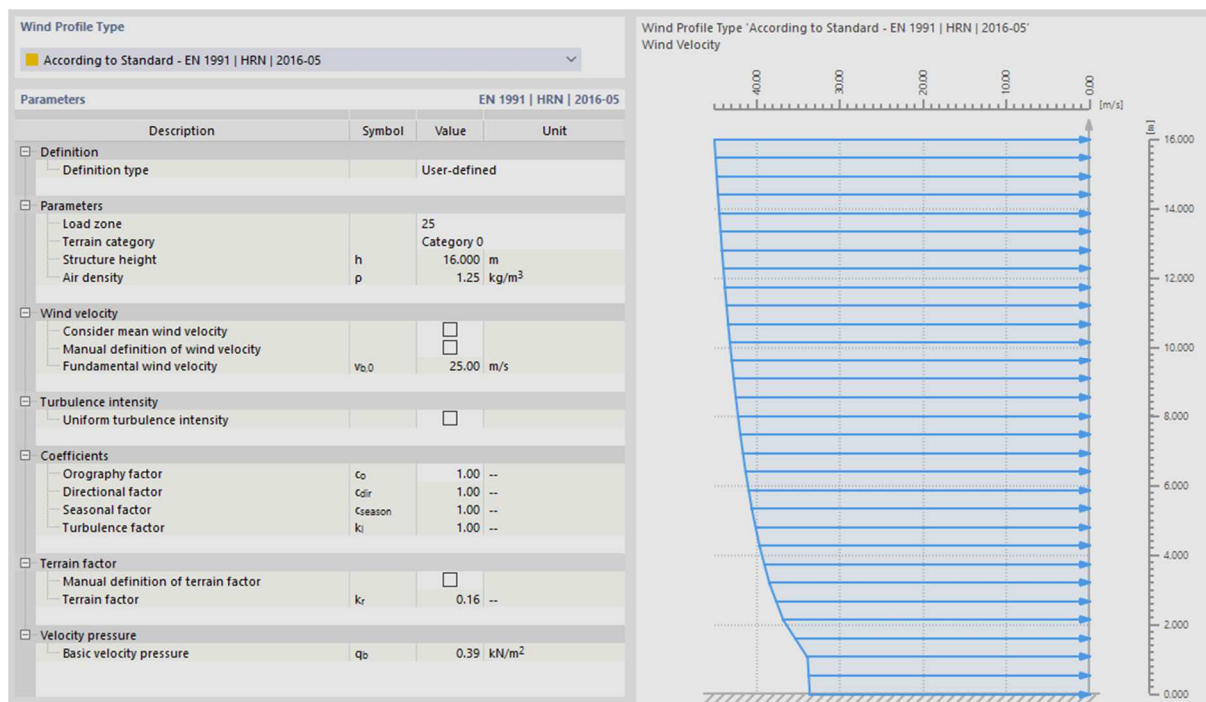
Osnovna brzina vjetra za područje Grada Zagreba očitana je s karte osnovne brzine vjetra Republike Hrvatske [2] (slika 3.4.)



Slika 3.4.: Karta osnovnih brzina vjetra $v_{b,0}$ (Izvor: [2])

Očitana osnovna brzina vjetra za Grad Zagreb iznosi $v_{b,0} = 25$ m/s.

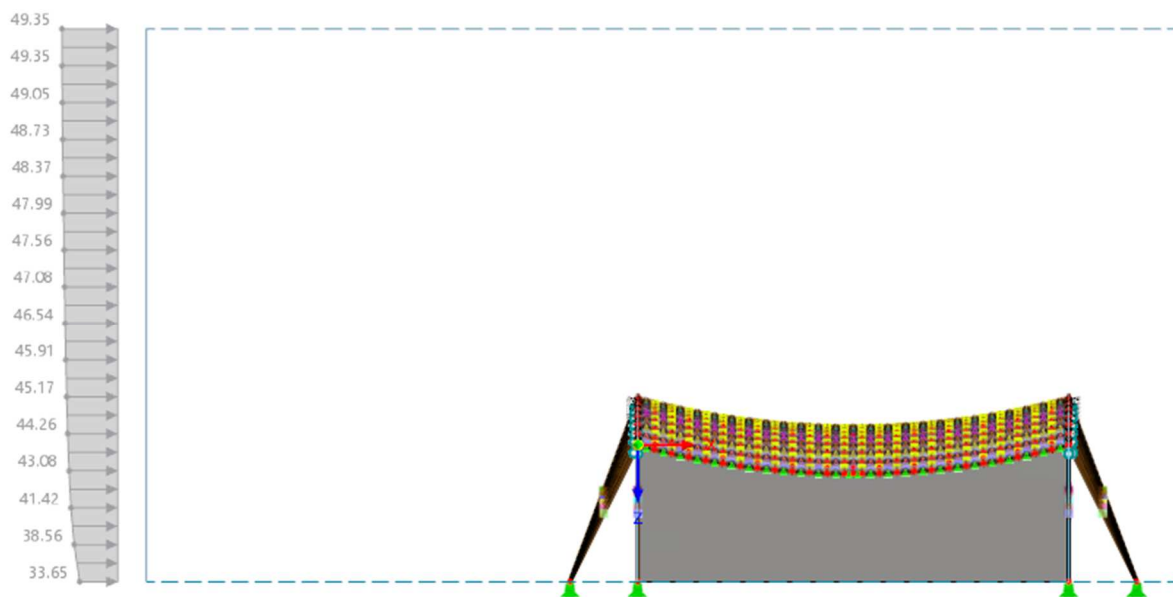
Djelovanje vjetra određeno je s obzirom na osnovnu brzinu vjetra simulacijom u software-u RWIND 3.01.



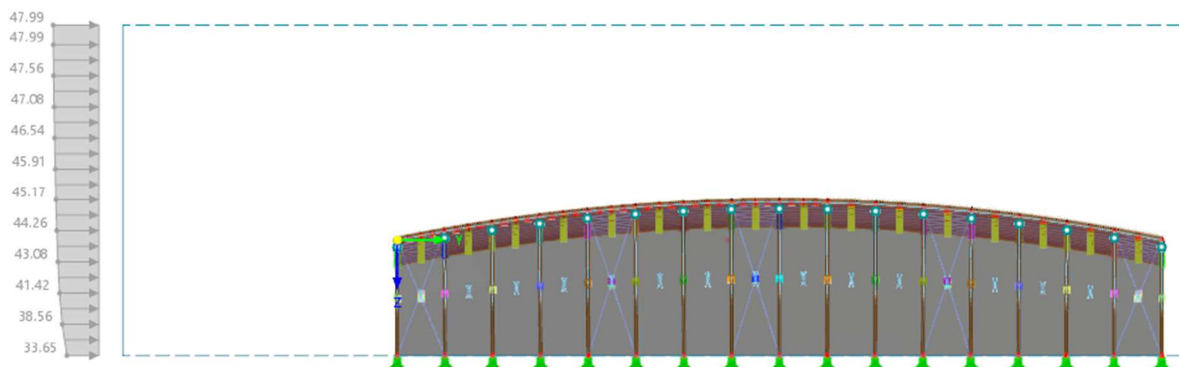
Slika 3.5.: Vjetrovni profil za simulaciju u software-u RWIND

Smjerovi djelovanja vjetra koji su analizirani su transferzalni ($\varphi=0^\circ$ i $\varphi=180^\circ$ za x smjer djelovanja vjetra), te longitudinalni ($\varphi=90^\circ$ i $\varphi=270^\circ$ za y smjer djelovanja vjetra).

Svi slučajevi djelovanja vjetra provedeni su za potpuno zatvorenu, potpuno otvorenu i djelomično otvorenu konstrukciju na strani djelovanja vjetra i na suprotnoj strani.



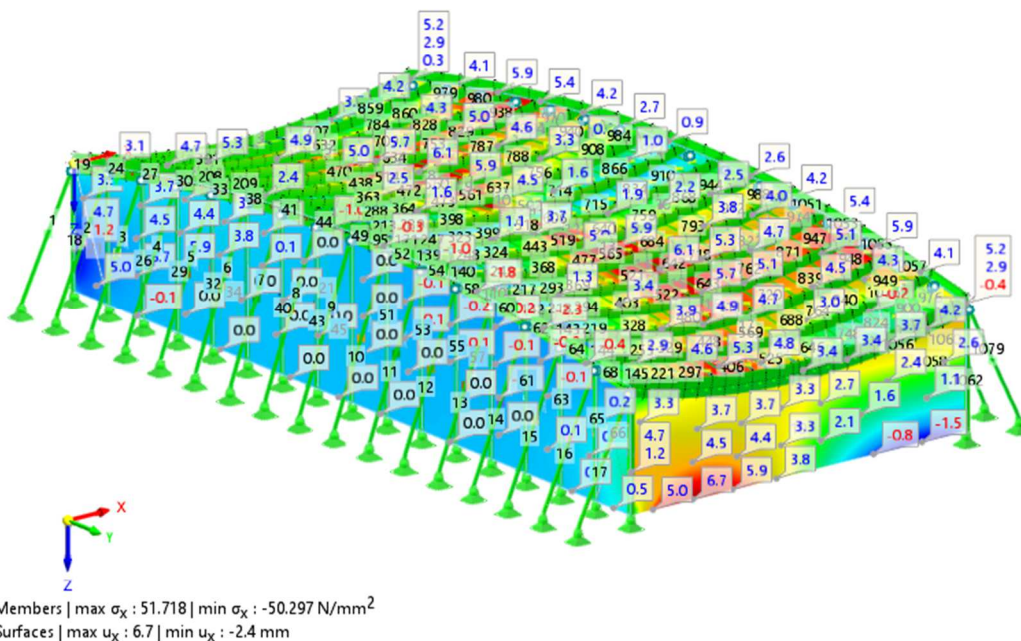
Slika 3.6.: Vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$



Slika 3.7.: Vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$

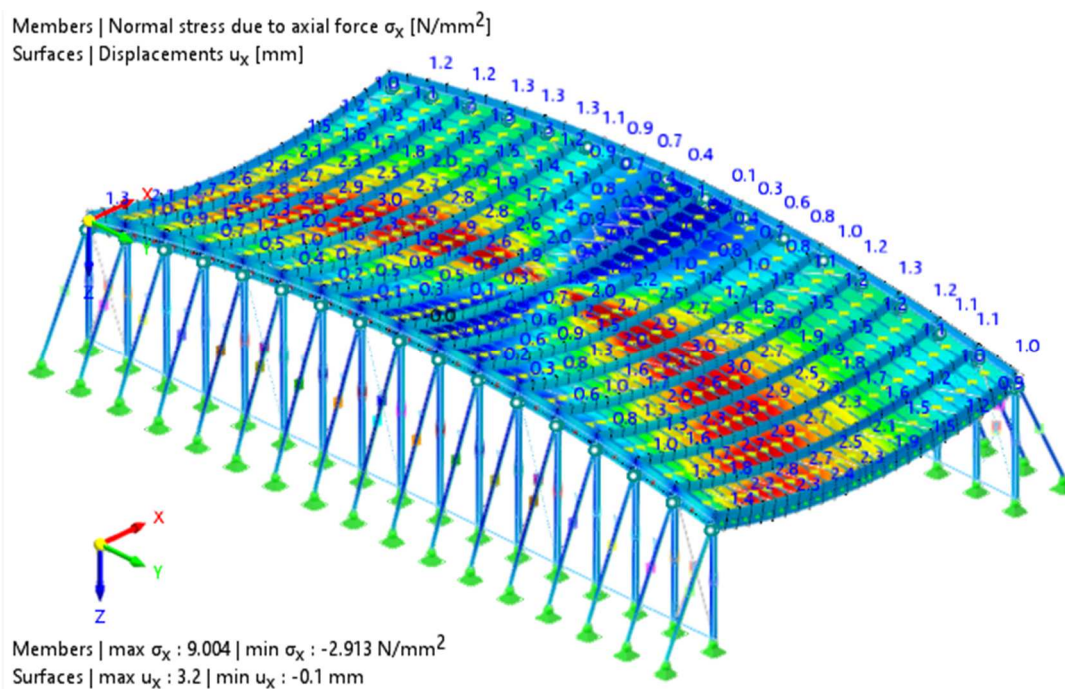
3.3.1. Slučaj vjetrovnog opterećenja 1; Transferzalni vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$

3.3.1.1. Transferzalni vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$ na zatvorenu konstrukciju



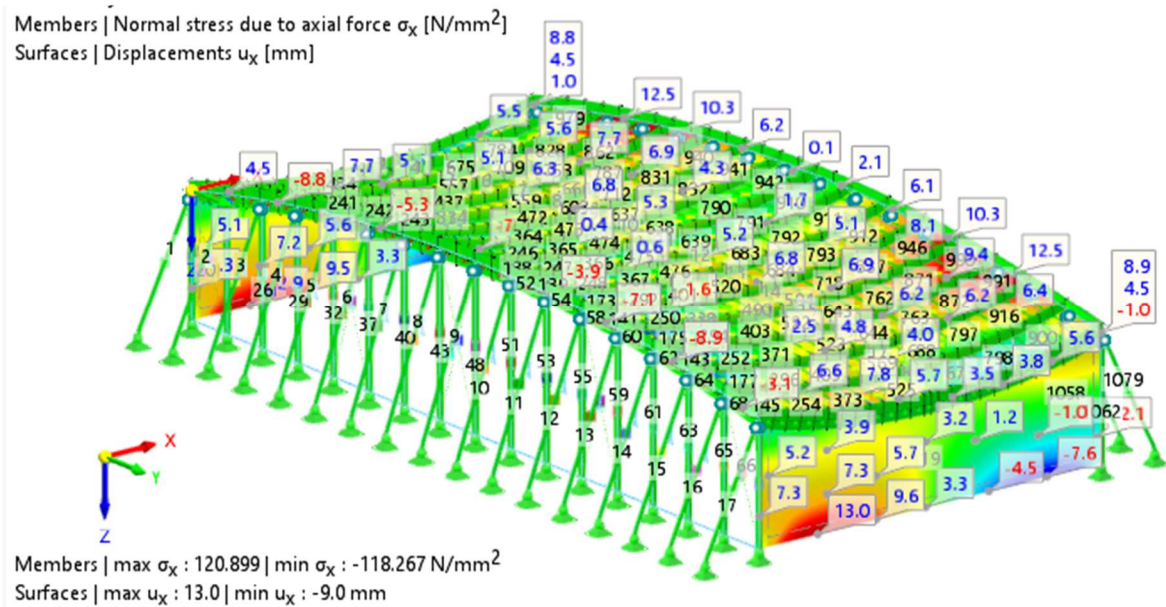
Slika 3.8.: Vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$ na zatvorenu konstrukciju

3.3.1.2. Transferzalni vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$ na otvorenu konstrukciju



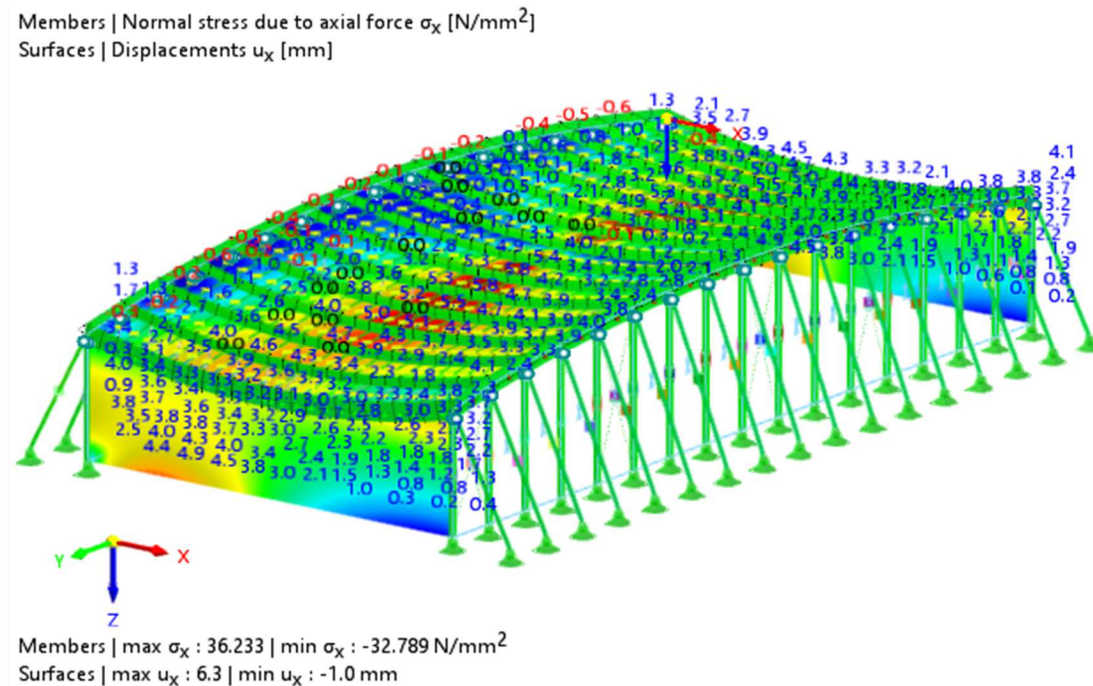
Slika 3.9.: Vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$ na otvorenu konstrukciju

3.3.1.3. Transferzalni vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$ na konstrukciju otvorenu na strani djelovanja vjetra



Slika 3.10.: Vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$ na konstrukciju otvorenu na strani djelovanja vjetra

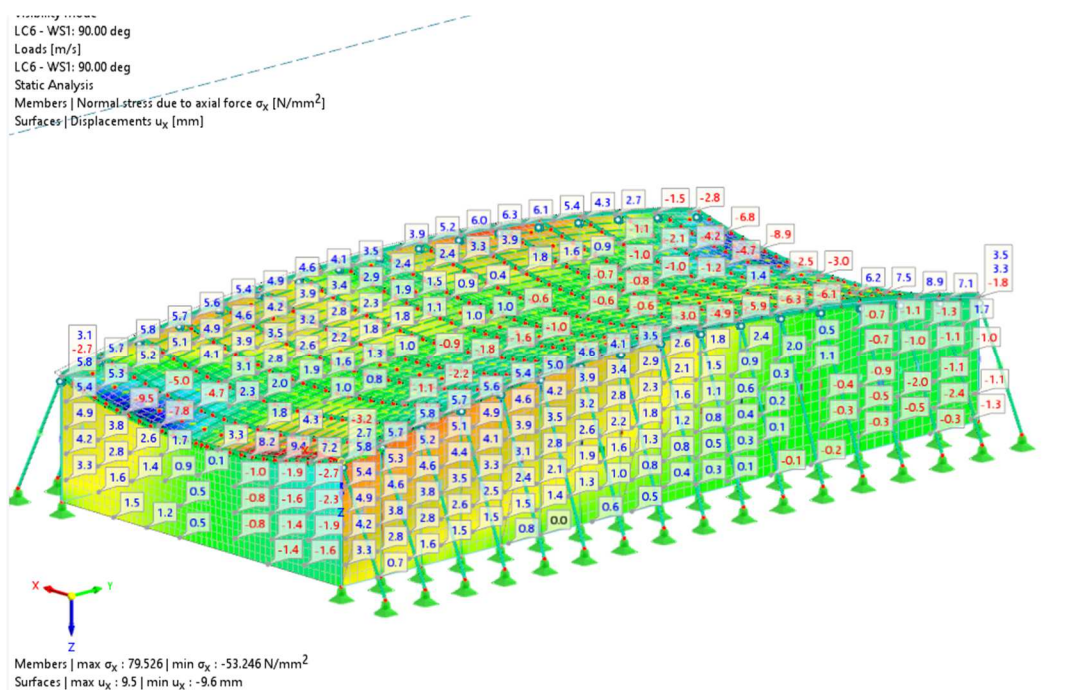
3.3.1.4. Transferzalni vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$ na konstrukciju otvorenu suprotno od strane djelovanja vjetra



Slika 3.11.: Vjetar $\varphi=0^\circ$ i $\varphi=180^\circ$ na konstrukciju otvorenu suprotno od strane djelovanja vjetra

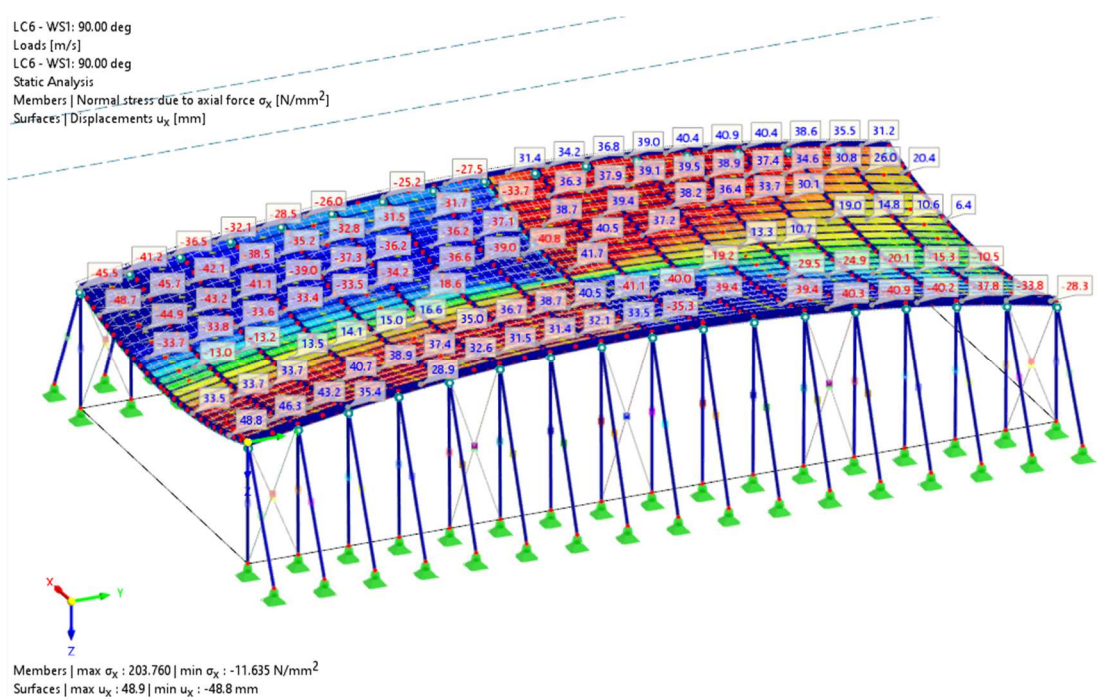
3.3.2. Slučaj vjetrovnog opterećenja 2; Longitudinalni vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$

3.3.2.1. Longitudinalni vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$ na zatvorenu konstrukciju



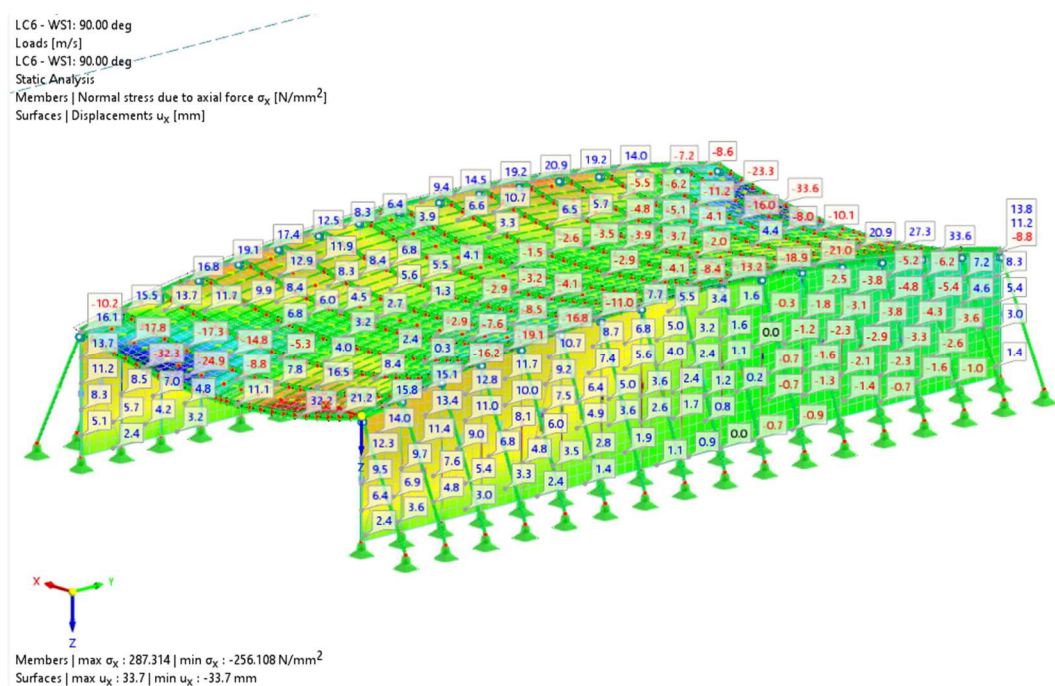
Slika 3.12.: Vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$ na zatvorenu konstrukciju

3.3.2.2. Longitudinalni vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$ na otvorenu konstrukciju



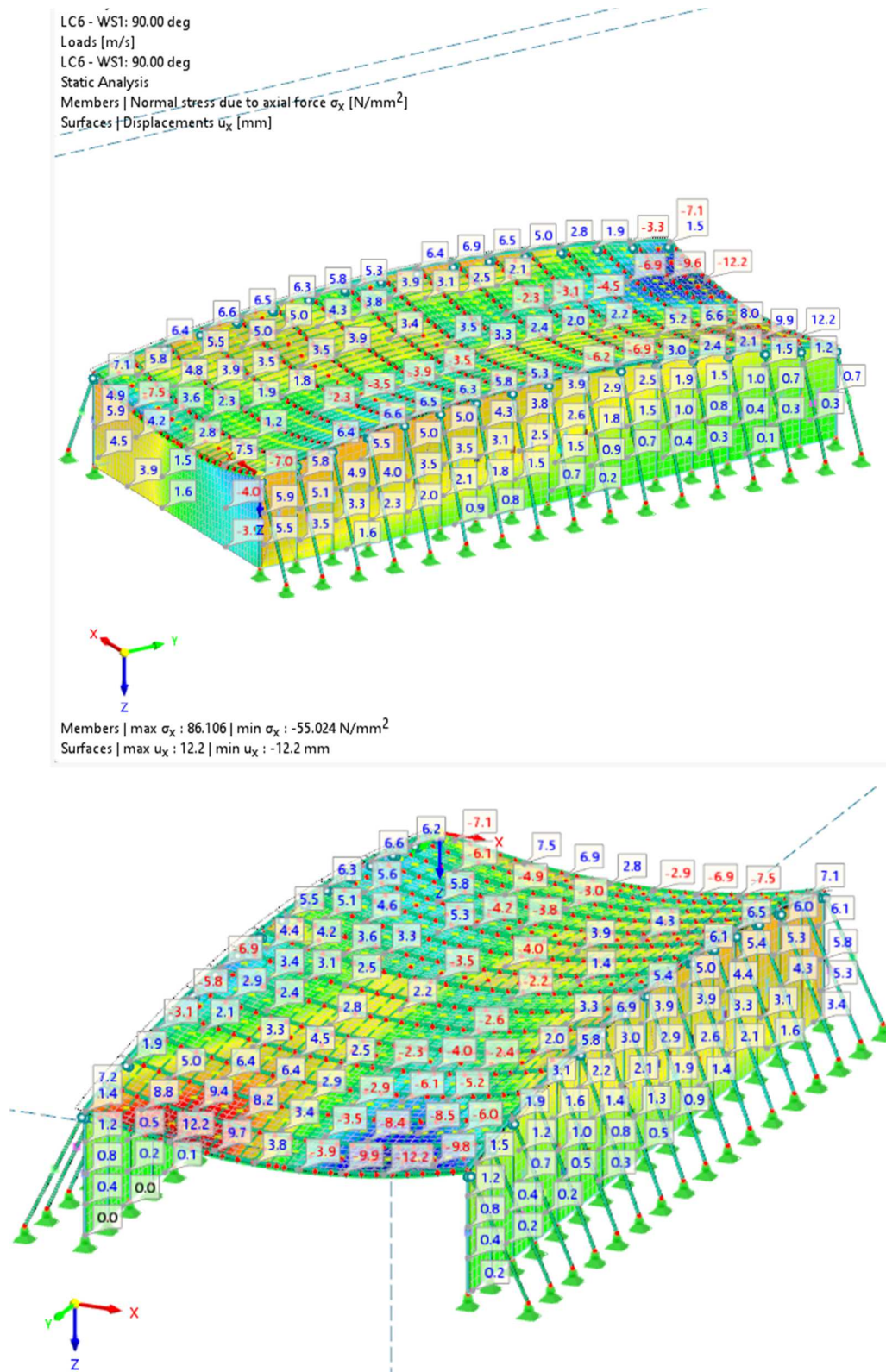
Slika 3.13.: Vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$ na otvorenu konstrukciju

3.3.2.3. Longitudinalni vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$ na konstrukciju otvorenu na strani djelovanja vjetra



Slika 3.14.: Vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$ na konstrukciju otvorenu na strani djelovanja vjetra

3.3.2.4. Longitudinalni vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$ na konstrukciju otvorenu suprotno od strane djelovanja vjetra



Slika 3.15.: Vjetar $\varphi=90^\circ$ i $\varphi=270^\circ$ na konstrukciju otvorenu suprotno od strane djelovanja vjetra

Mjerodavno opterećenje vjetrom je longitudinalno za situaciju kada vjetar puše na potpuno otvorenu konstrukciju.

U daljni proračun uzeta je ova situacija opterećenja.

3.4. Potresno opterećenje

Potresno opterećenje (ili seizmičko opterećenje) odnosi se na sile koje djeluju na građevinu ili objekt kao posljedica potresa, te se pri proračunu koristi EN 1998. [3]

Proračun potresnog opterećenja ovisi o lokalnoj seizmičnosti, karakteristikama tla, masi građevine, njenoj geometriji i konstrukcijskom sustavu, te o njenoj sposobnosti da podnese deformacije (duktilnost). Potresno opterećenje se izračunava na temelju seizmičkih karata, spektralnih vrijednosti ubrzanja i specifičnih inženjerskih standarda poput Eurokoda 8.

Proračun po EN 1998-1 (EC8)

Kvazistatička analiza – pojednostavljena modalna spektralna analiza – Metoda ekvivalentnog statičkog opterećenja:

Ukupna proračunska sila potresa na građevinu:

$$F_{bd} = S_d(T_1) \cdot \frac{W}{g} \cdot \lambda$$

gdje je:

$S_d(T_1)$ - ordinata proračunskog (projektnog) spektra za prvi period titranja građevine (okvira)

W – ukupna težina građevine

g – ubrzanje sile teže; $g = 9,81 \text{ m/s}^2$

λ – opravni (korekcijski) faktor – $\lambda = 0,85$ za $T_1 < 2T_c$ kada zgrada ima više od dvije etaže. Za sve ostale slučajeve $\lambda = 1,0$ (u ovom slučaju $\lambda = 1,0$)

Prvi period titranja okvira dobiven je dinamičkom analizom upotrebom programa za proračun statike konstrukcija.

$$T_1 = 0,5 \text{ sec}$$

Za vrstu tla B (iz tablice 3.2 (EN 1998-1)) očitano:

$$S = 1,2$$

$$T_B = 0,15 \text{ s}$$

$$T_C = 0,5 \text{ s}$$

$$T_D = 2,0 \text{ s}$$

Proračunani prvi period ($T_1 = T_c = 0,5$ s), pa je ordinata proračunskog (projektnog) spektra za prvi period titranja građevine:

$$S_d(T_1) = a_g \cdot S \cdot \frac{2,5}{q}$$

gdje je:

a_g – proračunsko ubrzanje tla (u ovom slučaju smatra se da se objekt nalazi u 8. Potresnom području, pa je $a_g = 0,25 \cdot g$)

q – faktor ponašanja

Faktor ponašanja: $q = q_0 \cdot k_w \geq 1,5$

$q_0 = 3,0 \cdot \frac{a_u}{a_1}$ za okvirne sustave ili dvojne sustave istovrijedne okvirnim

$\frac{a_u}{a_1} = 1,275$ za okvirne sustave ili dvojne sustave istovrijedne okvirnim

$k_w = 1,0$ za okvirne sustave ili dvojne sustave istovrijedne okvirnim

$$q_0 = 3,0 \cdot 1,275 = 3,9$$

$$q = q_0 \cdot k_w = 3,9 \cdot 1,0 = 3,9$$

$$S_d(T_1) = a_g \cdot S \cdot \frac{2,5}{q} = 0,25 \cdot 1,2 \cdot 9,81 \cdot \frac{2,5}{3,9} = 1,89$$

Faktor važnosti: $\gamma_1 = 1,2$ → za zgrade važnosti III – zgrade za koje je seizmička otpornost važna u smislu posljedica povezanih s rušenjem (škole, skupne hale, itd.)

Ukupna težina konstrukcije očitana je u software-u RFEM 6 (Tablica 3) i iznosi 935.406t, odnosno 9,176.33 kN

Tablica 3.: Fizikalne karakteristike konstrukcije

Center of Gravity			
Center of gravity coordinate X	X _c	19.000	m
Center of gravity coordinate Y	Y _c	39.999	m
Center of gravity coordinate Z	Z _c	-0.886	m
<input type="checkbox"/> Create new node at center of gravity			
Information About All Selected Objects			
Area of surfaces	A	3094.955	m ²
Length of members	L	4836.827	m
Surface of coating	S	10033.418	m ²
Volume	V	826.423	m ³
Mass	M	935.406	t
Information About Members			
Length of members	L	4836.827	m
Volume	V	207.432	m ³
Mass	M	99.769	t
Information About Surfaces			
Area of surfaces	A	3094.955	m ²
Volume	V	618.991	m ³
Mass	M	835.637	t

Ukupna seizmička sila iznosi;

$$F_{bd} = S_d(T_1) \cdot \frac{W}{g} \cdot \lambda = 1,89 \cdot \frac{9,176.33}{9,81} \cdot 1,0 = 1,767.92 \text{ kN}$$

Dok ukupna sila mjerodavnog slučaja vjetrovnog opterećenja iznosi 6,303.02 kN (Tablica 4)

Tablica 4.: Fizikalne karakteristike konstrukcije

Qw LC5 - WS1: 0.00 deg	
Drag forces	
Drag force in X	1907.490 kN
Drag force in Y	2.974 kN
Drag force in Z	-6007.450 kN
Drag force magnitude	6303.020 kN

Potres nije mjerodavno horizontalno opterećenje za dimenzioniranje konstrukcije, te se ne uzima u obzir daljnjom analizom.

3.5. Rekapitulacija opterećenja na konstrukciju

Tablica 5.: Pojedinačna opterećenja na konstrukciju

LOAD CASES		
LC No.	Settings	Value
1	Self-weight	
	Analysis type	Static Analysis
	Associated standard	EN 1990 Timber CEN 2010-04
	Static analysis settings	SA1 - Geometrically linear Newton-Raphson
	Action category	Permanent
	Self-weight - Factor in direction X	0.000
	Self-weight - Factor in direction Y	0.000
	Self-weight - Factor in direction Z	1.000
	Load duration	Permanent
Self-weight mode for geotechnical analysis	Normal	
2	INSTALACIJE	
	Analysis type	Static Analysis
	Associated standard	EN 1990 Timber CEN 2010-04
	Static analysis settings	SA1 - Geometrically linear Newton-Raphson
	Action category	Permanent
	Load duration	Permanent
	Self-weight mode for geotechnical analysis	Normal
3	SNIJEG	
	Analysis type	Static Analysis
	Associated standard	EN 1990 Timber CEN 2010-04
	Static analysis settings	SA1 - Geometrically linear Newton-Raphson
	Action category	Snow/ice loads - H <= 1000 m
	Load duration	Medium-term
	Self-weight mode for geotechnical analysis	Normal
4	WS1: 0.00 deg	
	Analysis type	Wind Simulation
	Associated standard	EN 1990 Timber CEN 2010-04
	Static analysis settings	SA1 - Geometrically linear Newton-Raphson
	Wind simulation analysis settings	WA1 - VJETAR
	Action category	Wind
	Load duration	Short-term
	Self-weight mode for geotechnical analysis	Normal
5	WS1: 90.00 deg	
	Analysis type	Wind Simulation
	Associated standard	EN 1990 Timber CEN 2010-04
	Static analysis settings	SA1 - Geometrically linear Newton-Raphson
	Wind simulation analysis settings	WA1 - VJETAR
	Action category	Wind
	Load duration	Short-term
	Self-weight mode for geotechnical analysis	Normal

Tablica 6.: Kombinacije opterećenja na konstrukciju za granično stanje nosivosti

LOAD COMBINATIONS				
CO No.	Settings	Value	Unit	To Solve
1	$1.35 \cdot LC1 + 1.35 \cdot LC2 + 1.50 \cdot LC3$ Analysis type Associated standard Static analysis settings Design Situation Load duration	Static Analysis EN 1990 Timber CEN 2010-04 SA1 - Geometrically linear Newton-Raphson ULS DS1 - ULS (STR/GEO) - Permanent and transient - Eq. 6.10 Medium-term		<input checked="" type="checkbox"/>
2	$1.35 \cdot LC1 + 1.35 \cdot LC2 + 1.50 \cdot LC4$ Analysis type Associated standard Static analysis settings Design Situation Load duration	Static Analysis EN 1990 Timber CEN 2010-04 SA2 - Second-order (P-Δ) Newton-Raphson 200 1 ULS DS1 - ULS (STR/GEO) - Permanent and transient - Eq. 6.10 Short-term		<input checked="" type="checkbox"/>
3	$1.35 \cdot LC1 + 1.35 \cdot LC2 + 1.50 \cdot LC5$ Analysis type Associated standard Static analysis settings Design Situation Load duration	Static Analysis EN 1990 Timber CEN 2010-04 SA2 - Second-order (P-Δ) Newton-Raphson 200 1 ULS DS1 - ULS (STR/GEO) - Permanent and transient - Eq. 6.10 Short-term		<input checked="" type="checkbox"/>
4	$1.35 \cdot LC1 + 1.35 \cdot LC2 + 1.50 \cdot LC3 + 0.90 \cdot LC4$ Analysis type Associated standard Static analysis settings Design Situation Load duration	Static Analysis EN 1990 Timber CEN 2010-04 SA2 - Second-order (P-Δ) Newton-Raphson 200 1 ULS DS1 - ULS (STR/GEO) - Permanent and transient - Eq. 6.10 Short-term		<input checked="" type="checkbox"/>
5	$1.35 \cdot LC1 + 1.35 \cdot LC2 + 1.50 \cdot LC3 + 0.90 \cdot LC5$ Analysis type Associated standard Static analysis settings Design Situation Load duration	Static Analysis EN 1990 Timber CEN 2010-04 SA2 - Second-order (P-Δ) Newton-Raphson 200 1 ULS DS1 - ULS (STR/GEO) - Permanent and transient - Eq. 6.10 Short-term		<input checked="" type="checkbox"/>
6	$1.35 \cdot LC1 + 1.35 \cdot LC2 + 0.75 \cdot LC3 + 1.50 \cdot LC4$ Analysis type Associated standard Static analysis settings Design Situation Load duration	Static Analysis EN 1990 Timber CEN 2010-04 SA2 - Second-order (P-Δ) Newton-Raphson 200 1 ULS DS1 - ULS (STR/GEO) - Permanent and transient - Eq. 6.10 Short-term		<input checked="" type="checkbox"/>
7	$1.35 \cdot LC1 + 1.35 \cdot LC2 + 0.75 \cdot LC3 + 1.50 \cdot LC5$ Analysis type Associated standard Static analysis settings Design Situation Load duration	Static Analysis EN 1990 Timber CEN 2010-04 SA2 - Second-order (P-Δ) Newton-Raphson 200 1 ULS DS1 - ULS (STR/GEO) - Permanent and transient - Eq. 6.10 Short-term		<input checked="" type="checkbox"/>

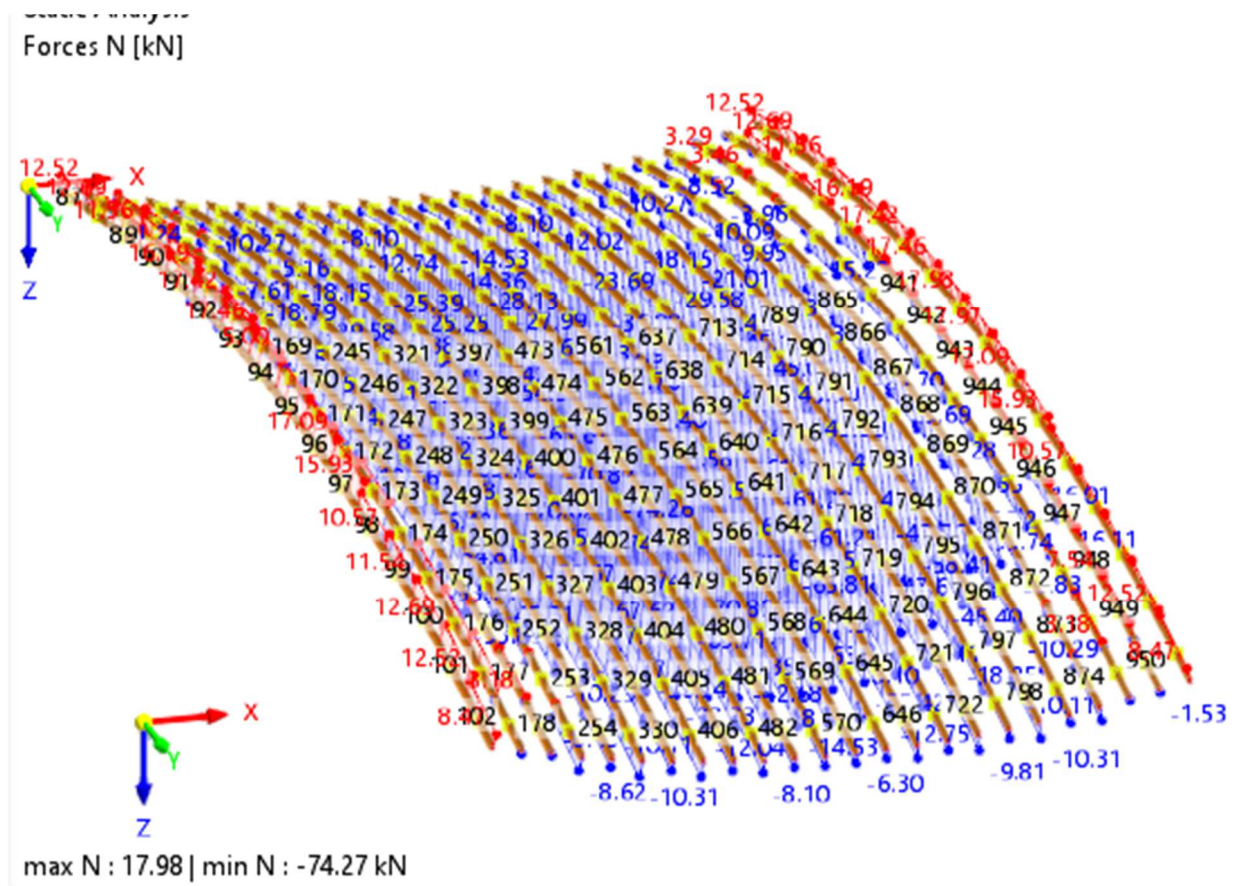
4. GRANIČNO STANJE NOSIVOSTI

4.1. Dimenzioniranje sekundarnih nosača

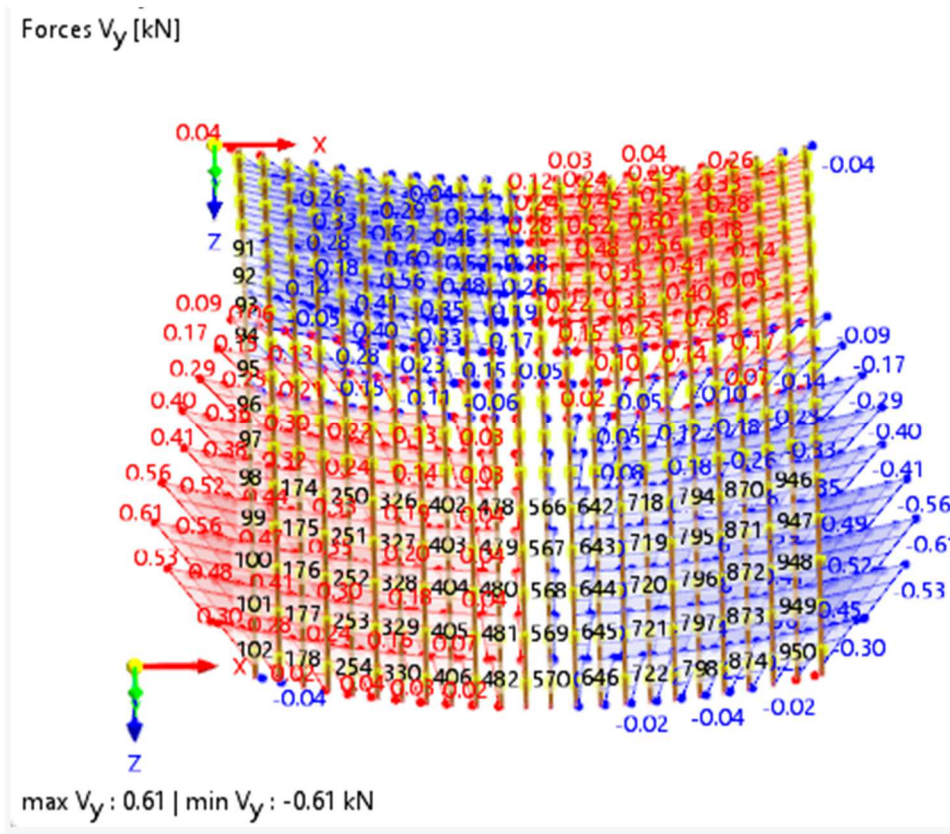
4.1.1. Ulazni podaci

4.1.1.1. Dijagrami unutarnjih sila

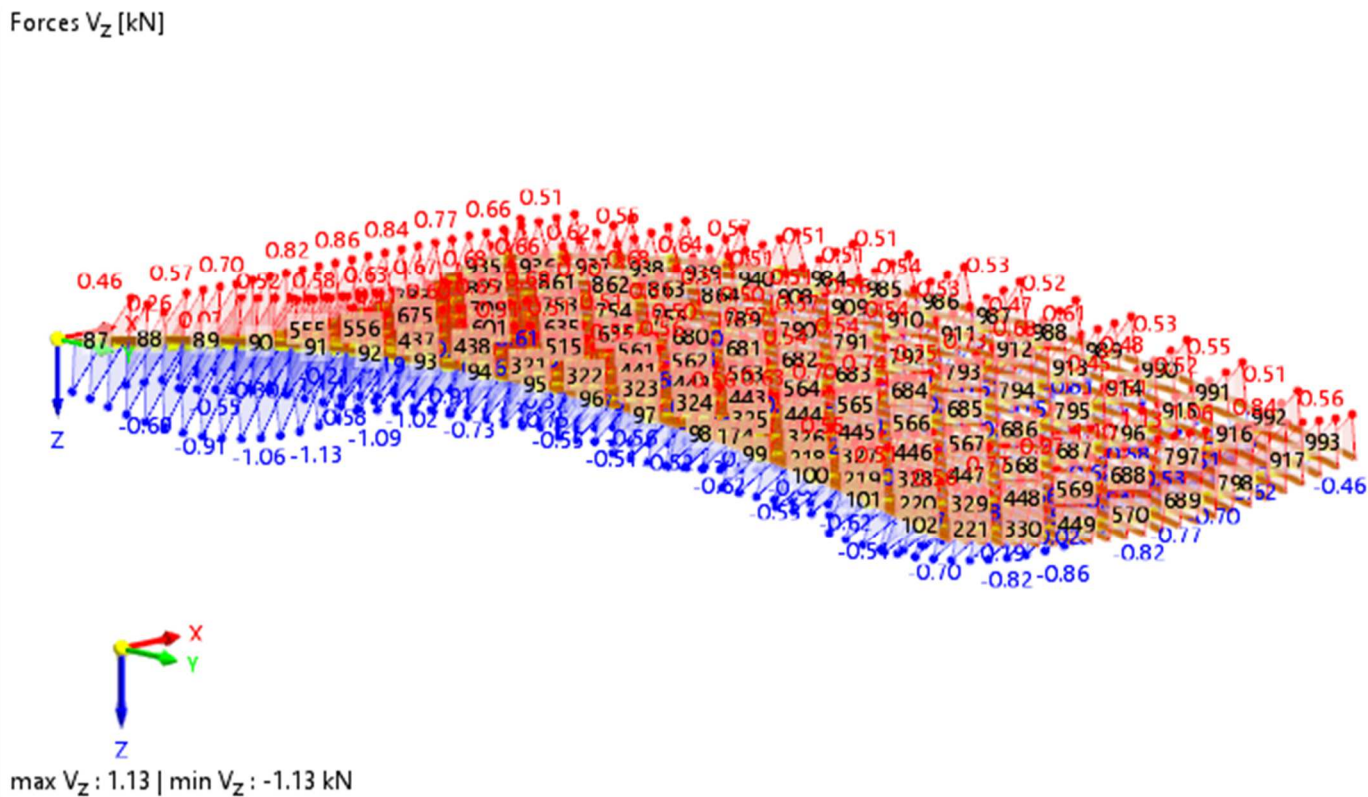
Mjerodavna kombinacija opterećenja na sekundarni nosač, odnosno kombinacija opterećenja koja uzrokuje najkritičnije stanje za konstrukciju u pogledu njene stabilnosti i sigurnosti je kombinacija CO1, odnosno $1.35 \cdot LC1 + 1.35 \cdot LC2 + 1.50 \cdot LC3$. Dijagrami unutarnjih sila za mjerodavnu kombinaciju dani su na idućim slikama.



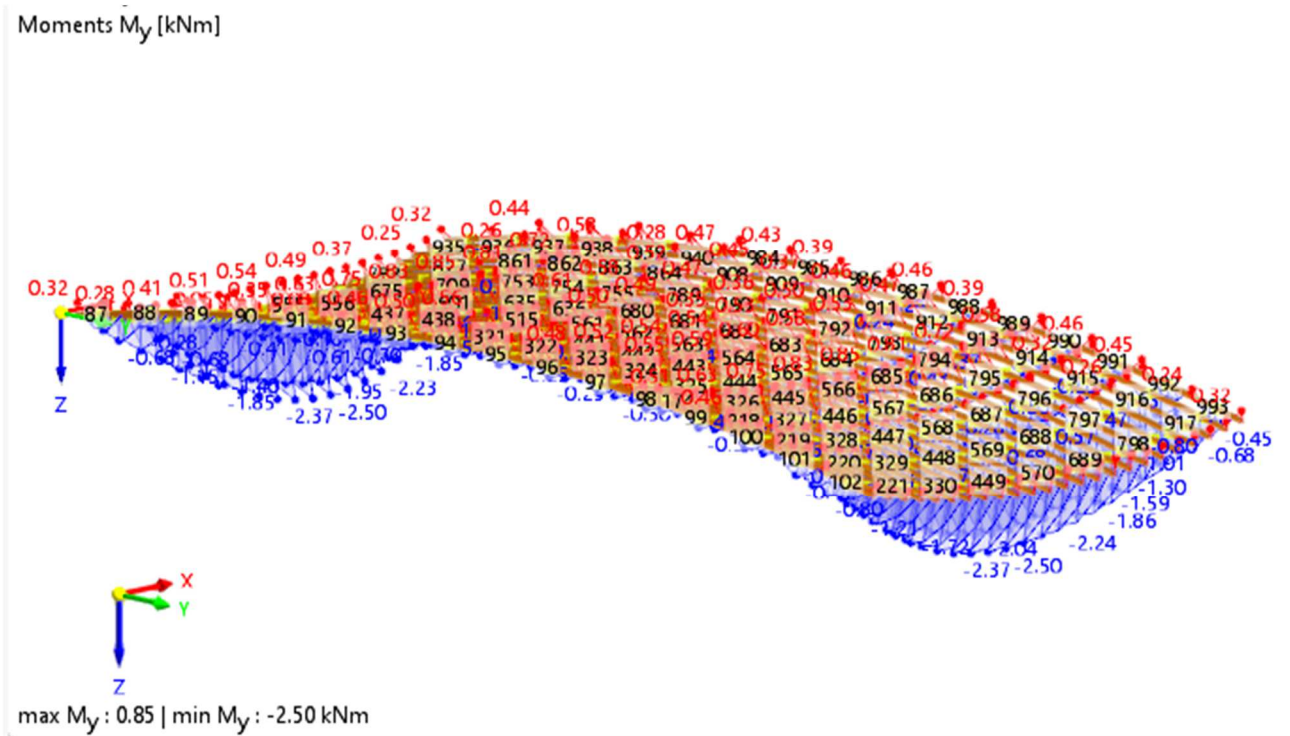
Slika 4.1.: Dijagram uzdužnih sila N [kN]



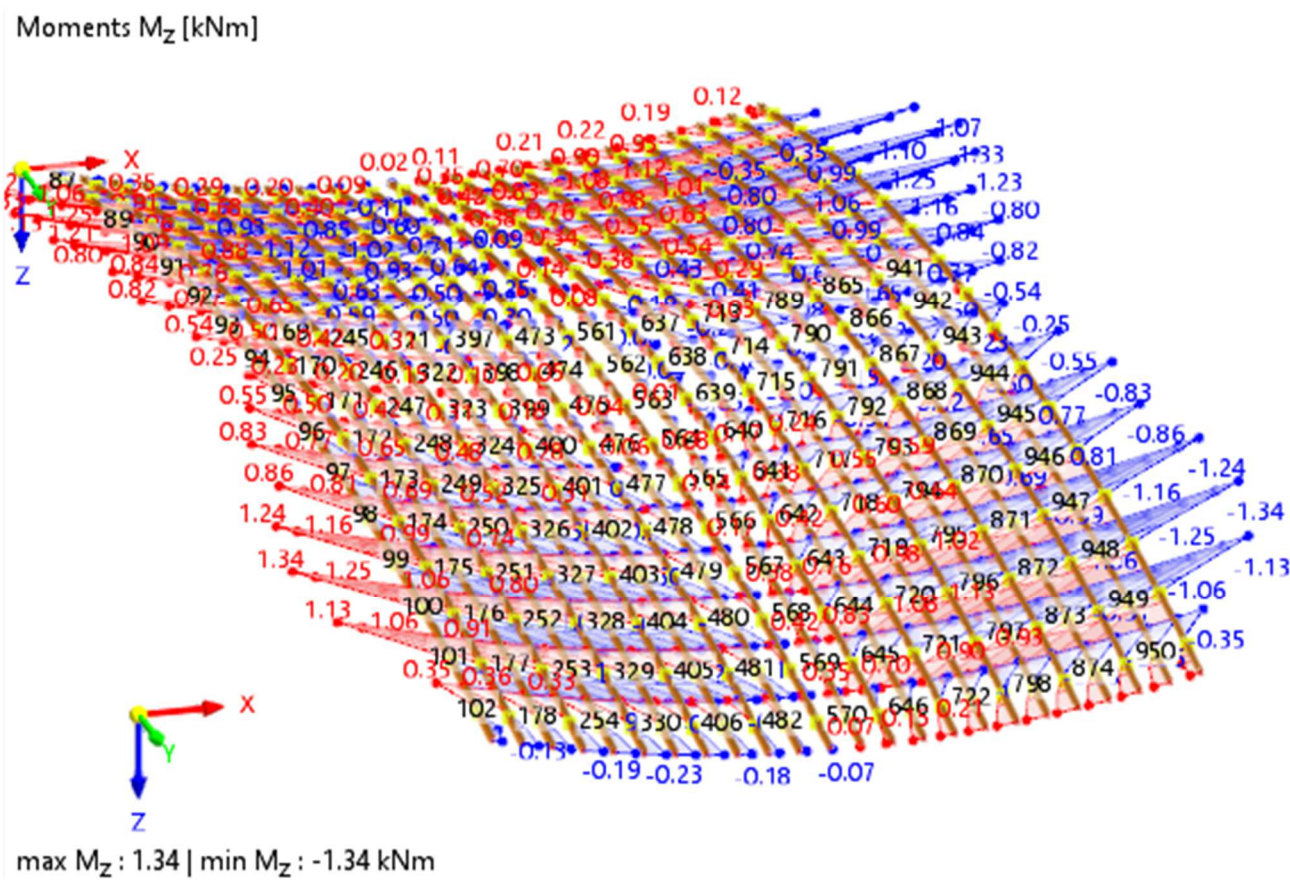
Slika 4.2.: Dijagram poprečnih sila V_y [kN]



Slika 4.3.: Dijagram poprečnih sila V_z [kN]



Slika 4.4.: Dijagram momenata savijanja M_y [kNm]



Slika 4.5.: Dijagram momenata savijanja M_z [kNm]

4.1.1.2. Geometrijske karakteristike nosača

Karakteristične vrijednosti čvrstoće drva GL32h

– Karakteristična čvrstoća savijanja	$f_{m,k} = 32,0 \text{ N/mm}^2$
– Karakteristična vlačna čvrstoća paralelno s vlakancima	$f_{t,0,k} = 26,5 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća paralelno s vlakancima	$f_{c,0,k} = 32 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća okomito na vlakanca	$f_{c,90,k} = 2,5 \text{ N/mm}^2$
– Karakteristična posmična torzijska čvrstoća	$f_{v,k} = 3,5 \text{ N/mm}^2$
– Karakteristični modul elastičnosti paralelno s vlakancima	$E_{0,05} = 11800 \text{ N/mm}^2$
– Srednji modul elastičnosti paralelno s vlakancima	$E_{0,mean} = 14200 \text{ N/mm}^2$
– Srednji modul posmika	$G_{mean} = 650 \text{ N/mm}^2$
– Srednja gustoća	$\rho_k = 440 \text{ N/mm}^2$
– Vrijednost čimbenika modifikacije	$k_{mod} = 0,8$

Proračunske vrijednosti čvrstoće

- Proračunska čvrstoća savijanja

$$f_{m,d} = k_{mod} \cdot \frac{f_{m,k}}{\gamma_M}$$

- Proračunska vlačna čvrstoća paralelno s vlakancima

$$f_{t,0,d} = k_{mod} \cdot \frac{f_{t,0,k}}{\gamma_M}$$

- Proračunska tlačna čvrstoća paralelno s vlakancima

$$f_{c,0,d} = k_{mod} \cdot \frac{f_{c,0,k}}{\gamma_M}$$

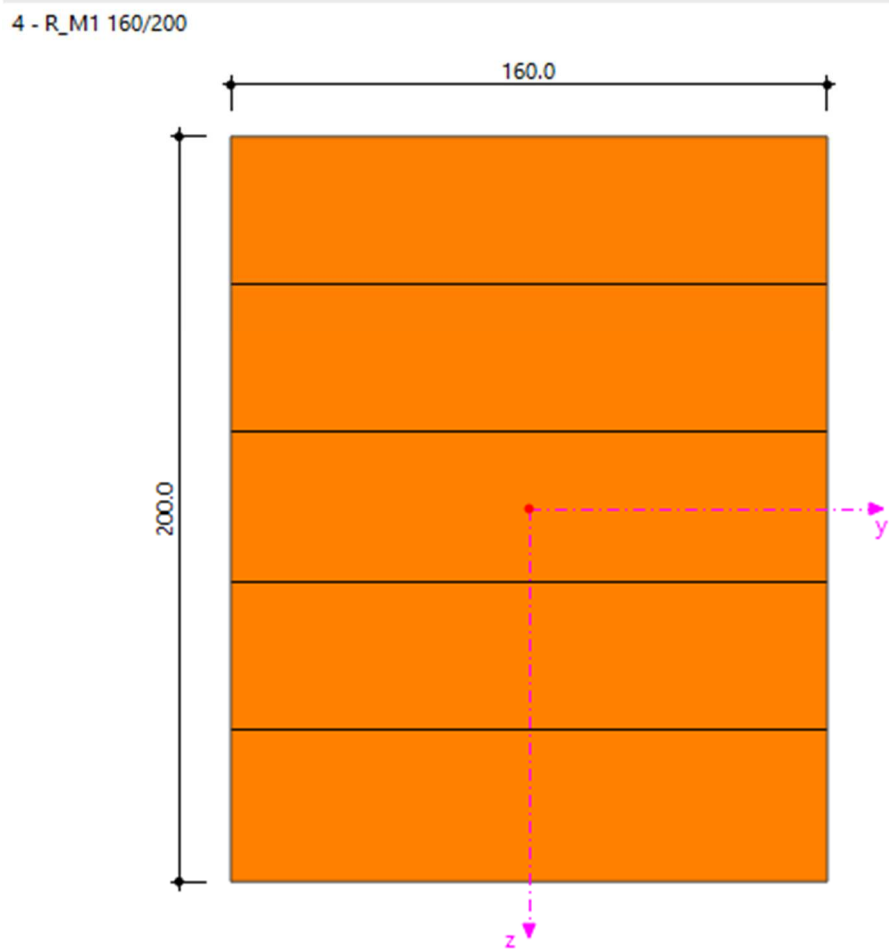
- Proračunska tlačna čvrstoća okomito na vlakancima

$$f_{c,90,d} = k_{mod} \cdot \frac{f_{c,90,k}}{\gamma_M}$$

- Proračunska posmična torzijska čvrstoća

$$f_{v,d} = k_{mod} \cdot \frac{f_{v,k}}{\gamma_M}$$

Odabrane dimenzije poprečnog presjeka



Slika 4.6.: Poprečni presjek sekundarnog nosača [mm]

$$h=200 \text{ mm}$$

$$b=160 \text{ mm}$$

$$A=320 \text{ cm}^2$$

$$I_y=10666.67 \text{ cm}^4$$

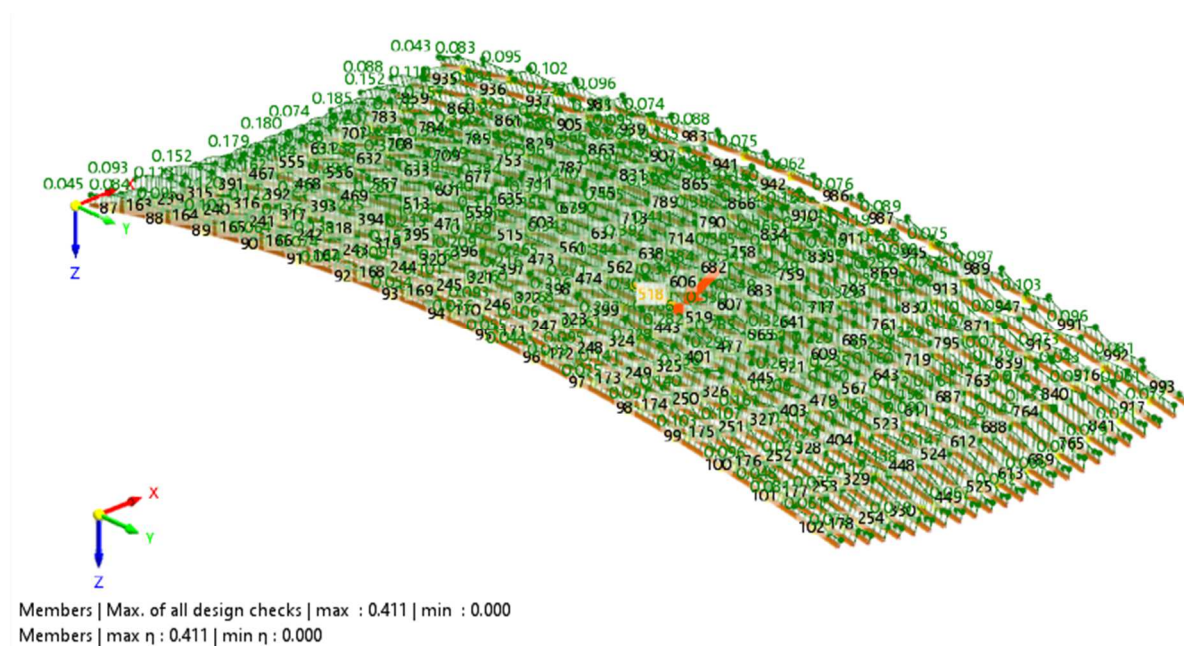
$$I_z=6826.67 \text{ cm}^4$$

$$W_y=1066.67 \text{ cm}^3$$

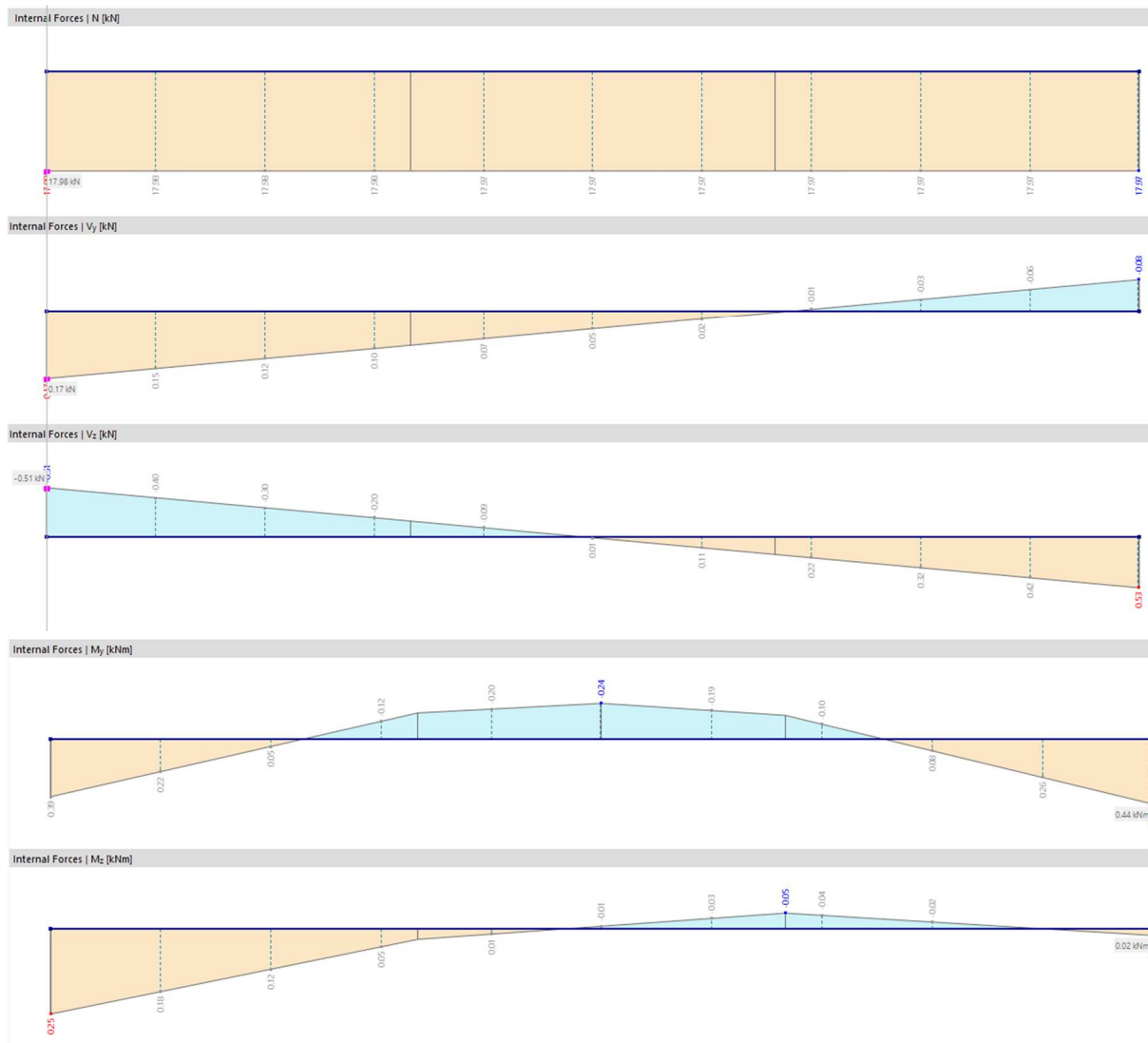
$$W_z=853.33 \text{ cm}^3$$

4.1.2. Dokaz nosivosti sekundarnog nosača

Najopterećeniji sekundarni nosač



Slika 4.7.: Iskoristivosti sekundarnog nosača [kN]



Slika 4.8.: Opterećenje mjerodavnog sekundarnog nosača [kN]

4.1.2.1. Dokazi nosivosti presjeka;

Vlak paralelno s vlakancima

Tablica 7.: Unutarnje sile

Design normal force	N_{Ed}	17.98	kN	Negligible
Design shear force	$V_{y,Ed}$	0.17	kN	
Design shear force	$V_{z,Ed}$	-0.51	kN	
Design torsional moment	T_{Ed}	0.00	kNm	
Design bending moment	$M_{y,Ed}$	0.39	kNm	
Design bending moment	$M_{z,Ed}$	0.25	kNm	

Tablica 8.: Parametri proračuna

⊕ Tensile strength				
Design tension force	$N_{t,Ed}$	17.98	kN	
Sectional area	A	320.00	cm ²	
Design tensile stress	$\sigma_{t,0,d}$	0.562	N/mm ²	
Design tensile strength	$f_{t,0,d}$	16.384	N/mm ²	
Design check ratio	η	0.034	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{\sigma_{t,0,d}}{f_{t,0,d}} \\ &= \frac{0.562 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} \\ &= 0.034 \end{aligned}$$

$$\eta = 0.034 \leq 1 \quad \checkmark$$

Provjera sekundarnog nosača na vlak paralelno s vlakancima zadovoljava s iskoristivosti od 3.40%.

Tlak paralelno s vlakancima

Tablica 9.: Unutarnje sile

Design normal force	N _{Ed}	-74.27	kN	
Design shear force	V _{y,Ed}	0.00	kN	Negligible
Design shear force	V _{z,Ed}	0.57	kN	
Design torsional moment	T _{Ed}	0.00	kNm	Negligible
Design bending moment	M _{y,Ed}	0.54	kNm	
Design bending moment	M _{z,Ed}	0.00	kNm	Negligible

Tablica 10.: Parametri proračuna

Compressive strength				
Design compression force	N _{c,Ed}	74.27	kN	
Sectional area	A	320.00	cm ²	
Design compressive stress	σ _{c,0,d}	-2.321	N/mm ²	
Design compressive strength	f _{c,0,d}	20.480	N/mm ²	
Design check ratio	η	0.113	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{|\sigma_{c,0,d}|}{f_{c,0,d}} \\ &= \frac{|-2.321 \text{ N/mm}^2|}{20.480 \text{ N/mm}^2} \\ &= 0.113 \end{aligned}$$

$$\eta = 0.113 \leq 1 \quad \checkmark$$

Provjera sekundarnog nosača na tlak paralelno s vlakancima zadovoljava s iskoristivosti od 11.30%.

Torzijski posmik

Tablica 11.: Unutarnje sile

Design normal force	NEd	8.67	kN	
Design shear force	V _{y,Ed}	0.21	kN	
Design shear force	V _{z,Ed}	-0.46	kN	
Design torsional moment	TEd	0.08	kNm	
Design bending moment	M _{y,Ed}	0.06	kNm	
Design bending moment	M _{z,Ed}	0.31	kNm	

Tablica 12.: Parametri proračuna

Design torsional moment	TEd	0.08	kNm	
Design torsional stress	τ _{tor,d}	0.071	N/mm ²	
Torsion factor	k _{shape}	1.06	--	
Design shear strength	f _{v,d}	2.240	N/mm ²	
Design check ratio	η	0.030	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{\tau_{tor,d}}{k_{shape} \cdot f_{v,d}} \\ &= \frac{0.071 \text{ N/mm}^2}{1.06 \cdot 2.240 \text{ N/mm}^2} \\ &= 0.030 \end{aligned}$$

$$\eta = 0.030 \leq 1 \quad \checkmark$$

Provjera sekundarnog nosača na torzijski posmik zadovoljava s iskoristivosti od 3.00%.

Posmik u vertikalnoj (z) osi

Tablica 13.: Unutarnje sile

Design normal force	N_{Ed}	-11.22 kN		
Design shear force	$V_{y,Ed}$	0.01 kN		Negligible
Design shear force	$V_{z,Ed}$	-1.44 kN		
Design torsional moment	T_{Ed}	0.00 kNm		Negligible
Design bending moment	$M_{y,Ed}$	-0.14 kNm		
Design bending moment	$M_{z,Ed}$	0.02 kNm		

Tablica 14.: Parametri proračuna

Design shear force	$V_{z,Ed}$	1.44 kN		
Shear stress	τ_{xz}	-0.067 N/mm ²		
Crack influence factor	k_{cr}	0.67	--	
Design shear stress	$\tau_{xz,d}$	-0.100 N/mm ²		
Design shear strength	$f_{v,z,d}$	2.520 N/mm ²		
Design check ratio	η	0.040	--	≤ 1

$$\begin{aligned} \eta &= \frac{|\tau_{xz,d}|}{f_{v,z,d}} \\ &= \frac{|-0.100 \text{ N/mm}^2|}{2.520 \text{ N/mm}^2} \\ &= 0.040 \end{aligned}$$

$$\eta = 0.040 \leq 1 \quad \checkmark$$

Provjera sekundarnog nosača na posmik u vertikalnoj (z) osi zadovoljava s iskoristivosti od 4.00%.

Posmik u horizontalnoj (y) osi

Tablica 15.: Unutarnje sile

Design normal force	N_{Ed}	7.68	kN	Negligible
Design shear force	$V_{y,Ed}$	0.61	kN	
Design shear force	$V_{z,Ed}$	-0.50	kN	
Design torsional moment	T_{Ed}	0.01	kNm	
Design bending moment	$M_{y,Ed}$	0.25	kNm	
Design bending moment	$M_{z,Ed}$	1.34	kNm	

Tablica 16.: Parametri proračuna

Design shear force	$V_{y,Ed}$	0.61	kN
Shear stress	τ_{xy}	0.028	N/m
Crack influence factor	k_{cr}	0.67	--
Design shear stress	$\tau_{xy,d}$	0.042	N/m
Design shear strength	$f_{v,y,d}$	2.240	N/m
Design check ratio	η	0.019	--

$$\begin{aligned} \eta &= \frac{|\tau_{xy,d}|}{f_{v,y,d}} \\ &= \frac{|0.042 \text{ N/mm}^2|}{2.240 \text{ N/mm}^2} \\ &= 0.019 \\ \eta &= 0.019 \leq 1 \quad \checkmark \end{aligned}$$

Provjera sekundarnog nosača na posmik u horizontalnoj (y) osi zadovoljava s iskoristivosti od 1.90%.

Dvoosno savijanje

Tablica 17.: Unutarnje sile

Design normal force	N _{Ed}	0.00	kN	Negligible
Design shear force	V _{y,Ed}	0.61	kN	
Design shear force	V _{z,Ed}	-0.43	kN	Negligible
Design torsional moment	T _{Ed}	0.01	kNm	
Design bending moment	M _{y,Ed}	0.27	kNm	
Design bending moment	M _{z,Ed}	1.36	kNm	

Tablica 18.: Parametri proračuna

Design bending moment	M _{y,Ed}	0.27	kNm	
Design bending moment	M _{z,Ed}	1.36	kNm	
Design bending stress	σ _{m,y,d}	-0.250	N/mm ²	
Design bending stress	σ _{m,z,d}	-1.595	N/mm ²	
Design bending strength	f _{m,y,d}	23.040	N/mm ²	
Design bending strength	f _{m,z,d}	23.040	N/mm ²	
Redistribution factor	k _m	0.70	--	
Design ratio 1	η ₁	0.059	--	
Design ratio 2	η ₂	0.077	--	
Design check ratio	η	0.077	--	≤ 1 ✓

$$\begin{aligned} \eta_1 &= \left| \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| \frac{-0.250 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-1.595 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.059 \end{aligned}$$

$$\begin{aligned} \eta_2 &= \left| k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| 0.70 \cdot \frac{-0.250 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + \frac{-1.595 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.077 \end{aligned}$$

$$\begin{aligned} \eta &= \max(\eta_1, \eta_2) \\ &= \max(0.059, 0.077) \\ &= 0.077 \end{aligned}$$

$$\eta = 0.077 \leq 1 \quad \checkmark$$

Provjera sekundarnog nosača na dvoosno savijanje zadovoljava s iskoristivosti od 7.70%.

Interakcija dvoosnog savijanja i vlaka paralelno s vlakancima

Tablica 19.: Unutarnje sile

Design normal force	N_{Ed}	11.54	kN		
Design shear force	$V_{y,Ed}$	0.59	kN		
Design shear force	$V_{z,Ed}$	-0.48	kN		
Design torsional moment	T_{Ed}	0.01	kNm		Negligible
Design bending moment	$M_{y,Ed}$	0.26	kNm		
Design bending moment	$M_{z,Ed}$	1.26	kNm		

Tablica 20.: Parametri proračuna

Design tension force	$N_{t,Ed}$	11.54	kN		
Design tensile stress	$\sigma_{t,0,d}$	0.361	N/mm ²		
Design bending moment	$M_{y,Ed}$	0.26	kNm		
Design bending stress	$\sigma_{m,y,d}$	0.247	N/mm ²		
Design bending moment	$M_{z,Ed}$	1.26	kNm		
Design bending stress	$\sigma_{m,z,d}$	1.480	N/mm ²		
Design tensile strength	$f_{t,0,d}$	16.384	N/mm ²		2.4.1, Eq. 2.14
Design bending strength	$f_{m,y,d}$	20.480	N/mm ²		2.4.1, Eq. 2.14
Design bending strength	$f_{m,z,d}$	20.480	N/mm ²		2.4.1, Eq. 2.14
Redistribution factor	k_m	0.70	--		6.1.6(2)
Design ratio 1	η_1	0.085	--		6.2.3, Eq. 6.17
Design ratio 2	η_2	0.103	--		6.2.3, Eq. 6.18
Design check ratio	η	0.103	--	≤ 1 ✓	EN 1995-1-1, 6.2.3

$$\eta_1 = \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right|$$

$$= \left| \frac{0.361 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} + \frac{0.247 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} + 0.70 \cdot \frac{1.480 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right|$$

$$= 0.085$$

$$\eta_2 = \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right|$$

$$= \left| \frac{0.361 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} + 0.70 \cdot \frac{0.247 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} + \frac{1.480 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right|$$

$$= 0.103$$

$$\eta = \max(\eta_1, \eta_2)$$

$$= \max(0.085, 0.103)$$

$$= 0.103$$

$$\eta = 0.103 \leq 1 \quad \checkmark$$

Provjera sekundarnog nosača interakciju dvoosnog savijanja i vlaka paralelno s vlakancima zadovoljava s iskoristivosti od 10.30%.

Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima

Tablica 21.: Unutarnje sile

Design normal force	N_{Ed}	-11.14	kN	Negligible
Design shear force	$V_{y,Ed}$	-0.04	kN	
Design shear force	$V_{z,Ed}$	-0.10	kN	
Design torsional moment	T_{Ed}	-0.01	kNm	
Design bending moment	$M_{y,Ed}$	-3.37	kNm	
Design bending moment	$M_{z,Ed}$	0.04	kNm	

Tablica 22.: Parametri proračuna

Design compression force	$N_{c,Ed}$	-11.14	kN	
Design compressive stress	$\sigma_{c,0,d}$	-0.348	N/mm ²	
Design bending moment	$M_{y,Ed}$	-3.37	kNm	
Design bending stress	$\sigma_{m,y,d}$	-3.161	N/mm ²	
Design bending moment	$M_{z,Ed}$	0.04	kNm	
Design bending stress	$\sigma_{m,z,d}$	-0.048	N/mm ²	
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²	
Design bending strength	$f_{m,y,d}$	23.040	N/mm ²	
Design bending strength	$f_{m,z,d}$	23.040	N/mm ²	
Redistribution factor	k_m	0.70	--	
Design ratio 1	η_1	0.139	--	
Design ratio 2	η_2	0.098	--	
Design check ratio	η	0.139	--	≤ 1 ✓

$$\eta_1 = \left| - \left(\frac{\sigma_{c,0,d}}{f_{c,0,d}} \right)^2 + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right|$$

$$= \left| - \left(\frac{-0.348 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right)^2 + \frac{-3.161 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.048 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right|$$

$$= 0.139$$

$$\eta_2 = \left| - \left(\frac{\sigma_{c,0,d}}{f_{c,0,d}} \right)^2 + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right|$$

$$= \left| - \left(\frac{-0.348 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right)^2 + 0.70 \cdot \frac{-3.161 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + \frac{-0.048 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right|$$

$$= 0.098$$

$$\eta = \max(\eta_1, \eta_2)$$

$$= \max(0.139, 0.098)$$

$$= 0.139$$

$$\eta = 0.139 \leq 1 \quad \checkmark$$

Provjera sekundarnog nosača interakciju dvoosnog savijanja i tlaka paralelno s vlakancima zadovoljava s iskoristivosti od 13.90%.

4.1.2.2. Dokazi nosivosti elementa;

Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima s izvijanjem

Tablica 23.: Unutarnje sile

Design normal force	N _{Ed}	-73.08	kN	
Design shear force	V _{y,Ed}	-0.03	kN	Negligible
Design shear force	V _{z,Ed}	0.50	kN	
Design torsional moment	T _{Ed}	0.00	kNm	Negligible
Design bending moment	M _{y,Ed}	0.35	kNm	
Design bending moment	M _{z,Ed}	0.05	kNm	

Tablica 24.: Parametri proračuna

Design compression force	N _{c,Ed}	73.08	kN	
Design compressive stress	σ _{c,0,d}	-2.284	N/mm ²	
Design bending moment	M _{y,Ed}	0.35	kNm	
Design bending stress	σ _{m,y,d}	-0.331	N/mm ²	
Design bending moment	M _{z,Ed}	0.05	kNm	
Design bending stress	σ _{m,z,d}	-0.053	N/mm ²	
Equivalent member length	L _{cr,y}	5.033	m	
Equivalent member length	L _{cr,z}	5.033	m	
Radius of gyration	i _y	57.7	mm	
Radius of gyration	i _z	46.2	mm	
Slenderness ratio	λ _y	87.18	--	
Slenderness ratio	λ _z	108.97	--	
Modulus of elasticity	E _{0,05,y}	11800.0	N/mm ²	
Modulus of elasticity	E _{0,05,z}	11800.0	N/mm ²	
Characteristic compressive strength	f _{c,0,k}	32.000	N/mm ²	
Relative slenderness ratio	λ _{rel,y}	1.45	--	
Relative slenderness ratio	λ _{rel,z}	1.81	--	
Straightness factor	β _c	0.10	--	
Instability factor	k _y	1.60	--	
Instability factor	k _z	2.21	--	
Instability factor	k _{c,y}	0.44	--	
Instability factor	k _{c,z}	0.29	--	
Design compressive strength	f _{c,0,d}	20.480	N/mm ²	
Design bending strength	f _{m,y,d}	20.480	N/mm ²	
Design bending strength	f _{m,z,d}	20.480	N/mm ²	
Redistribution factor	k _m	0.70	--	
Design ratio 1	η ₁	0.273	--	
Design ratio 2	η ₂	0.401	--	
Design check ratio	η	0.401	--	≤ 1 ✓

$$\begin{aligned} \lambda_y &= \frac{L_{cr,y}}{i_y} \\ &= \frac{5.033 \text{ m}}{57.7 \text{ mm}} \\ &= 87.18 \end{aligned}$$

$$\begin{aligned} \lambda_z &= \frac{L_{cr,z}}{i_z} \\ &= \frac{5.033 \text{ m}}{46.2 \text{ mm}} \\ &= 108.97 \end{aligned}$$

$$\begin{aligned}\lambda_{rel,y} &= \frac{\lambda_y}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,y}}} \\ &= \frac{87.18}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 1.45\end{aligned}$$

$$\begin{aligned}\lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\ &= \frac{108.97}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 1.81\end{aligned}$$

$$\lambda_{rel,y} > 0.3 \text{ or } \lambda_{rel,z} > 0.3$$

$$\begin{aligned}k_y &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,y} - 0.3) + (\lambda_{rel,y})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (1.45 - 0.3) + (1.45)^2\right) \\ &= 1.60\end{aligned}$$

$$\begin{aligned}k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (1.81 - 0.3) + (1.81)^2\right) \\ &= 2.21\end{aligned}$$

$$\begin{aligned}k_{c,y} &= \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \\ &= \frac{1}{1.60 + \sqrt{(1.60)^2 - (1.45)^2}} \\ &= 0.44\end{aligned}$$

$$\begin{aligned}k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\ &= \frac{1}{2.21 + \sqrt{(2.21)^2 - (1.81)^2}} \\ &= 0.29\end{aligned}$$

$$\begin{aligned}\eta_1 &= \left| \frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| \frac{-2.284 \text{ N/mm}^2}{0.44 \cdot 20.480 \text{ N/mm}^2} + \frac{-0.331 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.053 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\ &= 0.273\end{aligned}$$

$$\begin{aligned}\eta_2 &= \left| \frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| \frac{-2.284 \text{ N/mm}^2}{0.29 \cdot 20.480 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.331 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} + \frac{-0.053 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\ &= 0.401\end{aligned}$$

$$\begin{aligned}\eta &= \max(\eta_1, \eta_2) \\ &= \max(0.273, 0.401) \\ &= 0.401\end{aligned}$$

$$\eta = 0.401 \leq 1 \quad \checkmark$$

Provjera sekundarnog nosača na interakciju dvoosnog savijanja i tlaka paralelno s vlakancima s izvijanjem zadovoljava s iskoristivosti od 40.10%.

Savijanje s bočnim izvijanjem

Tablica 25.: Unutarnje sile

Design normal force	N _{Ed}	-0.70 kN	Negligible
Design shear force	V _{y,Ed}	0.11 kN	
Design shear force	V _{z,Ed}	0.02 kN	Negligible
Design torsional moment	T _{Ed}	0.03 kNm	
Design bending moment	M _{y,Ed}	-1.58 kNm	
Design bending moment	M _{z,Ed}	0.01 kNm	Negligible

Tablica 26.: Parametri proračuna

Design bending moment	M _{y,Ed}	-1.58 kNm	
Design bending stress	σ _{m,y,d}	-1.481 N/mm ²	
Modulus of elasticity	E _{0,05,z}	11800.0 N/mm ²	
Moment of inertia	I _z	6826.67 cm ⁴	
Shear modulus	G ₀₅	540.0 N/mm ²	
Torsional constant	I _t	14013.90 cm ⁴	
Equivalent member length	L _{cr}	5.433 m	
Elastic section modulus to more compre...	W _y	1066.67 cm ³	
Critical bending stress	σ _{m,crit}	133.842 N/mm ²	
Characteristic bending strength	f _{m,y,k}	32.000 N/mm ²	
Relative slenderness ratio	λ _{rel,m}	0.49 --	
Lateral buckling coefficient	k _{crit}	1.00 --	
Design bending strength	f _{m,y,d}	23.040 N/mm ²	
Design check ratio	η	0.064 --	≤ 1 ✓

$$\sigma_{m,crit} = \frac{\pi \cdot \sqrt{E_{0,05,z} \cdot I_z \cdot G_{05} \cdot I_t}}{L_{cr} \cdot W_y}$$

$$= \frac{\pi \cdot \sqrt{11800.0 \text{ N/mm}^2 \cdot 6826.67 \text{ cm}^4 \cdot 540.0 \text{ N/mm}^2 \cdot 14013.90 \text{ cm}^4}}{5.433 \text{ m} \cdot 1066.67 \text{ cm}^3}$$

$$= 133.842 \text{ N/mm}^2$$

$$\lambda_{rel,m} = \sqrt{\frac{f_{m,y,k}}{\sigma_{m,crit}}}$$

$$= \sqrt{\frac{32.000 \text{ N/mm}^2}{133.842 \text{ N/mm}^2}}$$

$$= 0.49$$

$$\lambda_{rel,m} \leq 0.75$$

$$k_{crit} = 1$$

$$\eta = \frac{|\sigma_{m,y,d}|}{k_{crit} \cdot f_{m,y,d}}$$

$$= \frac{|-1.481 \text{ N/mm}^2|}{1.00 \cdot 23.040 \text{ N/mm}^2}$$

$$= 0.064$$

$$\eta = 0.064 \leq 1 \checkmark$$

Provjera sekundarnog nosača na savijanje s bočnim izvijanjem zadovoljava s iskoristivosti od 6.40%.

Interakcija savijanja s bočnim izvijanjem i tlaka paralelno s vlakancima s izvijanjem

Tablica 27.: Unutarnje sile

Design normal force	N _{Ed}	-74.27	kN	
Design shear force	V _{y,Ed}	0.00	kN	Negligible
Design shear force	V _{z,Ed}	0.57	kN	
Design torsional moment	T _{Ed}	0.00	kNm	Negligible
Design bending moment	M _{y,Ed}	0.54	kNm	
Design bending moment	M _{z,Ed}	0.00	kNm	Negligible

Tablica 28.: Parametri proračuna

Design compression force	N _{c,Ed}	74.27	kN	
Design compressive stress	σ _{c,0,d}	-2.321	N/mm ²	
Design bending moment	M _{y,Ed}	0.54	kNm	
Design bending stress	σ _{m,y,d}	-0.509	N/mm ²	
Equivalent member length	L _{cr,z}	5.033	m	
Radius of gyration	i _z	46.2	mm	
Slenderness ratio	λ _z	108.97	--	
Modulus of elasticity	E _{0,05,z}	11800.0	N/mm ²	
Characteristic compressive strength	f _{c,0,k}	32.000	N/mm ²	
Relative slenderness ratio	λ _{rel,z}	1.81	--	
Straightness factor	β _c	0.10	--	
Instability factor	k _z	2.21	--	
Instability factor	k _{c,z}	0.29	--	
Moment of inertia	I _z	6826.67	cm ⁴	
Shear modulus	G ₀₅	540.0	N/mm ²	
Torsional constant	I _t	14013.90	cm ⁴	
Equivalent member length	L _{cr}	5.433	m	
Elastic section modulus to more compre...	W _y	1066.67	cm ³	
Critical bending stress	σ _{m,crit}	133.842	N/mm ²	
Characteristic bending strength	f _{m,y,k}	32.000	N/mm ²	
Relative slenderness ratio	λ _{rel,m}	0.49	--	
Lateral buckling coefficient	k _{crit}	1.00	--	
Design compressive strength	f _{c,0,d}	20.480	N/mm ²	
Design bending strength	f _{m,y,d}	20.480	N/mm ²	
Design check ratio	η	0.394	--	≤ 1 ✓

$$\begin{aligned}\lambda_z &= \frac{L_{cr,z}}{i_z} \\ &= \frac{5.033 \text{ m}}{46.2 \text{ mm}} \\ &= 108.97\end{aligned}$$

$$\begin{aligned}\lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\ &= \frac{108.97}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 1.81\end{aligned}$$

$$\begin{aligned}
 k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2 \right) \\
 &= 0.5 \cdot \left(1 + 0.10 \cdot (1.81 - 0.3) + (1.81)^2 \right) \\
 &= 2.21
 \end{aligned}$$

$$\begin{aligned}
 k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\
 &= \frac{1}{2.21 + \sqrt{(2.21)^2 - (1.81)^2}} \\
 &= 0.29
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,crit} &= \frac{\pi \cdot \sqrt{E_{0,05,z} \cdot I_z \cdot G_{05} \cdot I_t}}{L_{cr} \cdot W_y} \\
 &= \frac{\pi \cdot \sqrt{11800.0 \text{ N/mm}^2 \cdot 6826.67 \text{ cm}^4 \cdot 540.0 \text{ N/mm}^2 \cdot 14013.90 \text{ cm}^4}}{5.433 \text{ m} \cdot 1066.67 \text{ cm}^3} \\
 &= 133.842 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 \lambda_{rel,m} &= \sqrt{\frac{f_{m,y,k}}{\sigma_{m,crit}}} \\
 &= \sqrt{\frac{32.000 \text{ N/mm}^2}{133.842 \text{ N/mm}^2}} \\
 &= 0.49
 \end{aligned}$$

$$\lambda_{rel,m} \leq 0.75$$

$$k_{crit} = 1$$

$$\begin{aligned}
 \eta &= \left| - \left(\frac{\sigma_{m,y,d}}{k_{crit} \cdot f_{m,y,d}} \right)^2 + \frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} \right| \\
 &= \left| - \left(\frac{-0.509 \text{ N/mm}^2}{1.00 \cdot 20.480 \text{ N/mm}^2} \right)^2 + \frac{-2.321 \text{ N/mm}^2}{0.29 \cdot 20.480 \text{ N/mm}^2} \right| \\
 &= 0.394
 \end{aligned}$$

$$\eta = 0.394 \leq 1 \quad \checkmark$$

Provjera sekundarnog nosača na interakciju savijanja s bočnim izvijanjima tlaka paralelno s vlakancima s izvijanjem zadovoljava s iskoristivosti od 39.40%.

Tablica 29.: Rekapitulacija iskoristivosti sekundarnog nosača

SEKUNDARNI NOSAČ			
Provjera nosivosti elementa			Iskoristivost
1.	DOKAZI NOSIVOSTI PRESJEKA	Vlak paralelno s vlakancima	3,40%
2.		Tlak paralelno s vlakancima	11,30%
3.		Torzijski posmik	3,00%
4.		Posmik u vertikalnoj (z) osi	4,00%
5.		Posmik u horizontalnoj (y) osi	1,90%
6.		Dvoosno savijanje	7,70%
7.		Interakcija dvoosnog savijanja i vlaka paralelno s vlakancima	10,30%
8.		Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima	13,90%
9.	DOKAZI NOSIVOSTI ELEMENTA	Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima s izvijanjem	40,10%
10.		Savijanje s bočnim izvijanjem	6,40%
11.		Interakcija savijanja s bočnim izvijanjem i tlaka paralelno s vlakancima	39,40%
Mjerodavna iskoristivost			40,10%

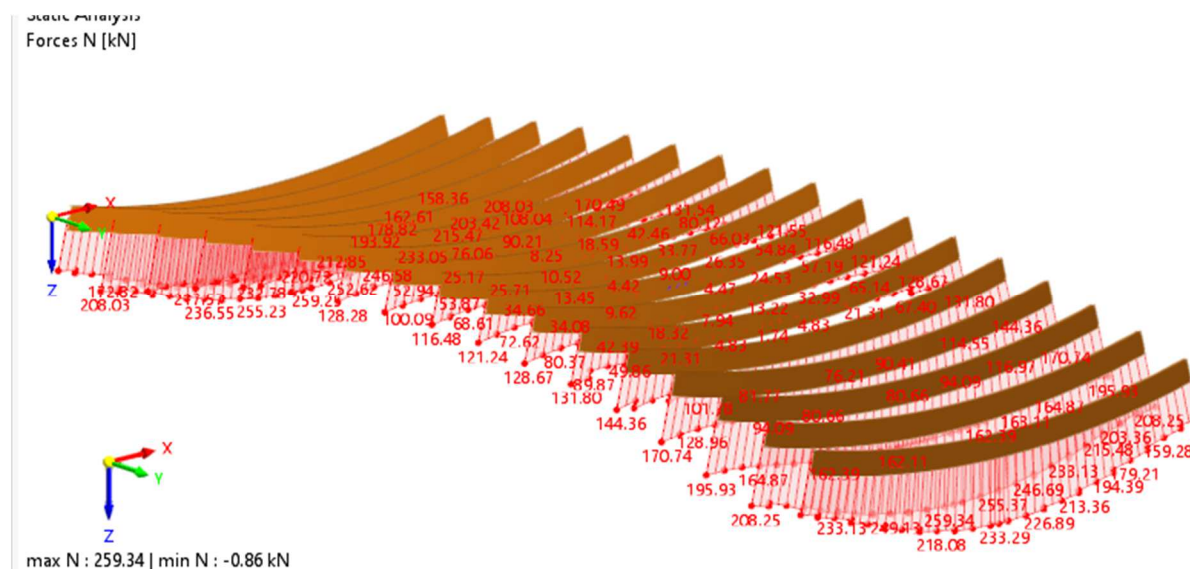
4.2. Dimenzioniranje glavnih poprečnih nosača

4.2.1. Ulazni podaci

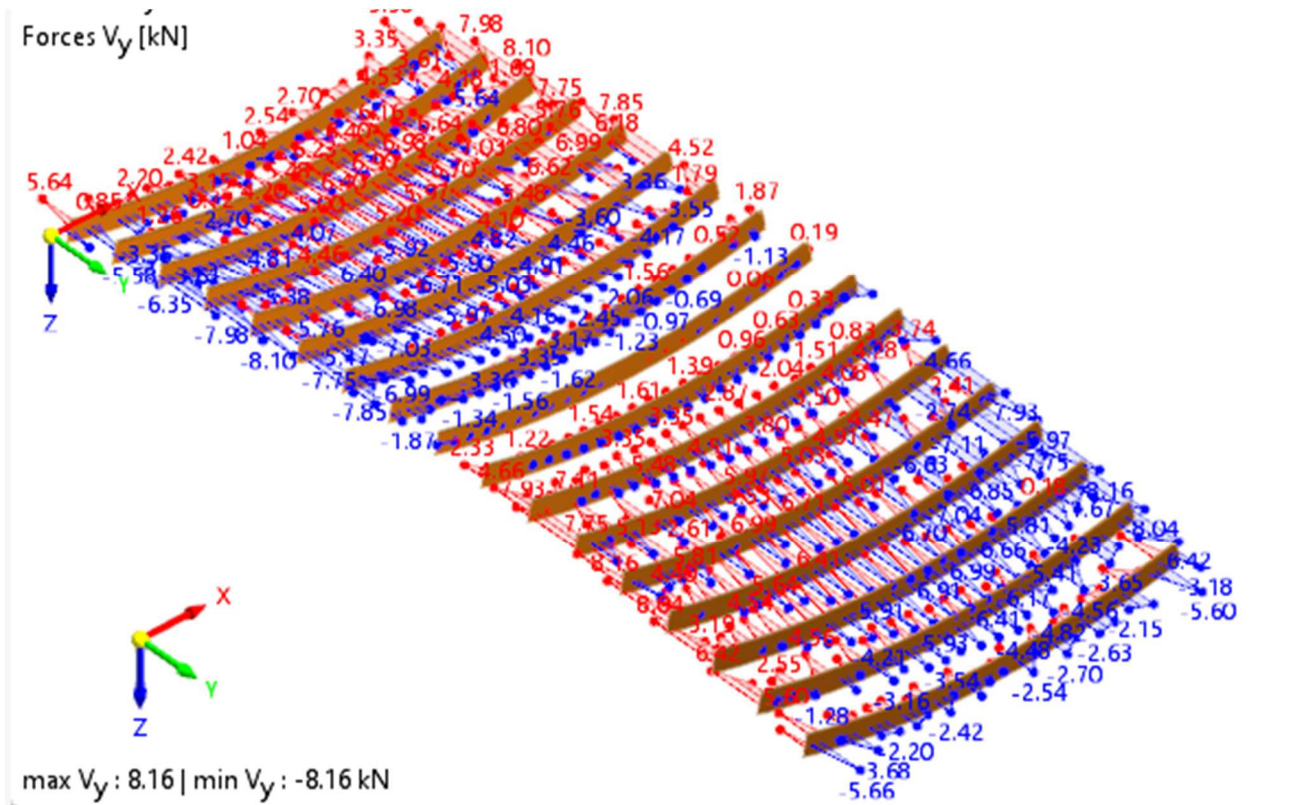
4.2.1.1. Dijagrami unutarnjih sila

Mjerodavna kombinacija opterećenja na glavni poprečni nosač, odnosno kombinacija opterećenja koja uzrokuje najkritičnije stanje za konstrukciju je kombinacija CO1, odnosno $1.35 \cdot LC1 + 1.35 \cdot LC2 + 1.50 \cdot LC3$.

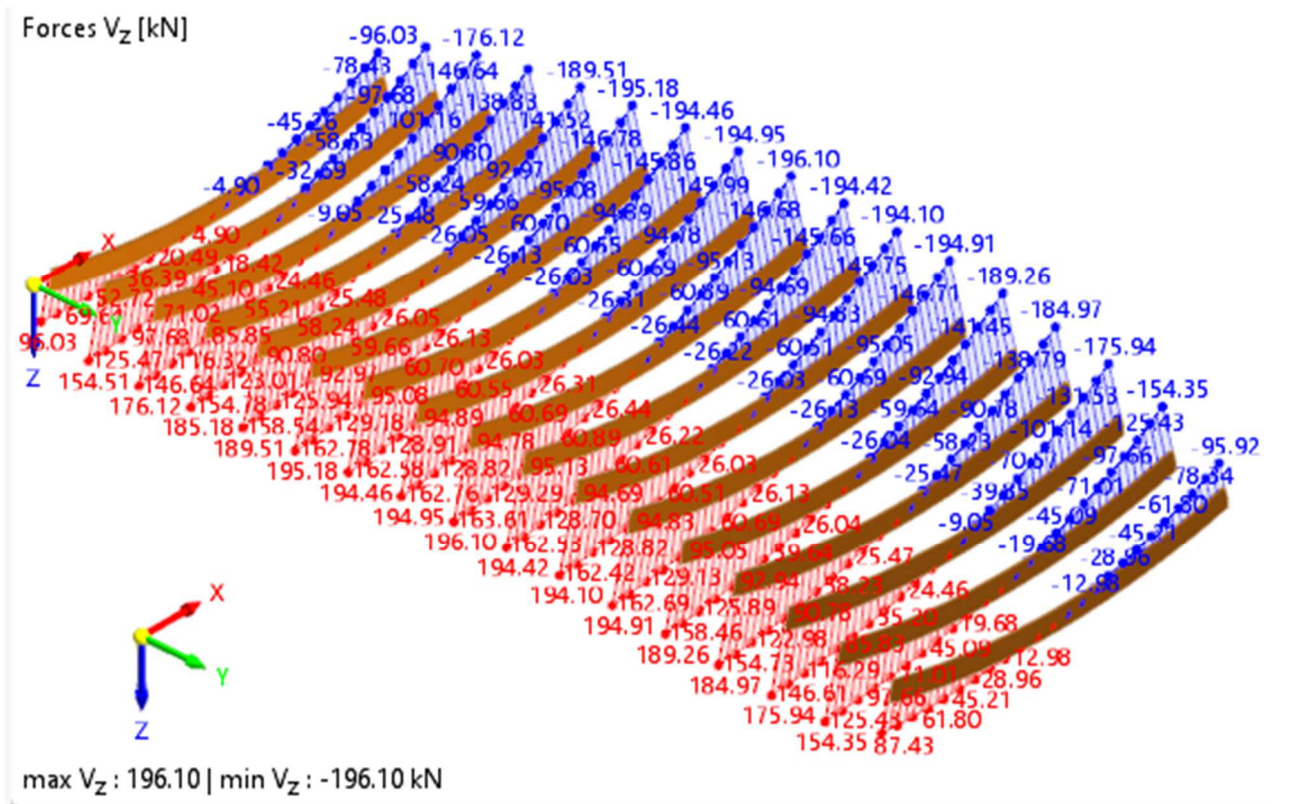
Dijagrami unutarnjih sila za mjerodavnu kombinaciju dani su na idućim slikama.



Slika 4.9.: Dijagram uzdužnih sila N [kN]

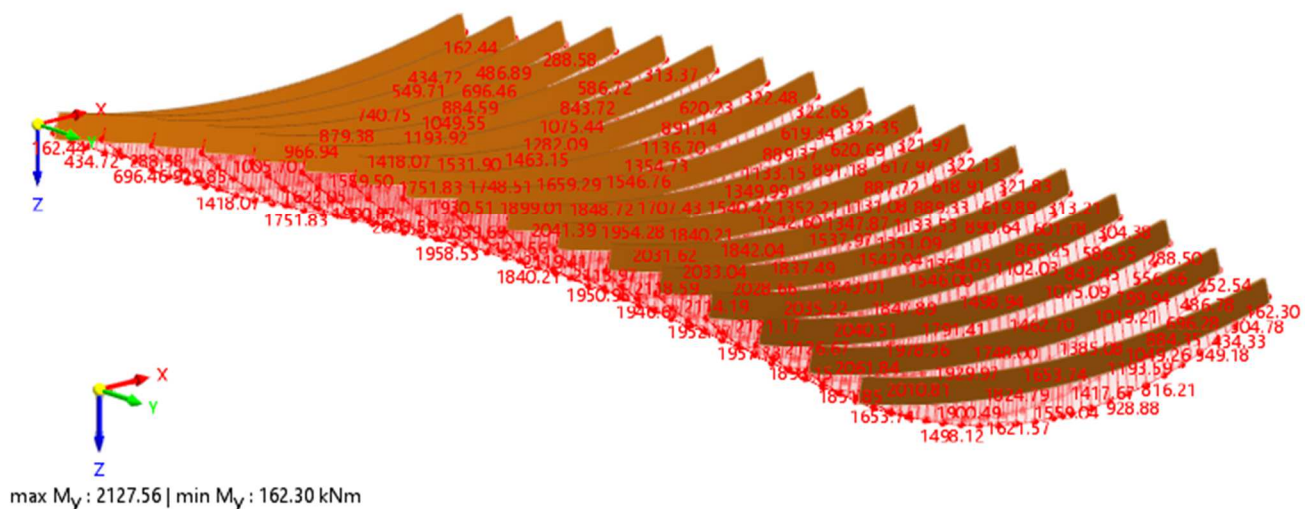


Slika 4.10.: Dijagram poprečnih sila V_y [kN]

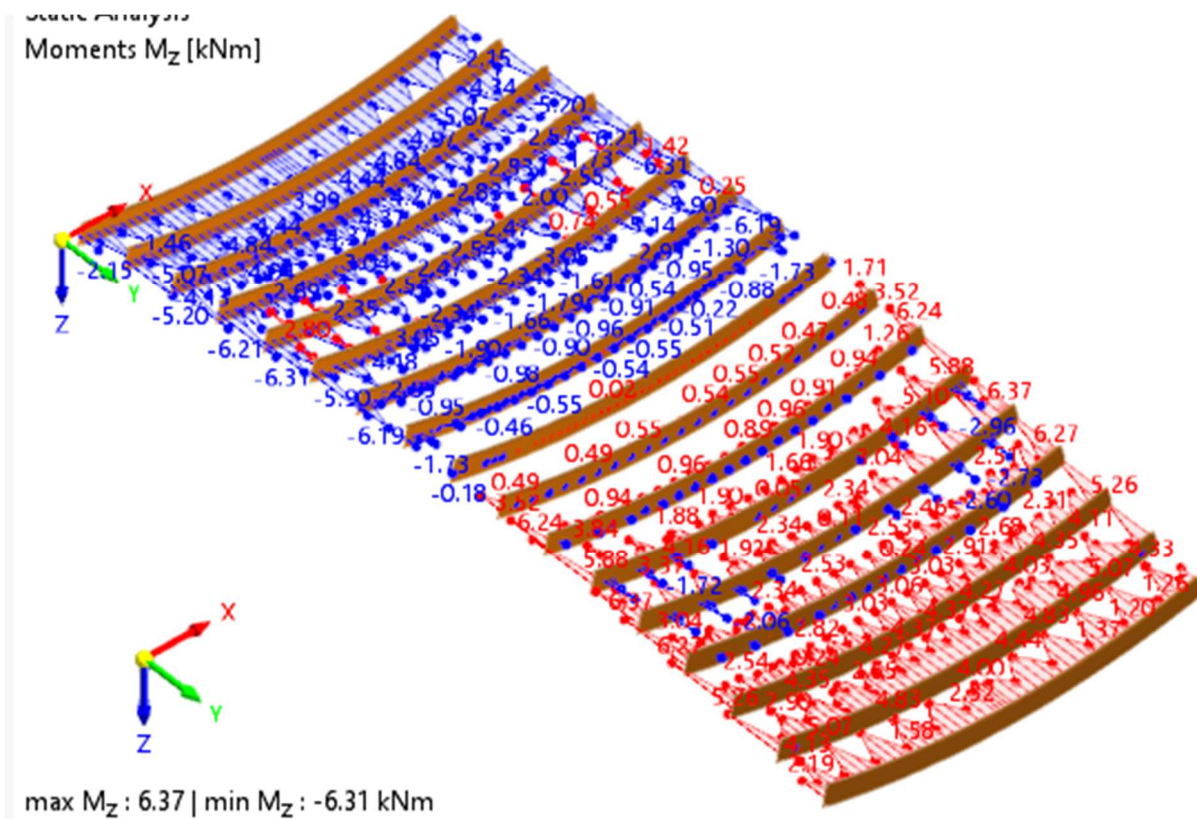


Slika 4.11.: Dijagram poprečnih sila V_z [kN]

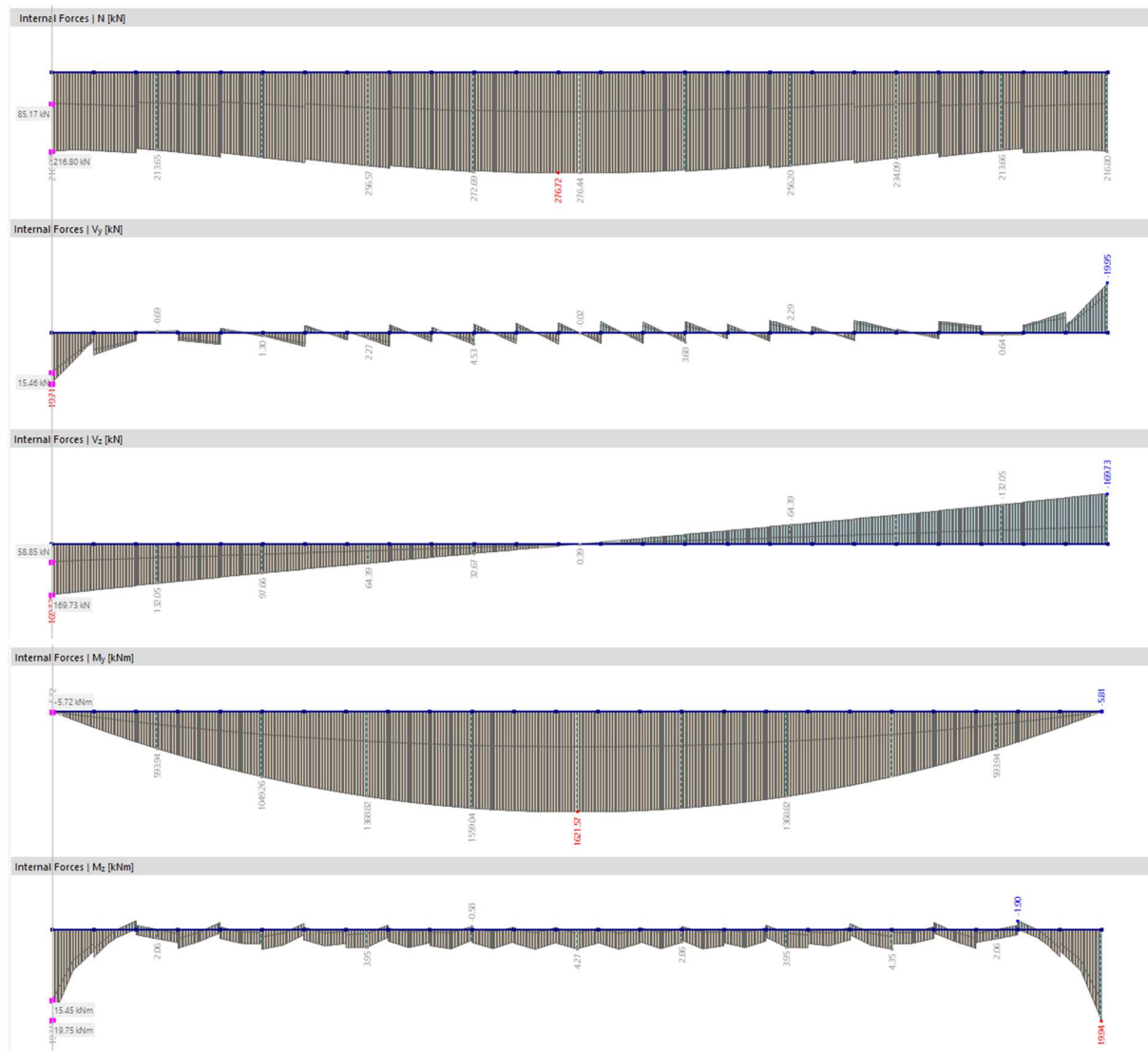
Moments M_y [kNm]



Slika 4.12.: Dijagram momenata savijanja M_y [kNm]

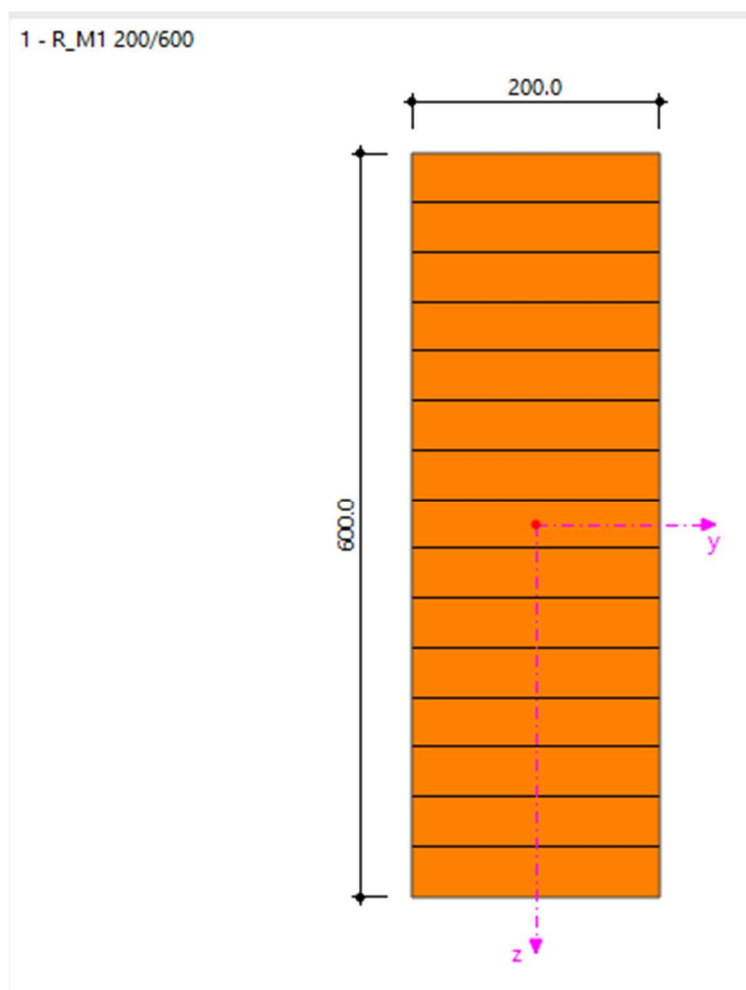


Slika 4.13.: Dijagram momenata savijanja M_z [kNm]



Slika 4.14.: Maksimalna opterećenja na glavne poprečne nosače [kN]

Poprečni presjek:



Slika 4.15.: Poprečni presjek glavnog poprečnog nosača [mm]

$$h=600 \text{ mm}$$

$$b=200 \text{ mm}$$

$$A= 1200.00 \text{ cm}^2$$

$$I_y= 360000.00 \text{ cm}^4$$

$$I_z= 40000.00 \text{ cm}^4$$

$$W_y= 12000.00 \text{ cm}^3$$

$$W_z= 4000.00 \text{ cm}^3$$

Karakteristične vrijednosti čvrstoće drva GL32h

– Karakteristična čvrstoća savijanja	$f_{m,k} = 32,0 \text{ N/mm}^2$
– Karakteristična vlačna čvrstoća paralelno s vlakancima	$f_{t,0,k} = 26,5 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća paralelno s vlakancima	$f_{c,0,k} = 32 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća okomito na vlakanca	$f_{c,90,k} = 2,5 \text{ N/mm}^2$
– Karakteristična posmična torzijska čvrstoća	$f_{v,k} = 3,5 \text{ N/mm}^2$
– Karakteristični modul elastičnosti paralelno s vlakancima	$E_{0,05} = 11800 \text{ N/mm}^2$
– Srednji modul elastičnosti paralelno s vlakancima	$E_{0,mean} = 14200 \text{ N/mm}^2$
– Srednji modul posmika	$G_{mean} = 650 \text{ N/mm}^2$
– Srednja gustoća	$\rho_k = 440 \text{ N/mm}^2$
– Vrijednost čimbenika modifikacije	$k_{mod} = 0,8$

Dvoosno savijanje i vlak paralelno s vlakancima

Tablica 30.: Unutarnje sile

Design normal force	N _{Ed}	397.43	kN	
Design shear force	V _{y,Ed}	0.00	kN	Negligible
Design shear force	V _{z,Ed}	0.00	kN	Negligible
Design torsional moment	T _{Ed}	0.00	kNm	Negligible
Design bending moment	M _{y,Ed}	281.59	kNm	
Design bending moment	M _{z,Ed}	-1.03	kNm	

Tablica 31.: Parametri proračuna

Design tension force	N _{t,Ed}	397.43	kN	
Design bending moment	M _{y,Ed}	281.59	kNm	
Design bending moment	M _{z,Ed}	-1.03	kNm	
Design tensile stress	σ _{t,0,d}	3.312	N/mm ²	
Design bending stress	σ _{m,y,d}	23.466	N/mm ²	
Design bending stress	σ _{m,z,d}	0.258	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k ₁	1.00	--	
Factor	k ₂	0.35	--	
Factor	k ₃	0.60	--	
Factor	k ₄	0.00	--	
Section height	h	600.0	mm	
Radius	r	73450.0	mm	
Factor	k _l	1.00	--	
Longitudinal stress	σ _{m,d}	23.534	N/mm ²	
Inner radius	r _{in}	73150.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k _r	1.00	--	
Design tensile strength	f _{t,0,d}	16.384	N/mm ²	
Design bending strength	f _{m,y,d}	20.480	N/mm ²	
Design bending strength	f _{m,z,d}	20.480	N/mm ²	
Redistribution factor	k _m	0.70	--	
Design ratio 1	η ₁	1.360	--	
Design ratio 2	η ₂	1.019	--	
Design check ratio	η	1.360	--	> 1 ❗

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{600.0 \text{ mm}}{73450.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{600.0 \text{ mm}}{73450.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{600.0 \text{ mm}}{73450.0 \text{ mm}}\right)^3 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\
 &= 1.00 \cdot 23.466 \text{ N/mm}^2 \\
 &= 23.534 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 r_{in} &= r - 0.5 \cdot h \\
 &= 73450.0 \text{ mm} - 0.5 \cdot 600.0 \text{ mm} \\
 &= 73150.0 \text{ mm}
 \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}
 \eta_1 &= \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{3.312 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} + \frac{23.534 \text{ N/mm}^2}{1.00 \cdot 20.480 \text{ N/mm}^2} + 0.70 \cdot \frac{0.258 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\
 &= 1.360
 \end{aligned}$$

$$\begin{aligned}
 \eta_2 &= \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + k_m \cdot \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{3.312 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} + 0.70 \cdot \frac{23.534 \text{ N/mm}^2}{1.00 \cdot 20.480 \text{ N/mm}^2} + \frac{0.258 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\
 &= 1.019
 \end{aligned}$$

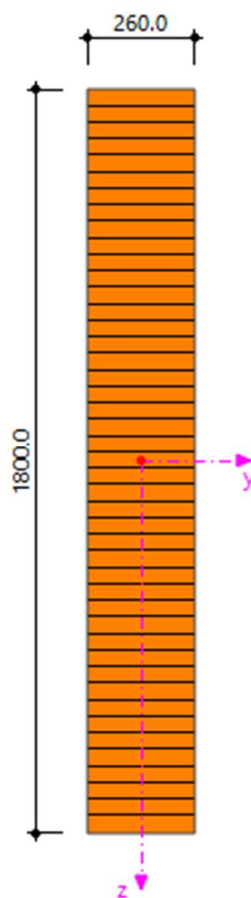
$$\begin{aligned}
 \eta &= \max(\eta_1, \eta_2) \\
 &= \max(1.360, 1.019) \\
 &= 1.360
 \end{aligned}$$

$$\eta = 1.360 > 1 \quad \text{❗}$$

Provjera glavnog poprečnog nosača ne zadovoljava provjeru nosivosti na interakciju djelovanja dvoosnog savijanja i vlaka paralelno s vlakancima, te je potrebno ponoviti proračun s novim presjekom.

Odabran novi poprečni presjek;

1 - R_M1 260/1800



Slika 4.16.: Poprečni presjek glavnog poprečnog nosača [mm]

$$h=1600 \text{ mm}$$

$$b=260 \text{ mm}$$

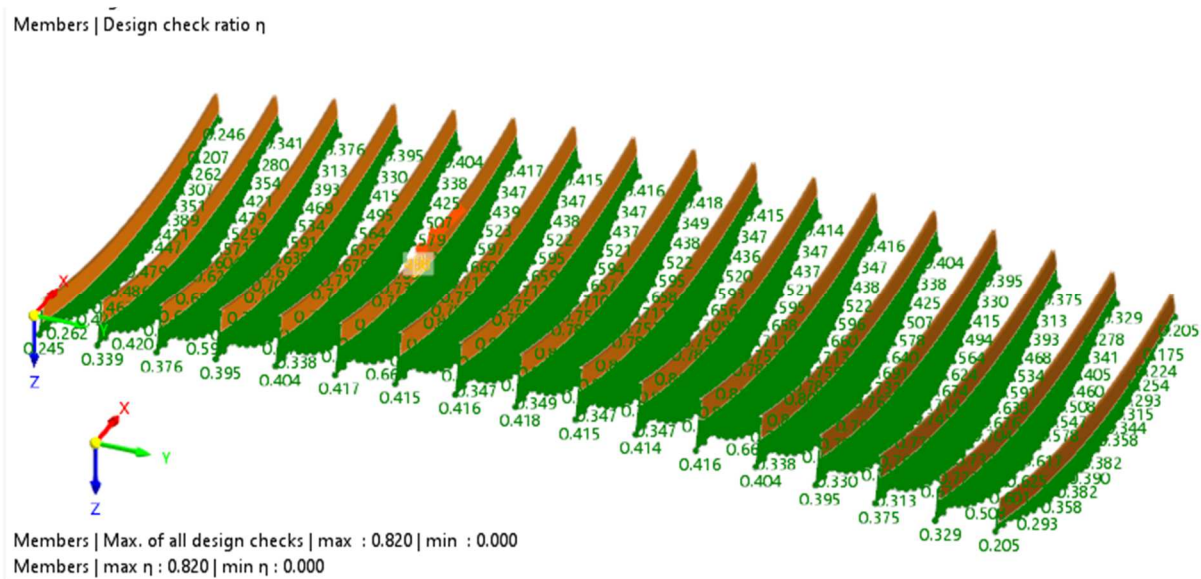
$$A= 4680.00\text{cm}^2$$

$$I_y= 12636000.00 \text{ cm}^4$$

$$I_z= 263640.00 \text{ cm}^4$$

$$W_y= 140400.00\text{cm}^3$$

$$W_z= 20280.00 \text{ cm}^3$$



Slika 4.17.: Iskoristivosti glavnih poprečnih nosača

4.2.2. Dokaz nosivosti glavnog poprečnog nosača

4.2.2.1. Dokazi nosivosti presjeka;

Vlak paralelno s vlakancima

Tablica 32.: Unutarnje sile

Design normal force	N_{Ed}	259.34	kN	Negligible
Design shear force	$V_{y,Ed}$	-3.33	kN	
Design shear force	$V_{z,Ed}$	5.66	kN	
Design torsional moment	T_{Ed}	0.07	kNm	
Design bending moment	$M_{y,Ed}$	1619.39	kNm	
Design bending moment	$M_{z,Ed}$	2.99	kNm	

Tablica 33.: Parametri proračuna

Tensile strength				
Design tension force	$N_{t,Ed}$	259.34	kN	
Sectional area	A	4680.00	cm ²	
Design tensile stress	$\sigma_{t,0,d}$	0.554	N/mm ²	
Design tensile strength	$f_{t,0,d}$	16.384	N/mm ²	
Design check ratio	η	0.034	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{\sigma_{t,0,d}}{f_{t,0,d}} \\ &= \frac{0.554 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} \\ &= 0.034 \end{aligned}$$

$$\eta = 0.034 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na vlak paralelno s vlakancima zadovoljava s iskoristivosti od 3.40%.

Tlak paralelno s vlakancima

Tablica 34.: Unutarnje sile

Design normal force	N_{Ed}	-51.26	kN	Negligible
Design shear force	$V_{y,Ed}$	-1.60	kN	
Design shear force	$V_{z,Ed}$	-60.03	kN	
Design torsional moment	T_{Ed}	0.85	kNm	
Design bending moment	$M_{y,Ed}$	865.88	kNm	
Design bending moment	$M_{z,Ed}$	-1.22	kNm	

Tablica 35.: Parametri proračuna

Compressive strength				
Design compression force	$N_{c,Ed}$	51.26	kN	
Sectional area	A	4680.00	cm ²	
Design compressive stress	$\sigma_{c,0,d}$	-0.110	N/mm ²	
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²	
Design check ratio	η	0.005	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{|\sigma_{c,0,d}|}{f_{c,0,d}} \\ &= \frac{|-0.110 \text{ N/mm}^2|}{23.040 \text{ N/mm}^2} \\ &= 0.005 \end{aligned}$$

$$\eta = 0.005 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na tlak paralelno s vlakancima zadovoljava s iskoristivosti od 0.50%.

Torzijski posmik

Tablica 36.: Unutarnje sile

Design normal force	N _{Ed}	153.82	kN		
Design shear force	V _{y,Ed}	3.18	kN		
Design shear force	V _{z,Ed}	95.92	kN		
Design torsional moment	T _{Ed}	-6.91	kNm		
Design bending moment	M _{y,Ed}	162.30	kNm		
Design bending moment	M _{z,Ed}	2.19	kNm		

Tablica 37.: Parametri proračuna

Design torsional moment	T _{Ed}	6.91	kNm		
Design torsional stress	τ _{tor,d}	0.187	N/mm ²		
Torsion factor	k _{shape}	1.30	--		
Design shear strength	f _{v,d}	2.240	N/mm ²		
Design check ratio	η	0.064	--	≤ 1	✓

$$\begin{aligned}
 \eta &= \frac{\tau_{tor,d}}{k_{shape} \cdot f_{v,d}} \\
 &= \frac{0.187 \text{ N/mm}^2}{1.30 \cdot 2.240 \text{ N/mm}^2} \\
 &= 0.064
 \end{aligned}$$

$$\eta = 0.064 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na torzijski posmik zadovoljava s iskoristivosti od 6.40%.

Posmik u vertikalnoj (z) osi

Tablica 38.: Unutarnje sile

Design normal force	N_{Ed}	116.48	kN	
Design shear force	$V_{y,Ed}$	-0.19	kN	Negligible
Design shear force	$V_{z,Ed}$	196.10	kN	
Design torsional moment	T_{Ed}	-0.02	kNm	Negligible
Design bending moment	$M_{y,Ed}$	323.35	kNm	
Design bending moment	$M_{z,Ed}$	-0.18	kNm	Negligible

Tablica 39.: Parametri proračuna

Design shear force	$V_{z,Ed}$	196.10	kN	
Shear stress	τ_{xz}	0.628	N/mm ²	
Crack influence factor	k_{cr}	0.67	--	
Design shear stress	$\tau_{xz,d}$	0.937	N/mm ²	
Design shear strength	$f_{v,z,d}$	2.240	N/mm ²	
Design check ratio	η	0.418	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{|\tau_{xz,d}|}{f_{v,z,d}} \\ &= \frac{|0.937 \text{ N/mm}^2|}{2.240 \text{ N/mm}^2} \\ &= 0.418 \end{aligned}$$

$$\eta = 0.418 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na posmik u vertikalnoj (z) osi zadovoljava s iskoristivosti od 41.80%.

Posmik u horizontalnoj (y) osi

Tablica 40.: Unutarnje sile

Design normal force	N _{Ed}	167.87	kN		
Design shear force	V _{y,Ed}	9.92	kN		
Design shear force	V _{z,Ed}	161.95	kN		
Design torsional moment	T _{Ed}	-0.49	kNm		Negligible
Design bending moment	M _{y,Ed}	266.64	kNm		
Design bending moment	M _{z,Ed}	6.45	kNm		

Tablica 41.: Parametri proračuna

Design shear force	V _{y,Ed}	9.92	kN		
Shear stress	τ _{xy}	0.031	N/mm ²		
Crack influence factor	k _{cr}	0.67	--		
Design shear stress	τ _{xy,d}	0.046	N/mm ²		
Design shear strength	f _{v,y,d}	2.520	N/mm ²		
Design check ratio	η	0.018	--	≤ 1	✓

$$\begin{aligned} \eta &= \frac{|\tau_{xy,d}|}{f_{v,y,d}} \\ &= \frac{|0.046 \text{ N/mm}^2|}{2.520 \text{ N/mm}^2} \\ &= 0.018 \\ \eta &= 0.018 \leq 1 \quad \checkmark \end{aligned}$$

Provjera glavnog poprečnog nosača na posmik u horizontalnoj (y) osi zadovoljava s iskoristivosti od 1.80%.

Savijanje oko horizontalne (y) osi

Tablica 42.: Unutarnje sile

Design normal force	N_{Ed}	1.57	kN	Negligible
Design shear force	$V_{y,Ed}$	3.25	kN	
Design shear force	$V_{z,Ed}$	6.72	kN	
Design torsional moment	T_{Ed}	-0.01	kNm	Negligible
Design bending moment	$M_{y,Ed}$	2124.98	kNm	
Design bending moment	$M_{z,Ed}$	-0.41	kNm	Negligible

Tablica 43.: Parametri proračuna

Design bending moment	$M_{y,Ed}$	2124.98	kNm	
Design bending stress	$\sigma_{m,y,d}$	-15.135	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k_1	1.00	--	
Factor	k_2	0.35	--	
Factor	k_3	0.60	--	
Factor	k_4	0.00	--	
Section height	h	1800.0	mm	
Radius	r	73450.0	mm	
Factor	k_l	1.01	--	
Longitudinal stress	$\sigma_{m,d}$	-15.270	N/mm ²	
Inner radius	r_{in}	72550.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k_r	1.00	--	
Design bending strength	$f_{m,y,d}$	20.480	N/mm ²	
Design check ratio	η	0.746	--	≤ 1 ✓

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^3 \\
 &= 1.01
 \end{aligned}$$

$$\begin{aligned}\sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\ &= 1.01 \cdot -15.135 \text{ N/mm}^2 \\ &= -15.270 \text{ N/mm}^2\end{aligned}$$

$$\begin{aligned}r_{in} &= r - 0.5 \cdot h \\ &= 73450.0 \text{ mm} - 0.5 \cdot 1800.0 \text{ mm} \\ &= 72550.0 \text{ mm}\end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}\eta &= \frac{|\sigma_{m,d}|}{k_r \cdot f_{m,y,d}} \\ &= \frac{|-15.270 \text{ N/mm}^2|}{1.00 \cdot 20.480 \text{ N/mm}^2} \\ &= 0.746\end{aligned}$$

$$\eta = 0.746 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na savijanje oko horizontalne (y) osi zadovoljava s iskoristivosti od 74.60%.

Savijanje oko vertikalne (z) osi

Tablica 44.: Unutarnje sile

Design Internal Forces				
Design normal force	N _{Ed}	8.10	kN	Negligible
Design shear force	V _{y,Ed}	-29.52	kN	
Design shear force	V _{z,Ed}	147.05	kN	
Design torsional moment	T _{Ed}	-2.18	kNm	Negligible
Design bending moment	M _{y,Ed}	-3.04	kNm	
Design bending moment	M _{z,Ed}	-30.13	kNm	

Tablica 45.: Parametri proračuna

Design Check Values				
Bending strength about z-axis				
Design bending moment	M _{z,Ed}	-30.13	kNm	
Design bending stress	σ _{m,z,d}	-1.486	N/mm ²	
Design bending strength	f _{m,z,d}	23.040	N/mm ²	
Design check ratio	η	0.064	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{|\sigma_{m,z,d}|}{f_{m,z,d}} \\ &= \frac{|-1.486 \text{ N/mm}^2|}{23.040 \text{ N/mm}^2} \\ &= 0.064 \end{aligned}$$

$$\eta = 0.064 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na savijanje oko vertikalne (z) osi zadovoljava s iskoristivosti od 6.40%.

Dvoosno savijanje

Tablica 46.: Unutarnje sile

Design normal force	N _{Ed}	1.54	kN	Negligible
Design shear force	V _{y,Ed}	0.00	kN	Negligible
Design shear force	V _{z,Ed}	0.00	kN	Negligible
Design torsional moment	T _{Ed}	0.00	kNm	Negligible
Design bending moment	M _{y,Ed}	2127.56	kNm	
Design bending moment	M _{z,Ed}	-1.66	kNm	

Tablica 47.: Parametri proračuna

Design bending moment	M _{y,Ed}	2127.56	kNm	
Design bending moment	M _{z,Ed}	-1.66	kNm	
Design bending stress	σ _{m,y,d}	-15.154	N/mm ²	
Design bending stress	σ _{m,z,d}	-0.082	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k ₁	1.00	--	
Factor	k ₂	0.35	--	
Factor	k ₃	0.60	--	
Factor	k ₄	0.00	--	
Section height	h	1800.0	mm	
Radius	r	73450.0	mm	
Factor	k _l	1.01	--	
Longitudinal stress	σ _{m,d}	-15.289	N/mm ²	
Inner radius	r _{in}	72550.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k _r	1.00	--	
Design bending strength	f _{m,y,d}	20.480	N/mm ²	
Design bending strength	f _{m,z,d}	20.480	N/mm ²	
Redistribution factor	k _m	0.70	--	
Design ratio 1	η ₁	0.749	--	
Design ratio 2	η ₂	0.527	--	
Design check ratio	η	0.749	--	≤ 1 ✓

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^3 \\
 &= 1.01
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\
 &= 1.01 \cdot -15.154 \text{ N/mm}^2 \\
 &= -15.289 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 r_{in} &= r - 0.5 \cdot h \\
 &= 73450.0 \text{ mm} - 0.5 \cdot 1800.0 \text{ mm} \\
 &= 72550.0 \text{ mm}
 \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}
 \eta_1 &= \left| \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{-15.289 \text{ N/mm}^2}{1.00 \cdot 20.480 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.082 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\
 &= 0.749
 \end{aligned}$$

$$\begin{aligned}
 \eta_2 &= \left| k_m \cdot \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| 0.70 \cdot \frac{-15.289 \text{ N/mm}^2}{1.00 \cdot 20.480 \text{ N/mm}^2} + \frac{-0.082 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\
 &= 0.527
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \max(\eta_1, \eta_2) \\
 &= \max(0.749, 0.527) \\
 &= 0.749
 \end{aligned}$$

$$\eta = 0.749 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na dvoosno savijanje zadovoljava s iskoristivosti od 74.90%.

Interakcija vlaka okomito na vlakanca i posmika

Tablica 48.: Unutarnje sile

Design Internal Forces				
Design normal force	N _{Ed}	100.48	kN	
Design shear force	V _{y,Ed}	-41.23	kN	
Design shear force	V _{z,Ed}	238.46	kN	
Design torsional moment	T _{Ed}	-0.36	kNm	Negligible
Design bending moment	M _{y,Ed}	-5.48	kNm	
Design bending moment	M _{z,Ed}	-42.38	kNm	

Tablica 49.: Parametri proračuna

Design Check Values				
+ Tensile strength perpendicular to grain at apex zone				
+ Shear strength in z-axis				
Design bending moment	M _{y,Ed}	-5.48	kNm	
Design shear force	V _{z,Ed}	238.46	kN	
Design bending stress	σ _{m,y,d}	0.039	N/mm ²	
Shear stress	τ _{xz}	0.764	N/mm ²	
Crack influence factor	k _{cr}	0.67	--	
Design shear stress	τ _{xz,d}	1.140	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k ₅	0.00	--	
Factor	k ₆	0.25	--	
Factor	k ₇	0.00	--	
Section height	h	1800.0	mm	
Radius	r	73450.0	mm	
Factor	k _p	0.01	--	
Design tensile stress perpendicular to grain	σ _{t,90,d}	0.000	N/mm ²	
Factor	k _{dis}	1.40	--	
Reference volume	V ₀	0.010	m ³	
Volume of apex zone	V	17.989	m ³	
Volume factor	k _{vol}	0.22	--	
Design tensile strength perpendicular to grain	f _{t,90,d}	0.320	N/mm ²	
Design shear strength	f _{v,z,d}	2.240	N/mm ²	
Design check ratio	η	0.511	--	≤ 1 ✓

$$\begin{aligned} \tau_{xz,d} &= \frac{\tau_{xz}}{k_{cr}} \\ &= \frac{0.764 \text{ N/mm}^2}{0.67} \\ &= 1.140 \text{ N/mm}^2 \end{aligned}$$

$$\begin{aligned} k_5 &= 0.2 \cdot \tan(\alpha) \\ &= 0.2 \cdot \tan(0.00 \text{ deg}) \\ &= 0.00 \end{aligned}$$

$$\begin{aligned} k_6 &= 0.25 - 1.5 \cdot \tan(\alpha) + 2.6 \cdot (\tan(\alpha))^2 \\ &= 0.25 - 1.5 \cdot \tan(0.00 \text{ deg}) + 2.6 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 0.25 \end{aligned}$$

$$\begin{aligned}k_7 &= 2.1 \cdot \tan(\alpha) - 4 \cdot (\tan(\alpha))^2 \\ &= 2.1 \cdot \tan(0.00 \text{ deg}) - 4 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 0.00\end{aligned}$$

$$\begin{aligned}k_p &= k_5 + k_6 \cdot \left(\frac{h}{r}\right) + k_7 \cdot \left(\frac{h}{r}\right)^2 \\ &= 0.00 + 0.25 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right) + 0.00 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^2 \\ &= 0.01\end{aligned}$$

$$\begin{aligned}\sigma_{t,90,d} &= k_p \cdot \sigma_{m,y,d} \\ &= 0.01 \cdot 0.039 \text{ N/mm}^2 \\ &= 0.000 \text{ N/mm}^2\end{aligned}$$

$$\begin{aligned}k_{vol} &= \left(\frac{V_0}{V}\right)^{0.2} \\ &= \left(\frac{0.010 \text{ m}^3}{17.989 \text{ m}^3}\right)^{0.2} \\ &= 0.22\end{aligned}$$

$$\begin{aligned}\eta &= \frac{\tau_{xz,d}}{f_{v,z,d}} + \frac{|\sigma_{t,90,d}|}{k_{dis} \cdot k_{vol} \cdot f_{t,90,d}} \\ &= \frac{1.140 \text{ N/mm}^2}{2.240 \text{ N/mm}^2} + \frac{|0.000 \text{ N/mm}^2|}{1.40 \cdot 0.22 \cdot 0.320 \text{ N/mm}^2} \\ &= 0.511\end{aligned}$$

$$\eta = 0.511 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača interakciju vlaka okomito na vlakanca i posmika zadovoljava s iskoristivosti od 51.10%.

Interakcija dvoosnog savijanja i vlaka paralelno s vlakancima

Tablica 50.: Unutarnje sile

Design normal force	N _{Ed}	8.20	kN	
Design shear force	V _{y,Ed}	0.00	kN	Negligible
Design shear force	V _{z,Ed}	0.00	kN	Negligible
Design torsional moment	T _{Ed}	0.00	kNm	Negligible
Design bending moment	M _{y,Ed}	2122.75	kNm	
Design bending moment	M _{z,Ed}	-0.90	kNm	

Tablica 51.: Parametri proračuna

Design tension force	N _{t,Ed}	8.20	kN	
Design bending moment	M _{y,Ed}	2122.75	kNm	
Design bending moment	M _{z,Ed}	-0.90	kNm	
Design tensile stress	σ _{t,0,d}	0.018	N/mm ²	
Design bending stress	σ _{m,y,d}	15.119	N/mm ²	
Design bending stress	σ _{m,z,d}	0.044	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k ₁	1.00	--	
Factor	k ₂	0.35	--	
Factor	k ₃	0.60	--	
Factor	k ₄	0.00	--	
Section height	h	1800.0	mm	
Radius	r	73450.0	mm	
Factor	k _l	1.01	--	
Longitudinal stress	σ _{m,d}	15.254	N/mm ²	
Inner radius	r _{in}	72550.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k _r	1.00	--	
Design tensile strength	f _{t,0,d}	16.384	N/mm ²	
Design bending strength	f _{m,y,d}	20.480	N/mm ²	
Design bending strength	f _{m,z,d}	20.480	N/mm ²	
Redistribution factor	k _m	0.70	--	
Design ratio 1	η ₁	0.747	--	
Design ratio 2	η ₂	0.525	--	
Design check ratio	η	0.747	--	≤ 1 ✓

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^3 \\
 &= 1.01
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\
 &= 1.01 \cdot 15.119 \text{ N/mm}^2 \\
 &= 15.254 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 r_{in} &= r - 0.5 \cdot h \\
 &= 73450.0 \text{ mm} - 0.5 \cdot 1800.0 \text{ mm} \\
 &= 72550.0 \text{ mm}
 \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}
 \eta_1 &= \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{0.018 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} + \frac{15.254 \text{ N/mm}^2}{1.00 \cdot 20.480 \text{ N/mm}^2} + 0.70 \cdot \frac{0.044 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\
 &= 0.747
 \end{aligned}$$

$$\begin{aligned}
 \eta_2 &= \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + k_m \cdot \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{0.018 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} + 0.70 \cdot \frac{15.254 \text{ N/mm}^2}{1.00 \cdot 20.480 \text{ N/mm}^2} + \frac{0.044 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\
 &= 0.525
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \max(\eta_1, \eta_2) \\
 &= \max(0.747, 0.525) \\
 &= 0.747
 \end{aligned}$$

$$\eta = 0.747 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača interakciju dvoosnog savijanja i vlaka paralelno s vlakancima zadovoljava s iskoristivosti od 74.70%.

Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima

Tablica 52.: Unutarnje sile

Design normal force	N_{Ed}	-34.41	kN			
Design shear force	$V_{y,Ed}$	0.03	kN	Negligible		
Design shear force	$V_{z,Ed}$	0.24	kN	Negligible		
Design torsional moment	T_{Ed}	-0.03	kNm	Negligible		
Design bending moment	$M_{y,Ed}$	1170.48	kNm			
Design bending moment	$M_{z,Ed}$	-2.15	kNm			

$$= 0.90 \cdot \frac{32.000 \text{ N/mm}^2}{1.25}$$

$$= 23.040 \text{ N/mm}^2$$

$$f_{m,y,d} = k_{mod} \cdot \frac{f_{m,y,k}}{\gamma_M}$$

$$= 0.90 \cdot \frac{32.000 \text{ N/mm}^2}{1.25}$$

Tablica 53.: Parametri proračuna

Design compression force	$N_{c,Ed}$	34.41	kN	
Design bending moment	$M_{y,Ed}$	1170.48	kNm	
Design bending moment	$M_{z,Ed}$	-2.15	kNm	
Design compressive stress	$\sigma_{c,0,d}$	-0.074	N/mm ²	
Design bending stress	$\sigma_{m,y,d}$	-8.337	N/mm ²	
Design bending stress	$\sigma_{m,z,d}$	-0.106	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k_1	1.00	--	
Factor	k_2	0.35	--	
Factor	k_3	0.60	--	
Factor	k_4	0.00	--	
Section height	h	1800.0	mm	
Radius	r	73450.0	mm	
Factor	k_l	1.01	--	
Longitudinal stress	$\sigma_{m,d}$	-8.411	N/mm ²	
Inner radius	r_{in}	72550.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k_r	1.00	--	
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²	
Design bending strength	$f_{m,y,d}$	23.040	N/mm ²	
Design bending strength	$f_{m,z,d}$	23.040	N/mm ²	
Redistribution factor	k_m	0.70	--	
Design ratio 1	η_1	0.368	--	
Design ratio 2	η_2	0.260	--	
Design check ratio	η	0.368	--	≤ 1 ✓

$$k_1 = 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2$$

$$= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2$$

$$= 1.00$$

$$k_2 = 0.35 - 8 \cdot \tan(\alpha)$$

$$= 0.35 - 8 \cdot \tan(0.00 \text{ deg})$$

$$= 0.35$$

$$k_3 = 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2$$

$$= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2$$

$$= 0.60$$

$$k_4 = 6 \cdot (\tan(\alpha))^2$$

$$= 6 \cdot (\tan(0.00 \text{ deg}))^2$$

$$= 0.00$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^3 \\
 &= 1.01
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\
 &= 1.01 \cdot -8.337 \text{ N/mm}^2 \\
 &= -8.411 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 r_{in} &= r - 0.5 \cdot h \\
 &= 73450.0 \text{ mm} - 0.5 \cdot 1800.0 \text{ mm} \\
 &= 72550.0 \text{ mm}
 \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}
 \eta_1 &= \left| -\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| -\left(\frac{-0.074 \text{ N/mm}^2}{23.040 \text{ N/mm}^2}\right)^2 + \frac{-8.411 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.106 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\
 &= 0.368
 \end{aligned}$$

$$\begin{aligned}
 \eta_2 &= \left| -\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \cdot \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| -\left(\frac{-0.074 \text{ N/mm}^2}{23.040 \text{ N/mm}^2}\right)^2 + 0.70 \cdot \frac{-8.411 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + \frac{-0.106 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\
 &= 0.260
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \max(\eta_1, \eta_2) \\
 &= \max(0.368, 0.260) \\
 &= 0.368
 \end{aligned}$$

$$\eta = 0.368 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača interakciju dvoosnog savijanja i tlaka paralelno s vlakancima zadovoljava s iskoristivosti od 36.80%.

4.2.2.2. Dokazi nosivosti elementa;

Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima s izvijanjem

Tablica 54.: Unutarnje sile

Design normal force	N_{Ed}	-34.41	kN	
Design shear force	$V_{y,Ed}$	0.03	kN	Negligible
Design shear force	$V_{z,Ed}$	0.24	kN	Negligible
Design torsional moment	T_{Ed}	-0.03	kNm	Negligible
Design bending moment	$M_{y,Ed}$	1170.48	kNm	
Design bending moment	$M_{z,Ed}$	-2.15	kNm	

Tablica 55.: Parametri proračuna

Design compression force	$N_{c,Ed}$	34.41	kN
Design compressive stress	$\sigma_{c,0,d}$	-0.074	N/mm ²
Design bending moment	$M_{y,Ed}$	1170.48	kNm
Design bending stress	$\sigma_{m,y,d}$	-8.337	N/mm ²
Design bending moment	$M_{z,Ed}$	-2.15	kNm
Design bending stress	$\sigma_{m,z,d}$	-0.106	N/mm ²
Cut-to-grain angle	α	0.00	deg
Factor	k_1	1.00	--
Factor	k_2	0.35	--
Factor	k_3	0.60	--
Factor	k_4	0.00	--
Section height	h	1800.0	mm
Radius	r	73450.0	mm
Factor	k_i	1.01	--
Longitudinal stress	$\sigma_{m,d}$	-8.411	N/mm ²
Inner radius	r_{in}	72550.0	mm
Lamination thickness	t	40.0	mm
Reduction factor	k_r	1.00	--
Equivalent member length	$L_{cr,y}$	1.537	m
Equivalent member length	$L_{cr,z}$	1.537	m
Radius of gyration	i_y	519.6	mm
Radius of gyration	i_z	75.1	mm
Slenderness ratio	λ_y	2.96	--
Slenderness ratio	λ_z	20.48	--
Modulus of elasticity	$E_{0,05,y}$	11800.0	N/mm ²
Modulus of elasticity	$E_{0,05,z}$	11800.0	N/mm ²
Characteristic compressive strength	$f_{c,0,k}$	32.000	N/mm ²
Relative slenderness ratio	$\lambda_{rel,y}$	0.05	--
Relative slenderness ratio	$\lambda_{rel,z}$	0.34	--
Straightness factor	β_c	0.10	--
Instability factor	k_y	0.49	--
Instability factor	k_z	0.56	--
Instability factor	$k_{c,y}$	1.00	--
Instability factor	$k_{c,z}$	1.00	--
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²
Design bending strength	$f_{m,y,d}$	23.040	N/mm ²
Design bending strength	$f_{m,z,d}$	23.040	N/mm ²
Redistribution factor	k_m	0.70	--

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^3 \\
 &= 1.01
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\
 &= 1.01 \cdot -8.337 \text{ N/mm}^2 \\
 &= -8.411 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 r_{in} &= r - 0.5 \cdot h \\
 &= 73450.0 \text{ mm} - 0.5 \cdot 1800.0 \text{ mm} \\
 &= 72550.0 \text{ mm}
 \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}
 \lambda_y &= \frac{L_{cr,y}}{i_y} \\
 &= \frac{1.537 \text{ m}}{519.6 \text{ mm}} \\
 &= 2.96
 \end{aligned}$$

$$\begin{aligned}
 \lambda_z &= \frac{L_{cr,z}}{i_z} \\
 &= \frac{1.537 \text{ m}}{75.1 \text{ mm}} \\
 &= 20.48
 \end{aligned}$$

$$\begin{aligned}
 \lambda_{rel,y} &= \frac{\lambda_y}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,y}}} \\
 &= \frac{2.96}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\
 &= 0.05
 \end{aligned}$$

$$\begin{aligned}
 \lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\
 &= \frac{20.48}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\
 &= 0.34
 \end{aligned}$$

$$\lambda_{rel,y} > 0.3 \text{ or } \lambda_{rel,z} > 0.3$$

$$\begin{aligned}
 k_y &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,y} - 0.3) + (\lambda_{rel,y})^2 \right) \\
 &= 0.5 \cdot \left(1 + 0.10 \cdot (0.05 - 0.3) + (0.05)^2 \right) \\
 &= 0.49
 \end{aligned}$$

$$\begin{aligned}
 k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2 \right) \\
 &= 0.5 \cdot \left(1 + 0.10 \cdot (0.34 - 0.3) + (0.34)^2 \right) \\
 &= 0.56
 \end{aligned}$$

$$\begin{aligned}
 k_{c,y} &= \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \\
 &= \frac{1}{0.49 + \sqrt{(0.49)^2 - (0.05)^2}} \\
 &= 1.03
 \end{aligned}$$

$$\begin{aligned}
 k_{c,y} &= \min(1, k_{c,y}) \\
 &= \min(1, 1.03) \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\
 &= \frac{1}{0.56 + \sqrt{(0.56)^2 - (0.34)^2}} \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 \eta_1 &= \left| \frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{-0.074 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + \frac{-8.411 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.106 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\
 &= 0.371
 \end{aligned}$$

$$\begin{aligned}
 \eta_2 &= \left| \frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{-0.074 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-8.411 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + \frac{-0.106 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\
 &= 0.263
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \max(\eta_1, \eta_2) \\
 &= \max(0.371, 0.263) \\
 &= 0.371
 \end{aligned}$$

$$\eta = 0.371 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na interakciju dvoosnog savijanja i tlaka paralelno s vlakancima s izvijanjem zadovoljava s iskoristivosti od 37.10%.

Savijanje s bočnim izvijanjem

Tablica 56.: Unutarnje sile

Design normal force	N_{Ed}	1.60	kN		Negligible
Design shear force	$V_{y,Ed}$	-4.36	kN		
Design shear force	$V_{z,Ed}$	8.92	kN		
Design torsional moment	T_{Ed}	0.03	kNm		Negligible
Design bending moment	$M_{y,Ed}$	2124.26	kNm		
Design bending moment	$M_{z,Ed}$	0.05	kNm		Negligible

Tablica 57.: Parametri proračuna

Design bending moment	$M_{y,Ed}$	2124.26	kNm		
Design bending stress	$\sigma_{m,y,d}$	-15.130	N/mm ²		
Cut-to-grain angle	α	0.00	deg		
Factor	k_1	1.00	--		
Factor	k_2	0.35	--		
Factor	k_3	0.60	--		
Factor	k_4	0.00	--		
Section height	h	1800.0	mm		
Radius	r	73450.0	mm		
Factor	k_l	1.01	--		
Longitudinal stress	$\sigma_{m,d}$	-15.265	N/mm ²		
Inner radius	r_{in}	72550.0	mm		
Lamination thickness	t	40.0	mm		
Reduction factor	k_r	1.00	--		
Modulus of elasticity	$E_{0,05,z}$	11800.0	N/mm ²		
Moment of inertia	I_z	263640...	cm ⁴		
Shear modulus	G_{05}	540.0	N/mm ²		
Torsional constant	I_t	958599...	cm ⁴		
Equivalent member length	L_{cr}	6.675	m		
Elastic section modulus to more compre...	W_y	140400...	cm ³		
Critical bending stress	$\sigma_{m,crit}$	42.540	N/mm ²		
Characteristic bending strength	$f_{m,y,k}$	32.000	N/mm ²		
Relative slenderness ratio	$\lambda_{rel,m}$	0.87	--		
Lateral buckling coefficient	k_{crit}	0.91	--		
Design bending strength	$f_{m,y,d}$	20.480	N/mm ²		
Design check ratio	η	0.820	--	≤ 1	✓

$$\begin{aligned} k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\ &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 1.00 \end{aligned}$$

$$\begin{aligned} k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\ &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\ &= 0.35 \end{aligned}$$

$$\begin{aligned} k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\ &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 0.60 \end{aligned}$$

$$k_4 = 6 \cdot (\tan(\alpha))^2$$

$$= 6 \cdot (\tan(0.00 \text{ deg}))^2$$

$$= 0.00$$

$$k_1 = k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3$$

$$= 1.00 + 0.35 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^3$$

$$= 1.01$$

$$\sigma_{m,d} = k_1 \cdot \sigma_{m,y,d}$$

$$= 1.01 \cdot -15.130 \text{ N/mm}^2$$

$$= -15.265 \text{ N/mm}^2$$

$$r_{in} = r - 0.5 \cdot h$$

$$= 73450.0 \text{ mm} - 0.5 \cdot 1800.0 \text{ mm}$$

$$= 72550.0 \text{ mm}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\sigma_{m,crit} = \frac{\pi \cdot \sqrt{E_{0,05,z} \cdot I_z \cdot G_{05} \cdot I_t}}{L_{cr} \cdot W_y}$$

$$= \frac{\pi \cdot \sqrt{11800.0 \text{ N/mm}^2 \cdot 263640.00 \text{ cm}^4 \cdot 540.0 \text{ N/mm}^2 \cdot 958599.00 \text{ cm}^4}}{6.675 \text{ m} \cdot 140400.00 \text{ cm}^3}$$

$$= 42.540 \text{ N/mm}^2$$

$$\lambda_{rel,m} = \sqrt{\frac{f_{m,y,k}}{\sigma_{m,crit}}}$$

$$= \sqrt{\frac{32.000 \text{ N/mm}^2}{42.540 \text{ N/mm}^2}}$$

$$= 0.87$$

$$0.75 < \lambda_{rel,m} \leq 1.4$$

$$k_{crit} = 1.56 - 0.75 \cdot \lambda_{rel,m}$$

$$= 1.56 - 0.75 \cdot 0.87$$

$$= 0.91$$

$$\eta = \left| \frac{\sigma_{m,d}}{k_{crit} \cdot k_r \cdot f_{m,y,d}} \right|$$

$$= \left| \frac{-15.265 \text{ N/mm}^2}{0.91 \cdot 1.00 \cdot 20.480 \text{ N/mm}^2} \right|$$

$$= 0.820$$

$$\eta = 0.820 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na savijanje s bočnim izvijanjem zadovoljava s iskoristivosti od 82.00%.

Interakcija savijanja s bočnim izvijanjem i tlaka paralelno s vlakancima

Tablica 58.: Unutarnje sile

Design normal force	N_{Ed}	-34.38	kN		
Design shear force	$V_{y,Ed}$	6.22	kN		
Design shear force	$V_{z,Ed}$	-5.72	kN		
Design torsional moment	T_{Ed}	0.22	kNm		Negligible
Design bending moment	$M_{y,Ed}$	1169.48	kNm		
Design bending moment	$M_{z,Ed}$	0.14	kNm		Negligible

Tablica 59.: Parametri proračuna

Design compression force	$N_{c,Ed}$	34.38	kN		
Design compressive stress	$\sigma_{c,0,d}$	-0.073	N/mm ²		
Design bending moment	$M_{y,Ed}$	1169.48	kNm		
Design bending stress	$\sigma_{m,y,d}$	-8.330	N/mm ²		
Cut-to-grain angle	α	0.00	deg		
Factor	k_1	1.00	--		
Factor	k_2	0.35	--		
Factor	k_3	0.60	--		
Factor	k_4	0.00	--		
Section height	h	1800.0	mm		
Radius	r	73450.0	mm		
Factor	k_l	1.01	--		
Longitudinal stress	$\sigma_{m,d}$	-8.404	N/mm ²		
Inner radius	r_{in}	72550.0	mm		
Lamination thickness	t	40.0	mm		
Reduction factor	k_r	1.00	--		
Equivalent member length	$L_{cr,z}$	3.075	m		
Radius of gyration	i_z	75.1	mm		
Slenderness ratio	λ_z	40.97	--		
Modulus of elasticity	$E_{0,05,z}$	11800.0	N/mm ²		
Characteristic compressive strength	$f_{c,0,k}$	32.000	N/mm ²		
Relative slenderness ratio	$\lambda_{rel,z}$	0.68	--		
Straightness factor	β_c	0.10	--		
Instability factor	k_z	0.75	--		
Instability factor	$k_{c,z}$	0.94	--		
Moment of inertia	I_z	263640...	cm ⁴		
Shear modulus	G_{05}	540.0	N/mm ²		
Torsional constant	I_t	958599...	cm ⁴		
Equivalent member length	L_{cr}	6.675	m		
Elastic section modulus to more compre...	W_y	140400...	cm ³		
Critical bending stress	$\sigma_{m,crit}$	42.540	N/mm ²		
Characteristic bending strength	$f_{m,y,k}$	32.000	N/mm ²		
Relative slenderness ratio	$\lambda_{rel,m}$	0.87	--		
Lateral buckling coefficient	k_{crit}	0.91	--		
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²		
Design bending strength	$f_{m,y,d}$	23.040	N/mm ²		
Design check ratio	η	0.164	--	≤ 1	✓

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{1800.0 \text{ mm}}{73450.0 \text{ mm}}\right)^3 \\
 &= 1.01
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\
 &= 1.01 \cdot -8.330 \text{ N/mm}^2 \\
 &= -8.404 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 r_{in} &= r - 0.5 \cdot h \\
 &= 73450.0 \text{ mm} - 0.5 \cdot 1800.0 \text{ mm} \\
 &= 72550.0 \text{ mm}
 \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}
 \lambda_z &= \frac{L_{cr,z}}{i_z} \\
 &= \frac{3.075 \text{ m}}{75.1 \text{ mm}} \\
 &= 40.97
 \end{aligned}$$

$$\begin{aligned}
 \lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\
 &= \frac{40.97}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\
 &= 0.68
 \end{aligned}$$

$$\begin{aligned}
 k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2\right) \\
 &= 0.5 \cdot \left(1 + 0.10 \cdot (0.68 - 0.3) + (0.68)^2\right) \\
 &= 0.75
 \end{aligned}$$

$$\begin{aligned}
 k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\
 &= \frac{1}{0.75 + \sqrt{(0.75)^2 - (0.68)^2}} \\
 &= 0.94
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,crit} &= \frac{\pi \cdot \sqrt{E_{0,05,z} \cdot I_z \cdot G_{05} \cdot I_t}}{L_{cr} \cdot W_y} \\
 &= \frac{\pi \cdot \sqrt{11800.0 \text{ N/mm}^2 \cdot 263640.00 \text{ cm}^4 \cdot 540.0 \text{ N/mm}^2 \cdot 958599.00 \text{ cm}^4}}{6.675 \text{ m} \cdot 140400.00 \text{ cm}^3} \\
 &= 42.540 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 \lambda_{rel,m} &= \sqrt{\frac{f_{m,y,k}}{\sigma_{m,crit}}} \\
 &= \sqrt{\frac{32.000 \text{ N/mm}^2}{42.540 \text{ N/mm}^2}} \\
 &= 0.87
 \end{aligned}$$

$$0.75 < \lambda_{rel,m} \leq 1.4$$

$$\begin{aligned}
 k_{crit} &= 1.56 - 0.75 \cdot \lambda_{rel,m} \\
 &= 1.56 - 0.75 \cdot 0.87 \\
 &= 0.91
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \left| - \left(\frac{\sigma_{m,d}}{k_{crit} \cdot k_r \cdot f_{m,y,d}} \right)^2 + \frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} \right| \\
 &= \left| - \left(\frac{-8.404 \text{ N/mm}^2}{0.91 \cdot 1.00 \cdot 23.040 \text{ N/mm}^2} \right)^2 + \frac{-0.073 \text{ N/mm}^2}{0.94 \cdot 23.040 \text{ N/mm}^2} \right| \\
 &= 0.164
 \end{aligned}$$

$$\eta = 0.164 \leq 1 \quad \checkmark$$

Provjera glavnog poprečnog nosača na interakciju savijanja s bočnim izvijanjima tlaka paralelno s vlakancima zadovoljava s iskoristivosti od 16.40%.

Tablica 60.: Rekapitulacija iskoristivosti glavnog poprečnog nosača

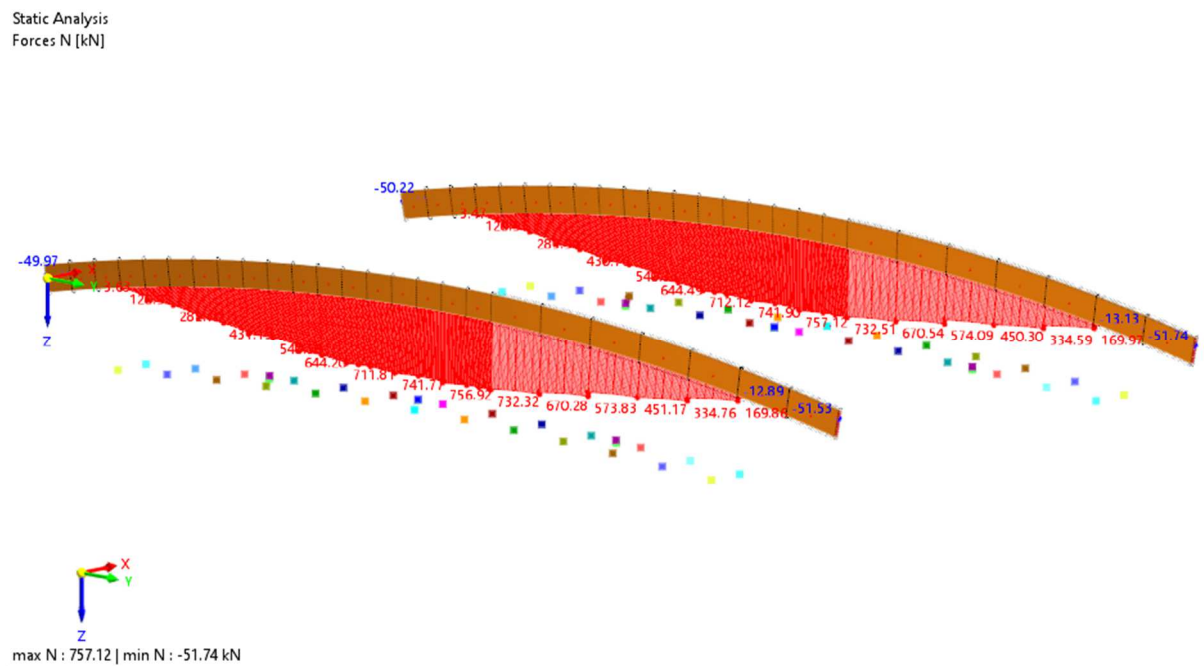
GLAVNI POPREČNI NOSAČ			
Provjera nosivosti elementa			Iskoristivost
1.	DOKAZI NOSIVOSTI PRESJEKA	Vlak paralelno s vlakancima	3,40%
2.		Tlak paralelno s vlakancima	0,50%
3.		Torzijski posmik	6,40%
4.		Posmik u vertikalnoj (z) osi	41,80%
5.		Posmik u horizontalnoj (y) osi	1,80%
6.		Savijanje oko horizontalne (y) osi	74,60%
7.		Interakcija vlaka okomito na vlakanca i posmika	51,10%
8.		Savijanje oko vertikalne (z) osi	6,40%
9.		Dvoosno savijanje	74,90%
10.		Interakcija dvoosnog savijanja i vlaka paralelno s vlakancima	74,70%
11.		Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima	36,80%
12.	DOKAZI NOSIVOSTI ELEMENTA	Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima s izvijanjem	37,10%
13.		Savijanje s bočnim izvijanjem	82,00%
14.		Interakcija savijanja s bočnim izvijanjem i tlaka paralelno s vlakancima	16,40%
Mjerodavna iskoristivost			82,00%

4.3. Dimenzioniranje glavnih uzdužnih nosača

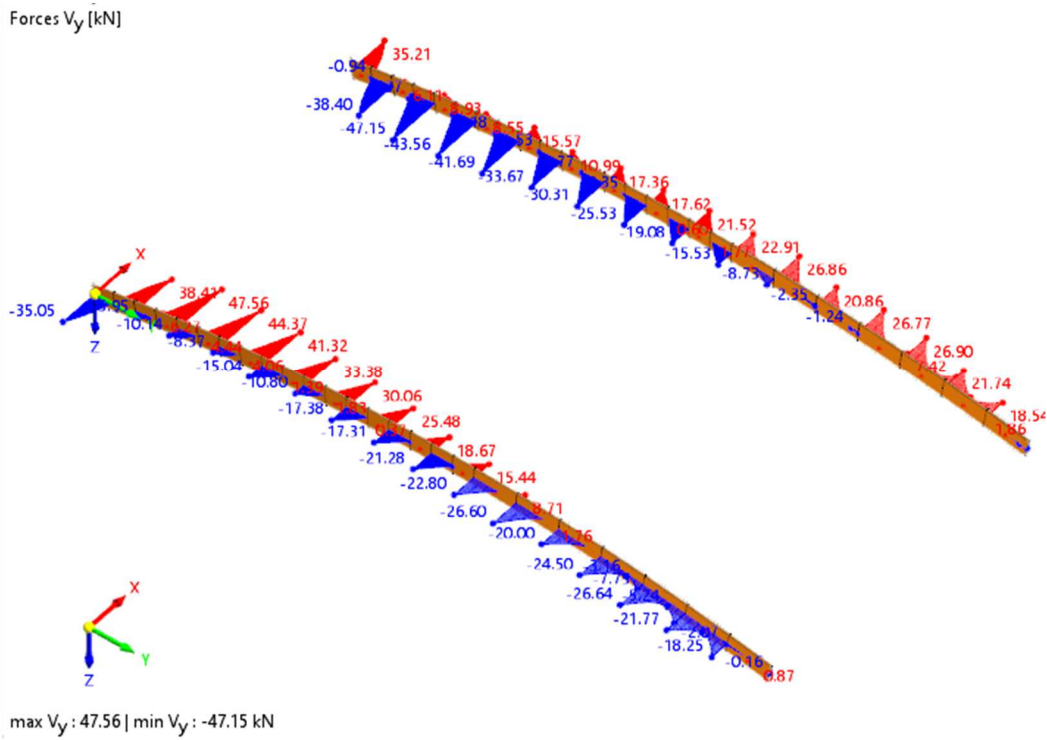
4.3.1. Ulazni podaci

4.3.1.1. Dijagrami unutarnjih sila

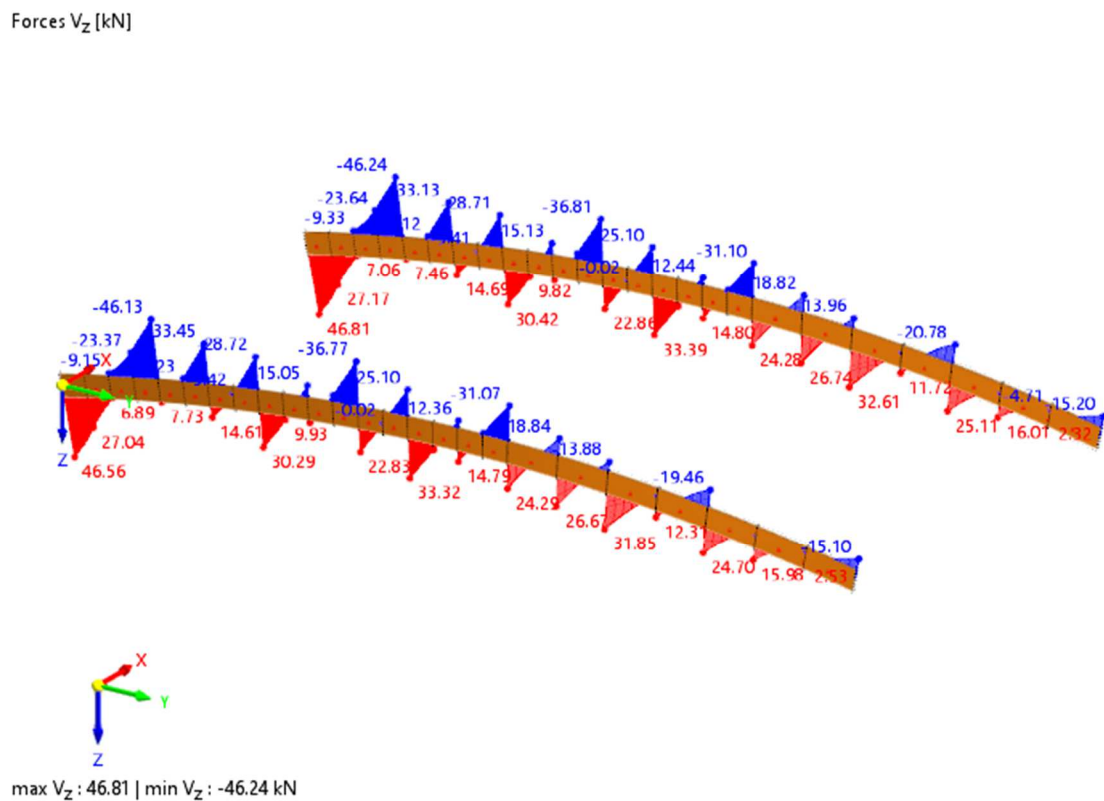
Mjerodavna kombinacija opterećenja na glavni uzdužni nosač, odnosno kombinacija opterećenja koja uzrokuje najkritičnije stanje za konstrukciju je kombinacija CO5, odnosno $1.35 \cdot LC1 + 1.35 \cdot LC2 + 1.50 \cdot LC3 + 0,9 \cdot LC5$ Dijagrami unutarnjih sila za mjerodavnu kombinaciju dani su na idućim slikama.



Slika 4.18.: Dijagram uzdužnih sila N [kN]

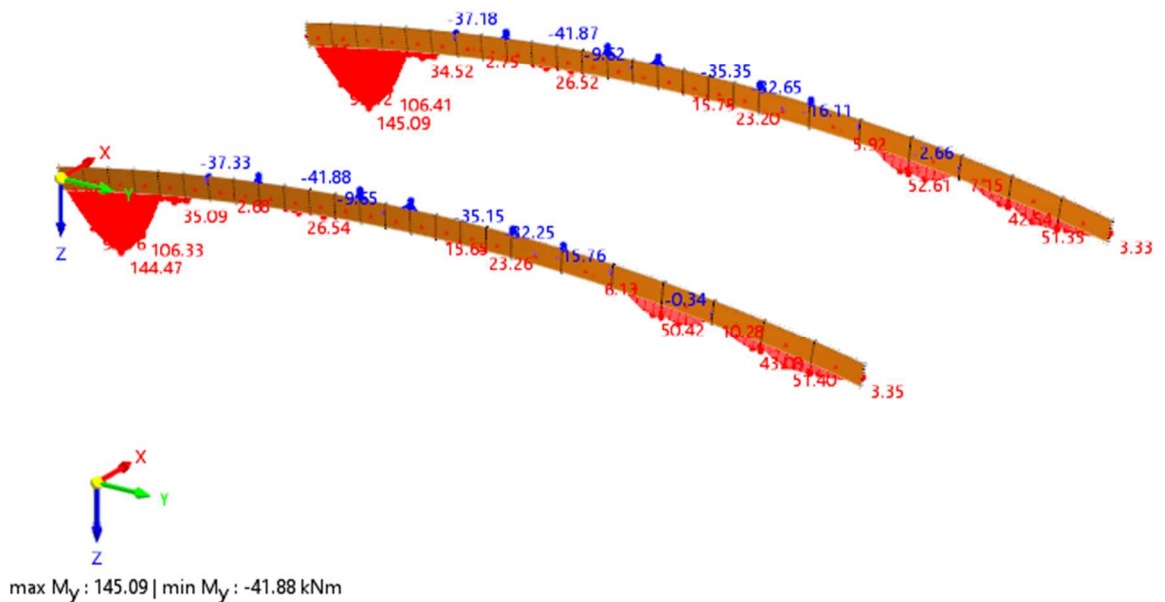


Slika 4.19.: Dijagram poprečnih sila V_y [kN]



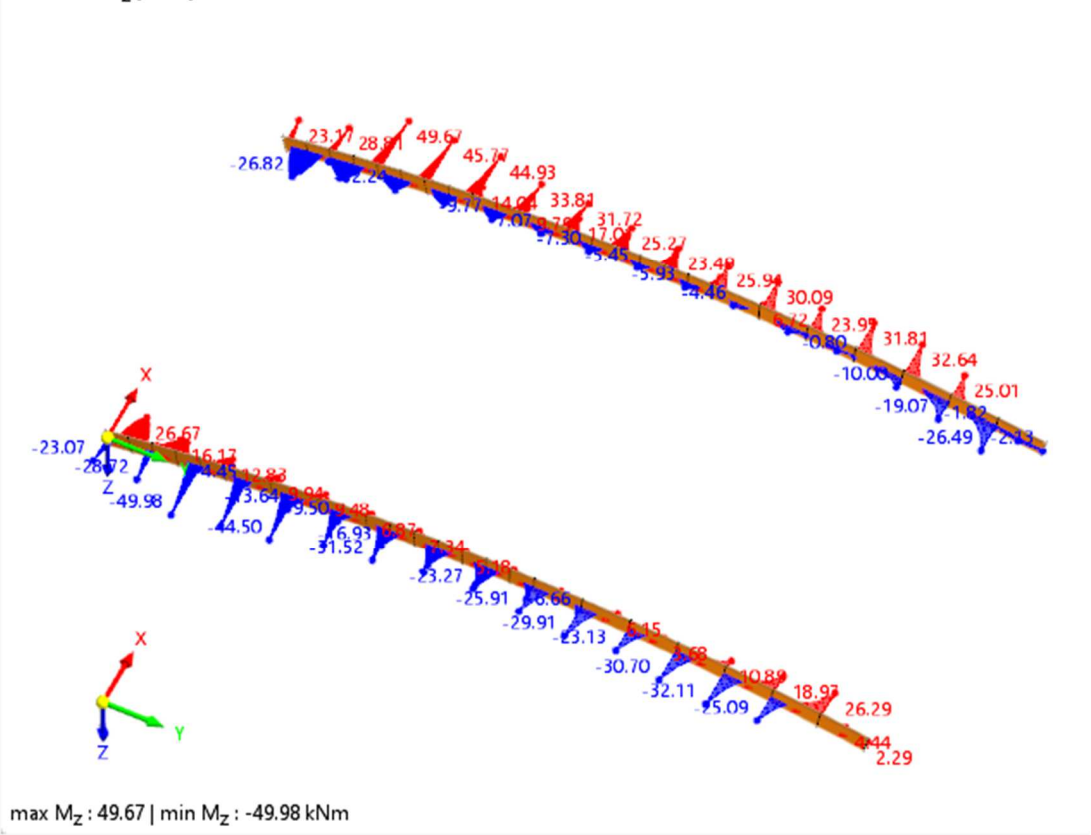
Slika 4.20.: Dijagram poprečnih sila V_z [kN]

Moments M_y [kNm]

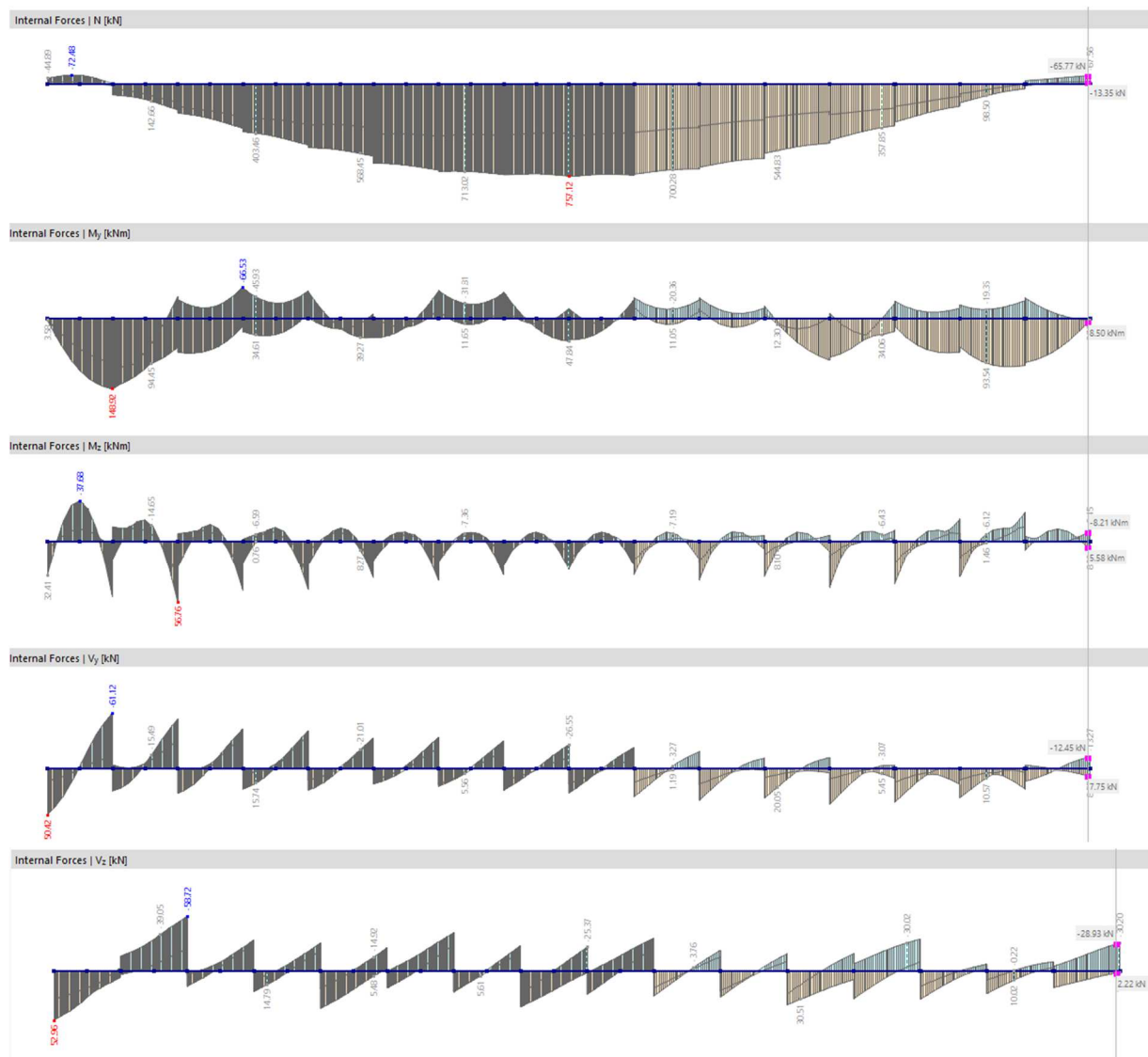


Slika 4.21.: Dijagram momenata savijanja M_y [kNm]

Moments M_z [kNm]

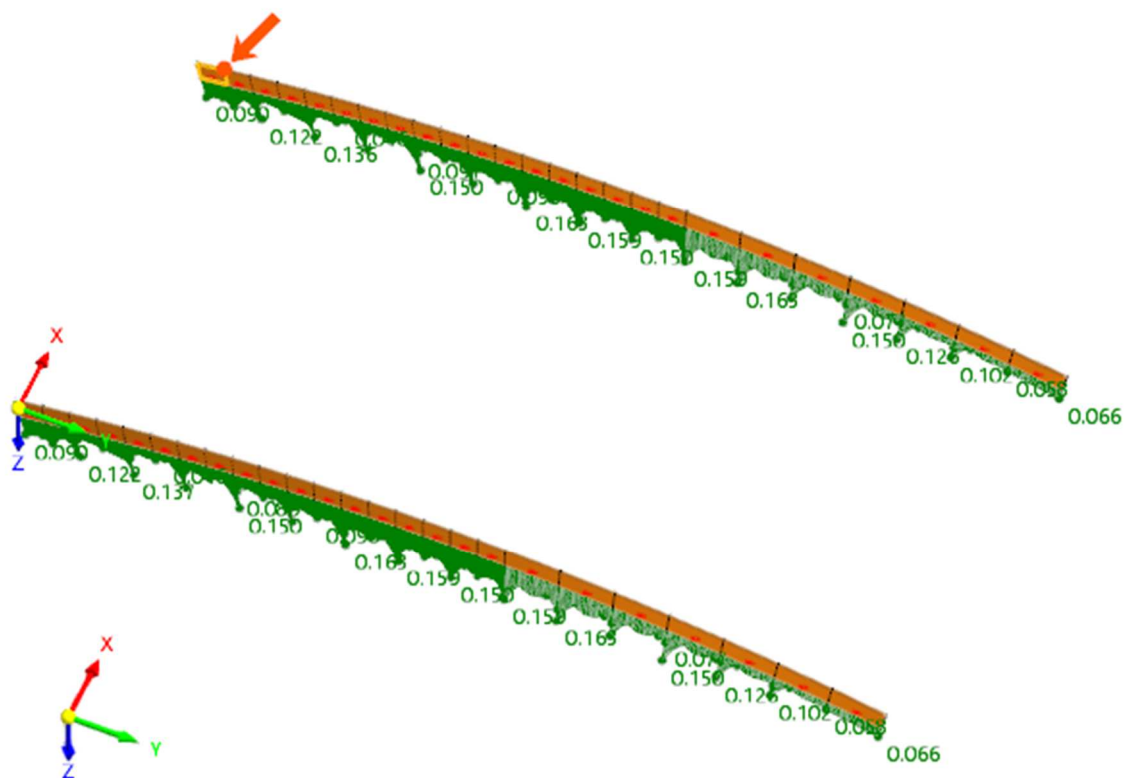


Slika 4.22.: Dijagram momenata savijanja M_z [kNm]



Slika 4.23.: Maksimalna opterećenja na glavne uzdužne nosače [kN]

Timber Design
Members | Design check ratio η



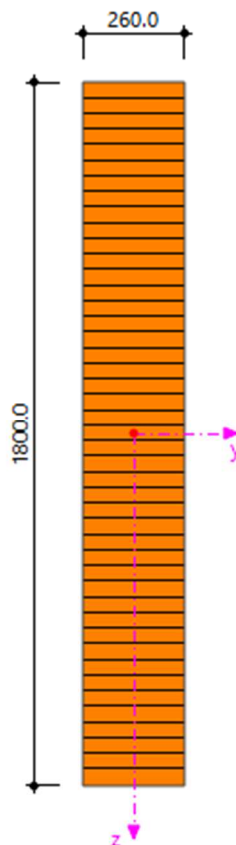
Members | Max. of all design checks | max : 0.163 | min : 0.000
Members | max η : 0.163 | min η : 0.000

Slika 4.24.: Iskoristivosti glavnih uzdužnih nosača

Poprečni presjek:

Odabrana je visina poprečnog presjeka jednaka glavnom poprečnom nosaču radi estetike i jasnog vizualnog prijenosa djelovanja.

1 - R_M1 260/1800



Slika 4.25.: Poprečni presjek glavnog uzdužnog nosača [mm]

$$h=1600 \text{ mm}$$

$$b=260 \text{ mm}$$

$$A= 4680.00\text{cm}^2$$

$$I_y= 12636000.00 \text{ cm}^4$$

$$I_z= 263640.00 \text{ cm}^4$$

$$W_y= 140400.00\text{cm}^3$$

$$W_z= 20280.00 \text{ cm}^3$$

Karakteristične vrijednosti čvrstoće drva GL32h

– Karakteristična čvrstoća savijanja	$f_{m,k} = 32,0 \text{ N/mm}^2$
– Karakteristična vlačna čvrstoća paralelno s vlakancima	$f_{t,0,k} = 26,5 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća paralelno s vlakancima	$f_{c,0,k} = 32 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća okomito na vlakanca	$f_{c,90,k} = 2,5 \text{ N/mm}^2$
– Karakteristična posmična torzijska čvrstoća	$f_{v,k} = 3,5 \text{ N/mm}^2$
– Karakteristični modul elastičnosti paralelno s vlakancima	$E_{0,05} = 11800 \text{ N/mm}^2$
– Srednji modul elastičnosti paralelno s vlakancima	$E_{0,mean} = 14200 \text{ N/mm}^2$
– Srednji modul posmika	$G_{mean} = 650 \text{ N/mm}^2$
– Srednja gustoća	$\rho_k = 440 \text{ N/mm}^2$
– Vrijednost čimbenika modifikacije	$k_{mod} = 0,8$

4.3.2. Dokaz nosivosti glavnog uzdužnog nosača

4.3.2.1. Dokazi nosivosti presjeka;

Vlak paralelno s vlakancima

Tablica 61.: Unutarnje sile

Design normal force	N_{Ed}	756.93	kN	Negligible
Design shear force	$V_{y,Ed}$	-26.74	kN	
Design shear force	$V_{z,Ed}$	25.41	kN	
Design torsional moment	T_{Ed}	-0.32	kNm	
Design bending moment	$M_{y,Ed}$	-21.15	kNm	
Design bending moment	$M_{z,Ed}$	-26.33	kNm	

Tablica 62.: Parametri proračuna

Design Check Values				
⊕ Tensile strength				
Design tension force	$N_{t,Ed}$	756.93	kN	
Sectional area	A	5200.00	cm ²	
Design tensile stress	$\sigma_{t,0,d}$	1.456	N/mm ²	
Design tensile strength	$f_{t,0,d}$	16.384	N/mm ²	
Design check ratio	η	0.089	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{\sigma_{t,0,d}}{f_{t,0,d}} \\ &= \frac{1.456 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} \\ &= 0.089 \end{aligned}$$

$$\eta = 0.089 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na vlak paralelno s vlakancima zadovoljava s iskoristivosti od 8.90%.

Tlak paralelno s vlakancima

Tablica 63.: Unutarnje sile

Design normal force	N_{Ed}	-72.48	kN		
Design shear force	$V_{y,Ed}$	14.43	kN		
Design shear force	$V_{z,Ed}$	36.12	kN		
Design torsional moment	T_{Ed}	4.26	kNm		
Design bending moment	$M_{y,Ed}$	89.57	kNm		
Design bending moment	$M_{z,Ed}$	-32.56	kNm		

Tablica 64.: Parametri proračuna

Design compression force	$N_{c,Ed}$	72.48	kN		
Sectional area	A	5200.00	cm ²		
Design compressive stress	$\sigma_{c,0,d}$	-0.139	N/mm ²		
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²		
Design check ratio	η	0.006	--	≤ 1	✓

$$\begin{aligned} \eta &= \frac{|\sigma_{c,0,d}|}{f_{c,0,d}} \\ &= \frac{|-0.139 \text{ N/mm}^2|}{23.040 \text{ N/mm}^2} \\ &= 0.006 \end{aligned}$$

$$\eta = 0.006 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na tlak paralelno s vlakancima zadovoljava s iskoristivosti od 0.60%.

Torzijski posmik

Tablica 65.: Unutarnje sile

Design normal force	N _{Ed}	-12.96	kN		
Design shear force	V _{y,Ed}	13.27	kN		
Design shear force	V _{z,Ed}	-30.20	kN		
Design torsional moment	T _{Ed}	7.97	kNm		
Design bending moment	M _{y,Ed}	2.36	kNm		Negligible
Design bending moment	M _{z,Ed}	-8.09	kNm		

Tablica 66.: Parametri proračuna

Design torsional moment	T _{Ed}	7.97	kNm		
Design torsional stress	τ _{tor,d}	0.192	N/mm ²		
Torsion factor	k _{shape}	1.30	--		
Design shear strength	f _{v,d}	2.240	N/mm ²		
Design check ratio	η	0.066	--	≤ 1	✓

$$\begin{aligned} \eta &= \frac{\tau_{tor,d}}{k_{shape} \cdot f_{v,d}} \\ &= \frac{0.192 \text{ N/mm}^2}{1.30 \cdot 2.240 \text{ N/mm}^2} \\ &= 0.066 \end{aligned}$$

$$\eta = 0.066 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na torzijski posmik zadovoljava s iskoristivosti od 6.60%.

Posmik u vertikalnoj (z) osi

Tablica 67.: Unutarnje sile

Design normal force	N _{Ed}	192.91	kN	
Design shear force	V _{y,Ed}	-54.57	kN	
Design shear force	V _{z,Ed}	-58.72	kN	
Design torsional moment	T _{Ed}	-2.18	kNm	
Design bending moment	M _{y,Ed}	-46.25	kNm	
Design bending moment	M _{z,Ed}	56.07	kNm	

Tablica 68.: Parametri proračuna

Design shear force	V _{z,Ed}	58.72	kN	
Shear stress	τ _{xz}	-0.169	N/mm ²	
Crack influence factor	k _{cr}	0.67	--	
Design shear stress	τ _{xz,d}	-0.253	N/mm ²	
Design shear strength	f _{v,z,d}	2.520	N/mm ²	
Design check ratio	η	0.100	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{|\tau_{xz,d}|}{f_{v,z,d}} \\ &= \frac{|-0.253 \text{ N/mm}^2|}{2.520 \text{ N/mm}^2} \\ &= 0.100 \end{aligned}$$

$$\eta = 0.100 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na posmik u vertikalnoj (z) osi zadovoljava s iskoristivosti od 10.00%.

Posmik u horizontalnoj (y) osi

Tablica 69.: Unutarnje sile

Design normal force	N _{Ed}	-1.34	kN	Negligible
Design shear force	V _{y,Ed}	61.13	kN	
Design shear force	V _{z,Ed}	-3.29	kN	Negligible
Design torsional moment	T _{Ed}	-0.80	kNm	
Design bending moment	M _{y,Ed}	123.53	kNm	
Design bending moment	M _{z,Ed}	-51.80	kNm	

Tablica 70.: Parametri proračuna

Design shear force	V _{y,Ed}	61.13	kN	
Shear stress	τ _{xy}	0.170	N/mm ²	
Crack influence factor	k _{cr}	0.67	--	
Design shear stress	τ _{xy,d}	0.253	N/mm ²	
Design shear strength	f _{v,y,d}	2.520	N/mm ²	
Design check ratio	η	0.101	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{|\tau_{xy,d}|}{f_{v,y,d}} \\ &= \frac{|0.253 \text{ N/mm}^2|}{2.520 \text{ N/mm}^2} \\ &= 0.101 \end{aligned}$$

$$\eta = 0.101 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na posmik u horizontalnoj (y) osi zadovoljava s iskoristivosti od 10.10%.

Savijanje oko horizontalne (y) osi

Tablica 71.: Unutarnje sile

Design normal force	N _{Ed}	8.08	kN	Negligible
Design shear force	V _{y,Ed}	11.16	kN	
Design shear force	V _{z,Ed}	8.11	kN	
Design torsional moment	T _{Ed}	-7.16	kNm	
Design bending moment	M _{y,Ed}	89.22	kNm	
Design bending moment	M _{z,Ed}	-0.25	kNm	Negligible

Tablica 72.: Parametri proračuna

⊕ Bending strength about y-axis				
Design bending moment	M _{y,Ed}	89.22	kNm	
Design bending stress	σ _{m,y,d}	-0.515	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k ₁	1.00	--	
Factor	k ₂	0.35	--	
Factor	k ₃	0.60	--	
Factor	k ₄	0.00	--	
Section height	h	2000.0	mm	
Radius	r	202000.0	mm	
Factor	k _l	1.00	--	
Longitudinal stress	σ _{m,d}	-0.517	N/mm ²	
Inner radius	r _{in}	201000.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k _r	1.00	--	
Design bending strength	f _{m,y,d}	20.480	N/mm ²	
Design check ratio	η	0.025	--	≤ 1 ✓

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned} k_4 &= 6 \cdot (\tan(\alpha))^2 \\ &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 0.00 \end{aligned}$$

$$\begin{aligned} k_i &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\ &= 1.00 + 0.35 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^3 \\ &= 1.00 \end{aligned}$$

$$\begin{aligned} \sigma_{m,d} &= k_i \cdot \sigma_{m,y,d} \\ &= 1.00 \cdot -0.515 \text{ N/mm}^2 \\ &= -0.517 \text{ N/mm}^2 \end{aligned}$$

$$\begin{aligned} r_{in} &= r - 0.5 \cdot h \\ &= 202000.0 \text{ mm} - 0.5 \cdot 2000.0 \text{ mm} \\ &= 201000.0 \text{ mm} \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned} \eta &= \frac{|\sigma_{m,d}|}{k_r \cdot f_{m,y,d}} \\ &= \frac{|-0.517 \text{ N/mm}^2|}{1.00 \cdot 20.480 \text{ N/mm}^2} \\ &= 0.025 \end{aligned}$$

$$\eta = 0.025 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na savijanje oko horizontalne (y) osi zadovoljava s iskoristivosti od 2.50%.

Interakcija vlaka okomito na vlakanca i savijanja

Tablica 73.: Unutarnje sile

Design normal force	N_{Ed}	-10.20	kN	Negligible
Design shear force	$V_{y,Ed}$	-56.44	kN	Negligible
Design shear force	$V_{z,Ed}$	-0.38	kN	
Design torsional moment	T_{Ed}	0.88	kNm	Negligible
Design bending moment	$M_{y,Ed}$	124.55	kNm	
Design bending moment	$M_{z,Ed}$	36.65	kNm	

Tablica 74.: Parametri proračuna

⊕ Tensile strength perpendicular to grain at apex zone				
Design bending moment	$M_{y,Ed}$	124.55	kNm	
Design bending stress	$\sigma_{m,y,d}$	-0.719	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k_5	0.00	--	
Factor	k_6	0.25	--	
Factor	k_7	0.00	--	
Section height	h	2000.0	mm	
Radius	r	202000.0	mm	
Factor	k_p	0.00	--	
Design tensile stress perpendicular to grain	$\sigma_{t,90,d}$	-0.002	N/mm ²	
Factor	k_{dis}	1.40	--	
Reference volume	V_0	0.010	m ³	
Volume of apex zone	V	41.877	m ³	
Volume factor	k_{vol}	0.19	--	
Design tensile strength perpendicular to grain	$f_{t,90,d}$	0.360	N/mm ²	
Design check ratio	η	0.019	--	≤ 1 ✓

$$\begin{aligned}
k_5 &= 0.2 \cdot \tan(\alpha) \\
&= 0.2 \cdot \tan(0.00 \text{ deg}) \\
&= 0.00 \\
k_6 &= 0.25 - 1.5 \cdot \tan(\alpha) + 2.6 \cdot (\tan(\alpha))^2 \\
&= 0.25 - 1.5 \cdot \tan(0.00 \text{ deg}) + 2.6 \cdot (\tan(0.00 \text{ deg}))^2 \\
&= 0.25 \\
k_7 &= 2.1 \cdot \tan(\alpha) - 4 \cdot (\tan(\alpha))^2 \\
&= 2.1 \cdot \tan(0.00 \text{ deg}) - 4 \cdot (\tan(0.00 \text{ deg}))^2 \\
&= 0.00 \\
k_p &= k_5 + k_6 \cdot \left(\frac{h}{r}\right) + k_7 \cdot \left(\frac{h}{r}\right)^2 \\
&= 0.00 + 0.25 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right) + 0.00 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^2 \\
&= 0.00 \\
\sigma_{t,90,d} &= k_p \cdot \sigma_{m,y,d} \\
&= 0.00 \cdot -0.719 \text{ N/mm}^2 \\
&= -0.002 \text{ N/mm}^2 \\
k_{vol} &= \left(\frac{V_0}{V}\right)^{0.2} \\
&= \left(\frac{0.010 \text{ m}^3}{41.877 \text{ m}^3}\right)^{0.2} \\
&= 0.19 \\
\eta &= \frac{|\sigma_{t,90,d}|}{k_{dis} \cdot k_{vol} \cdot f_{t,90,d}} \\
&= \frac{|-0.002 \text{ N/mm}^2|}{1.40 \cdot 0.19 \cdot 0.360 \text{ N/mm}^2} \\
&= 0.019 \\
\eta &= 0.019 \leq 1 \quad \checkmark
\end{aligned}$$

Provjera glavnog uzdužnog nosača interakciju vlaka okomito na vlakanca i savijanja zadovoljava s iskoristivosti od 1.90%.

Interakcija dvoosnog savijanja i vlaka paralelno s vlakancima

Tablica 75.: Unutarnje sile

Design normal force	N _{Ed}	680.47	kN	Negligible
Design shear force	V _{y,Ed}	-34.47	kN	
Design shear force	V _{z,Ed}	28.25	kN	
Design torsional moment	T _{Ed}	-0.46	kNm	
Design bending moment	M _{y,Ed}	-20.10	kNm	
Design bending moment	M _{z,Ed}	-36.38	kNm	

Tablica 76.: Parametri proračuna

Design tension force	N _{t,Ed}	680.47	kN	
Design bending moment	M _{y,Ed}	-20.10	kNm	
Design bending moment	M _{z,Ed}	-36.38	kNm	
Design tensile stress	σ _{t,0,d}	1.309	N/mm ²	
Design bending stress	σ _{m,y,d}	0.116	N/mm ²	
Design bending stress	σ _{m,z,d}	1.615	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k ₁	1.00	--	
Factor	k ₂	0.35	--	
Factor	k ₃	0.60	--	
Factor	k ₄	0.00	--	
Section height	h	2000.0	mm	
Radius	r	202000.0	mm	
Factor	k _l	1.00	--	
Longitudinal stress	σ _{m,d}	0.116	N/mm ²	
Inner radius	r _{in}	201000.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k _r	1.00	--	
Design tensile strength	f _{t,0,d}	16.384	N/mm ²	
Design bending strength	f _{m,y,d}	20.480	N/mm ²	
Design bending strength	f _{m,z,d}	20.480	N/mm ²	
Redistribution factor	k _m	0.70	--	
Design ratio 1	η ₁	0.141	--	
Design ratio 2	η ₂	0.163	--	
Design check ratio	η	0.163	--	≤ 1 ✓

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^3 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\
 &= 1.00 \cdot 0.116 \text{ N/mm}^2 \\
 &= 0.116 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 r_{in} &= r - 0.5 \cdot h \\
 &= 202000.0 \text{ mm} - 0.5 \cdot 2000.0 \text{ mm} \\
 &= 201000.0 \text{ mm}
 \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}
 \eta_1 &= \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{1.309 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} + \frac{0.116 \text{ N/mm}^2}{1.00 \cdot 20.480 \text{ N/mm}^2} + 0.70 \cdot \frac{1.615 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\
 &= 0.141
 \end{aligned}$$

$$\begin{aligned}
 \eta_2 &= \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + k_m \cdot \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{1.309 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} + 0.70 \cdot \frac{0.116 \text{ N/mm}^2}{1.00 \cdot 20.480 \text{ N/mm}^2} + \frac{1.615 \text{ N/mm}^2}{20.480 \text{ N/mm}^2} \right| \\
 &= 0.163
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \max(\eta_1, \eta_2) \\
 &= \max(0.141, 0.163) \\
 &= 0.163
 \end{aligned}$$

$$\eta = 0.163 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača interakciju dvoosnog savijanja i vlaka paralelno s vlakancima zadovoljava s iskoristivosti od 16.30%.

Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima

Tablica 77.: Unutarnje sile

Design normal force	N_{Ed}	-69.52	kN		
Design shear force	$V_{y,Ed}$	-2.25	kN		
Design shear force	$V_{z,Ed}$	28.46	kN		
Design torsional moment	T_{Ed}	3.70	kNm		
Design bending moment	$M_{y,Ed}$	109.72	kNm		
Design bending moment	$M_{z,Ed}$	-36.82	kNm		

Tablica 78.: Parametri proračuna

Design compression force	$N_{c,Ed}$	69.52	kN		
Design bending moment	$M_{y,Ed}$	109.72	kNm		
Design bending moment	$M_{z,Ed}$	-36.82	kNm		
Design compressive stress	$\sigma_{c,0,d}$	-0.134	N/mm ²		
Design bending stress	$\sigma_{m,y,d}$	-0.633	N/mm ²		
Design bending stress	$\sigma_{m,z,d}$	-1.634	N/mm ²		
Cut-to-grain angle	α	0.00	deg		
Factor	k_1	1.00	--		
Factor	k_2	0.35	--		
Factor	k_3	0.60	--		
Factor	k_4	0.00	--		
Section height	h	2000.0	mm		
Radius	r	202000.0	mm		
Factor	k_l	1.00	--		
Longitudinal stress	$\sigma_{m,d}$	-0.635	N/mm ²		
Inner radius	r_{in}	201000.0	mm		
Lamination thickness	t	40.0	mm		
Reduction factor	k_r	1.00	--		
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²		
Design bending strength	$f_{m,y,d}$	23.040	N/mm ²		
Design bending strength	$f_{m,z,d}$	23.040	N/mm ²		
Redistribution factor	k_m	0.70	--		
Design ratio 1	η_1	0.077	--		
Design ratio 2	η_2	0.090	--		
Design check ratio	η	0.090	--	≤ 1	✓

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^3 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\
 &= 1.00 \cdot -0.633 \text{ N/mm}^2 \\
 &= -0.635 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 r_{in} &= r - 0.5 \cdot h \\
 &= 202000.0 \text{ mm} - 0.5 \cdot 2000.0 \text{ mm} \\
 &= 201000.0 \text{ mm}
 \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}
 \eta_1 &= \left| -\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| -\left(\frac{-0.134 \text{ N/mm}^2}{23.040 \text{ N/mm}^2}\right)^2 + \frac{-0.635 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-1.634 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\
 &= 0.077
 \end{aligned}$$

$$\begin{aligned}
 \eta_2 &= \left| -\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \cdot \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| -\left(\frac{-0.134 \text{ N/mm}^2}{23.040 \text{ N/mm}^2}\right)^2 + 0.70 \cdot \frac{-0.635 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + \frac{-1.634 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\
 &= 0.090
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \max(\eta_1, \eta_2) \\
 &= \max(0.077, 0.090) \\
 &= 0.090
 \end{aligned}$$

$$\eta = 0.090 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača interakciju dvoosnog savijanja i tlaka paralelno s vlakancima zadovoljava s iskoristivosti od 9.00%.

4.3.2.2. Dokazi nosivosti elementa;

Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima s izvijanjem

Tablica 79.: Unutarnje sile

Design normal force	N_{Ed}	-69.52	kN
Design shear force	$V_{y,Ed}$	-2.25	kN
Design shear force	$V_{z,Ed}$	28.46	kN
Design torsional moment	T_{Ed}	3.70	kNm
Design bending moment	$M_{y,Ed}$	109.72	kNm
Design bending moment	$M_{z,Ed}$	-36.82	kNm

Tablica 80.: Parametri proračuna

Design compression force	$N_{c,Ed}$	69.52	kN	
Design compressive stress	$\sigma_{c,0,d}$	-0.134	N/mm ²	
Design bending moment	$M_{y,Ed}$	109.72	kNm	
Design bending stress	$\sigma_{m,y,d}$	-0.633	N/mm ²	
Design bending moment	$M_{z,Ed}$	-36.82	kNm	
Design bending stress	$\sigma_{m,z,d}$	-1.634	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k_1	1.00	--	
Factor	k_2	0.35	--	
Factor	k_3	0.60	--	
Factor	k_4	0.00	--	
Section height	h	2000.0	mm	
Radius	r	202000.0	mm	
Factor	k_l	1.00	--	
Longitudinal stress	$\sigma_{m,d}$	-0.635	N/mm ²	
Inner radius	r_{in}	201000.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k_r	1.00	--	
Equivalent member length	$L_{cr,y}$	5.033	m	
Equivalent member length	$L_{cr,z}$	5.033	m	
Radius of gyration	i_y	577.4	mm	
Radius of gyration	i_z	75.1	mm	
Slenderness ratio	λ_y	8.72	--	
Slenderness ratio	λ_z	67.06	--	
Modulus of elasticity	$E_{0,05,y}$	11800.0	N/mm ²	
Modulus of elasticity	$E_{0,05,z}$	11800.0	N/mm ²	
Characteristic compressive strength	$f_{c,0,k}$	32.000	N/mm ²	
Relative slenderness ratio	$\lambda_{rel,y}$	0.14	--	
Relative slenderness ratio	$\lambda_{rel,z}$	1.11	--	
Straightness factor	β_c	0.10	--	
Instability factor	k_y	0.50	--	
Instability factor	k_z	1.16	--	
Instability factor	$k_{c,y}$	1.00	--	
Instability factor	$k_{c,z}$	0.67	--	
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²	
Design bending strength	$f_{m,y,d}$	23.040	N/mm ²	
Design bending strength	$f_{m,z,d}$	23.040	N/mm ²	
Redistribution factor	k_m	0.70	--	
Design ratio 1	η_1	0.083	--	
Design ratio 2	η_2	0.099	--	
Design check ratio	η	0.099	--	≤ 1 ✓

$$\begin{aligned} k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\ &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 1.00 \end{aligned}$$

$$\begin{aligned} k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\ &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\ &= 0.35 \end{aligned}$$

$$\begin{aligned} k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\ &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 0.60 \end{aligned}$$

$$\begin{aligned} k_4 &= 6 \cdot (\tan(\alpha))^2 \\ &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 0.00 \end{aligned}$$

$$\begin{aligned} k_t &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\ &= 1.00 + 0.35 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^3 \\ &= 1.00 \end{aligned}$$

$$\begin{aligned} \sigma_{m,d} &= k_t \cdot \sigma_{m,y,d} \\ &= 1.00 \cdot -0.633 \text{ N/mm}^2 \\ &= -0.635 \text{ N/mm}^2 \end{aligned}$$

$$\begin{aligned} r_{in} &= r - 0.5 \cdot h \\ &= 202000.0 \text{ mm} - 0.5 \cdot 2000.0 \text{ mm} \\ &= 201000.0 \text{ mm} \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned} \lambda_y &= \frac{L_{cr,y}}{i_y} \\ &= \frac{5.033 \text{ m}}{577.4 \text{ mm}} \\ &= 8.72 \end{aligned}$$

$$\begin{aligned} \lambda_z &= \frac{L_{cr,z}}{i_z} \\ &= \frac{5.033 \text{ m}}{75.1 \text{ mm}} \\ &= 67.06 \end{aligned}$$

$$\begin{aligned} \lambda_{rel,y} &= \frac{\lambda_y}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,y}}} \\ &= \frac{8.72}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 0.14 \end{aligned}$$

$$\begin{aligned} \lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\ &= \frac{67.06}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 1.11 \end{aligned}$$

$$\lambda_{rel,y} > 0.3 \text{ or } \lambda_{rel,z} > 0.3$$

$$\begin{aligned}
 k_y &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,y} - 0.3) + (\lambda_{rel,y})^2 \right) \\
 &= 0.5 \cdot \left(1 + 0.10 \cdot (0.14 - 0.3) + (0.14)^2 \right) \\
 &= 0.50
 \end{aligned}$$

$$\begin{aligned}
 k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2 \right) \\
 &= 0.5 \cdot \left(1 + 0.10 \cdot (1.11 - 0.3) + (1.11)^2 \right) \\
 &= 1.16
 \end{aligned}$$

$$\begin{aligned}
 k_{c,y} &= \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \\
 &= \frac{1}{0.50 + \sqrt{(0.50)^2 - (0.14)^2}} \\
 &= 1.02
 \end{aligned}$$

$$\begin{aligned}
 k_{c,y} &= \min(1, k_{c,y}) \\
 &= \min(1, 1.02) \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\
 &= \frac{1}{1.16 + \sqrt{(1.16)^2 - (1.11)^2}} \\
 &= 0.67
 \end{aligned}$$

$$\begin{aligned}
 \eta_1 &= \left| \frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{-0.134 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + \frac{-0.635 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-1.634 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\
 &= 0.083
 \end{aligned}$$

$$\begin{aligned}
 \eta_2 &= \left| \frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,d}}{k_r \cdot f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\
 &= \left| \frac{-0.134 \text{ N/mm}^2}{0.67 \cdot 23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.635 \text{ N/mm}^2}{1.00 \cdot 23.040 \text{ N/mm}^2} + \frac{-1.634 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\
 &= 0.099
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \max(\eta_1, \eta_2) \\
 &= \max(0.083, 0.099) \\
 &= 0.099
 \end{aligned}$$

$$\boxed{\eta = 0.099 \leq 1 \checkmark}$$

Provjera glavnog uzdužnog nosača na interakciju dvoosnog savijanja i tlaka paralelno s vlakancima s izvijanjem zadovoljava s iskoristivosti od 9.90%.

Savijanje s bočnim izvijanjem

Tablica 81.: Unutarnje sile

Design normal force	N _{Ed}	90.62	kN	
Design shear force	V _{y,Ed}	17.20	kN	
Design shear force	V _{z,Ed}	-15.78	kN	
Design torsional moment	T _{Ed}	-0.06	kNm	Negligible
Design bending moment	M _{y,Ed}	148.92	kNm	
Design bending moment	M _{z,Ed}	8.66	kNm	

Tablica 82.: Parametri proračuna

Design bending moment	M _{y,Ed}	148.92	kNm	
Design bending stress	σ _{m,y,d}	-0.859	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k ₁	1.00	--	
Factor	k ₂	0.35	--	
Factor	k ₃	0.60	--	
Factor	k ₄	0.00	--	
Section height	h	2000.0	mm	
Radius	r	202000.0	mm	
Factor	k _l	1.00	--	
Longitudinal stress	σ _{m,d}	-0.862	N/mm ²	
Inner radius	r _{in}	201000.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k _r	1.00	--	
Modulus of elasticity	E _{0,05,z}	11800.0	N/mm ²	
Moment of inertia	I _z	292933.00	cm ⁴	
Shear modulus	G ₀₅	540.0	N/mm ²	
Torsional constant	I _t	1075770...	cm ⁴	
Equivalent member length	L _{cr}	9.033	m	
Elastic section modulus to more compressed ...	W _y	173333.00	cm ³	
Critical bending stress	σ _{m,crit}	28.432	N/mm ²	
Characteristic bending strength	f _{m,y,k}	32.000	N/mm ²	
Relative slenderness ratio	λ _{rel,m}	1.06	--	
Lateral buckling coefficient	k _{crit}	0.76	--	
Design bending strength	f _{m,y,d}	23.040	N/mm ²	
Design check ratio	η	0.049	--	≤ 1 ✓

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\
 &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\
 &= 0.35
 \end{aligned}$$

$$\begin{aligned}
 k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\
 &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.60
 \end{aligned}$$

$$\begin{aligned}
 k_4 &= 6 \cdot (\tan(\alpha))^2 \\
 &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 0.00
 \end{aligned}$$

$$\begin{aligned}
 k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\
 &= 1.00 + 0.35 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^3 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\
 &= 1.00 \cdot -0.859 \text{ N/mm}^2 \\
 &= -0.862 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 r_{in} &= r - 0.5 \cdot h \\
 &= 202000.0 \text{ mm} - 0.5 \cdot 2000.0 \text{ mm} \\
 &= 201000.0 \text{ mm}
 \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned}
 \sigma_{m,crit} &= \frac{\pi \cdot \sqrt{E_{0,05,z} \cdot I_z \cdot G_{05} \cdot I_t}}{L_{cr} \cdot W_y} \\
 &= \frac{\pi \cdot \sqrt{11800.0 \text{ N/mm}^2 \cdot 292933.00 \text{ cm}^4 \cdot 540.0 \text{ N/mm}^2 \cdot 1075770.00 \text{ cm}^4}}{9.033 \text{ m} \cdot 173333.00 \text{ cm}^3} \\
 &= 28.432 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 \lambda_{rel,m} &= \sqrt{\frac{f_{m,y,k}}{\sigma_{m,crit}}} \\
 &= \sqrt{\frac{32.000 \text{ N/mm}^2}{28.432 \text{ N/mm}^2}} \\
 &= 1.06
 \end{aligned}$$

$$0.75 < \lambda_{rel,m} \leq 1.4$$

$$\begin{aligned}
 k_{crit} &= 1.56 - 0.75 \cdot \lambda_{rel,m} \\
 &= 1.56 - 0.75 \cdot 1.06 \\
 &= 0.76
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \left| \frac{\sigma_{m,d}}{k_{crit} \cdot k_r \cdot f_{m,y,d}} \right| \\
 &= \left| \frac{-0.862 \text{ N/mm}^2}{0.76 \cdot 1.00 \cdot 23.040 \text{ N/mm}^2} \right| \\
 &= 0.049
 \end{aligned}$$

$$\eta = 0.049 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na savijanje s bočnim izvijanjem zadovoljava s iskoristivosti od 4.90%.

Interakcija savijanja s bočnim izvijanjem i tlaka paralelno s vlakancima

Tablica 83.: Unutarnje sile

Design normal force	N_{Ed}	-69.52	kN	
Design shear force	$V_{y,Ed}$	-2.25	kN	
Design shear force	$V_{z,Ed}$	28.46	kN	
Design torsional moment	T_{Ed}	3.70	kNm	
Design bending moment	$M_{y,Ed}$	109.72	kNm	
Design bending moment	$M_{z,Ed}$	-36.82	kNm	

Tablica 84.: Parametri proračuna

Design compression force	$N_{c,Ed}$	69.52	kN	
Design compressive stress	$\sigma_{c,0,d}$	-0.134	N/mm ²	
Design bending moment	$M_{y,Ed}$	109.72	kNm	
Design bending stress	$\sigma_{m,y,d}$	-0.633	N/mm ²	
Cut-to-grain angle	α	0.00	deg	
Factor	k_1	1.00	--	
Factor	k_2	0.35	--	
Factor	k_3	0.60	--	
Factor	k_4	0.00	--	
Section height	h	2000.0	mm	
Radius	r	202000.0	mm	
Factor	k_l	1.00	--	
Longitudinal stress	$\sigma_{m,d}$	-0.635	N/mm ²	
Inner radius	r_{in}	201000.0	mm	
Lamination thickness	t	40.0	mm	
Reduction factor	k_r	1.00	--	
Equivalent member length	$L_{cr,z}$	5.033	m	
Radius of gyration	i_z	75.1	mm	
Slenderness ratio	λ_z	67.06	--	
Modulus of elasticity	$E_{0,05,z}$	11800.0	N/mm ²	
Characteristic compressive strength	$f_{c,0,k}$	32.000	N/mm ²	
Relative slenderness ratio	$\lambda_{rel,z}$	1.11	--	
Straightness factor	β_c	0.10	--	
Instability factor	k_z	1.16	--	
Instability factor	$k_{c,z}$	0.67	--	
Moment of inertia	I_z	292933.00	cm ⁴	
Shear modulus	G_{05}	540.0	N/mm ²	
Torsional constant	I_t	1075770...	cm ⁴	
Equivalent member length	L_{cr}	9.033	m	
Elastic section modulus to more compressed ...	W_y	173333.00	cm ³	
Critical bending stress	$\sigma_{m,crit}$	28.432	N/mm ²	
Characteristic bending strength	$f_{m,y,k}$	32.000	N/mm ²	
Relative slenderness ratio	$\lambda_{rel,m}$	1.06	--	
Lateral buckling coefficient	k_{crit}	0.76	--	
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²	
Design bending strength	$f_{m,y,d}$	23.040	N/mm ²	
Design check ratio	η	0.010	--	≤ 1 ✓

$$\begin{aligned}
 k_1 &= 1 + 1.4 \cdot \tan(\alpha) + 5.4 \cdot (\tan(\alpha))^2 \\
 &= 1 + 1.4 \cdot \tan(0.00 \text{ deg}) + 5.4 \cdot (\tan(0.00 \text{ deg}))^2 \\
 &= 1.00
 \end{aligned}$$

$$\begin{aligned} k_2 &= 0.35 - 8 \cdot \tan(\alpha) \\ &= 0.35 - 8 \cdot \tan(0.00 \text{ deg}) \\ &= 0.35 \end{aligned}$$

$$\begin{aligned} k_3 &= 0.6 + 8.3 \cdot \tan(\alpha) - 7.8 \cdot (\tan(\alpha))^2 \\ &= 0.6 + 8.3 \cdot \tan(0.00 \text{ deg}) - 7.8 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 0.60 \end{aligned}$$

$$\begin{aligned} k_4 &= 6 \cdot (\tan(\alpha))^2 \\ &= 6 \cdot (\tan(0.00 \text{ deg}))^2 \\ &= 0.00 \end{aligned}$$

$$\begin{aligned} k_l &= k_1 + k_2 \cdot \left(\frac{h}{r}\right) + k_3 \cdot \left(\frac{h}{r}\right)^2 + k_4 \cdot \left(\frac{h}{r}\right)^3 \\ &= 1.00 + 0.35 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right) + 0.60 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^2 + 0.00 \cdot \left(\frac{2000.0 \text{ mm}}{202000.0 \text{ mm}}\right)^3 \\ &= 1.00 \end{aligned}$$

$$\begin{aligned} \sigma_{m,d} &= k_l \cdot \sigma_{m,y,d} \\ &= 1.00 \cdot -0.633 \text{ N/mm}^2 \\ &= -0.635 \text{ N/mm}^2 \end{aligned}$$

$$\begin{aligned} r_{in} &= r - 0.5 \cdot h \\ &= 202000.0 \text{ mm} - 0.5 \cdot 2000.0 \text{ mm} \\ &= 201000.0 \text{ mm} \end{aligned}$$

$$\frac{r_{in}}{t} \geq 240$$

$$k_r = 1$$

$$\begin{aligned} \lambda_z &= \frac{L_{cr,z}}{i_z} \\ &= \frac{5.033 \text{ m}}{75.1 \text{ mm}} \\ &= 67.06 \end{aligned}$$

$$\begin{aligned} \lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\ &= \frac{67.06}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 1.11 \end{aligned}$$

$$\begin{aligned} k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (1.11 - 0.3) + (1.11)^2\right) \\ &= 1.16 \end{aligned}$$

$$\begin{aligned}
 k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\
 &= \frac{1}{1.16 + \sqrt{(1.16)^2 - (1.11)^2}} \\
 &= 0.67
 \end{aligned}$$

$$\begin{aligned}
 \sigma_{m,crit} &= \frac{\pi \cdot \sqrt{E_{0,05,z} \cdot I_z \cdot G_{05} \cdot I_t}}{L_{cr} \cdot W_y} \\
 &= \frac{\pi \cdot \sqrt{11800.0 \text{ N/mm}^2 \cdot 292933.00 \text{ cm}^4 \cdot 540.0 \text{ N/mm}^2 \cdot 1075770.00 \text{ cm}^4}}{9.033 \text{ m} \cdot 173333.00 \text{ cm}^3} \\
 &= 28.432 \text{ N/mm}^2
 \end{aligned}$$

$$\begin{aligned}
 \lambda_{rel,m} &= \sqrt{\frac{f_{m,y,k}}{\sigma_{m,crit}}} \\
 &= \sqrt{\frac{32.000 \text{ N/mm}^2}{28.432 \text{ N/mm}^2}} \\
 &= 1.06
 \end{aligned}$$

$$0.75 < \lambda_{rel,m} \leq 1.4$$

$$\begin{aligned}
 k_{crit} &= 1.56 - 0.75 \cdot \lambda_{rel,m} \\
 &= 1.56 - 0.75 \cdot 1.06 \\
 &= 0.76
 \end{aligned}$$

$$\begin{aligned}
 \eta &= \left| - \left(\frac{\sigma_{m,d}}{k_{crit} \cdot k_r \cdot f_{m,y,d}} \right)^2 + \frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} \right| \\
 &= \left| - \left(\frac{-0.635 \text{ N/mm}^2}{0.76 \cdot 1.00 \cdot 23.040 \text{ N/mm}^2} \right)^2 + \frac{-0.134 \text{ N/mm}^2}{0.67 \cdot 23.040 \text{ N/mm}^2} \right| \\
 &= 0.010
 \end{aligned}$$

$$\eta = 0.010 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na interakciju savijanja s bočnim izvijanjima tlaka paralelno s vlakancima zadovoljava s iskoristivosti od 1.00%.

Tablica 85.: Rekapitulacija iskoristivosti glavnog uzdužnog nosača

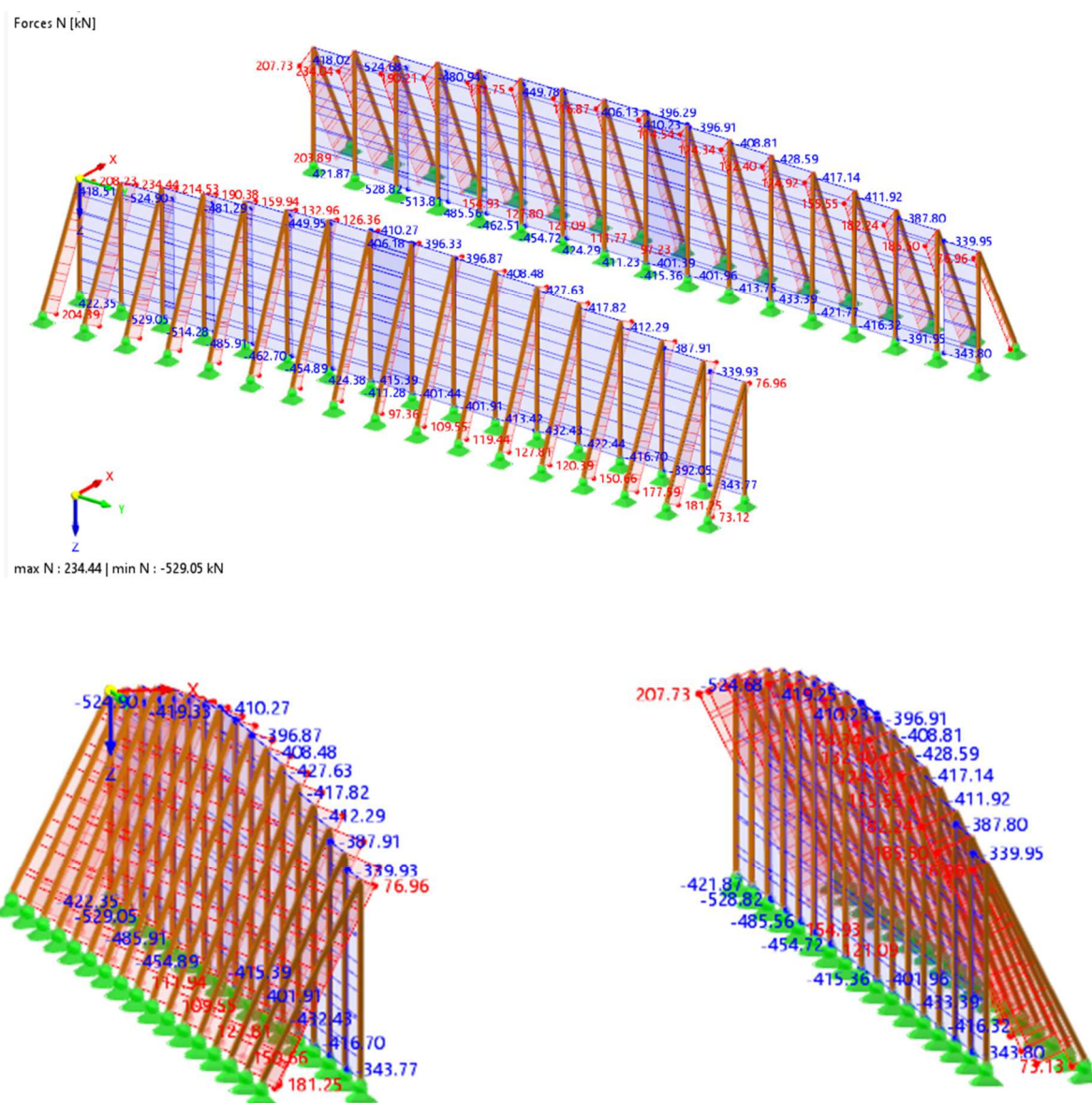
GLAVNI UZDUŽNI NOSAČ			
Provjera nosivosti elementa			Iskoristivost
1.	DOKAZI NOSIVOSTI PRESIEKA	Vlak paralelno s vlakancima	8,90%
2.		Tlak paralelno s vlakancima	0,60%
3.		Torzijski posmik	6,60%
4.		Posmik u vertikalnoj (z) osi	10,00%
5.		Posmik u horizontalnoj (y) osi	10,10%
6.		Savijanje oko horizontalne (y) osi	2,50%
7.		Interakcija vlaka okomito na vlakanca i savijanja	1,10%
8.		Interakcija dvoosnog savijanja i vlaka paralelno s vlakancima	16,30%
9.		Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima	9,00%
10.	DOKAZI NOSIVOSTI ELEMENTA	Interakcija dvoosnog savijanja i tlaka paralelno s vlakancima s izvijanjem	9,90%
11.		Savijanje s bočnim izvijanjem	4,90%
12.		Interakcija savijanja s bočnim izvijanjem i tlaka paralelno s vlakancima	1,00%
Mjerodavna iskoristivost			16,30%

4.4. Dimenzioniranje stupova

4.4.1. Ulazni podaci

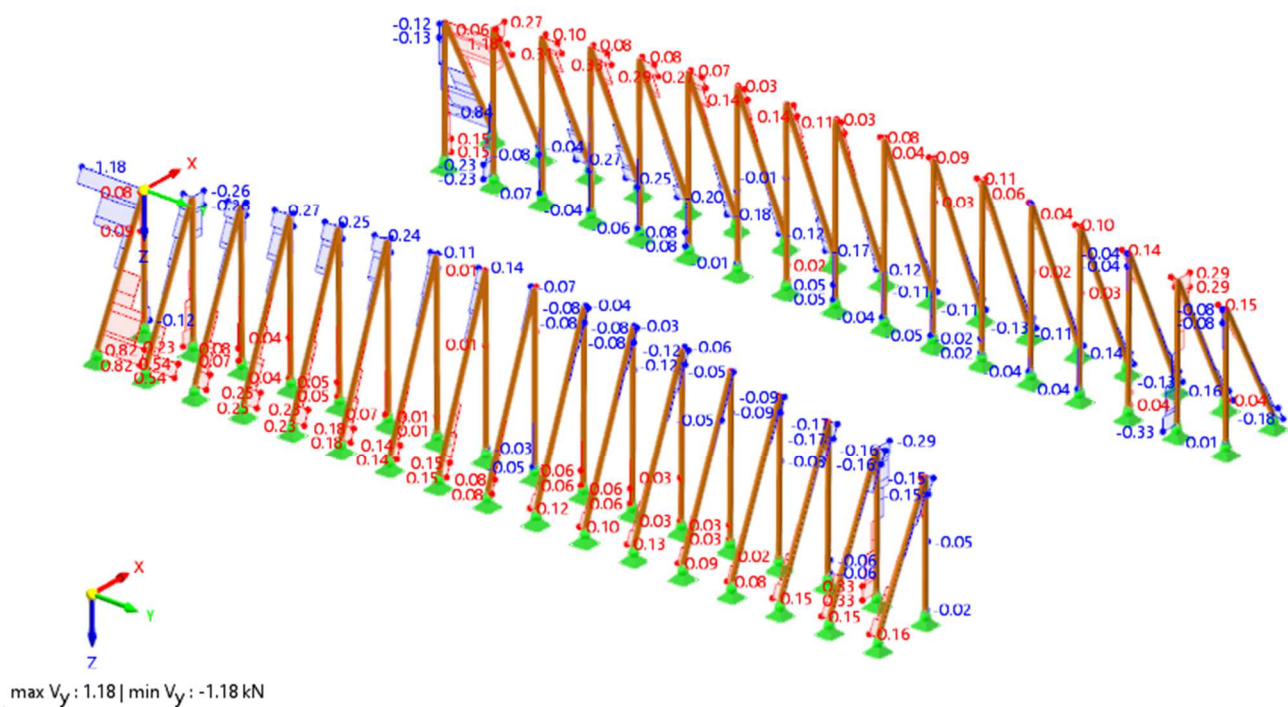
4.4.1.1. Dijagrami unutarnjih sila

Mjerodavna kombinacija opterećenja na stupove, odnosno kombinacija opterećenja koja uzrokuje najkritičnije stanje za konstrukciju je kombinacija CO5, odnosno $1.35 \cdot LC1 + 1.35 \cdot LC2 + 1.50 \cdot LC3 + 0,9 \cdot LC5$ Dijagrami unutarnjih sila za mjerodavnu kombinaciju dani su na idućim slikama.



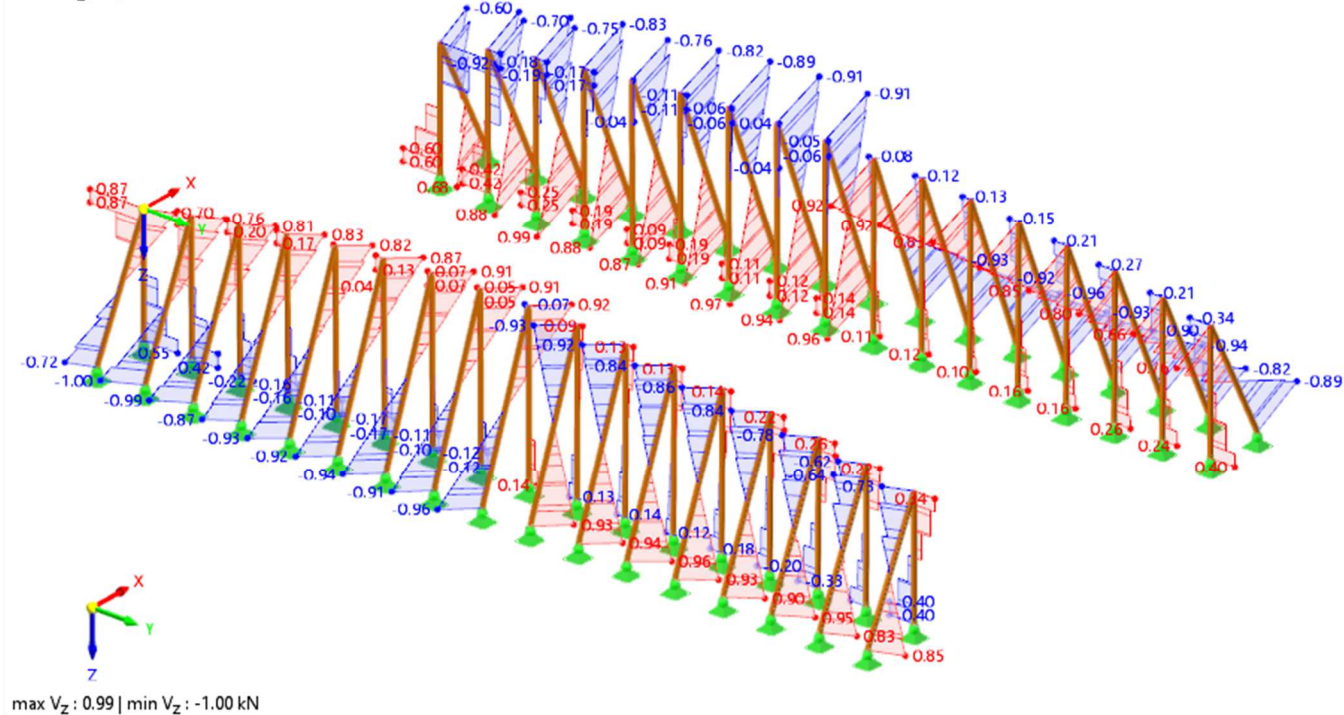
Slika 4.26.: Dijagram uzdužnih sila N [kN]

Forces V_y [kN]



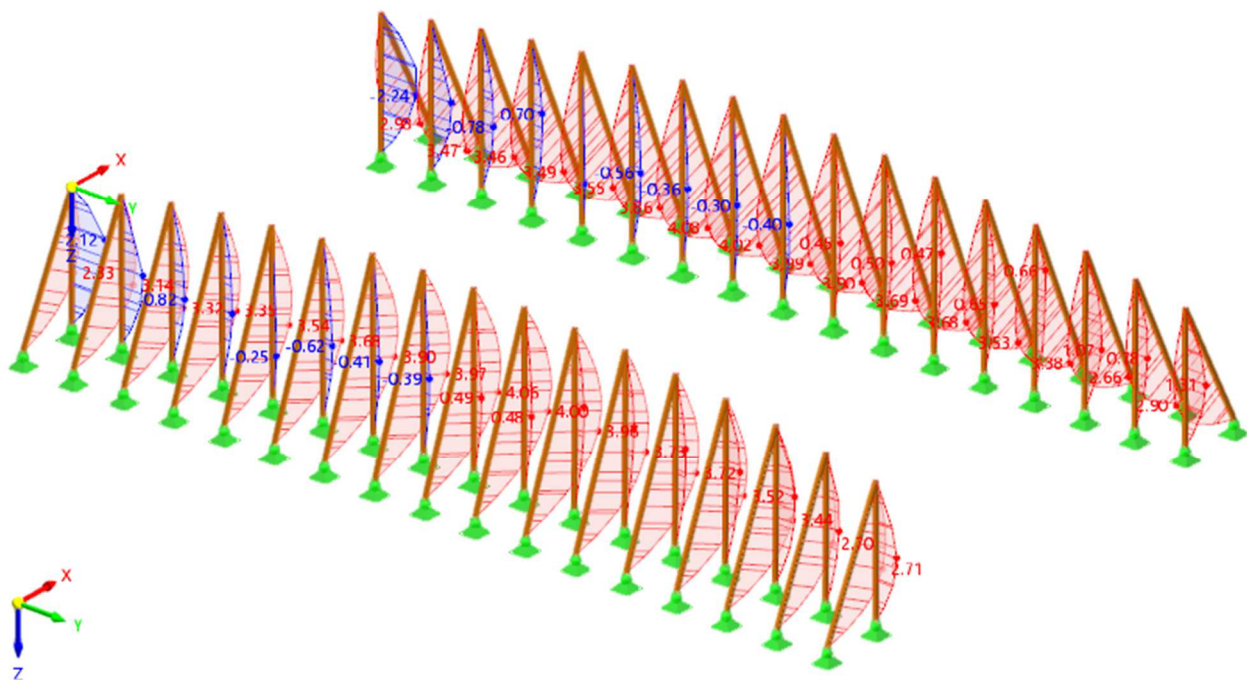
Slika 4.27.: Dijagram poprečnih sila V_y [kN]

Forces V_z [kN]



Slika 4.28.: Dijagram poprečnih sila V_z [kN]

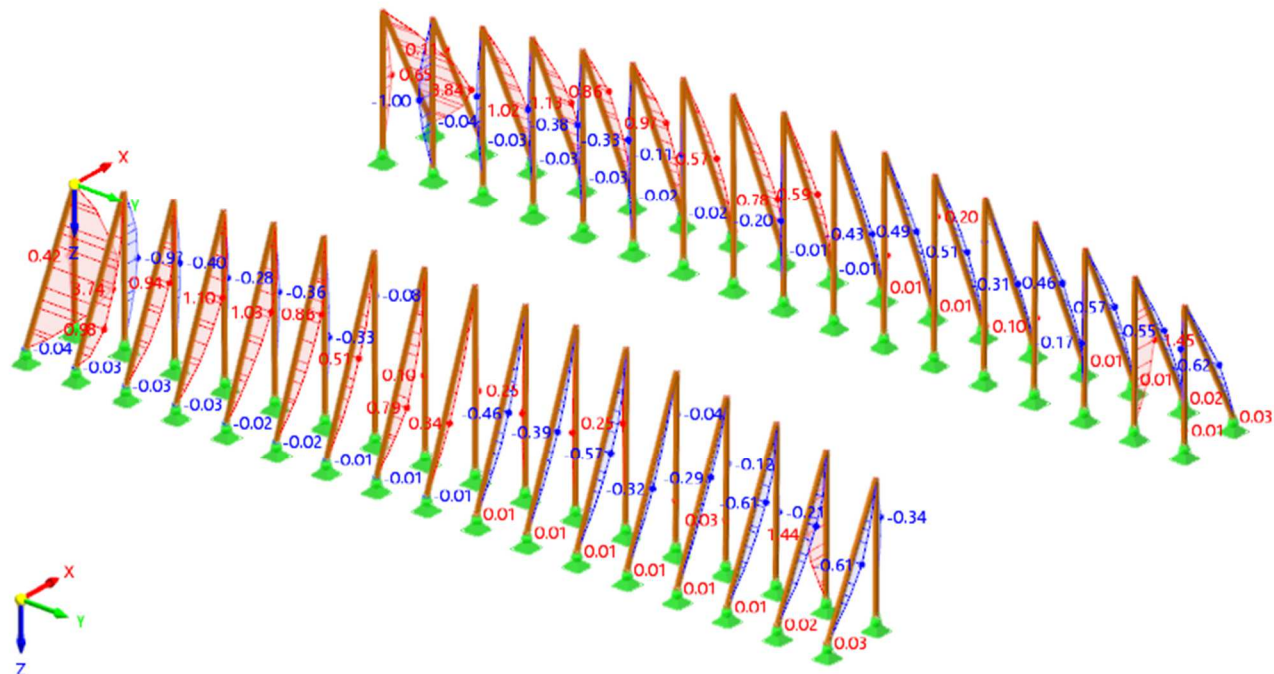
Moments M_y [kNm]



max M_y : 4.08 | min M_y : -2.24 kNm

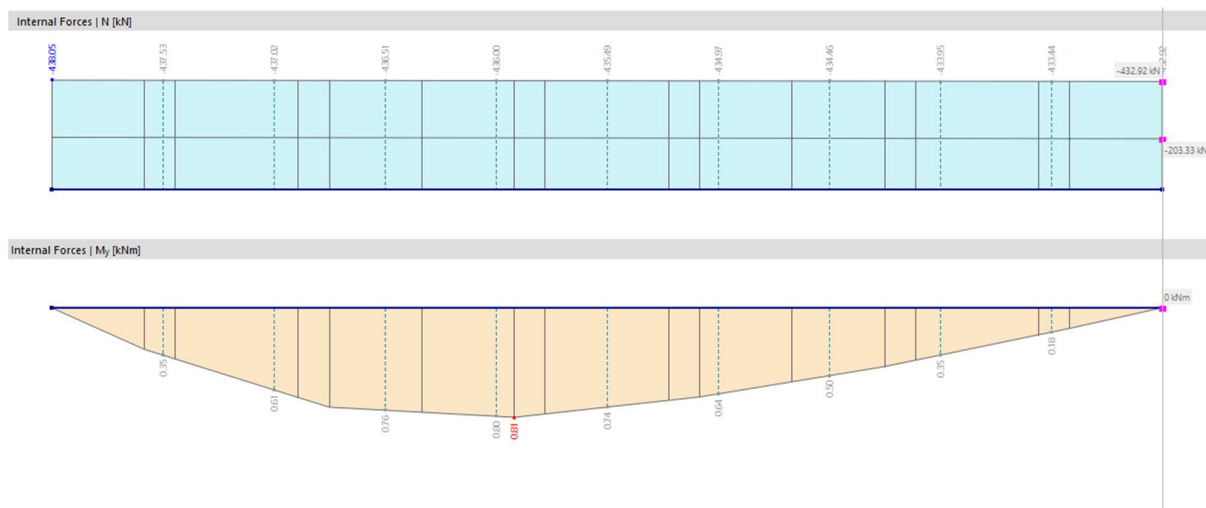
Slika 4.29.: Dijagram momenata savijanja M_y [kNm]

Moments M_z [kNm]



max M_z : 3.84 | min M_z : -1.00 kNm

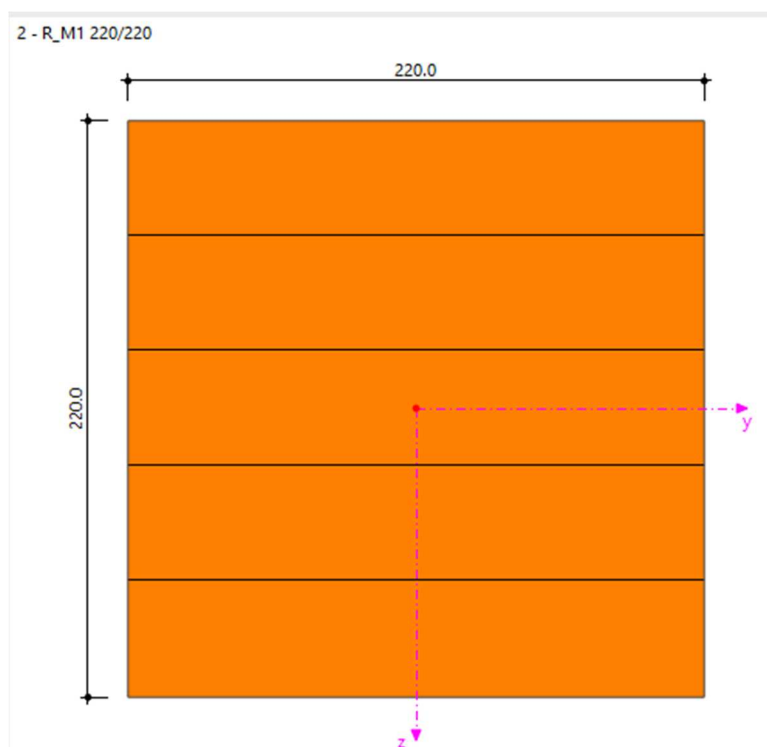
Slika 4.30.: Dijagram momenata savijanja M_z [kNm]



Slika 4.31.: Maksimalna opterećenja na stupove [kN]

Stupovi su štapni elementi, ali radi horizontalnog opterećenja vjetrom, također su pod utjecajem posmičnih naprezanja i naprezanja od savijanja.

Poprečni presjek:



Slika 4.32.: Poprečni presjek stupa [mm]

$$h=220 \text{ mm}$$

$$b=220 \text{ mm}$$

$$A= 484.00\text{cm}^2$$

$$I_y= 19521.33 \text{ cm}^4$$

$$I_z= 19521.33 \text{ cm}^4$$

$$W_y= 1774.67 \text{ cm}^3$$

$$W_z= 1774.67 \text{ cm}^3$$

Karakteristične vrijednosti čvrstoće drva GL32h

– Karakteristična čvrstoća savijanja	$f_{m,k} = 32,0 \text{ N/mm}^2$
– Karakteristična vlačna čvrstoća paralelno s vlakancima	$f_{t,0,k} = 26,5 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća paralelno s vlakancima	$f_{c,0,k} = 32 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća okomito na vlakanca	$f_{c,90,k} = 2,5 \text{ N/mm}^2$
– Karakteristična posmična torzijska čvrstoća	$f_{v,k} = 3,5 \text{ N/mm}^2$
– Karakteristični modul elastičnosti paralelno s vlakancima	$E_{0,05} = 11800 \text{ N/mm}^2$
– Srednji modul elastičnosti paralelno s vlakancima	$E_{0,mean} = 14200 \text{ N/mm}^2$
– Srednji modul posmika	$G_{mean} = 650 \text{ N/mm}^2$
– Srednja gustoća	$\rho_k = 440 \text{ N/mm}^2$
– Vrijednost čimbenika modifikacije	$k_{mod} = 0,8$

Tlak paralelno s vlakancima sa izvijanjem

Tablica 86.: Unutarnje sile

Design normal force	N_{Ed}	-438.05	kN	
Design shear force	$V_{y,Ed}$	0.00	kN	Negligible
Design shear force	$V_{z,Ed}$	0.00	kN	Negligible
Design torsional moment	T_{Ed}	0.00	kNm	Negligible
Design bending moment	$M_{y,Ed}$	0.00	kNm	Negligible
Design bending moment	$M_{z,Ed}$	0.00	kNm	Negligible

Tablica 87.: Parametri proračuna

Design compression force	$N_{c,Ed}$	438.05	kN	
Design compressive stress	$\sigma_{c,0,d}$	-9.051	N/mm ²	
Equivalent member length	$L_{cr,y}$	16.000	m	
Equivalent member length	$L_{cr,z}$	16.000	m	
Radius of gyration	i_y	63.5	mm	
Radius of gyration	i_z	63.5	mm	
Slenderness ratio	λ_y	251.93	--	
Slenderness ratio	λ_z	251.93	--	
Modulus of elasticity	$E_{0,05,y}$	11800.0	N/mm ²	
Modulus of elasticity	$E_{0,05,z}$	11800.0	N/mm ²	
Characteristic compressive strength	$f_{c,0,k}$	32.000	N/mm ²	
Relative slenderness ratio	$\lambda_{rel,y}$	4.18	--	
Relative slenderness ratio	$\lambda_{rel,z}$	4.18	--	
Straightness factor	β_c	0.10	--	
Instability factor	k_y	9.41	--	
Instability factor	k_z	9.41	--	
Instability factor	k_{cy}	0.06	--	
Instability factor	k_{cz}	0.06	--	
Design compressive strength	$f_{c,0,d}$	20.480	N/mm ²	
Design ratio 1	η_1	7.889	--	
Design ratio 2	η_2	7.889	--	
Design check ratio	η	7.889	--	> 1 ❗

$$\begin{aligned}\lambda_y &= \frac{L_{cr,y}}{i_y} \\ &= \frac{16.000 \text{ m}}{63.5 \text{ mm}} \\ &= 251.93\end{aligned}$$

$$\begin{aligned}\lambda_z &= \frac{L_{cr,z}}{i_z} \\ &= \frac{16.000 \text{ m}}{63.5 \text{ mm}} \\ &= 251.93\end{aligned}$$

$$\begin{aligned}\lambda_{rel,y} &= \frac{\lambda_y}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,y}}} \\ &= \frac{251.93}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 4.18\end{aligned}$$

$$\begin{aligned}\lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\ &= \frac{251.93}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 4.18\end{aligned}$$

$$\lambda_{rel,y} > 0.3 \text{ or } \lambda_{rel,z} > 0.3$$

$$\begin{aligned}k_y &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,y} - 0.3) + (\lambda_{rel,y})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (4.18 - 0.3) + (4.18)^2\right) \\ &= 9.41\end{aligned}$$

$$\begin{aligned}k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (4.18 - 0.3) + (4.18)^2\right) \\ &= 9.41\end{aligned}$$

$$\begin{aligned}k_{c,y} &= \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \\ &= \frac{1}{9.41 + \sqrt{(9.41)^2 - (4.18)^2}} \\ &= 0.06\end{aligned}$$

$$\begin{aligned}k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\ &= \frac{1}{9.41 + \sqrt{(9.41)^2 - (4.18)^2}} \\ &= 0.06\end{aligned}$$

$$\begin{aligned}\eta_1 &= \frac{|\sigma_{c,0,d}|}{k_{c,y} \cdot f_{c,0,d}} \\ &= \frac{|-9.051 \text{ N/mm}^2|}{0.06 \cdot 20.480 \text{ N/mm}^2} \\ &= 7.889\end{aligned}$$

$$\begin{aligned}\eta_2 &= \frac{|\sigma_{c,0,d}|}{k_{c,z} \cdot f_{c,0,d}} \\ &= \frac{|-9.051 \text{ N/mm}^2|}{0.06 \cdot 20.480 \text{ N/mm}^2} \\ &= 7.889\end{aligned}$$

$$\begin{aligned}\eta &= \max(\eta_1, \eta_2) \\ &= \max(7.889, 7.889) \\ &= 7.889\end{aligned}$$

$$\eta = 7.889 > 1 \quad \color{red}\blacktriangledown$$

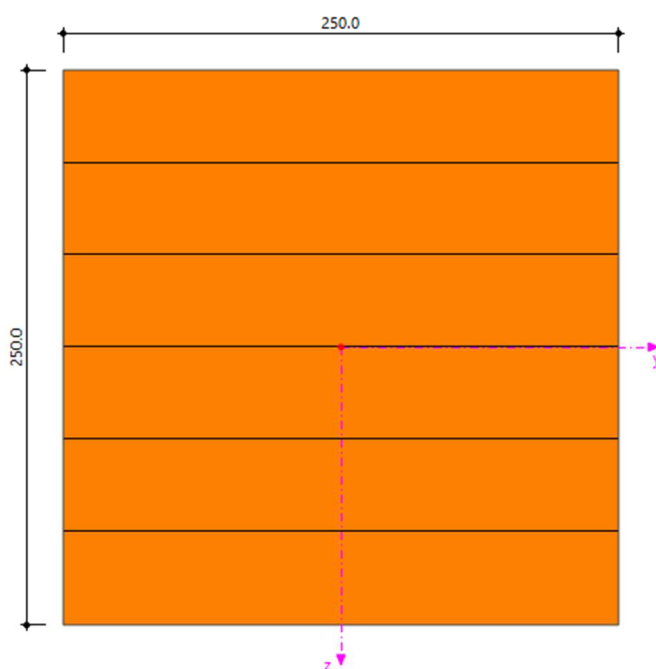
Provjera stupa na tlak paralelno s vlakancima sa izvijanjem ne zadovoljava provjeru nosivosti, te je potrebno ponoviti proračun s novim presjekom.

S obzirom na veliku razliku u iskoristivosti između vlačno i tlačno opterećenih stupova, odabrani su različiti presjeci za stupove kako bi se povećala iskoristivost.

Odabrani novi poprečni presjeci;

Vlačni stup

6 - R_M1 250/250



Slika 4.33.: Poprečni presjek vlačnog stupa [mm]

$$h=250 \text{ mm}$$

$$b=250 \text{ mm}$$

$$A=625.00 \text{ cm}^2$$

$$I_y= 32552.08 \text{ cm}^4$$

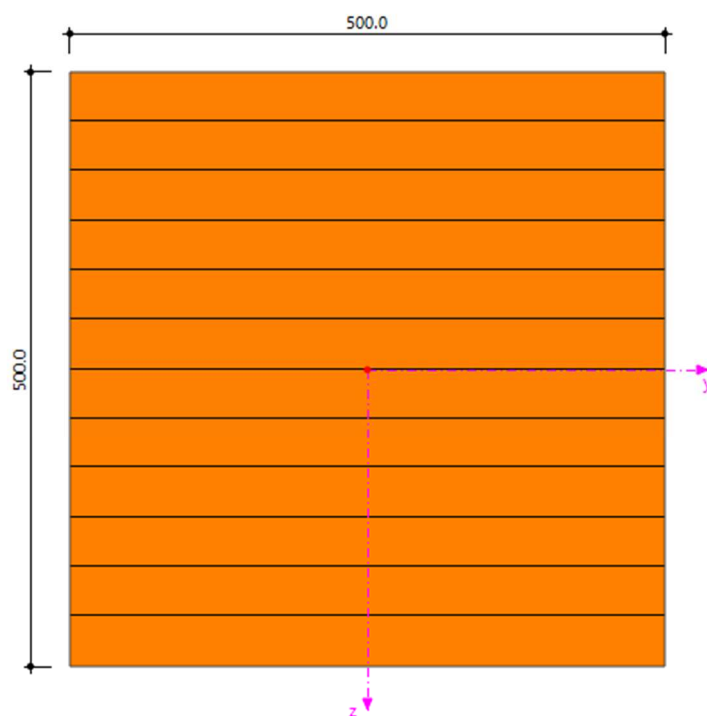
$$I_z= 32552.08 \text{ cm}^4$$

$$W_y= 2604.17 \text{ cm}^3$$

$$W_z= 2604.17 \text{ cm}^3$$

Tlačni stup

2 - R_M1 500/500



Slika 4.34.: Poprečni presjek tlačnog stupa [mm]

$$h=500 \text{ mm}$$

$$b=500 \text{ mm}$$

$$A= 2500.00 \text{ cm}^2$$

$$I_y= 520833.33 \text{ cm}^4$$

$$I_z= 520833.33 \text{ cm}^4$$

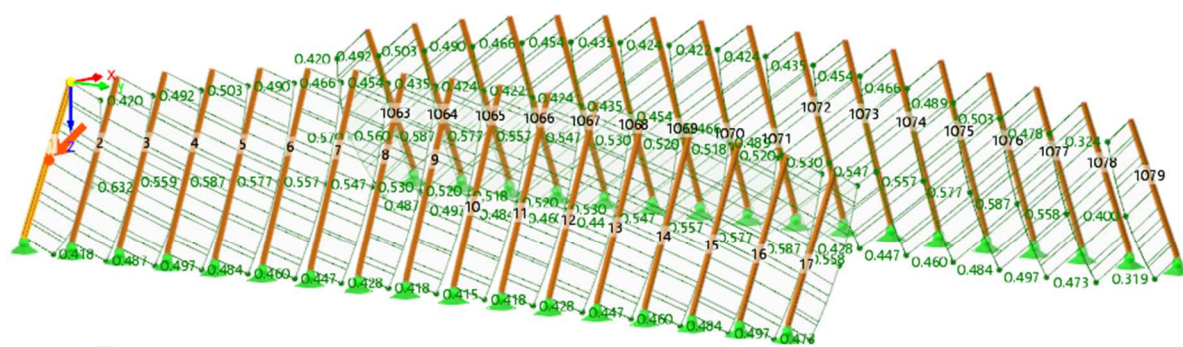
$$W_y= 20833.33 \text{ cm}^3$$

$$W_z= 20833.33 \text{ cm}^3$$

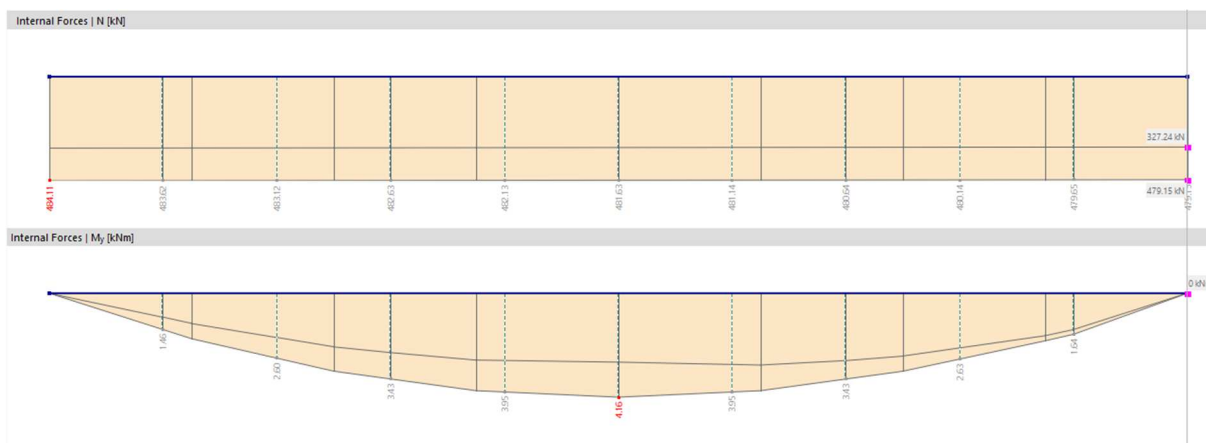
Karakteristične vrijednosti čvrstoće drva GL32h

– Karakteristična čvrstoća savijanja	$f_{m,k} = 32,0 \text{ N/mm}^2$
– Karakteristična vlačna čvrstoća paralelno s vlakancima	$f_{t,0,k} = 26,5 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća paralelno s vlakancima	$f_{c,0,k} = 32 \text{ N/mm}^2$
– Karakteristična tlačna čvrstoća okomito na vlakanca	$f_{c,90,k} = 2,5 \text{ N/mm}^2$
– Karakteristična posmična torzijska čvrstoća	$f_{v,k} = 3,5 \text{ N/mm}^2$
– Karakteristični modul elastičnosti paralelno s vlakancima	$E_{0,05} = 11800 \text{ N/mm}^2$
– Srednji modul elastičnosti paralelno s vlakancima	$E_{0,mean} = 14200 \text{ N/mm}^2$
– Srednji modul posmika	$G_{mean} = 650 \text{ N/mm}^2$
– Srednja gustoća	$\rho_k = 440 \text{ N/mm}^2$
– Vrijednost čimbenika modifikacije	$k_{mod} = 0,8$

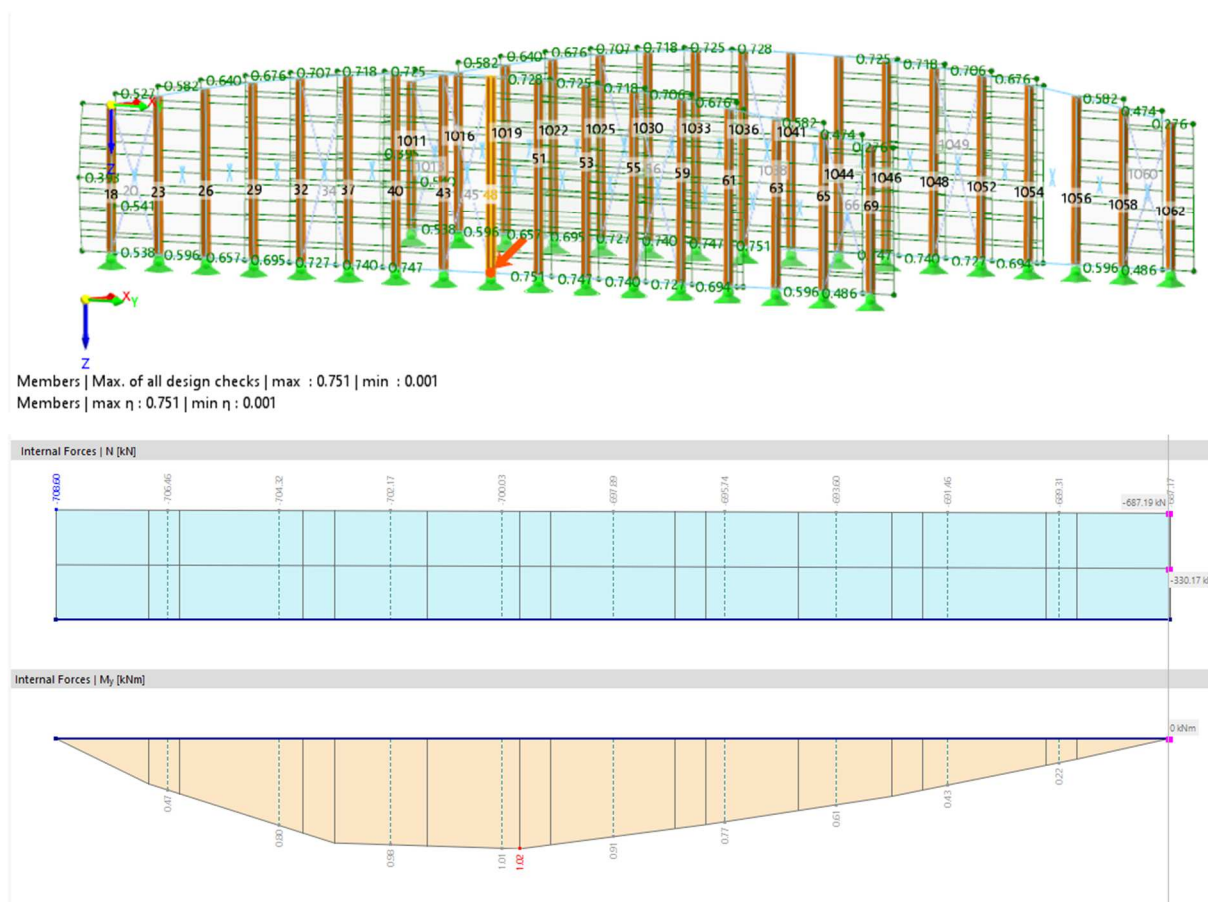
Najopterećeniji stup



Members | Max. of all design checks | max : 0.632 | min : 0.000
 Members | max η : 0.632 | min η : 0.000



Slika 4.35.: Najopterećeniji vlačni stup [kN]



Slika 4.36.: Najopterećeniji tlačni stup [kN]

4.4.2. Dokaz nosivosti vlačnih stupova

4.4.2.1. Dokazi nosivosti presjeka;

Vlak paralelno s vlakancima

Tablica 88.: Unutarnje sile

Design normal force	N_{Ed}	491.20	kN	
Design shear force	$V_{y,Ed}$	0.00	kN	Negligible
Design shear force	$V_{z,Ed}$	1.24	kN	
Design torsional moment	T_{Ed}	-0.02	kNm	Negligible
Design bending moment	$M_{y,Ed}$	0.00	kNm	Negligible
Design bending moment	$M_{z,Ed}$	0.00	kNm	Negligible

Tablica 89.: Parametri proračuna

Design tension force	$N_{t,Ed}$	491.20	kN	
Sectional area	A	625.00	cm ²	
Design tensile stress	$\sigma_{t,0,d}$	7.859	N/mm ²	
Design tensile strength	$f_{t,0,d}$	16.384	N/mm ²	
Design check ratio	η	0.480	--	≤ 1 ✓

$$\begin{aligned}\eta &= \frac{\sigma_{t,0,d}}{f_{t,0,d}} \\ &= \frac{7.859 \text{ N/mm}^2}{16.384 \text{ N/mm}^2} \\ &= 0.480\end{aligned}$$

$$\eta = 0.480 \leq 1 \quad \checkmark$$

Provjera stupa na vlak paralelno s vlakancima zadovoljava s iskoristivosti od 48.00%.

Torzijski posmik

Tablica 90.: Unutarnje sile

Design normal force	N _{Ed}	411.69	kN	
Design shear force	V _{y,Ed}	-2.66	kN	
Design shear force	V _{z,Ed}	1.09	kN	
Design torsional moment	T _{Ed}	-0.23	kNm	
Design bending moment	M _{y,Ed}	0.00	kNm	Negligible
Design bending moment	M _{z,Ed}	0.00	kNm	Negligible

Tablica 91.: Parametri proračuna

Design torsional moment	T _{Ed}	0.23	kNm	
Design torsional stress	τ _{tor,d}	0.070	N/mm ²	
Torsion factor	k _{shape}	1.05	--	
Design shear strength	f _{v,d}	2.520	N/mm ²	
Design check ratio	η	0.026	--	≤ 1 ✓

$$\begin{aligned}
 \eta &= \frac{\tau_{tor,d}}{k_{shape} \cdot f_{v,d}} \\
 &= \frac{0.070 \text{ N/mm}^2}{1.05 \cdot 2.520 \text{ N/mm}^2} \\
 &= 0.026
 \end{aligned}$$

$$\eta = 0.026 \leq 1 \quad \checkmark$$

Provjera stupa na torzijski posmik zadovoljava s iskoristivosti od 2.60%.

Posmik u vertikalnoj (z) osi

Tablica 92.: Unutarnje sile

Design normal force	N_{Ed}	476.92	kN	
Design shear force	$V_{y,Ed}$	0.00	kN	Negligible
Design shear force	$V_{z,Ed}$	1.24	kN	
Design torsional moment	T_{Ed}	-0.02	kNm	Negligible
Design bending moment	$M_{y,Ed}$	0.00	kNm	Negligible
Design bending moment	$M_{z,Ed}$	0.00	kNm	Negligible

Tablica 93.: Parametri proračuna

Design shear force	$V_{z,Ed}$	1.24	kN	
Shear stress	τ_{xz}	0.030	N/mm ²	
Crack influence factor	k_{cr}	0.67	--	
Design shear stress	$\tau_{xz,d}$	0.044	N/mm ²	
Design shear strength	$f_{v,z,d}$	2.240	N/mm ²	
Design check ratio	η	0.020	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{|\tau_{xz,d}|}{f_{v,z,d}} \\ &= \frac{|0.044 \text{ N/mm}^2|}{2.240 \text{ N/mm}^2} \\ &= 0.020 \end{aligned}$$

$$\eta = 0.020 \leq 1 \quad \checkmark$$

Provjera stupa na posmik u vertikalnoj (z) osi zadovoljava s iskoristivosti od 2.00%.

Posmik u horizontalnoj (y) osi

Tablica 94.: Unutarnje sile

Design normal force	N _{Ed}	464.51	kN		
Design shear force	V _{y,Ed}	-2.66	kN		
Design shear force	V _{z,Ed}	0.95	kN		
Design torsional moment	T _{Ed}	-0.22	kNm		
Design bending moment	M _{y,Ed}	0.00	kNm		Negligible
Design bending moment	M _{z,Ed}	0.00	kNm		Negligible

Tablica 95.: Parametri proračuna

Design shear force	V _{y,Ed}	2.66	kN		
Shear stress	τ _{xy}	-0.064	N/mm ²		
Crack influence factor	k _{cr}	0.67	--		
Design shear stress	τ _{xy,d}	-0.095	N/mm ²		
Design shear strength	f _{v,y,d}	2.520	N/mm ²		
Design check ratio	η	0.038	--	≤ 1	✓

$$\begin{aligned} \eta &= \frac{|\tau_{xy,d}|}{f_{v,y,d}} \\ &= \frac{|-0.095 \text{ N/mm}^2|}{2.520 \text{ N/mm}^2} \\ &= 0.038 \end{aligned}$$

$$\eta = 0.038 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na posmik u horizontalnoj (y) osi zadovoljava s iskoristivosti od 3.80%.

Interakcija dvoosnog savijanja i vlaka paralelno s vlakancima

Tablica 96.: Unutarnje sile

Design normal force	N _{Ed}	462.03	kN
Design shear force	V _{y,Ed}	-0.64	kN
Design shear force	V _{z,Ed}	-0.07	kN
Design torsional moment	T _{Ed}	-0.22	kNm
Design bending moment	M _{y,Ed}	3.21	kNm
Design bending moment	M _{z,Ed}	10.09	kNm

Tablica 97.: Parametri proračuna

Design tension force	N _{t,Ed}	462.03	kN
Design tensile stress	σ _{t,0,d}	7.392	N/mm ²
Design bending moment	M _{y,Ed}	3.21	kNm
Design bending stress	σ _{m,y,d}	1.233	N/mm ²
Design bending moment	M _{z,Ed}	10.09	kNm
Design bending stress	σ _{m,z,d}	3.874	N/mm ²
Design tensile strength	f _{t,0,d}	18.432	N/mm ²
Design bending strength	f _{m,y,d}	23.040	N/mm ²
Design bending strength	f _{m,z,d}	23.040	N/mm ²
Redistribution factor	k _m	0.70	--
Design ratio 1	η ₁	0.572	--
Design ratio 2	η ₂	0.607	--
Design check ratio	η	0.607	-- ≤ 1 ✓

$$\begin{aligned} \eta_1 &= \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| \frac{7.392 \text{ N/mm}^2}{18.432 \text{ N/mm}^2} + \frac{1.233 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{3.874 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.572 \end{aligned}$$

$$\begin{aligned} \eta_2 &= \left| \frac{\sigma_{t,0,d}}{f_{t,0,d}} + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| \frac{7.392 \text{ N/mm}^2}{18.432 \text{ N/mm}^2} + 0.70 \cdot \frac{1.233 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + \frac{3.874 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.607 \end{aligned}$$

$$\begin{aligned} \eta &= \max(\eta_1, \eta_2) \\ &= \max(0.572, 0.607) \\ &= 0.607 \end{aligned}$$

$$\eta = 0.607 \leq 1 \quad \checkmark$$

Provjera stupa na interakciju dvoosnog savijanja i vlaka paralelno s vlakancima zadovoljava s iskoristivosti od 60.70%.

Tablica 98.: Rekapitulacija iskoristivosti vlačnih stupova

VLAČNI STUPOVI			
Provjera nosivosti elementa			Iskoristivost
1.	DOKAZI NOSIVOSTI PRESJEKA	Vlak paralelno s vlakancima	48,00%
2.		Torzijski posmik	2,60%
3.		Posmik u vertikalnoj (z) osi	2,00%
4.		Posmik u horizontalnoj (y) osi	3,80%
5.		Dvoosno savijanje	60,70%
Mjerodavna iskoristivost			60,70%

4.4.3. Dokaz nosivosti tlačnih stupova

4.4.3.1. Dokazi nosivosti presjeka;

Tlak paralelno s vlakancima

Tablica 99.: Unutarnje sile

Design normal force	N_{Ed}	-857.18	kN	
Design shear force	$V_{y,Ed}$	-0.09	kN	Negligible
Design shear force	$V_{z,Ed}$	-0.76	kN	
Design torsional moment	T_{Ed}	-0.39	kNm	Negligible
Design bending moment	$M_{y,Ed}$	0.00	kNm	Negligible
Design bending moment	$M_{z,Ed}$	0.00	kNm	Negligible

Tablica 100.: Parametri proračuna

Compressive strength				
Design compression force	$N_{c,Ed}$	857.18	kN	
Sectional area	A	2025.00	cm ²	
Design compressive stress	$\sigma_{c,0,d}$	-4.233	N/mm ²	
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²	
Design check ratio	η	0.184	--	≤ 1 ✓

$$\begin{aligned}\eta &= \frac{|\sigma_{c,0,d}|}{f_{c,0,d}} \\ &= \frac{|-4.233 \text{ N/mm}^2|}{23.040 \text{ N/mm}^2} \\ &= 0.184\end{aligned}$$

$$\eta = 0.184 \leq 1 \quad \checkmark$$

Provjera stupa na tlak paralelno s vlakancima zadovoljava s iskoristivosti od 18.40%.

Torzijski posmik

Tablica 101.: Unutarnje sile

Design normal force	N _{Ed}	-806.94	kN	
Design shear force	V _{y,Ed}	-0.16	kN	Negligible
Design shear force	V _{z,Ed}	-1.28	kN	
Design torsional moment	T _{Ed}	-0.53	kNm	
Design bending moment	M _{y,Ed}	0.00	kNm	Negligible
Design bending moment	M _{z,Ed}	0.00	kNm	Negligible

Tablica 102.: Parametri proračuna

Design torsional moment	T _{Ed}	0.53	kNm	
Design torsional stress	τ _{tor,d}	0.028	N/mm ²	
Torsion factor	k _{shape}	1.05	--	
Design shear strength	f _{v,d}	2.520	N/mm ²	
Design check ratio	η	0.011	--	≤ 1 ✓

$$\begin{aligned}
 \eta &= \frac{\tau_{tor,d}}{k_{shape} \cdot f_{v,d}} \\
 &= \frac{0.028 \text{ N/mm}^2}{1.05 \cdot 2.520 \text{ N/mm}^2} \\
 &= 0.011
 \end{aligned}$$

$$\eta = 0.011 \leq 1 \quad \checkmark$$

Provjera stupa na torzijski posmik zadovoljava s iskoristivosti od 1.10%.

Posmik u vertikalnoj (z) osi

Tablica 103.: Unutarnje sile

Design normal force	N _{Ed}	-568.68	kN	
Design shear force	V _{y,Ed}	-0.45	kN	
Design shear force	V _{z,Ed}	-4.33	kN	
Design torsional moment	T _{Ed}	0.15	kNm	Negligible
Design bending moment	M _{y,Ed}	0.00	kNm	Negligible
Design bending moment	M _{z,Ed}	0.00	kNm	Negligible

Tablica 104.: Parametri proračuna

Design shear force	V _{z,Ed}	4.33	kN	
Shear stress	τ _{xz}	-0.032	N/mm ²	
Crack influence factor	k _{cr}	0.67	--	
Design shear stress	τ _{xz,d}	-0.048	N/mm ²	
Design shear strength	f _{v,z,d}	2.520	N/mm ²	
Design check ratio	η	0.019	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{|\tau_{xz,d}|}{f_{v,z,d}} \\ &= \frac{|-0.048 \text{ N/mm}^2|}{2.520 \text{ N/mm}^2} \\ &= 0.019 \end{aligned}$$

$$\eta = 0.019 \leq 1 \quad \checkmark$$

Provjera stupa na posmik u vertikalnoj (z) osi zadovoljava s iskoristivosti od 1.90%.

Posmik u horizontalnoj (y) osi

Tablica 105.: Unutarnje sile

Design normal force	N _{Ed}	-274.35	kN	Negligible
Design shear force	V _{y,Ed}	1.90	kN	
Design shear force	V _{z,Ed}	-1.61	kN	
Design torsional moment	T _{Ed}	0.06	kNm	
Design bending moment	M _{y,Ed}	2.09	kNm	
Design bending moment	M _{z,Ed}	2.46	kNm	

Tablica 106.: Parametri proračuna

Design shear force	V _{y,Ed}	1.90	kN	
Shear stress	τ _{xy}	0.014	N/mm ²	
Crack influence factor	k _{cr}	0.67	--	
Design shear stress	τ _{xy,d}	0.021	N/mm ²	
Design shear strength	f _{v,y,d}	2.520	N/mm ²	
Design check ratio	η	0.008	--	≤ 1 ✓

$$\begin{aligned} \eta &= \frac{|\tau_{xy,d}|}{f_{v,y,d}} \\ &= \frac{|0.021 \text{ N/mm}^2|}{2.520 \text{ N/mm}^2} \\ &= 0.008 \end{aligned}$$

$$\eta = 0.008 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na posmik u horizontalnoj (y) osi zadovoljava s iskoristivosti od 0.80%.

Dvoosno savijanje

Tablica 107.: Unutarnje sile

Design normal force	N _{Ed}	-649.03	kN	Negligible
Design shear force	V _{y,Ed}	-0.88	kN	
Design shear force	V _{z,Ed}	-0.36	kN	
Design torsional moment	T _{Ed}	0.08	kNm	
Design bending moment	M _{y,Ed}	-11.26	kNm	
Design bending moment	M _{z,Ed}	4.10	kNm	

Tablica 108.: Parametri proračuna

Design compression force	N _{c,Ed}	649.03	kN	
Design compressive stress	σ _{c,0,d}	-3.205	N/mm ²	
Design bending moment	M _{y,Ed}	-11.26	kNm	
Design bending stress	σ _{m,y,d}	-0.742	N/mm ²	
Design bending moment	M _{z,Ed}	4.10	kNm	
Design bending stress	σ _{m,z,d}	-0.270	N/mm ²	
Design compressive strength	f _{c,0,d}	23.040	N/mm ²	
Design bending strength	f _{m,y,d}	23.040	N/mm ²	
Design bending strength	f _{m,z,d}	23.040	N/mm ²	
Redistribution factor	k _m	0.70	--	
Design ratio 1	η ₁	0.060	--	
Design ratio 2	η ₂	0.054	--	
Design check ratio	η	0.060	--	≤ 1 ✓

$$\eta_1 = \left| - \left(\frac{\sigma_{c,0,d}}{f_{c,0,d}} \right)^2 + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right|$$

$$= \left| - \left(\frac{-3.205 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right)^2 + \frac{-0.742 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.270 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right|$$

$$= 0.060$$

$$\eta_2 = \left| - \left(\frac{\sigma_{c,0,d}}{f_{c,0,d}} \right)^2 + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right|$$

$$= \left| - \left(\frac{-3.205 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right)^2 + 0.70 \cdot \frac{-0.742 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + \frac{-0.270 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right|$$

$$= 0.054$$

$$\eta = \max(\eta_1, \eta_2)$$

$$= \max(0.060, 0.054)$$

$$= 0.060$$

$$\eta = 0.060 \leq 1 \checkmark$$

Provjera glavnog uzdužnog nosača na dvoosno savijanje zadovoljava s iskoristivosti od 6.00%.

4.4.3.2. Dokazi nosivosti elementa;

Tlak paralelno s vlakancima s izvijanjem

Tablica 109.: Unutarnje sile

Design normal force	N _{Ed}	-708.60	kN	
Design shear force	V _{y,Ed}	0.00	kN	Negligible
Design shear force	V _{z,Ed}	0.00	kN	Negligible
Design torsional moment	T _{Ed}	0.00	kNm	Negligible
Design bending moment	M _{y,Ed}	0.00	kNm	Negligible
Design bending moment	M _{z,Ed}	0.00	kNm	Negligible

Tablica 110.: Parametri proračuna

Design compression force	N _{c,Ed}	708.60	kN	
Design compressive stress	σ _{c,0,d}	-3.499	N/mm ²	
Equivalent member length	L _{cr,y}	16.000	m	
Equivalent member length	L _{cr,z}	16.000	m	
Radius of gyration	i _y	129.9	mm	
Radius of gyration	i _z	129.9	mm	
Slenderness ratio	λ _y	123.17	--	
Slenderness ratio	λ _z	123.17	--	
Modulus of elasticity	E _{0,05,y}	11800.0	N/mm ²	
Modulus of elasticity	E _{0,05,z}	11800.0	N/mm ²	
Characteristic compressive strength	f _{c,0,k}	32.000	N/mm ²	
Relative slenderness ratio	λ _{rel,y}	2.04	--	
Relative slenderness ratio	λ _{rel,z}	2.04	--	
Straightness factor	β _c	0.10	--	
Instability factor	k _y	2.67	--	
Instability factor	k _z	2.67	--	
Instability factor	k _{c,y}	0.23	--	
Instability factor	k _{c,z}	0.23	--	
Design compressive strength	f _{c,0,d}	20.480	N/mm ²	
Design ratio 1	η ₁	0.751	--	
Design ratio 2	η ₂	0.751	--	
Design check ratio	η	0.751	--	≤ 1 ✓

$$\begin{aligned} \lambda_y &= \frac{L_{cr,y}}{i_y} \\ &= \frac{16.000 \text{ m}}{129.9 \text{ mm}} \\ &= 123.17 \end{aligned}$$

$$\begin{aligned} \lambda_z &= \frac{L_{cr,z}}{i_z} \\ &= \frac{16.000 \text{ m}}{129.9 \text{ mm}} \\ &= 123.17 \end{aligned}$$

$$\begin{aligned} \lambda_{rel,y} &= \frac{\lambda_y}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,y}}} \\ &= \frac{123.17}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \end{aligned}$$

$$\begin{aligned}\lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\ &= \frac{123.17}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 2.04\end{aligned}$$

$$\lambda_{rel,y} > 0.3 \text{ or } \lambda_{rel,z} > 0.3$$

$$\begin{aligned}k_y &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,y} - 0.3) + (\lambda_{rel,y})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (2.04 - 0.3) + (2.04)^2\right) \\ &= 2.67\end{aligned}$$

$$\begin{aligned}k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (2.04 - 0.3) + (2.04)^2\right) \\ &= 2.67\end{aligned}$$

$$\begin{aligned}k_{c,y} &= \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \\ &= \frac{1}{2.67 + \sqrt{(2.67)^2 - (2.04)^2}} \\ &= 0.23\end{aligned}$$

$$\begin{aligned}k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\ &= \frac{1}{2.67 + \sqrt{(2.67)^2 - (2.04)^2}} \\ &= 0.23\end{aligned}$$

$$\begin{aligned}\eta_1 &= \frac{|\sigma_{c,0,d}|}{k_{c,y} \cdot f_{c,0,d}} \\ &= \frac{|-3.499 \text{ N/mm}^2|}{0.23 \cdot 20.480 \text{ N/mm}^2} \\ &= 0.751\end{aligned}$$

$$\begin{aligned}\eta_2 &= \frac{|\sigma_{c,0,d}|}{k_{c,z} \cdot f_{c,0,d}} \\ &= \frac{|-3.499 \text{ N/mm}^2|}{0.23 \cdot 20.480 \text{ N/mm}^2} \\ &= 0.751\end{aligned}$$

$$\begin{aligned}\eta &= \max(\eta_1, \eta_2) \\ &= \max(0.751, 0.751) \\ &= 0.751\end{aligned}$$

$$\eta = 0.751 \leq 1 \quad \checkmark$$

Provjera stupa na tlak paralelno s vlakancima s izvijanjem zadovoljava s iskoristivosti od 75.10%.

Interakcija savijanja s bočnim izvijanjem u y osi i tlaka paralelno s vlakancima s izvijanjem

Tablica 111.: Unutarnje sile

Design normal force	N _{Ed}	-734.07	kN	
Design shear force	V _{y,Ed}	-0.06	kN	Negligible
Design shear force	V _{z,Ed}	-0.32	kN	
Design torsional moment	T _{Ed}	-0.24	kNm	Negligible
Design bending moment	M _{y,Ed}	-0.41	kNm	
Design bending moment	M _{z,Ed}	0.08	kNm	Negligible

Tablica 112.: Parametri proračuna

Design compression force	N _{c,Ed}	734.07	kN	
Design compressive stress	σ _{c,0,d}	-3.625	N/mm ²	
Design bending moment	M _{y,Ed}	-0.41	kNm	
Design bending stress	σ _{m,y,d}	-0.027	N/mm ²	
Equivalent member length	L _{cr,y}	15.436	m	
Equivalent member length	L _{cr,z}	15.436	m	
Radius of gyration	i _y	129.9	mm	
Radius of gyration	i _z	129.9	mm	
Slenderness ratio	λ _y	118.83	--	
Slenderness ratio	λ _z	118.83	--	
Modulus of elasticity	E _{0,05,y}	11800.0	N/mm ²	
Modulus of elasticity	E _{0,05,z}	11800.0	N/mm ²	
Characteristic compressive strength	f _{c,0,k}	32.000	N/mm ²	
Relative slenderness ratio	λ _{rel,y}	1.97	--	
Relative slenderness ratio	λ _{rel,z}	1.97	--	
Straightness factor	β _c	0.10	--	
Instability factor	k _y	2.52	--	
Instability factor	k _z	2.52	--	
Instability factor	k _{c,y}	0.24	--	
Instability factor	k _{c,z}	0.24	--	
Design compressive strength	f _{c,0,d}	23.040	N/mm ²	
Design bending strength	f _{m,y,d}	23.040	N/mm ²	
Redistribution factor	k _m	0.70	--	
Design ratio 1	η ₁	0.646	--	
Design ratio 2	η ₂	0.646	--	
Design check ratio	η	0.646	--	≤ 1 ✓

$$\begin{aligned} \lambda_y &= \frac{L_{cr,y}}{i_y} \\ &= \frac{15.436 \text{ m}}{129.9 \text{ mm}} \\ &= 118.83 \end{aligned}$$

$$\begin{aligned} \lambda_z &= \frac{L_{cr,z}}{i_z} \\ &= \frac{15.436 \text{ m}}{129.9 \text{ mm}} \\ &= 118.83 \end{aligned}$$

$$\begin{aligned}\lambda_{rel,y} &= \frac{\lambda_y}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,y}}} \\ &= \frac{118.83}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 1.97\end{aligned}$$

$$\begin{aligned}\lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\ &= \frac{118.83}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 1.97\end{aligned}$$

$$\lambda_{rel,y} > 0.3 \text{ or } \lambda_{rel,z} > 0.3$$

$$\begin{aligned}k_y &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,y} - 0.3) + (\lambda_{rel,y})^2 \right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (1.97 - 0.3) + (1.97)^2 \right) \\ &= 2.52\end{aligned}$$

$$\begin{aligned}k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2 \right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (1.97 - 0.3) + (1.97)^2 \right) \\ &= 2.52\end{aligned}$$

$$\begin{aligned}k_{c,y} &= \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \\ &= \frac{1}{2.52 + \sqrt{(2.52)^2 - (1.97)^2}} \\ &= 0.24\end{aligned}$$

$$\begin{aligned}k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\ &= \frac{1}{2.52 + \sqrt{(2.52)^2 - (1.97)^2}} \\ &= 0.24\end{aligned}$$

$$\begin{aligned}\eta_1 &= \left| \frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} \right| \\ &= \left| \frac{-3.625 \text{ N/mm}^2}{0.24 \cdot 23.040 \text{ N/mm}^2} + \frac{-0.027 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.646\end{aligned}$$

$$\begin{aligned}\eta_2 &= \left| \frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} \right| \\ &= \left| \frac{-3.625 \text{ N/mm}^2}{0.24 \cdot 23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.027 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.646\end{aligned}$$

$$\begin{aligned}\eta &= \max(\eta_1, \eta_2) \\ &= \max(0.646, 0.646) \\ &= 0.646\end{aligned}$$

$$\eta = 0.646 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na interakciju savijanja s bočnim izvijanjem u y osi i tlaka paralelno s vlakancima s izvijanjem zadovoljava s iskoristivosti od 64.60%.

Interakcija savijanja s bočnim izvijanjem u z osi i tlaka paralelno s vlakancima s izvijanjem

Tablica 113.: Unutarnje sile

Design normal force	N_{Ed}	-652.78	kN	
Design shear force	$V_{y,Ed}$	0.08	kN	Negligible
Design shear force	$V_{z,Ed}$	-0.06	kN	Negligible
Design torsional moment	T_{Ed}	-0.10	kNm	Negligible
Design bending moment	$M_{y,Ed}$	-0.33	kNm	Negligible
Design bending moment	$M_{z,Ed}$	-0.37	kNm	

Tablica 114.: Parametri proračuna

Design compression force	$N_{c,Ed}$	652.78	kN	
Design compressive stress	$\sigma_{c,0,d}$	-3.224	N/mm ²	
Design bending moment	$M_{z,Ed}$	-0.37	kNm	
Design bending stress	$\sigma_{m,z,d}$	-0.025	N/mm ²	
Equivalent member length	$L_{cr,y}$	15.937	m	
Equivalent member length	$L_{cr,z}$	15.937	m	
Radius of gyration	i_y	129.9	mm	
Radius of gyration	i_z	129.9	mm	
Slenderness ratio	λ_y	122.69	--	
Slenderness ratio	λ_z	122.69	--	
Modulus of elasticity	$E_{0,05,y}$	11800.0	N/mm ²	
Modulus of elasticity	$E_{0,05,z}$	11800.0	N/mm ²	
Characteristic compressive strength	$f_{c,0,k}$	32.000	N/mm ²	
Relative slenderness ratio	$\lambda_{rel,y}$	2.03	--	
Relative slenderness ratio	$\lambda_{rel,z}$	2.03	--	
Straightness factor	β_c	0.10	--	
Instability factor	k_y	2.65	--	
Instability factor	k_z	2.65	--	
Instability factor	$k_{c,y}$	0.23	--	
Instability factor	$k_{c,z}$	0.23	--	
Design compressive strength	$f_{c,0,d}$	23.040	N/mm ²	
Design bending strength	$f_{m,z,d}$	23.040	N/mm ²	
Redistribution factor	k_m	0.70	--	
Design ratio 1	η_1	0.611	--	
Design ratio 2	η_2	0.611	--	
Design check ratio	η	0.611	--	≤ 1 ✓

$$\begin{aligned} \lambda_y &= \frac{L_{cr,y}}{i_y} \\ &= \frac{15.937 \text{ m}}{129.9 \text{ mm}} \\ &= 122.69 \end{aligned}$$

$$\begin{aligned} \lambda_z &= \frac{L_{cr,z}}{i_z} \\ &= \frac{15.937 \text{ m}}{129.9 \text{ mm}} \\ &= 122.69 \end{aligned}$$

$$\begin{aligned}\lambda_{rel,y} &= \frac{\lambda_y}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,y}}} \\ &= \frac{122.69}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 2.03\end{aligned}$$

$$\begin{aligned}\lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\ &= \frac{122.69}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 2.03\end{aligned}$$

$$\lambda_{rel,y} > 0.3 \text{ or } \lambda_{rel,z} > 0.3$$

$$\begin{aligned}k_y &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,y} - 0.3) + (\lambda_{rel,y})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (2.03 - 0.3) + (2.03)^2\right) \\ &= 2.65\end{aligned}$$

$$\begin{aligned}k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (2.03 - 0.3) + (2.03)^2\right) \\ &= 2.65\end{aligned}$$

$$\begin{aligned}k_{c,y} &= \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \\ &= \frac{1}{2.65 + \sqrt{(2.65)^2 - (2.03)^2}} \\ &= 0.23\end{aligned}$$

$$\begin{aligned}k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\ &= \frac{1}{2.65 + \sqrt{(2.65)^2 - (2.03)^2}} \\ &= 0.23\end{aligned}$$

$$\begin{aligned}\eta_1 &= \left| \frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| \frac{-3.224 \text{ N/mm}^2}{0.23 \cdot 23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.025 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.611\end{aligned}$$

$$\begin{aligned}\eta_2 &= \left| \frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| \frac{-3.224 \text{ N/mm}^2}{0.23 \cdot 23.040 \text{ N/mm}^2} + \frac{-0.025 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.611\end{aligned}$$

$$\begin{aligned}\eta &= \max(\eta_1, \eta_2) \\ &= \max(0.611, 0.611) \\ &= 0.611\end{aligned}$$

$$\eta = 0.611 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na interakciju savijanja s bočnim izvijanjem u z osi i tlaka paralelno s vlakancima s izvijanjem zadovoljava s iskoristivosti od 61.10%.

Interakcija dvoosnog savijanja s bočnim izvijanjem i tlaka paralelno s vlakancima s izvijanjem

Tablica 115.: Unutarnje sile

Design normal force	N _{Ed}	-672.42	kN	
Design shear force	V _{y,Ed}	-0.02	kN	Negligible
Design shear force	V _{z,Ed}	0.01	kN	Negligible
Design torsional moment	T _{Ed}	-0.02	kNm	Negligible
Design bending moment	M _{y,Ed}	0.59	kNm	
Design bending moment	M _{z,Ed}	0.35	kNm	

Tablica 116.: Parametri proračuna

Design compression force	N _{c,Ed}	672.42	kN	
Design compressive stress	σ _{c,0,d}	-3.321	N/mm ²	
Design bending moment	M _{y,Ed}	0.59	kNm	
Design bending stress	σ _{m,y,d}	-0.039	N/mm ²	
Design bending moment	M _{z,Ed}	0.35	kNm	
Design bending stress	σ _{m,z,d}	-0.023	N/mm ²	
Equivalent member length	L _{cr,y}	16.000	m	
Equivalent member length	L _{cr,z}	16.000	m	
Radius of gyration	i _y	129.9	mm	
Radius of gyration	i _z	129.9	mm	
Slenderness ratio	λ _y	123.17	--	
Slenderness ratio	λ _z	123.17	--	
Modulus of elasticity	E _{0,05,y}	11800.0	N/mm ²	
Modulus of elasticity	E _{0,05,z}	11800.0	N/mm ²	
Characteristic compressive strength	f _{c,0,k}	32.000	N/mm ²	
Relative slenderness ratio	λ _{rel,y}	2.04	--	
Relative slenderness ratio	λ _{rel,z}	2.04	--	
Straightness factor	β _c	0.10	--	
Instability factor	k _y	2.67	--	
Instability factor	k _z	2.67	--	
Instability factor	k _{c,y}	0.23	--	
Instability factor	k _{c,z}	0.23	--	
Design compressive strength	f _{c,0,d}	23.040	N/mm ²	
Design bending strength	f _{m,y,d}	23.040	N/mm ²	
Design bending strength	f _{m,z,d}	23.040	N/mm ²	
Redistribution factor	k _m	0.70	--	
Design ratio 1	η ₁	0.636	--	
Design ratio 2	η ₂	0.635	--	
Design check ratio	η	0.636	--	≤ 1 ✓

$$\begin{aligned} \lambda_y &= \frac{L_{cr,y}}{i_y} \\ &= \frac{16.000 \text{ m}}{129.9 \text{ mm}} \\ &= 123.17 \end{aligned}$$

$$\begin{aligned} \lambda_z &= \frac{L_{cr,z}}{i_z} \\ &= \frac{16.000 \text{ m}}{129.9 \text{ mm}} \\ &= 123.17 \end{aligned}$$

$$\begin{aligned}\lambda_{rel,y} &= \frac{\lambda_y}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,y}}} \\ &= \frac{123.17}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 2.04\end{aligned}$$

$$\begin{aligned}\lambda_{rel,z} &= \frac{\lambda_z}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05,z}}} \\ &= \frac{123.17}{\pi} \cdot \sqrt{\frac{32.000 \text{ N/mm}^2}{11800.0 \text{ N/mm}^2}} \\ &= 2.04\end{aligned}$$

$$\lambda_{rel,y} > 0.3 \text{ or } \lambda_{rel,z} > 0.3$$

$$\begin{aligned}k_y &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,y} - 0.3) + (\lambda_{rel,y})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (2.04 - 0.3) + (2.04)^2\right) \\ &= 2.67\end{aligned}$$

$$\begin{aligned}k_z &= 0.5 \cdot \left(1 + \beta_c \cdot (\lambda_{rel,z} - 0.3) + (\lambda_{rel,z})^2\right) \\ &= 0.5 \cdot \left(1 + 0.10 \cdot (2.04 - 0.3) + (2.04)^2\right) \\ &= 2.67\end{aligned}$$

$$\begin{aligned}k_{c,y} &= \frac{1}{k_y + \sqrt{(k_y)^2 - (\lambda_{rel,y})^2}} \\ &= \frac{1}{2.67 + \sqrt{(2.67)^2 - (2.04)^2}} \\ &= 0.23\end{aligned}$$

$$\begin{aligned}k_{c,z} &= \frac{1}{k_z + \sqrt{(k_z)^2 - (\lambda_{rel,z})^2}} \\ &= \frac{1}{2.67 + \sqrt{(2.67)^2 - (2.04)^2}} \\ &= 0.23\end{aligned}$$

$$\begin{aligned}\eta_1 &= \left| \frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \cdot \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| \frac{-3.321 \text{ N/mm}^2}{0.23 \cdot 23.040 \text{ N/mm}^2} + \frac{-0.039 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.023 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.636\end{aligned}$$

$$\begin{aligned}\eta_2 &= \left| \frac{\sigma_{c,0,d}}{k_{c,z} \cdot f_{c,0,d}} + k_m \cdot \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \right| \\ &= \left| \frac{-3.321 \text{ N/mm}^2}{0.23 \cdot 23.040 \text{ N/mm}^2} + 0.70 \cdot \frac{-0.039 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} + \frac{-0.023 \text{ N/mm}^2}{23.040 \text{ N/mm}^2} \right| \\ &= 0.635\end{aligned}$$

$$\begin{aligned}\eta &= \max(\eta_1, \eta_2) \\ &= \max(0.636, 0.635) \\ &= 0.636\end{aligned}$$

$$\eta = 0.636 \leq 1 \quad \checkmark$$

Provjera glavnog uzdužnog nosača na interakciju dvoosnog savijanja s bočnim izvijanjem i tlaka paralelno s vlakancima s izvijanjem zadovoljava s iskoristivosti od 63.60%.

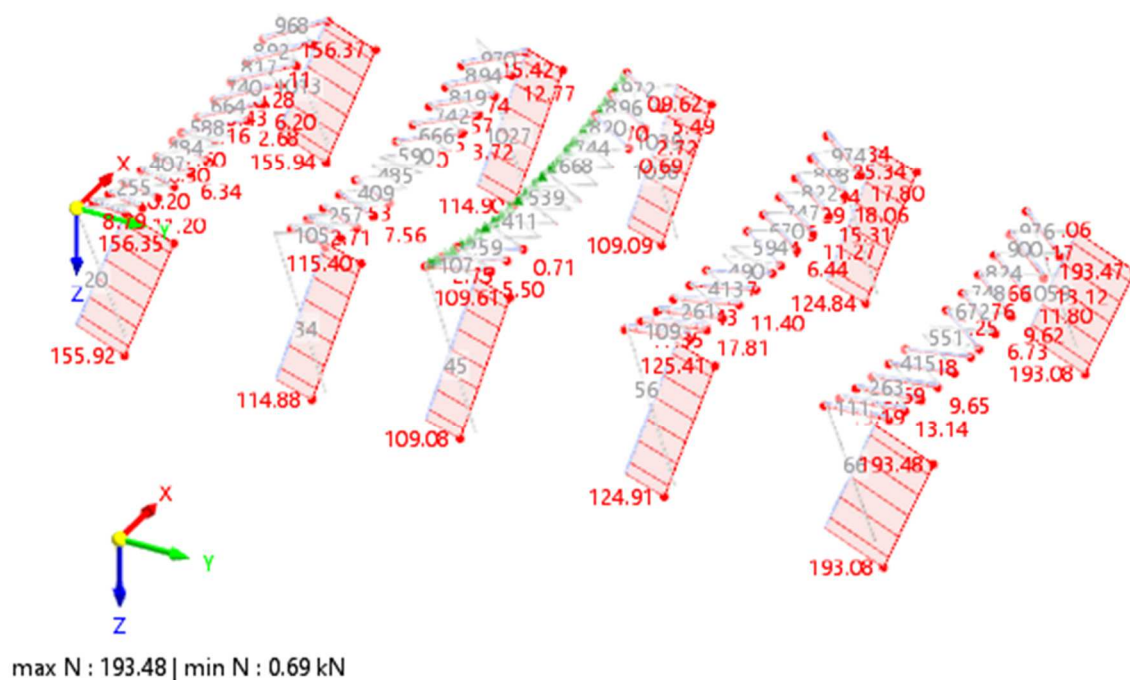
Tablica 117.: Rekapitulacija iskoristivosti tlačnih stupova

TLAČNI STUPOVI			
Provjera nosivosti elementa			Iskoristivost
1.	DOKAZI NOSIVOSTI PRESJEKA	Tlak paralelno s vlakancima	18,40%
2.		Torzijski posmik	1,10%
3.		Posmik u vertikalnoj (z) osi	1,90%
4.		Posmik u horizontalnoj (y) osi	0,80%
5.		Dvoosno savijanje	6,00%
12.	DOKAZI NOSIVOSTI ELEMENTA	Tlak paralelno s vlakancima s izvijanjem	75,10%
13.		Interakcija savijanja s bočnim izvijanjem u y osi i tlaka paralelno s vlakancima s izvijanjem	64,60%
14.		Interakcija savijanja s bočnim izvijanjem u z osi i tlaka paralelno s vlakancima s izvijanjem	61,10%
15.		Interakcija dvoosnog savijanja s bočnim izvijanjem i tlaka paralelno s vlakancima s izvijanjem	63,60%
Mjerodavna iskoristivost			75,10%

4.5. Dimenzioniranje stabilizacijskih čeličnih spregova

4.5.1. Ulazni podaci

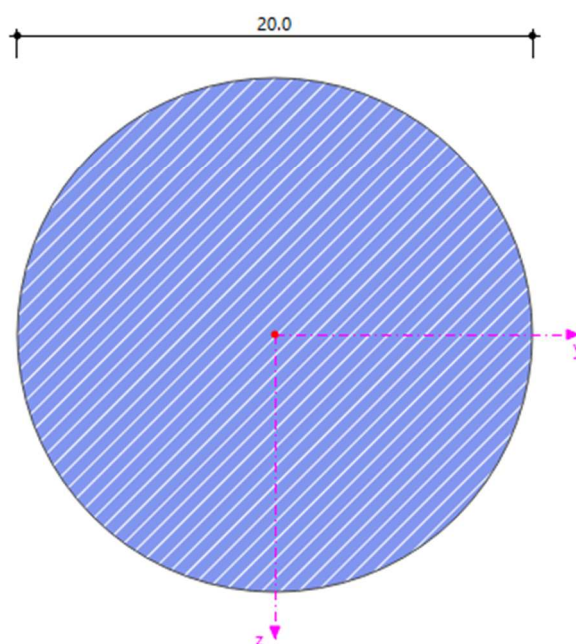
4.5.1.1. Dijagrami unutarnjih sila



Slika 4.37.: Dijagram uzdužnih sila N [kN]

Poprečni presjek:

5 - R 20 | EN 10060:2003 | ArcelorMittal (2018)



Slika 4.38.: Poprečni presjek sprega [mm]

$R=20\text{ mm}$

$A= 3.14\text{ cm}^2$

$I_y= 0.79\text{ cm}^4$

$W_y= 0.79\text{ cm}^3$

4.5.1.2. Klasa čelika: S355

Dokazi nosivosti presjeka;

Provjera vlačnih naprezanja

Tablica 118.: Unutarnje sile

Design axial force	N_{Ed}	193.48	kN	
Design shear force	$V_{z,Ed}$	0.00	kN	Negligible
Design shear force	$V_{y,Ed}$	0.00	kN	Negligible
Design torsional moment	T_{Ed}	0.00	kNm	Negligible
Design bending moment	$M_{y,Ed}$	0.00	kNm	Negligible
Design bending moment	$M_{z,Ed}$	0.00	kNm	Negligible

Tablica 119.: Parametri proračuna

Design tension force	$N_{t,Ed}$	193.48	kN	
Plastic axial resistance	N_{pl}	111.470	kN	
Partial factor	γ_{M0}	1.00	--	
Design plastic axial resistance	$N_{pl,Rd}$	111.470	kN	
Design axial force resistance	$N_{t,Rd}$	111.47	kN	
Design check ratio	η	1.736	--	> 1 ❗

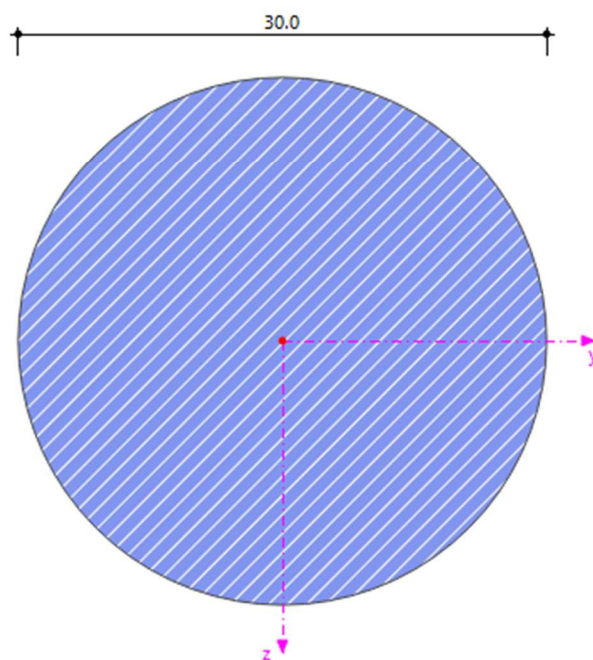
$$\begin{aligned} \eta &= \frac{N_{t,Ed}}{N_{t,Rd}} \\ &= \frac{193.48 \text{ kN}}{111.47 \text{ kN}} \\ &= 1.736 \end{aligned}$$

$$\eta = 1.736 > 1 \text{ ❗}$$

Stabilizacijski spreg ne zadovoljava provjeru nosivosti vlačna naprezanja, te je potrebno ponoviti proračun s novim presjekom.

Novi poprečni presjek:

5 - R 30 | EN 10060:2003 | ArcelorMittal (2018)



Slika 4.39.: Poprečni presjek sprega [mm]

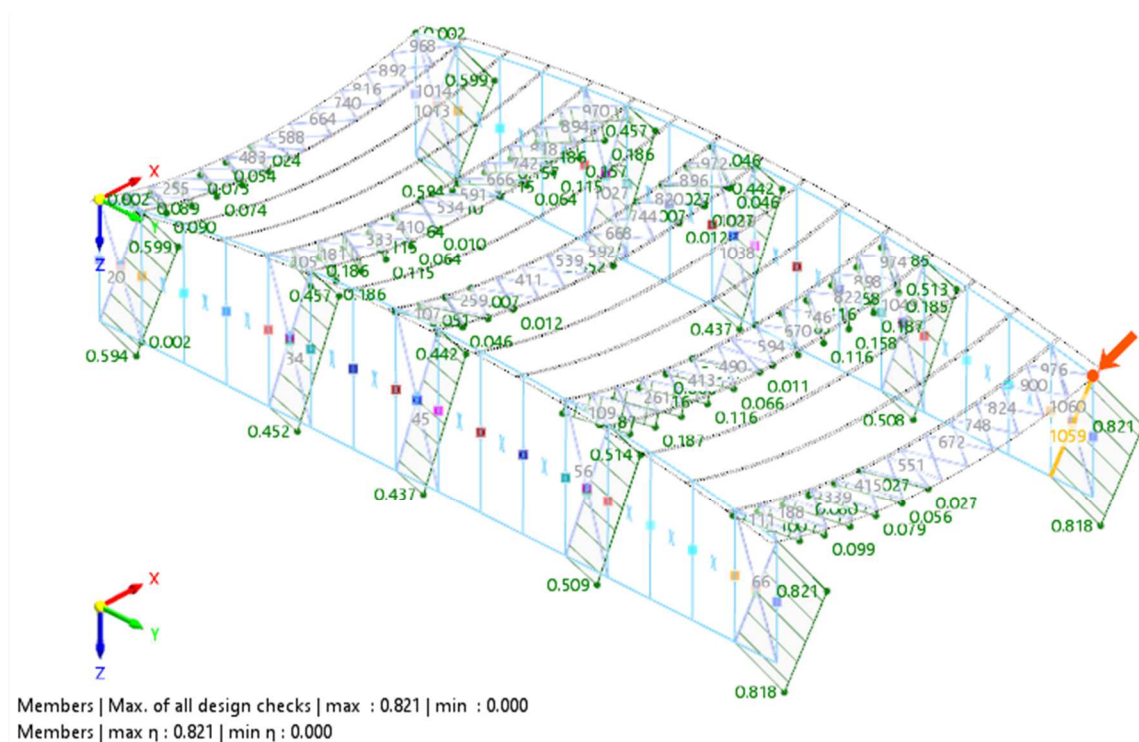
$R=30\text{ mm}$

$A= 7.07\text{ cm}^2$

$I_y= 3.98\text{ cm}^4$

$W_y= 2.65\text{ cm}^3$

Klasa čelika: S355



Slika 4.40.: Iskoristivost sprega

4.5.1.3. Dokazi nosivosti presjeka;

Provjera vlačnih naprezanja

Tablica 120.: Unutarnje sile

Design axial force	N_{Ed}	206.18	kN	
Design shear force	$V_{z,Ed}$	0.00	kN	Negligible
Design shear force	$V_{y,Ed}$	0.00	kN	Negligible
Design torsional moment	T_{Ed}	0.00	kNm	Negligible
Design bending moment	$M_{y,Ed}$	0.00	kNm	Negligible
Design bending moment	$M_{z,Ed}$	0.00	kNm	Negligible

Tablica 121.: Parametri proračuna

Design tension force	$N_{t,Ed}$	206.18	kN	
Plastic axial resistance	N_{pl}	250.985	kN	
Partial factor	γ_{M0}	1.00	--	
Design plastic axial resistance	$N_{pl,Rd}$	250.985	kN	
Design axial force resistance	$N_{t,Rd}$	250.99	kN	
Design check ratio	η	0.821	--	≤ 1 ✓

$$\begin{aligned}\eta &= \frac{N_{t,Ed}}{N_{t,Rd}} \\ &= \frac{206.18 \text{ kN}}{250.99 \text{ kN}} \\ &= 0.821\end{aligned}$$

$$\eta = 0.821 \leq 1 \quad \checkmark$$

Stabilizacijski spreg zadovoljava provjeru nosivosti vlačna naprezanja sa iskoristivosti od 82.10%.

5. GRANIČNO STANJE UPORABIVOSTI

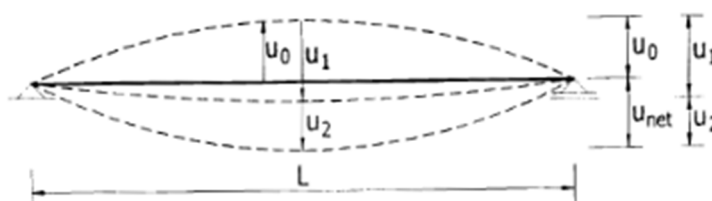
5.1. Ulazni podaci

Konačne deformacije graničenja progiba drvenih elemenata prema Eurocode 5 [8].

Konačna deformacija, u_{fin} , izračunava se prema (EC5, dio 4.3):

$$u_{fin} = \sum u_{fin,i} = \sum u_{inst,j} \cdot (1 + k_{def,j}) - u_0 \quad (5.5.c)$$

- u_0 nadvišenje nosača u neopterećenom stanju
- u_1 progib nosača od stalnog djelovanja (G)
- u_2 progib nosača od promjenjivog djelovanja (Q)



Slika 5.1.: Konačna deformacija elementa [8]

- a) u projektnim situacijama kad se smatra pogodnijim ograničiti trenutni progib prouzročen promjenjivim djelovanjem, $u_{2,inst}$:

$$u_{2,inst} \leq L/300 \quad (5.5.e)$$

$$u_{2,inst} \leq L_k/150 \quad \text{za konzole}$$

- b) u projektnim situacijama kad se smatra pravilnim ograničiti konačni progib, u_{fin} :

$$u_{2,fin} \leq L/200 \quad (5.5.f)$$

$$u_{2,fin} \leq L_k/100 \quad \text{za konzole}$$

(Mjerodavno u slučaju kad su $u_0 > u_{1,fin}$ i $u_{net} < u_2$)

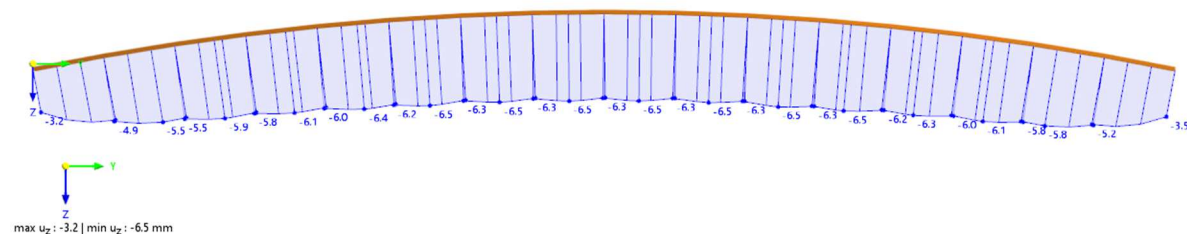
$$u_{net,fin} \leq L/200 \quad (5.5.g)$$

$$u_{net,fin} \leq L_k/100 \quad \text{za konzole}$$

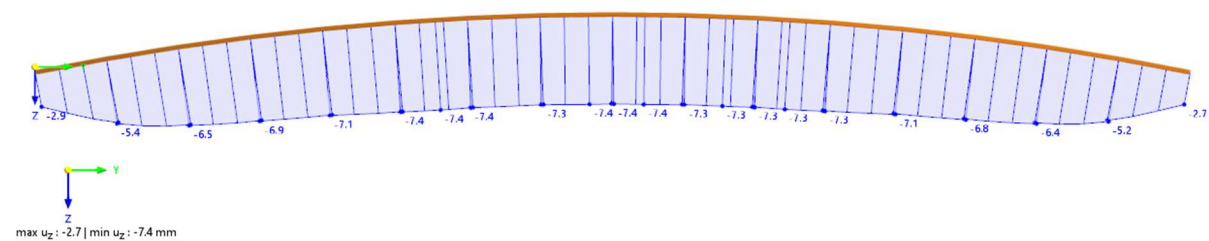
Slika 5.2.: Ograničenja progiba [8]

5.1.1. Provjera progiba

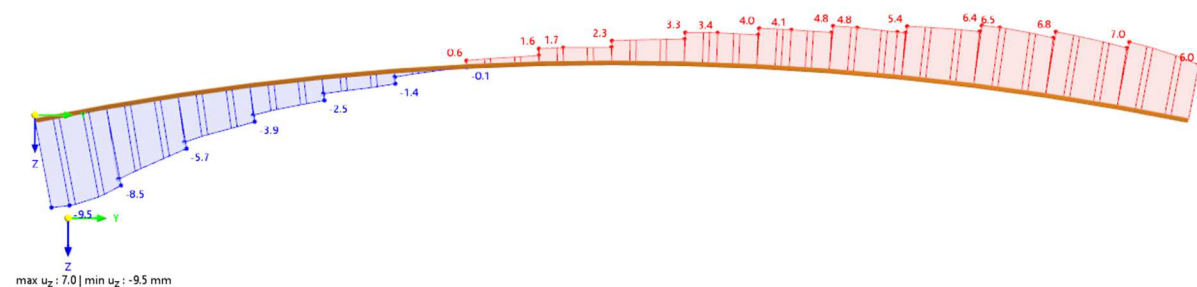
5.1.1.1. Selkundarni nosač



Slika 5.3.: Progib uslijed stalnog opterećenja [mm]



Slika 5.4.: Progib uslijed opterećenja snijegom [mm]



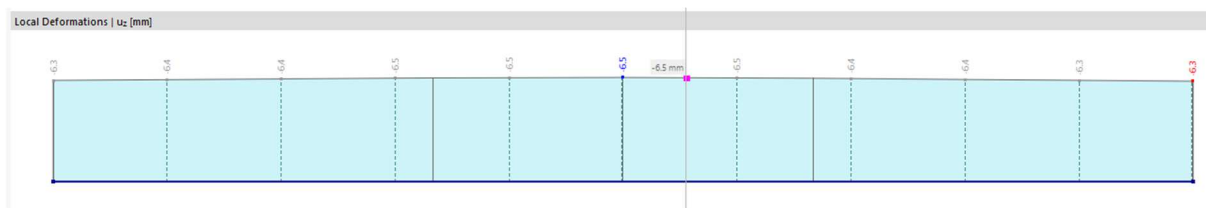
Slika 5.5.: Progib uslijed opterećenja vjetrom [mm]

Utjecaji vjetra na ukupni progib uzet će se u obzir samo u nepovoljnoj varijanti koja doprinosi ukupnom progibu.

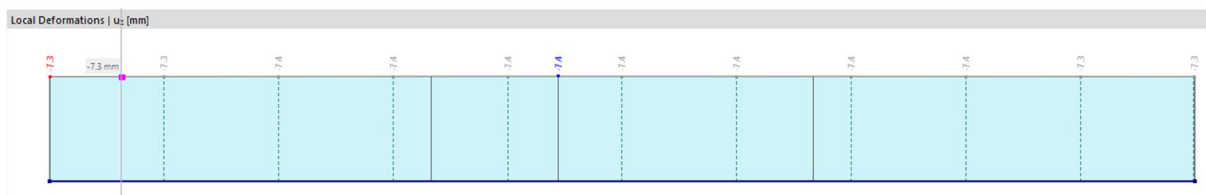
$$u_{inst,max} = 9.5 \text{ mm} < \frac{L}{300} = \frac{5033}{300} = 16.78 \text{ mm}$$

Maksimalni kratkotrajni progib zadovoljava provjeru graničnog stanja uporabivosti.

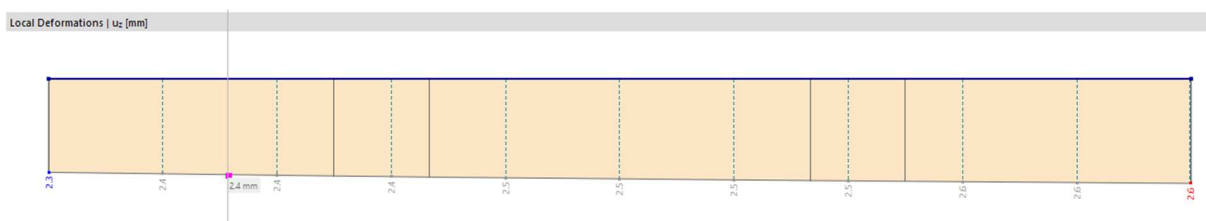
Provjera konačnih progiba na poziciji maksimalnog progiba od pritišćućih opterećenja;



Slika 5.6.: $u_{inst}^{G_{k,j}}$ [mm]



Slika 5.7.: $u_{inst}^{Q_{k,s}}$ [mm]



Slika 5.8.: $u_{inst}^{Q_{k,w}}$ [mm]

Utjecaji vjetra na poziciji maksimalnog progiba od pritišćućih opterećenja mogu se zanemariti radi povoljnog doprinosa vjetra progibu.

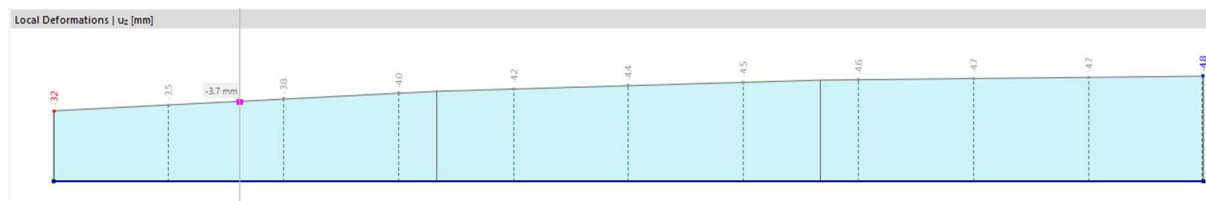
$$u_{fin} = (1 + k_{def}) \cdot u_{inst}^{G_{k,j}} + (1 + k_{def}) \cdot u_{inst}^{Q_{k,s}}$$

$$u_{fin} = (1 + 0.6) \cdot 6.50 + (1 + 0.25) \cdot 7.40$$

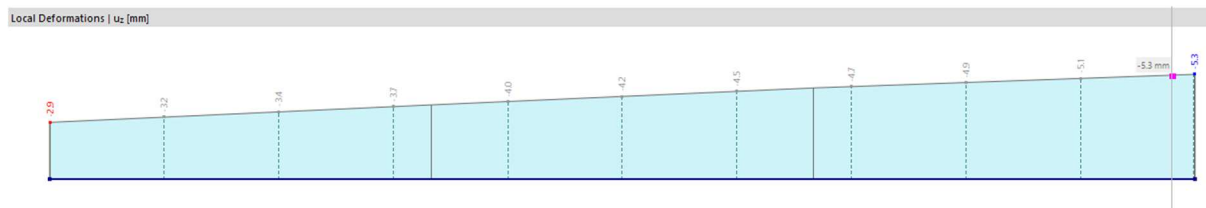
$$u_{fin} = 19.65 \text{ mm} < \frac{L}{200} = \frac{5033}{200} = 25.17 \text{ mm}$$

Dugotrajni progib zadovoljava provjeru graničnog stanja uporabivosti.

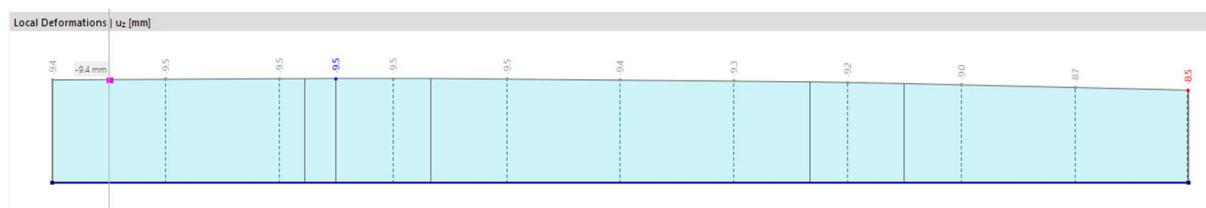
Provjera konačnih progiba na poziciji maksimalnog progiba od vjetra;



Slika 5.9.: $u_{inst}^{G_{k,j}}$ [mm]



Slika 5.10.: $u_{inst}^{Q_{k,s}}$ [mm]



Slika 5.11.: $u_{inst}^{Q_{k,w}}$ [mm]

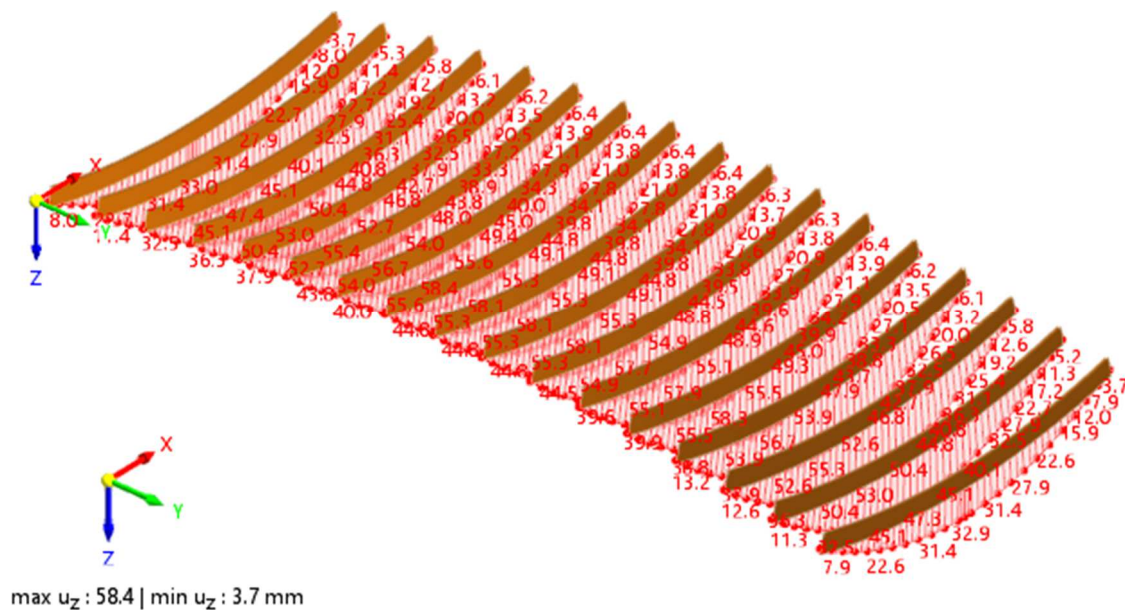
$$u_{fin} = (1 + k_{def}) \cdot u_{inst}^{G_{k,j}} + (1 + k_{def}) \cdot u_{inst}^{Q_{k,s}} + (1 + k_{def}) \cdot u_{inst}^{Q_{k,w}}$$

$$u_{fin} = (1 + 0.6) \cdot 4.80 + (1 + 0.25) \cdot 5.30 + (1 + 0) \cdot 9.50$$

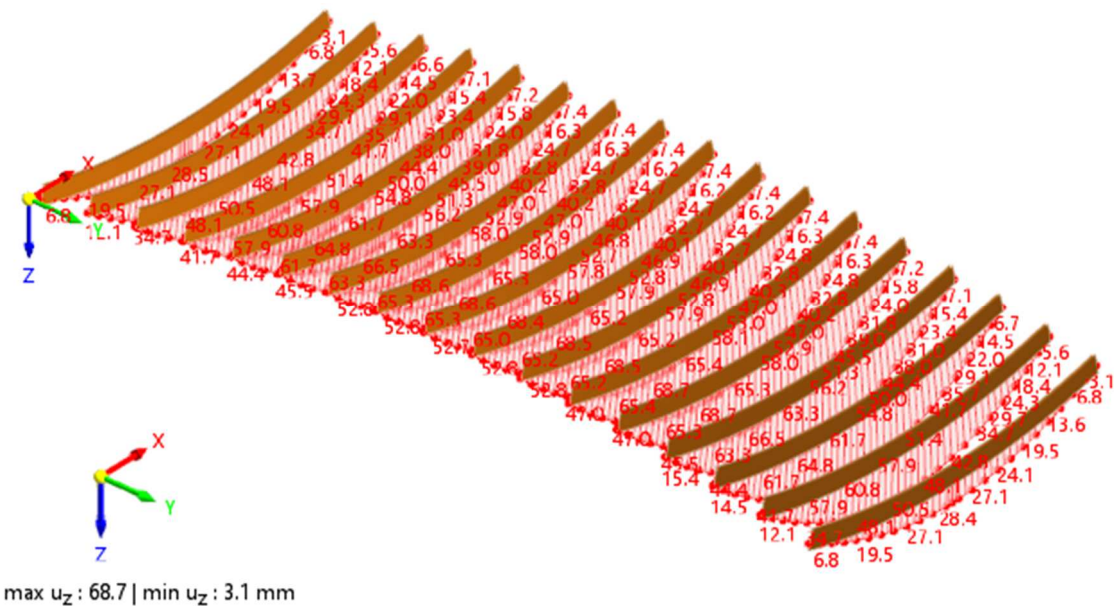
$$u_{fin} = 23.81 \text{ mm} < \frac{L}{200} = \frac{5033}{200} = 25.17 \text{ mm}$$

Dugotrajni progib zadovoljava provjeru graničnog stanja uporabivosti.

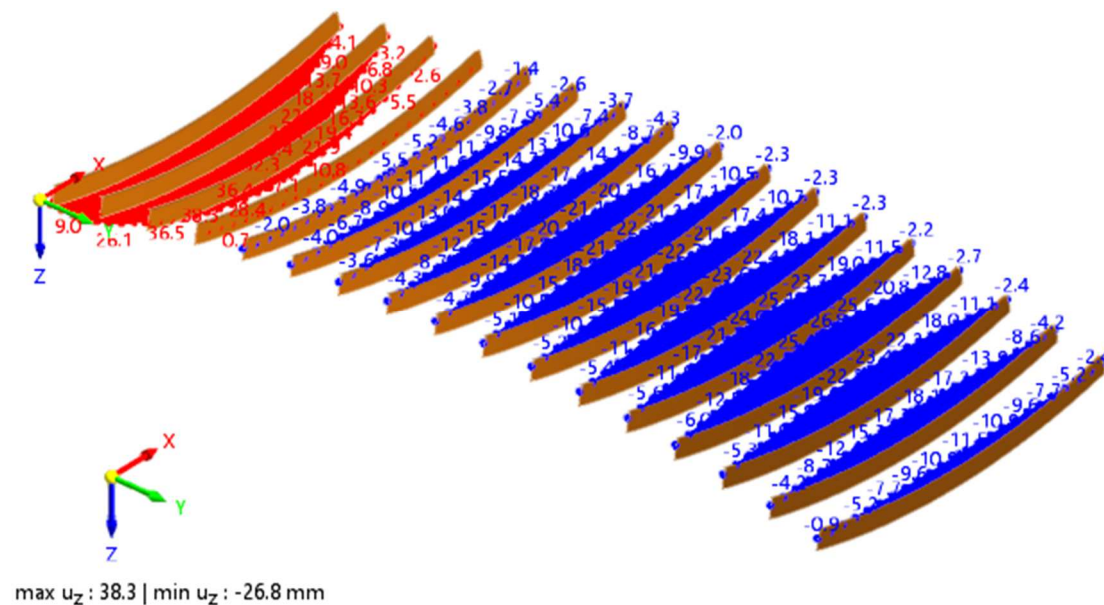
5.1.1.2. Glavni poprečni nosač



Slika 5.12.: Progib uslijed stalnog opterećenja [mm]



Slika 5.13.: Progib uslijed opterećenja snijegom [mm]



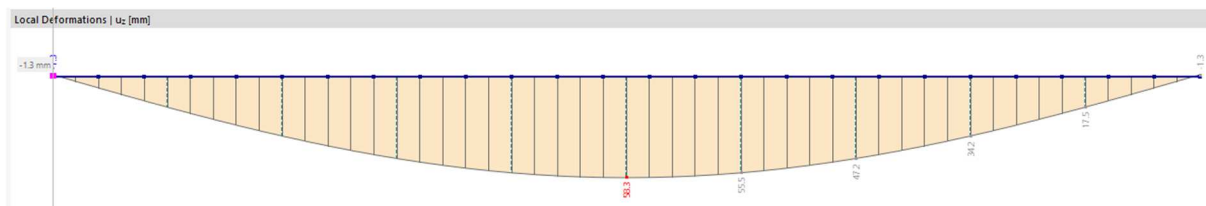
Slika 5.14.: Progib uslijed opterećenja vjetrom [mm]

Utjecaji vjetra na ukupni progib uzet će se u obzir samo u nepovoljnoj varijanti koja doprinosi ukupnom progibu.

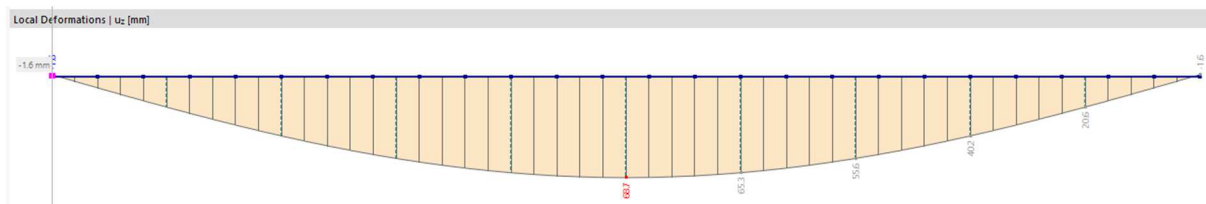
$$u_{inst,max} = 68.70mm < \frac{L}{300} = \frac{38437}{300} = 128.12mm$$

Maksimalni kratkotrajni progib zadovoljava provjeru graničnog stanja uporabivosti.

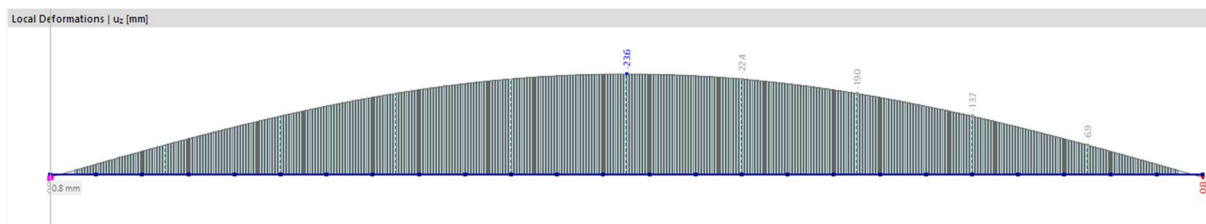
Provjera konačnih progiba na poziciji maksimalnog progiba od pritišćućih opterećenja;



Slika 5.15.: $u_{inst}^{G_{k,j}}$ [mm]



Slika 5.16.: $u_{inst}^{Q_{k,s}}$ [mm]



Slika 5.17.: $u_{inst}^{Q_{k,w}}$ [mm]

Utjecaji vjetra na poziciji maksimalnog progiba od pritišćućih opterećenja mogu se zanemariti radi povoljnog doprinosa vjetra progibu.

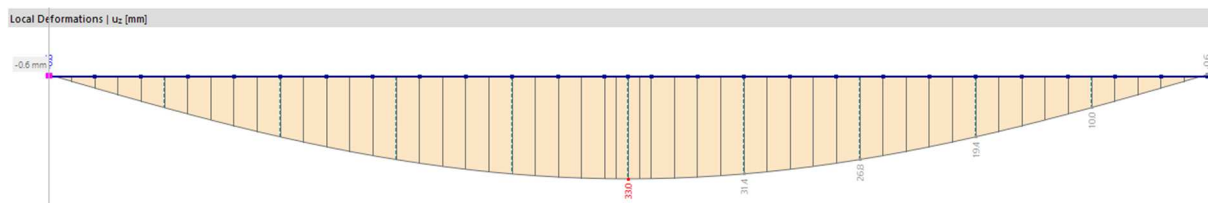
$$u_{fin} = (1 + k_{def}) \cdot u_{inst}^{G_{k,j}} + (1 + k_{def}) \cdot u_{inst}^{Q_{k,s}}$$

$$u_{fin} = (1 + 0.6) \cdot 58.30 + (1 + 0.25) \cdot 68.70$$

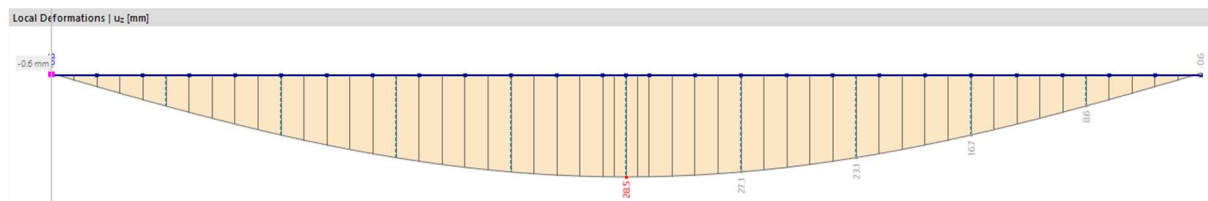
$$u_{fin} = 179.16\text{mm} < \frac{L}{200} = \frac{38437}{200} = 192.20\text{mm}$$

Dugotrajni progib zadovoljava provjeru graničnog stanja uporabivosti.

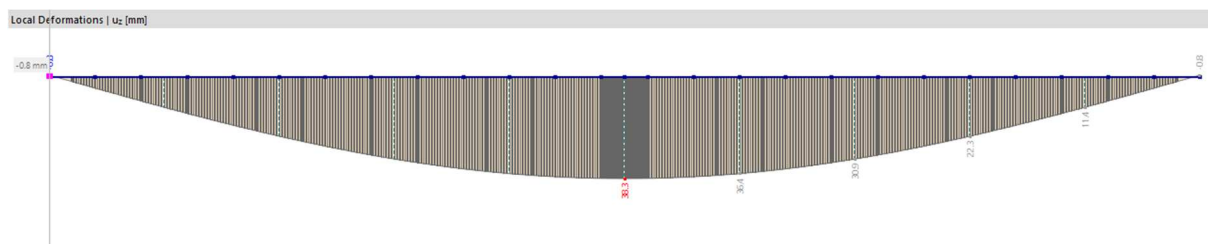
Provjera konačnih progiba na poziciji maksimalnog progiba od vjetra;



Slika 5.18.: $u_{inst}^{G_{k,j}}$ [mm]



Slika 5.19.: $u_{inst}^{Q_{k,s}}$ [mm]



Slika 5.20.: $u_{inst}^{Q_{k,w}}$ [mm]

$$u_{fin} = (1 + k_{def}) \cdot u_{inst}^{G_{k,j}} + (1 + k_{def}) \cdot u_{inst}^{Q_{k,s}} + (1 + k_{def}) \cdot u_{inst}^{Q_{k,w}}$$

$$u_{fin} = (1 + 0.6) \cdot 33.00 + (1 + 0.25) \cdot 28.50 + (1 + 0) \cdot 38.30$$

$$u_{fin} = 126.73\text{mm} < \frac{L}{200} = \frac{38437}{200} = 192.20\text{mm}$$

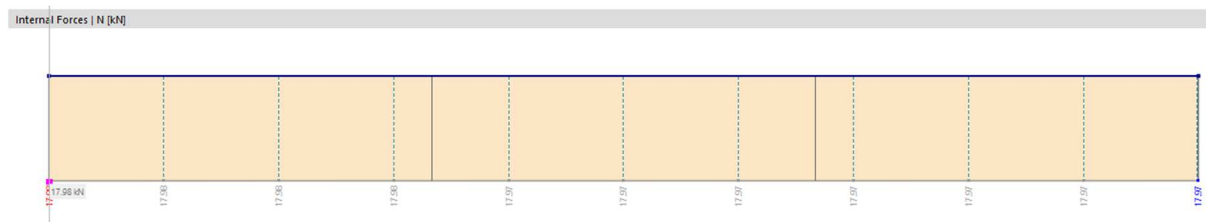
Dugotrajni progib zadovoljava provjeru graničnog stanja uporabivosti.

6. PRORAČUN SPOJEVA

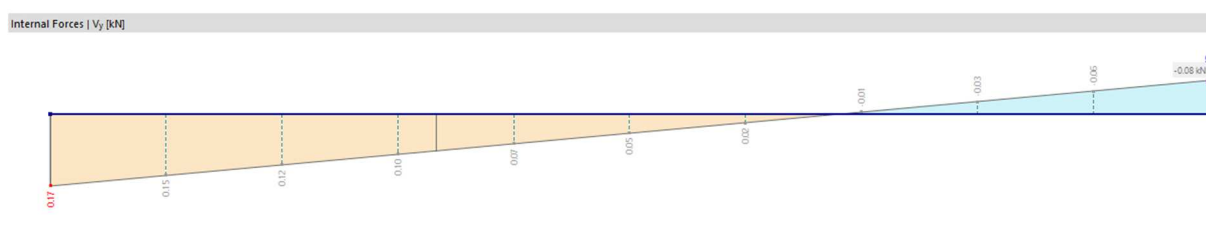
Proračun spojeva računa se u skladu sa EC5 [8] i uputama proizvođača spojnih elemenata.

6.1. Spoj sekundarnog i glavnog poprečnog nosača

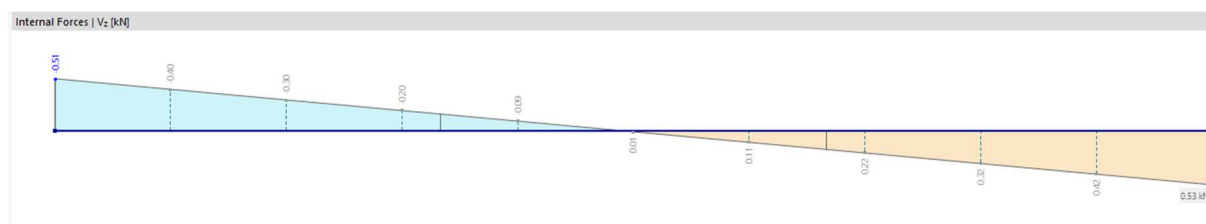
Dimenzionira se spoj na najkritičnijem mjestu na konstrukciji.



Slika 6.1.: Dijagram uzdužnih sila N [kN]

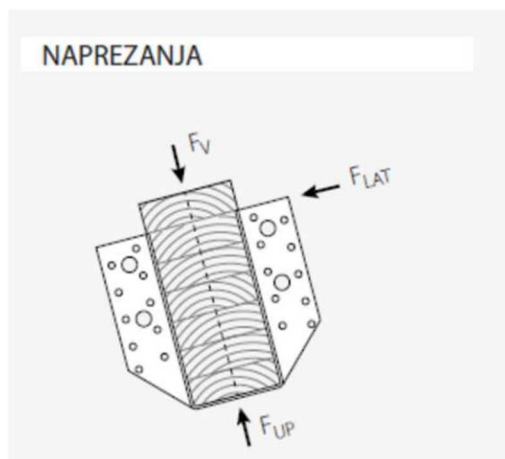


Slika 6.2.: Dijagram poprečnih sila Vy [kN]

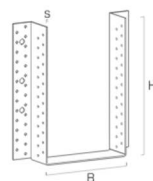


Slika 6.3.: Dijagram poprečnih sila Vz [kN]

Za prijenos sile odabran čelični lim od proizvođača Rothoblaas tipa BSAG160200, a za povezivanje odabrani čavli LBA 4x60 od proizvođača Rothoblaas. Moguće je primijeniti i elemente drugih proizvođača koji su jednako vrijedni.



Slika 6.4.: Prikaz sila na čelični element

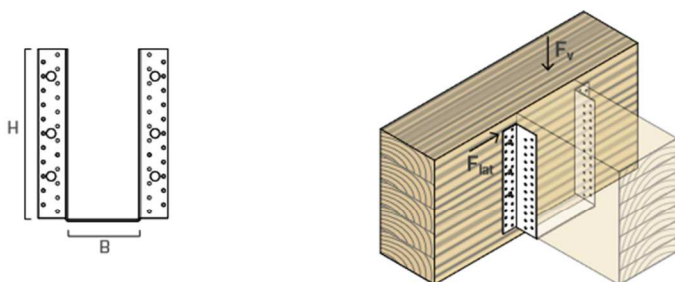


CODE	B [mm]	H [mm]	s [mm]	pcs.
BSAG100240	100	240	2.5	20
BSAG100280	100	280	2.5	20
BSAG120240	120	240	2.5	20
BSAG120280	120	280	2.5	20
BSAG140240	140	240	2.5	20
BSAG140280	140	280	2.5	20
BSAG160160	160	160	2.5	15
BSAG160200	160	200	2.5	15

Slika 6.5.: Odabran čelični lim

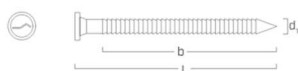
STRUCTURAL VALUES | TIMBER-TO-TIMBER | F_v | F_{lat}

PARTIAL/TOTAL NAILING⁽¹⁾



BSAG - LARGE SIZE			PARTIAL NAILING				FULL NAILING			
B [mm]	H [mm]	LBA nails d x L [mm]	fastening number		characteristic values		fastening number		characteristic values	
			$n_H^{(2)}$ [pcs]	$n_J^{(3)}$ [pcs]	$R_{v,k}$ [kN]	$R_{lat,k}$ [kN]	$n_H^{(2)}$ [pcs]	$n_J^{(3)}$ [pcs]	$R_{v,k}$ [kN]	$R_{lat,k}$ [kN]
100	240	Ø4 x 60	24	16	40,7	10,7	46	30	75,6	19,9
100	280	Ø4 x 60	28	18	47,3	10,8	54	34	85,1	20,3
120	240	Ø4 x 60	24	16	40,7	12,3	46	30	75,6	22,9
120	280	Ø4 x 60	28	18	47,3	12,6	54	34	85,1	23,5
140	240	Ø4 x 60	24	16	40,7	13,7	46	30	75,6	25,6
140	280	Ø4 x 60	28	18	47,3	14,1	54	34	85,1	26,4
160	160	Ø4 x 60	16	10	21,2	11,1	30	18	41,6	19,9
160	200	Ø4 x 60	20	12	30,7	12,3	38	22	56,7	22,4
160	240	Ø4 x 60	24	16	40,7	15,0	46	30	75,6	27,9
160	280	Ø4 x 60	28	18	47,3	15,5	54	34	85,1	29,0
160	320	Ø4 x 60	32	20	52,0	15,9	62	38	94,6	30,0

Slika 6.6.: Tablice proizvađača za čelični element



CODE	info	d_1 [mm]	L [mm]	b [mm]	d_1 [in]	L [in]	b [in]	pcs.
LBA440	-	4	40	30	0.16	1 9/16"	1 3/16"	250
LBA450	-	4	50	40	0.16	1 15/16"	1 9/16"	250
LBA460	-	4	60	-	0.16	2 3/8"	-	250
LBA475	-	4	75	60	0.16	2 15/16"	2 3/8"	250
LBA4100	-	4	100	80	0.16	4"	3 1/8"	250
LBA660	-	6	60	50	0.24	2 3/8"	1 15/16"	250
LBA680	-	6	80	70	0.24	3 1/8"	2 3/4"	250
LBA6100	-	6	100	80	0.24	4"	3 1/8"	250

Slika 6.7.: Tablice proizvađača za odabrani čavao

Prema uputama proizvođača, spoj čeličnog elementa i glavnog nosača ostvaruje se sa 20 čavala, 10 sa jedne i 10 sa druge strane, a iste postaviti u red rupa koji je dalji od ruba papuče. Spoj čeličnog elementa i podrožnice ostvaruje se sa 12 čavala, 6 sa jedne i 6 sa druge strane. Čavli se postavljaju s obje strane radi prisutnog uzdužnog naprezanja.

GENERAL PRINCIPLES

- Characteristic values are consistent with EN 1995:2014 and in accordance with ETA.
- Design values can be obtained from characteristic values as follows:

$$R_d = \frac{R_k \cdot k_{mod}}{\gamma_M}$$

The coefficients k_{mod} and γ_M should be taken according to the current regulations used for the calculation.

- A timber density of $\rho_k = 350 \text{ kg/m}^3$ was considered for the calculation process.
- Dimensioning and verification of the timber elements must be carried out separately.
- In case of F_v parallel to the grain, partial nailing is required.
- The following verification shall be satisfied for combined loading:

$$\left(\frac{F_{v,d}}{R_{v,d}}\right)^2 + \left(\frac{F_{lat,d}}{R_{lat,d}}\right)^2 \leq 1$$

Slika 6.8.: Uputa proizvođača za dimenzioniranje

$$R_{v,d} = k_{mod} \cdot \frac{R_{v,k}}{\gamma_m} = 0,8 \cdot \frac{30.70}{1.3} = 18.89 \text{ kN/mm}^2$$

$$R_{lat,d} = k_{mod} \cdot \frac{R_{lat,k}}{\gamma_m} = 0,8 \cdot \frac{12.30}{1.3} = 7.57 \text{ kN/mm}^2$$

$$F_{v,d} = 0.17 \text{ kN}$$

$$F_{lat,d} = 0.51 \text{ kN}$$

$$\left(\frac{F_{v,d}}{R_{v,d}}\right)^2 + \left(\frac{F_{lat,d}}{R_{lat,d}}\right)^2 < 1$$

$$\left(\frac{0.17}{18.89}\right)^2 + \left(\frac{0.51}{7.57}\right)^2 < 1$$

Nosivost bočno opterećenog čavla [8]

Nosivost bočno opterećenih čavala u jednoj reznoj ravnini spoja drvo – drvo može se, za praktične potrebe, odrediti i korištenjem približnih izraza danih u tablici 6.18.

Tablica 6.18 Približne vrijednosti nosivosti R_d jednog čavla u jednoj reznoj ravnini veze drvo – drvo

Jednoredni i dvoredni čavlani spojevi drvo – drvo za razred vlažnosti 1 ili 2		
Bez prebušenja rupa i za stalna djelovanja	Bez prebušenja rupa i za kratkotrajna djelovanja S prebušenjem rupa i za stalna djelovanja	S prebušenjem rupa i za kratkotrajna djelovanja
$R_d \approx 40d^2$	$R_d \approx 50d^2$	$R_d \approx 60d^2$

Slika 6.9.: Nosivost bočno opterećenog čavla

$$R_d = 40 \cdot d^2 = 40 \cdot 4 = 16.00 \text{ N/mm}^2$$

Na podrožnicu je postavljeno ukupno 12 čavala.

$$N_d = 17.98 \text{ kN}$$

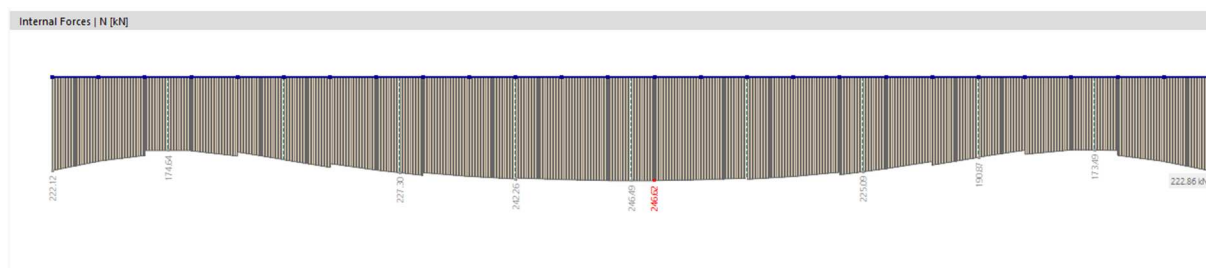
$$\frac{N_d}{R_d \cdot n} < 1$$

$$\frac{17.98}{16.00 \cdot 12} = 0,09 < 1$$

Spoj sekundarnog i glavnog nosača zadovoljava sa 9 % iskoristivosti.

6.2. Spoj glavnog poprečnog i glavnog uzdužnog nosača

Dimenzionira se spoj na najkritičnijem mjestu na konstrukciji.



Slika 6.10.: Dijagram uzdužnih sila N [kN]

Spoj glavnog poprečnog i glavnog uzdužnog nosača bit će izveden sa obostranim limom S235, debljine 5mm i vijcima M20, k.v. 8.6. na poprečnom nosaču, te jednostranim limom S235, debljine 5mm i vijcima M20, k.v. 8.6. na uzdužnom nosaču.

Limovi se međusobno spajaju pomoću vara debljine 3mm kvalitete S235

Drvo je klase GL32h i razreda uporabivosti 1. Karakteristična gustoća je $\rho_k = 430 \text{ kg/m}^3$.

Dimenzije uzdužnih i poprečnih glavnih nosača su $b/h = 26/180\text{cm}$.

Uzdužna vlačna sila na kraju najopterećenijeg poprečnog nosača iznosi 222.86 kN.

Spoj lima i poprečnog nosača pomoću vijka M20 - kut upada sile u odnosu na vlakanca $\alpha=0^\circ$

Proračun projektne vrijednosti čvrstoće pritiska po omotaču drva

$$f_{h,0,k} = 0,082 \cdot (1 - 0,01 \cdot d) \cdot \rho_k = 0,082 \cdot (1 - 0,01 \cdot 20) \cdot 430 = 28,21 \text{ N/mm}^2$$

$$f_{h,0,d} = k_{mod} \cdot \frac{f_{h,0,k}}{\gamma_M} = 0,9 \cdot \frac{28,21}{1,3} = 19,53 \text{ N/mm}^2$$

Moment plastifikacije za vijak M20, k.v. 8.6.

$$M_{y,k} = \frac{0,8 \cdot f_{u,k} \cdot d^3}{6} = \frac{0,8 \cdot 800 \cdot 20^3}{6} = 853333,3 \text{ Nmm}$$

$$M_{y,d} = \frac{M_{y,k}}{\gamma_M} = \frac{853333,3}{1,1} = 775757,58 \text{ Nmm}$$

Nosivost spajala:

$$R_d = 0.5 \cdot f_{h,0,d} \cdot t_2 \cdot d = 0.5 \cdot 19.53 \cdot 260 \cdot 20 = 50778 \text{ N}$$

$$R_d = 1,1\sqrt{2 \cdot M_{y,d} \cdot f_{h,0,d} \cdot d} = 1,1\sqrt{2 \cdot 775757,58 \cdot 19.53 \cdot 20} = 27079.26 \text{ N}$$

Reznost, m=2

Ukupna nosivost jednog vijka u spoju:

$$R_d = 2 \cdot 27079.26 = 54158.52 \text{ N}$$

Odabir broja spojnih sredstava;

$$n_{potr} \geq \frac{N_d}{\Sigma R_d} = \frac{222,86 \cdot 10^3}{54158.52} = 4.11 \text{ kom}$$

Za spoj lima i poprečnog glavnog nosača odabrano je 6 vijaka M20, k.v. 8.6.

Proračun minimalnih razmaka:

$$a_1 = (4 + 3 \cdot |\cos \alpha|) \cdot d = 7 \cdot d = 7 \cdot 20 = 140 \text{ mm}$$

$$a_2 = 4 \cdot d = 4 \cdot 20 = 80 \text{ mm}$$

$$a_{3,t} = 7 \cdot d = 7 \cdot 20 = 140 \text{ mm}$$

$$a_{3,c} = 4 \cdot d = 4 \cdot 20 = 80 \text{ mm}$$

$$a_{4,t} = (2 + 2 \cdot \sin \alpha) \cdot d = 2 \cdot d = 2 \cdot 20 = 40 \text{ mm} < 4 \cdot d = 80 \text{ mm}$$

$$a_{4,c} = 3 \cdot d = 3 \cdot 20 = 60 \text{ mm}$$

$$\frac{222,86 \cdot 10^3 \cdot 6}{54158.52} = 0.686 < 1$$

Spoj glavnog poprečnog nosača zadovoljava sa 68.60 % iskoristivosti.

Spoj lima i uzdužnog nosača pomoću vijka M20 - kut upada sile u odnosu na vlakanca $\alpha=90^\circ$

Proračun projektne vrijednosti čvrstoće pritiska po omotaču drva

$$f_{h,0,k} = 0,082 \cdot (1 - 0,01 \cdot d) \cdot \rho_k = 0,082 \cdot (1 - 0,01 \cdot 20) \cdot 430 = 28,21 \text{ N/mm}^2$$

$$f_{h,0,d} = k_{mod} \cdot \frac{f_{h,0,k}}{\gamma_M} = 0,9 \cdot \frac{28,21}{1,3} = 19,53 \text{ N/mm}^2$$

Proračun projektne vrijednosti čvrstoće pritiska po omotaču drva za djelovanje pod kutem u odnosu na vlakanca:

$$k_{90} = 1,35 + 0,015 \cdot d = 1,35 + 0,015 \cdot 20 = 1,65$$

$$f_{h,90,d} = \frac{f_{h,0,d}}{k_{90} \cdot \sin^2 \alpha + \cos^2 \alpha} = \frac{19,53}{1,65 \cdot \sin^2 90^\circ + \cos^2 90^\circ} = 10,52 \text{ N/mm}^2$$

Moment plastifikacije za vijak M20, k.v. 8.6.

$$M_{y,k} = \frac{0,8 \cdot f_{u,k} \cdot d^3}{6} = \frac{0,8 \cdot 800 \cdot 20^3}{6} = 853333,3 \text{ Nmm}$$

$$M_{y,d} = \frac{M_{y,k}}{\gamma_M} = \frac{853333,3}{1,1} = 775757,58 \text{ Nmm}$$

Nosivost spajala:

$$R_d = (\sqrt{2} - 1) f_{h,90,d} \cdot t_1 \cdot d = 10,52 \cdot 260 \cdot 20 = 22659,14 \text{ N}$$

$$R_d = 1,1 \sqrt{2 \cdot M_{y,d} \cdot f_{h,0,d} \cdot d} = 1,1 \sqrt{2 \cdot 775757,58 \cdot 10,52 \cdot 20} = 19874,38 \text{ N}$$

Reznost, $m=1$

Ukupna nosivost jednog vijka u spoju:

$$R_d = 1 \cdot 19874,38 = 19874,38 \text{ N}$$

Odabir broja spojnih sredstava;

$$n_{potr} \geq \frac{N_d}{\sum R_d} = \frac{222,86 \cdot 10^3}{19874,38} = 11,21 \text{ kom}$$

Za spoj lima i uzdužnog glavnog nosača odabrano je 12 vijaka M20, k.v. 8.6.

Proračun minimalnih razmaka:

$$a_1 = (4 + 3 \cdot |\cos \alpha|) \cdot d = 80 \text{ mm}$$

$$a_2 = 4 \cdot d = 4 \cdot 20 = 80 \text{ mm}$$

$$a_{3,t} = 7 \cdot d = 7 \cdot 20 = 140 \text{ mm}$$

$$a_{3,c} = 4 \cdot d = 4 \cdot 20 = 80 \text{ mm}$$

$$a_{4,t} = (2 + 2 \cdot \sin \alpha) \cdot d = 80 \text{ mm} < 4 \cdot d = 80 \text{ mm}$$

$$a_{4,c} = 3 \cdot d = 3 \cdot 20 = 60 \text{ mm}$$

$$\frac{222,86 \cdot 10^3 \cdot 12}{19874,38} = 0,934 < 1$$

Spoj glavnog uzdužnog nosača zadovoljava sa 93.40 % iskoristivosti.

Spoj čeličnih elementa međusobno - proračun vara

$$F_{v,w,d} = \frac{f_u}{\sqrt{3} \cdot \beta_w \cdot \gamma_{M2}} = \frac{360}{\sqrt{3} \cdot 0,8 \cdot 1,25} = 249,61 \text{ N/mm}^2$$

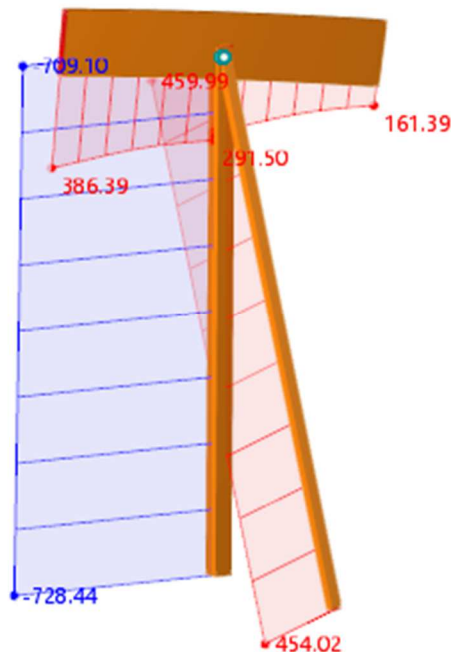
$$F_{v,Rd} = 3 \cdot 249,61 \cdot 1800 \cdot 4 = 5391577 \text{ N} = 5391,58 \text{ kN}$$

$$222,86 < 5391,58 \text{ kN}$$

Var zadovoljava sa iskoristivosti od 4.13 %

6.3. Spoj glavnog uzdužnog nosača i stupa

Dimenzionira se spoj na najkritičnijem mjestu na konstrukciji.



Slika 6.11.: Dijagram uzdužnih sila N [kN]

Zglobni spoj glavnog uzdužnog nosača i stupova bit će izveden sa utisnutim limom S235, debljine 5mm i vijcima M20, k.v. 8.6.

Lim će se po narudžbi izrezati u potrebnom 3D obliku.

Čelična ploča koja dolazi na stup predviđena je debljine 25 mm i kvalitete čelika S235, na koju se spaja pomoću vara debljine 3mm kvalitete S235 utisnuti lim u elementima debljine 5mm kvalitete S235.

Drvo je klase GL32h i razreda uporabivosti 1. Karakteristična gustoća je $\rho_k = 430 \text{ kg/m}^3$.

Dimenzije uzdužnih glavnih nosača su $b/h = 26/180\text{cm}$, tlačnog stupa $b/h = 45/45\text{cm}$ i vlačnog stupa $b/h = 25/25\text{cm}$.

Uzdužna vlačna sila na glavnom nosaču iznosi 386.39 kN, na tlačnom stupu 728.44 kN, te 454.02 kN na vlačnom stupu.

Spoj lima i uzdužnog nosača pomoću vijka M20 - kut upada sile u odnosu na vlakanca $\alpha=0^\circ$

Proračun projektne vrijednosti čvrstoće pritiska po omotaču drva

$$f_{h,0,k} = 0,082 \cdot (1 - 0,01 \cdot d) \cdot \rho_k = 0,082 \cdot (1 - 0,01 \cdot 20) \cdot 430 = 28,21 \text{ N/mm}^2$$

$$f_{h,0,d} = k_{mod} \cdot \frac{f_{h,0,k}}{\gamma_M} = 0,9 \cdot \frac{28,21}{1,3} = 19,53 \text{ N/mm}^2$$

Moment plastifikacije za vijak M20, k.v. 8.6.

$$M_{y,k} = \frac{0,8 \cdot f_{u,k} \cdot d^3}{6} = \frac{0,8 \cdot 800 \cdot 20^3}{6} = 853333,3 \text{ Nmm}$$

$$M_{y,d} = \frac{M_{y,k}}{\gamma_M} = \frac{853333,3}{1,1} = 775757,58 \text{ Nmm}$$

Nosivost spajala:

$$R_d = f_{h,0,d} \cdot t_1 \cdot d = 19,53 \cdot 127,5 \cdot 20 = 49798,0 \text{ N}$$

$$R_d = 1,1 \cdot f_{h,0,d} \cdot t_1 \cdot d \left(\sqrt{2 + \frac{4 \cdot M_{y,d}}{f_{h,0,d} \cdot t^2 d}} - 1 \right)$$

$$= 1,1 \cdot 19,53 \cdot 127,5 \cdot 20 \left(\sqrt{2 + \frac{4 \cdot 775757,58}{19,53 \cdot 127,5^2 \cdot 20}} - 1 \right) = 31638,0 \text{ N}$$

$$R_d = 1,5 \sqrt{2 \cdot M_{y,d} \cdot f_{h,0,d} \cdot d} = 1,5 \sqrt{2 \cdot 775757,58 \cdot 19,53 \cdot 20} = 36925,0 \text{ N}$$

Reznost, $m=2$

Ukupna nosivost jednog vijka u spoju:

$$R_d = 2 \cdot 31638,0 = 63275,9 \text{ N}$$

Odabir broja spojnih sredstava;

$$n_{potr} \geq \frac{R_{u,d}}{\Sigma R_d} = \frac{386,39 \cdot 10^3}{63275,9} = 6,11 \text{ kom} \quad \text{odabrano 8 komada}$$

Za spoj lima i uzdužnog glavnog nosača odabrano je 8 vijaka M20, k.v. 8.6.

$$\frac{386,39 \cdot 10^3}{54158,52 \cdot 8} = 0,76 < 1$$

Spoj glavnog uzdužnog nosača zadovoljava sa 76 % iskoristivosti.

Spoj lima i tlačnog stupa pomoću vijka M20 - kut upada sile u odnosu na vlakanca $\alpha=0^\circ$

Proračun projektne vrijednosti čvrstoće pritiska po omotaču drva

$$f_{h,0,k} = 0,082 \cdot (1 - 0,01 \cdot d) \cdot \rho_k = 0,082 \cdot (1 - 0,01 \cdot 20) \cdot 430 = 28,21 \text{ N/mm}^2$$

$$f_{h,0,d} = k_{mod} \cdot \frac{f_{h,0,k}}{\gamma_M} = 0,9 \cdot \frac{28,21}{1,3} = 19,53 \text{ N/mm}^2$$

Moment plastifikacije za vijak M20, k.v. 8.6.

$$M_{y,k} = \frac{0,8 \cdot f_{u,k} \cdot d^3}{6} = \frac{0,8 \cdot 800 \cdot 20^3}{6} = 853333,3 \text{ Nmm}$$

$$M_{y,d} = \frac{M_{y,k}}{\gamma_M} = \frac{853333,3}{1,1} = 775757,58 \text{ Nmm}$$

Nosivost spajala:

$$R_d = f_{h,0,d} \cdot t_1 \cdot d = 19,53 \cdot 222,5 \cdot 20 = 86902,3 \text{ N}$$

$$R_d = 1,1 \cdot f_{h,0,d} \cdot t_1 \cdot d \left(\sqrt{2 + \frac{4 \cdot M_{y,d}}{f_{h,0,d} \cdot t^2 d}} - 1 \right)$$

$$= 1,1 \cdot 19,53 \cdot 222,5 \cdot 20 \left(\sqrt{2 + \frac{4 \cdot 775757,58}{19,53 \cdot 222,5^2 \cdot 20}} - 1 \right) = 44914,9 \text{ N}$$

$$R_d = 1,5 \sqrt{2 \cdot M_{y,d} \cdot f_{h,0,d} \cdot d} = 1,5 \sqrt{2 \cdot 775757,58 \cdot 19,53 \cdot 20} = 36925,0 \text{ N}$$

Reznost, $m=2$

Ukupna nosivost jednog vijka u spoju:

$$R_d = 2 \cdot 36925,0 = 73849,9 \text{ N}$$

Odabir broja spojnih sredstava;

$$n_{potr} \geq \frac{R_{u,v}}{\sum R_d} = \frac{728,44 \cdot 10^3}{73849,9} = 9,86 \text{ kom} \quad \text{odabrano 10 komada}$$

Za spoj lima i tlačnog stupa odabrano je 10 vijaka M20, k.v. 8.6.

$$\frac{728,44 \cdot 10^3}{73849,9 \cdot 10} = 0,98 < 1$$

Spoj lima i tlačnog stupa zadovoljava sa 98 % iskoristivosti.

Spoj lima i vlačnog stupa pomoću vijka M20 - kut upada sile u odnosu na vlakanca $\alpha=0^\circ$

Proračun projektne vrijednosti čvrstoće pritiska po omotaču drva

$$f_{h,0,k} = 0,082 \cdot (1 - 0,01 \cdot d) \cdot \rho_k = 0,082 \cdot (1 - 0,01 \cdot 20) \cdot 430 = 28,21 \text{ N/mm}^2$$

$$f_{h,0,d} = k_{mod} \cdot \frac{f_{h,0,k}}{\gamma_M} = 0,9 \cdot \frac{28,21}{1,3} = 19,53 \text{ N/mm}^2$$

Moment plastifikacije za vijak M20, k.v. 8.6.

$$M_{y,k} = \frac{0,8 \cdot f_{u,k} \cdot d^3}{6} = \frac{0,8 \cdot 800 \cdot 20^3}{6} = 853333,3 \text{ Nmm}$$

$$M_{y,d} = \frac{M_{y,k}}{\gamma_M} = \frac{853333,3}{1,1} = 775757,58 \text{ Nmm}$$

Nosivost spajala:

$$R_d = f_{h,0,d} \cdot t_1 \cdot d = 19,53 \cdot 122,5 \cdot 20 = 47845,1 \text{ N}$$

$$R_d = 1,1 \cdot f_{h,0,d} \cdot t_1 \cdot d \left(\sqrt{2 + \frac{4 \cdot M_{y,d}}{f_{h,0,d} \cdot t^2 d}} - 1 \right)$$

$$= 1,1 \cdot 19,53 \cdot 122,5 \cdot 20 \left(\sqrt{2 + \frac{4 \cdot 775757,58}{19,53 \cdot 122,5^2 \cdot 20}} - 1 \right) = 31073,6 \text{ N}$$

$$R_d = 1,5 \sqrt{2 \cdot M_{y,d} \cdot f_{h,0,d} \cdot d} = 1,5 \sqrt{2 \cdot 775757,58 \cdot 19,53 \cdot 20} = 36925,0 \text{ N}$$

Reznost, $m=2$

Ukupna nosivost jednog vijka u spoju:

$$R_d = 2 \cdot 31073,6 = 62147,1 \text{ N}$$

Odabir broja spojnih sredstava;

$$n_{potr} \geq \frac{R_{u,d}}{\sum R_d} = \frac{454,02 \cdot 10^3}{62147,1} = 7,31 \text{ kom} \quad \text{odabrano 8 komada}$$

Za spoj lima i vlačnog stupa odabrano je 8 vijaka M20, k.v. 8.6.

$$\frac{454,02 \cdot 10^3}{62147,1 \cdot 8} = 0,91 < 1$$

Spoj glavnog uzdužnog nosača zadovoljava sa 91 % iskoristivosti.

Proračun minimalnih razmaka:

$$a_1 = (4 + 3 \cdot |\cos \alpha|) \cdot d = 7 \cdot d = 7 \cdot 20 = 140 \text{ mm}$$

$$a_2 = 4 \cdot d = 4 \cdot 20 = 80 \text{ mm}$$

$$a_{3,t} = 7 \cdot d = 7 \cdot 20 = 140 \text{ mm}$$

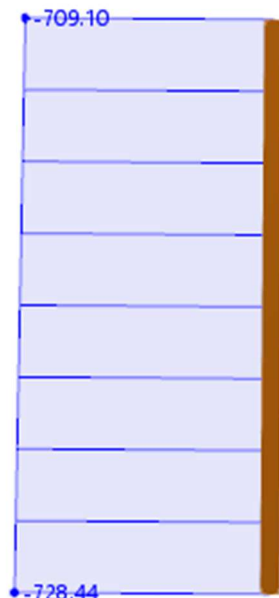
$$a_{3,c} = 4 \cdot d = 4 \cdot 20 = 80 \text{ mm}$$

$$a_{4,t} = (2 + 2 \cdot \sin \alpha) \cdot d = 2 \cdot d = 2 \cdot 20 = 40 \text{ mm} < 4 \cdot d = 80 \text{ mm}$$

$$a_{4,c} = 3 \cdot d = 3 \cdot 20 = 60 \text{ mm}$$

6.4. Spoj stupa i temelja

Dimenzionira se spoj na najkritičnijem mjestu na konstrukciji.



Slika 6.12.: Dijagram uzdužnih sila N [kN]

Čelična ploča koja dolazi na temelj predviđena je debljine 20 mm i kvalitete čelika S235, na koju se spajaju pomoću vara debljine 3mm kvalitete S235 čelične ploče debljine 5mm kvalitete S235.

Vijci koji su predviđeni za spoj su M20 k.v. 8.6.

$$f_{h,0,k} = 0,082 \cdot (1 - 0,01) \cdot \rho_k = 0,082 \cdot (1 - 0,01 \cdot 20) \cdot 430 = 28,21 \text{ N/mm}^2$$

$$f_{h,0,d} = 0,9 \cdot \frac{28,21}{1,3} = 19,53 \text{ N/mm}^2$$

$$M_{y,k} = \frac{0,8 \cdot f_{u,k} \cdot d^3}{6} = \frac{0,8 \cdot 800 \cdot 20^3}{6} = 853333,3 \text{ Nm}$$

$$M_{y,d} = \frac{M_{y,k}}{\gamma_M} = \frac{853333,3}{1,1} = 775757,58 \text{ Nm}$$

$$R_d = 0,5 \cdot f_{h,90,d} \cdot t_2 \cdot d = 0,5 \cdot 19,53 \cdot 450 \cdot 20 = 87885 \text{ N}$$

$$R_d = 1,1 \cdot \sqrt{2 \cdot M_{y,d} \cdot f_{h,90,d} \cdot d} = 1,1 \cdot \sqrt{2 \cdot 775757,58 \cdot 19,53 \cdot 20} = 27079,26 \text{ N}$$

Ukupna nosivost jednog vijka u spoju

$$R_d = m \cdot R_{min,d} = 2 \cdot 27079,26 = 54158,52 \text{ N}$$

Odabir broja spojnih sredstava;

$$n_{potr} \geq \frac{N_d}{\Sigma R_d} = \frac{728,44 \cdot 10^3}{54158,52} = 13,45 \text{ kom}$$

Za spoj lima i stupa odabrano je 14 vijaka M20, k.v. 8.6.

Proračun minimalnih razmaka:

$$a_{1,t} = (4 + 3 \cdot |\cos \alpha|) \cdot d = 7 \cdot d = 7 \cdot 20 = 140 \text{ mm}$$

$$a_{2,t} = 4 \cdot d = 4 \cdot 20 = 80 \text{ mm}$$

$$a_{3,t} = 7 \cdot d = 7 \cdot 20 = 140 \text{ mm}$$

$$a_{3,c} = 4 \cdot d = 4 \cdot 20 = 80 \text{ mm}$$

$$a_{4,t} = (2 + 2 \cdot \sin \alpha) \cdot d = 2 \cdot d = 2 \cdot 20 = 40 \text{ mm} < 4 \cdot d = 80 \text{ mm}$$

$$a_{4,c} = 3 \cdot d = 3 \cdot 20 = 60 \text{ mm}$$

$$\frac{728,44 \cdot 10^3 \cdot 6}{54158,52} = 0,96 < 1$$

Spoj stupa s temeljem zadovoljava sa 96 % iskoristivosti.

Spoj čeličnih elementa međusobno - proračun vara

$$F_{v,w,d} = \frac{f_u}{\sqrt{3} \cdot \beta_w \cdot \gamma_{M2}} = \frac{360}{\sqrt{3} \cdot 0,8 \cdot 1,25} = 249,61 \text{ N/mm}^2$$

$$F_{v,Rd} = 3 \cdot 249,61 \cdot 450 \cdot 4 = 1347894 \text{ N} = 1347,90 \text{ kN}$$

$$728,44 < 1347,90 \text{ kN}$$

Var zadovoljava sa 54 % iskoristivosti

6.5. Proračun pokrova na odizanje

Vijci koji su predviđeni za spoj pokrova su M8 k.v. 8.6.

Sila odizanja pokrova je; $N_d = 3.175 \text{ kN/m}$

Proračun vijaka na čupanje

$$l_{ef} = 80 \text{ mm}$$

$$f_{\check{c},k} = (1,5 + 0,6 \cdot d) \cdot \sqrt{\rho_k} = (1,5 + 0,6 \cdot 8) \cdot \sqrt{430} = 130.64 \text{ N/mm}$$

$$f_{\check{c},k} = 0,9 \cdot \frac{130.64}{1,3} = 90.44 \text{ N/mm}$$

$$R_d = (l_{ef} - d) \cdot f_{\check{c},k} = (80 - 8) \cdot 90.44 = 6511.68 \text{ N} = 6.51$$

$$n_{potr} \geq \frac{N_d}{\Sigma R_d} = \frac{3.175}{6.51} = 0.48$$

Odabrano 2 kom

Potrebno je ugraditi 2 vijka po m' nosača za sprječavanje odizanja pokrova.

7. ISKAZ MATERIJALA

7.1. Sekundarni nosači

Tablica 122.: Iskaz materijala za sekundarne nosače

Material No.	Material Name	Section Name	Members No.	Quantity Q [-]	Length L [m]	Unit Surf. Area A_m [m ² /m]	Volume V [m ³]	Unit Mass M [kg/m]	Member Mass M [t]
		R_M1 160/200	87-102,130-145,163-178, 206-221,239-254,282-297,315-330,358-373,391-406,434-449,467-482,510-525,555-570,598-613,631-646,674-689,707-722,750-765,783-798,826-841,859-874,902-917,935-950,978-993	384.00	5.033	0.720	0.161	15.7	0.079

7.2. Glavni poprečni nosači

Tablica 123.: Iskaz materijala za glavne poprečne nosače

Material No.	Material Name	Section Name	Member Sets No.	Quantity Q [-]	Length L [m]	Tot. Length L_z [m]	Tot. Surf. Area $A_{m,z}$ [m ²]	Tot. Volume V_z [m ³]	Total Mass M_z [t]
1	GL32h	R_M1 260/1800	2-5,7-19	17.00	38.437	653.431	2708.046	305.805	149.845

7.3. Glavni uzdužni nosači

Tablica 124.: Iskaz materijala za glavne uzdužne nosače

Material No.	Material Name	Section Name	Members No.	Quantity Q [-]	Length L [m]	Unit Surf. Area A_m [m ² /m]	Volume V [m ³]	Unit Mass M [kg/m]	Member Mass M [t]
1	GL32h	R_M1 260/1800	1,20	2.00	80.532	161.065	665.458	75.378	36.935

7.4. Vlačni stupovi

Tablica 125.: Iskaz materijala za vlačne stupove

Material No.	Material Name	Section Name	Members No.	Quantity Q [-]	Length L [m]	Unit Surf. Area A_m [m ² /m]	Volume V [m ³]	Unit Mass M [kg/m]	Member Mass M [t]
1	GL32h	R_M1 250/250	5	1.00	17.088	1.000	2.136	30.6	1.047
		R_M1 250/250	7	1.00	17.029	1.000	4.257	30.6	2.086
		R_M1 250/250	9	1.00	16.854	1.000	4.213	30.6	2.065
		R_M1 250/250	11	1.00	16.561	1.000	4.140	30.6	2.029
		R_M1 250/250	14	1.00	16.153	1.000	4.038	30.6	1.979
		R_M1 250/250	17	1.00	15.632	1.000	3.908	30.6	1.915
		R_M1 250/250	18	1.00	14.999	1.000	3.750	30.6	1.837
		R_M1 250/250	20	1.00	14.259	1.000	3.565	30.6	1.747
		R_M1 250/250	23	1.00	13.416	1.000	3.354	30.6	1.644

7.5. Tlačni stupovi

Tablica 126.: Iskaz materijala za tlačne stupove

Material No.	Material Name	Section Name	Members No.	Quantity Q [-]	Length L [m]	Unit Surf. Area A _u [m ² /m]	Volume V [m ³]	Unit Mass M [kg/m]	Member Mass M [t]
1	GL32h	R_M1 450/450	6	1.00	16.000	1.800	6.480	99.2	3.175
		R_M1 450/450	8	1.00	15.937	1.800	12.909	99.2	6.326
		R_M1 450/450	10	1.00	15.749	1.800	12.757	99.2	6.251
		R_M1 450/450	12	1.00	15.436	1.800	12.503	99.2	6.127
		R_M1 450/450	15	1.00	14.998	1.800	12.148	99.2	5.953
		R_M1 450/450	1,26	2.00	14.435	1.800	5.846	99.2	2.865
		R_M1 450/450	19	1.00	13.747	1.800	11.135	99.2	5.456
		R_M1 450/450	21	1.00	12.935	1.800	10.478	99.2	5.134
		R_M1 450/450	24	1.00	12.000	1.800	9.720	99.2	4.763

7.6. Čelični spregovi

Tablica 127.: Iskaz materijala za čelične spregove

Material No.	Material Name	Section Name	Representatives No.	Quantity Q [-]	Length L [m]	Tot. Length L _z [m]	Tot. Surf. Area A _{m,z} [m ²]	Tot. Volume V _z [m ³]	Total Mass M _z [t]
4	S355	R 30	3	1.00	16.763	33.526	3.162	0.024	0.186
		R 30	2	1.00	16.713	33.426	3.152	0.024	0.186
		R 30	13	1.00	16.199	64.797	6.111	0.046	0.360
		R 30	16	1.00	15.841	63.363	5.976	0.045	0.352
		R 30	22	1.00	13.848	55.393	5.225	0.039	0.307
		R 30	25	1.00	13.000	52.000	4.905	0.037	0.289
		Total			6.00		302.506	28.530	0.214

7.7. Pokrov

7.7.1. Trevira – krovni pokrov

Tablica 128.: Iskaz materijala krovni pokrov

Material No.	Material Name	Thickness Name	Surfaces No.	Quantity Q [-]	Surface S [m ²]	Tot. Coating C _z [m ²]	Tot. Surface S _z [m ²]	Tot. Volume V _z [m ³]	Total Mass M _z [t]
2	Trevira CS	Uniform d : 20.0 mm 2 - Trevira CS	10,11	2.00	193.464	773.855	386.927	7.739	10.447
		Uniform d : 20.0 mm 2 - Trevira CS	9,12	2.00	193.461	773.844	386.922	7.738	10.447
		Uniform d : 20.0 mm 2 - Trevira CS	8,13	2.00	193.456	773.822	386.911	7.738	10.447
		Uniform d : 20.0 mm 2 - Trevira CS	7,14	2.00	193.447	773.790	386.895	7.738	10.446
		Uniform d : 20.0 mm 2 - Trevira CS	6,15	2.00	193.437	773.747	386.874	7.737	10.446
		Uniform d : 20.0 mm 2 - Trevira CS	5,16	2.00	193.423	773.693	386.847	7.737	10.445
		Uniform d : 20.0 mm 2 - Trevira CS	4,17	2.00	193.407	773.630	386.815	7.736	10.444
		Uniform d : 20.0 mm 2 - Trevira CS	3,18	2.00	193.389	773.555	386.778	7.736	10.443
		Total			16.00		6189.936	3094.968	61.899
Σ Total				16.00		6189.936	3094.968	61.899	83.564

7.7.2. Leksan – bočni pokrov

Tablica 129.: Iskaz materijala bočni pokrov

Surface No.	Boundary Lines No.	Stiffness Type	Geometry Type	Thickness No.	Material	Eccentricity No.	Nodes No.	Integrated Objects Lines No.	Openings No.	Area A [m ²]	Volume V [m ³]	Mass M [t]
2	18,93,136,169,212,245,288,321,364,397,...	Standard	Quadrangle	1	5 - Leksan LTC d=20mm					392.448	7.849	9.419
19	92,109,152,185,228,261,304,337,380,413,...	Standard	Quadrangle	1	5 - Leksan LTC d=20mm					392.448	7.849	9.419
20	1036,1037,1042,1044,1047,1049,1052,10...	Standard	Quadrangle	1	5 - Leksan LTC d=20mm			1038,1043,1,...		1173.759	23.475	28.170
21	18,19,24,26,29,31,34,36,39,41,46,48,51,5...	Standard	Quadrangle	1	5 - Leksan LTC d=20mm			20,25,27,30,...		1173.759	23.475	28.170

8. ZAKLJUČAK

Zaključak ovog diplomskog rada temelji se na sveobuhvatnom proračunu konstrukcije sportske hale, pri čemu su svi ključni elementi projektirani s naglaskom na nosivost i otpornost na opterećenja, uzimajući u obzir specifične izazove lokacije i dimenzija objekta.

Konstrukcija sportske hale podvrgnuta je detaljnoj statičkoj analizi koja je uključivala stalna, promjenjiva i izvanredna opterećenja, poput vjetra i snijega, prema Eurocode standardima. Opterećenje vjetrom, simulirano pomoću softvera RWIND, pokazalo je da najveća ukupna sila vjetra pri djelovanju longitudinalnog vjetra na potpuno otvorenu konstrukciju predstavlja najzahtjevniji scenarij, zbog čega su postavljene horizontalne i vertikalne stabilizacije kako bi se osigurala horizontalna stabilnost konstrukcije.

Proračun seizmičkog opterećenja prema Eurocode 8 normama pokazao je da je seizmička sila značajno manje opterećenje od opterećenja vjetrom, te potres nije bio mjerodavno horizontalno opterećenje za dimenzioniranje hale.

Stabilnost je dodatno osigurana spojnim elementima između komponenti konstrukcije, čiji su proračuni izvedeni prema odgovarajućim normama.

Sveukupno, analiza nosivosti i opterećenja pokazuje da je projektirana sportska hala sposobna podnijeti specifične klimatske i seizmičke uvjete lokacije, uz održavanje visokih standarda stabilnosti i sigurnosti.

Ovaj projekt demonstrira kako dimenzioniranje drvene konstrukcije primjenom naprednih softverskih alata u kombinaciji s pažljivom optimizacijom konstrukcijskih elemenata može rezultirati efikasnim i dugotrajnim rješenjem, osiguravajući maksimalnu stabilnost i sigurnost objekta, te pružajući visoku razinu sigurnosti i funkcionalnosti za korisnike.

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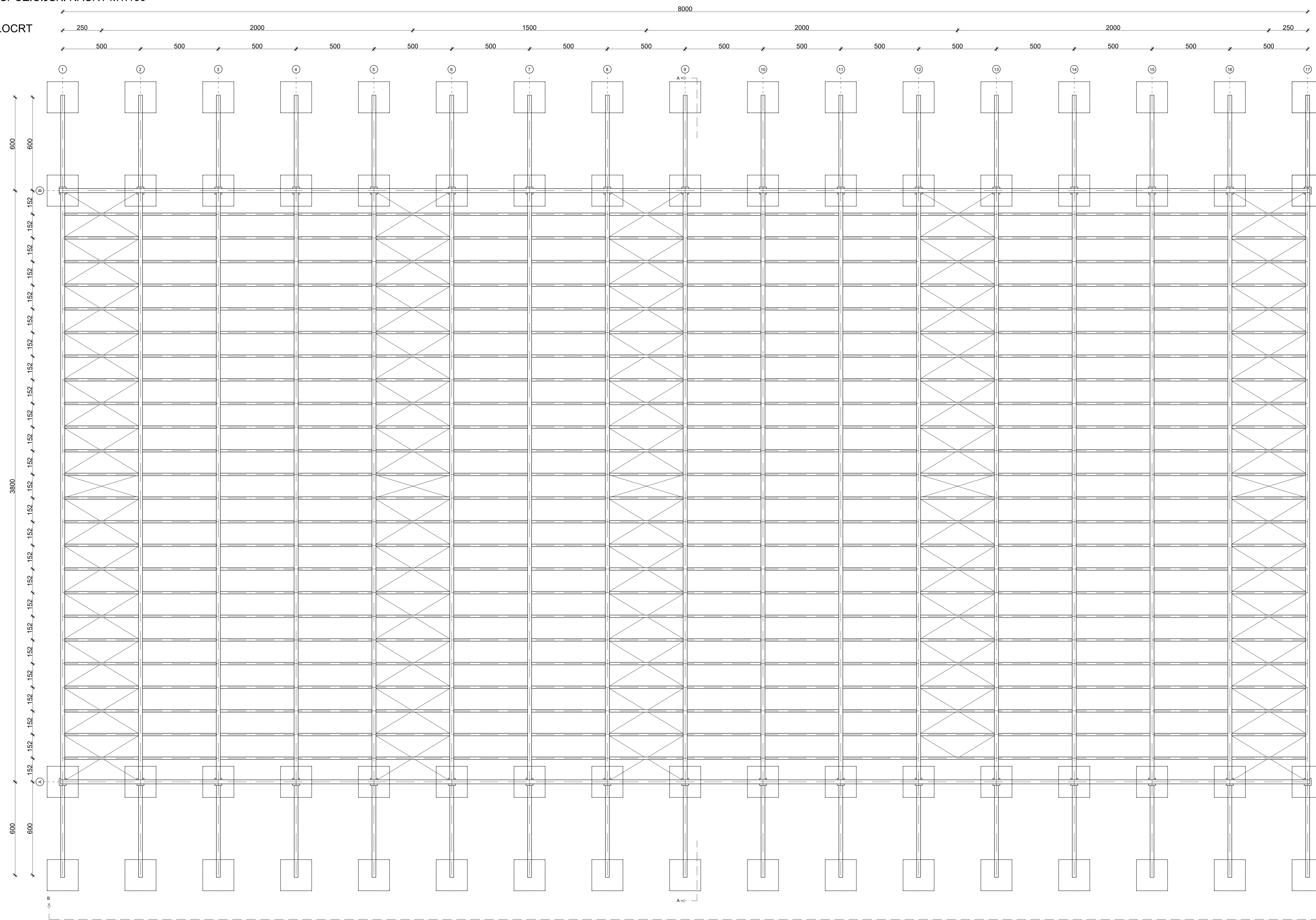
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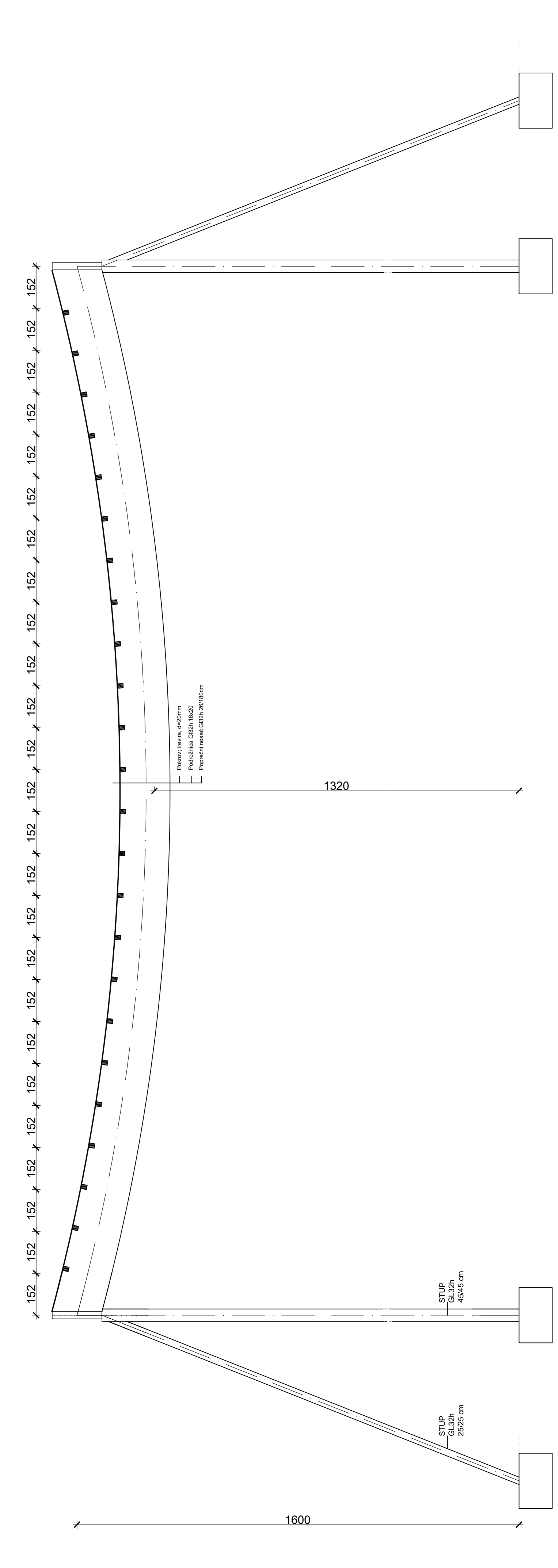
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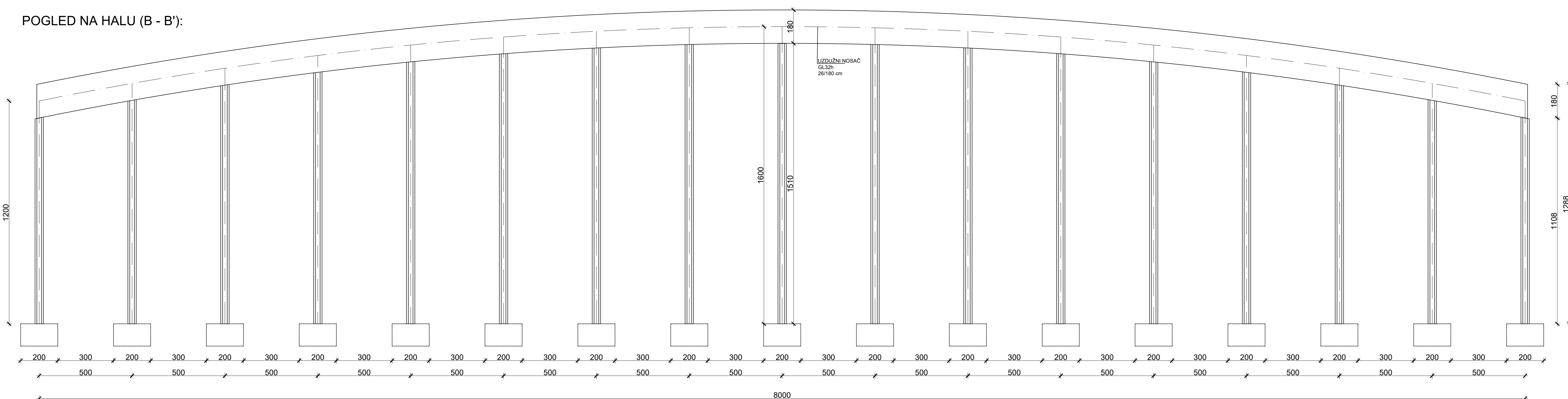
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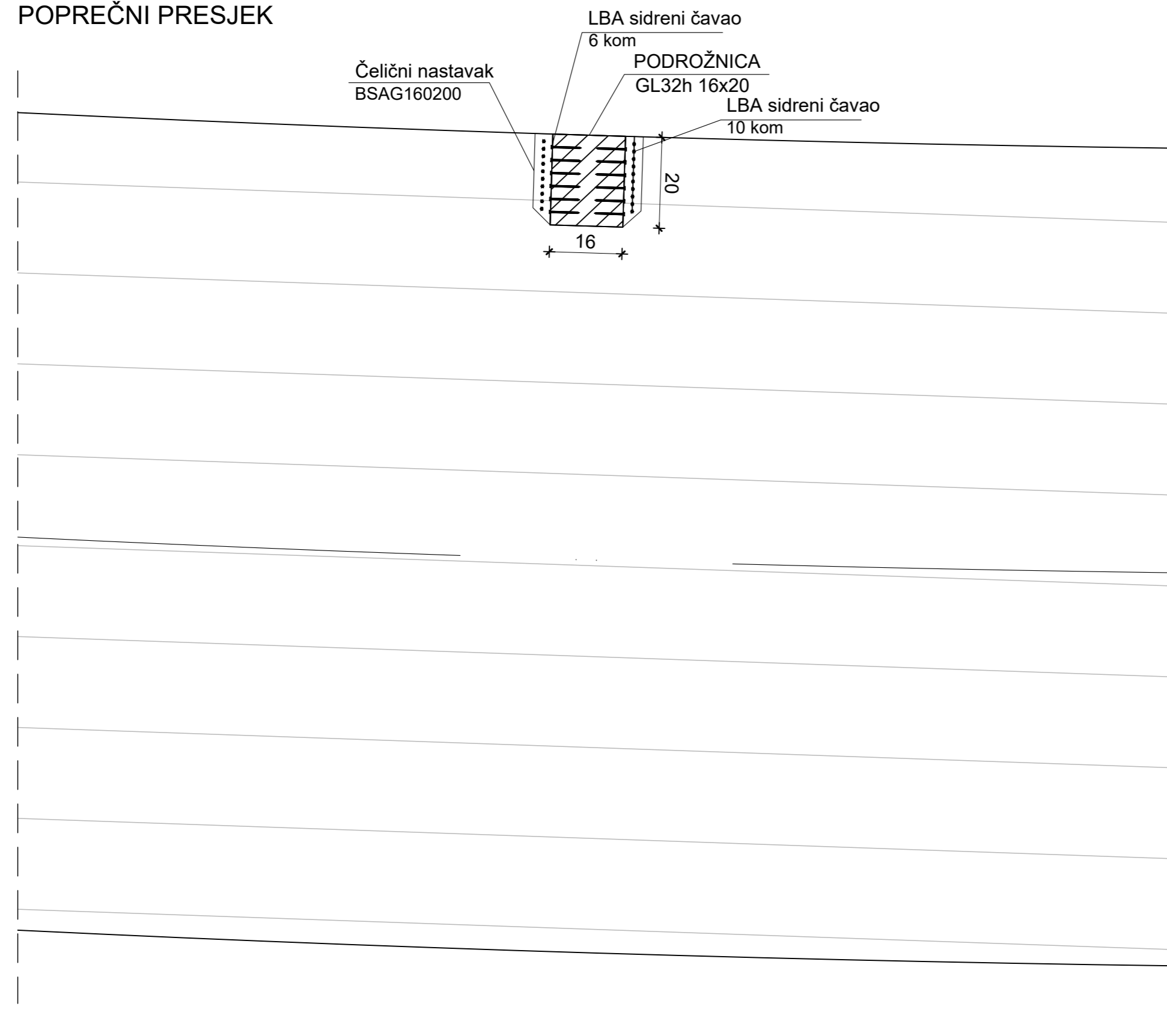
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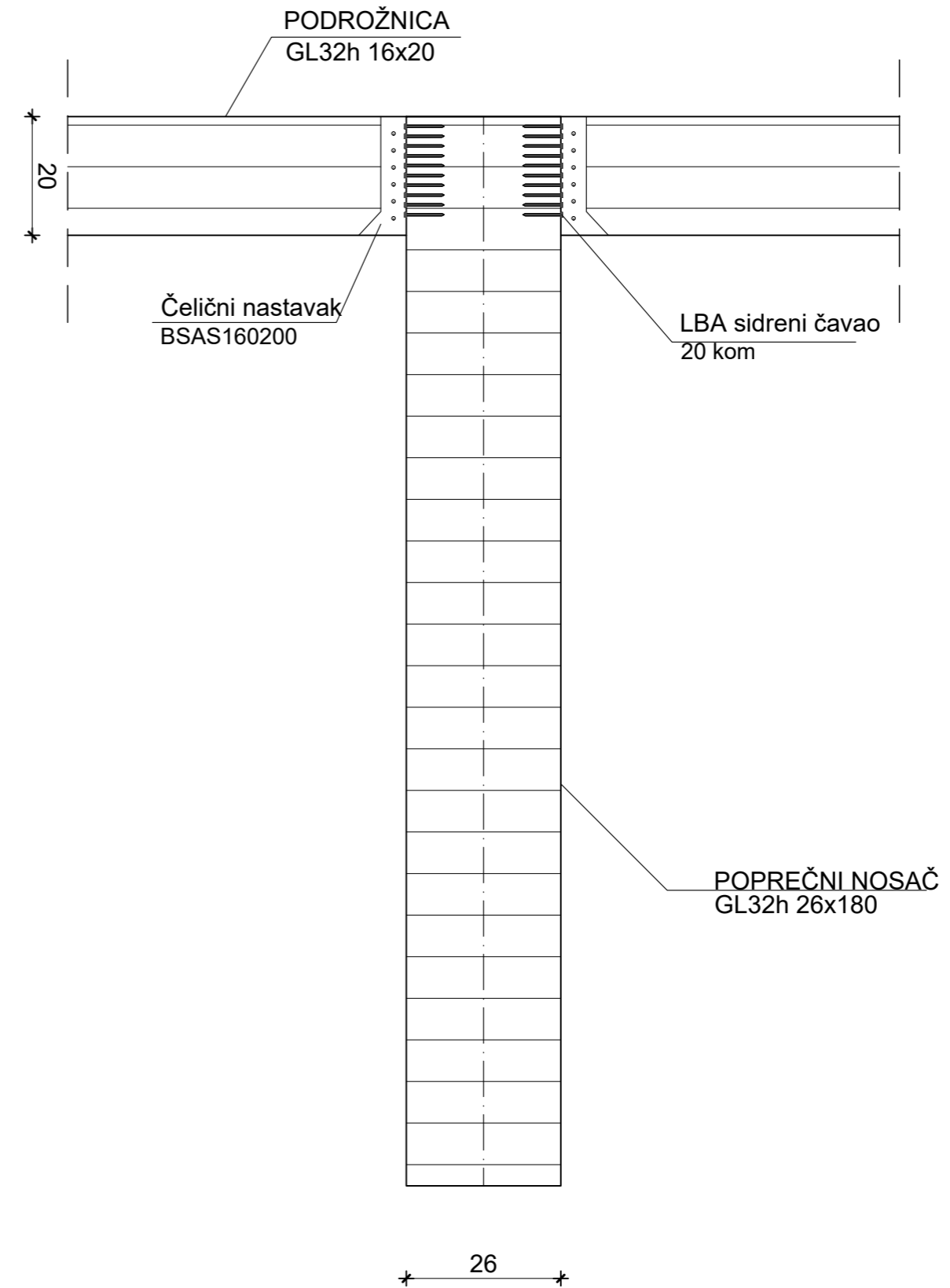
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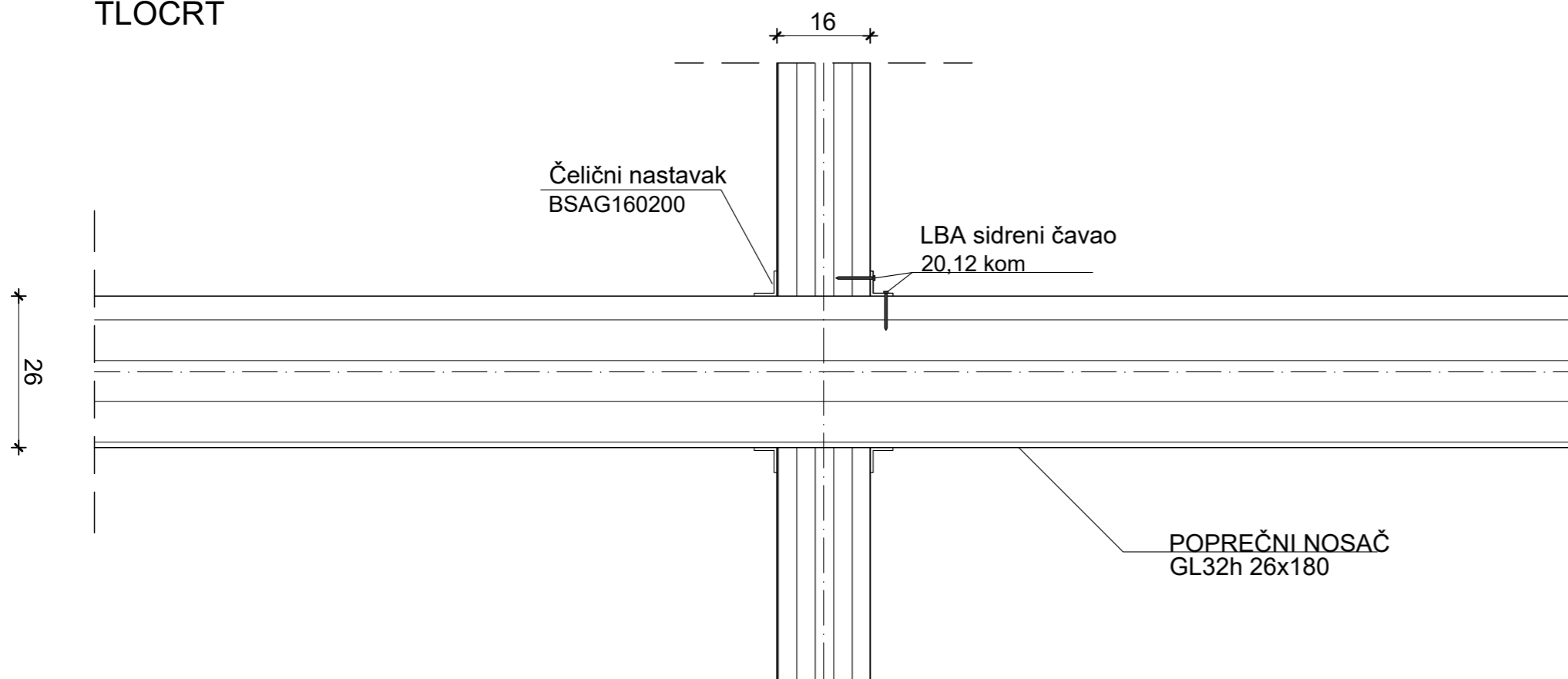
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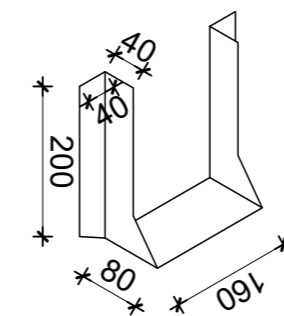
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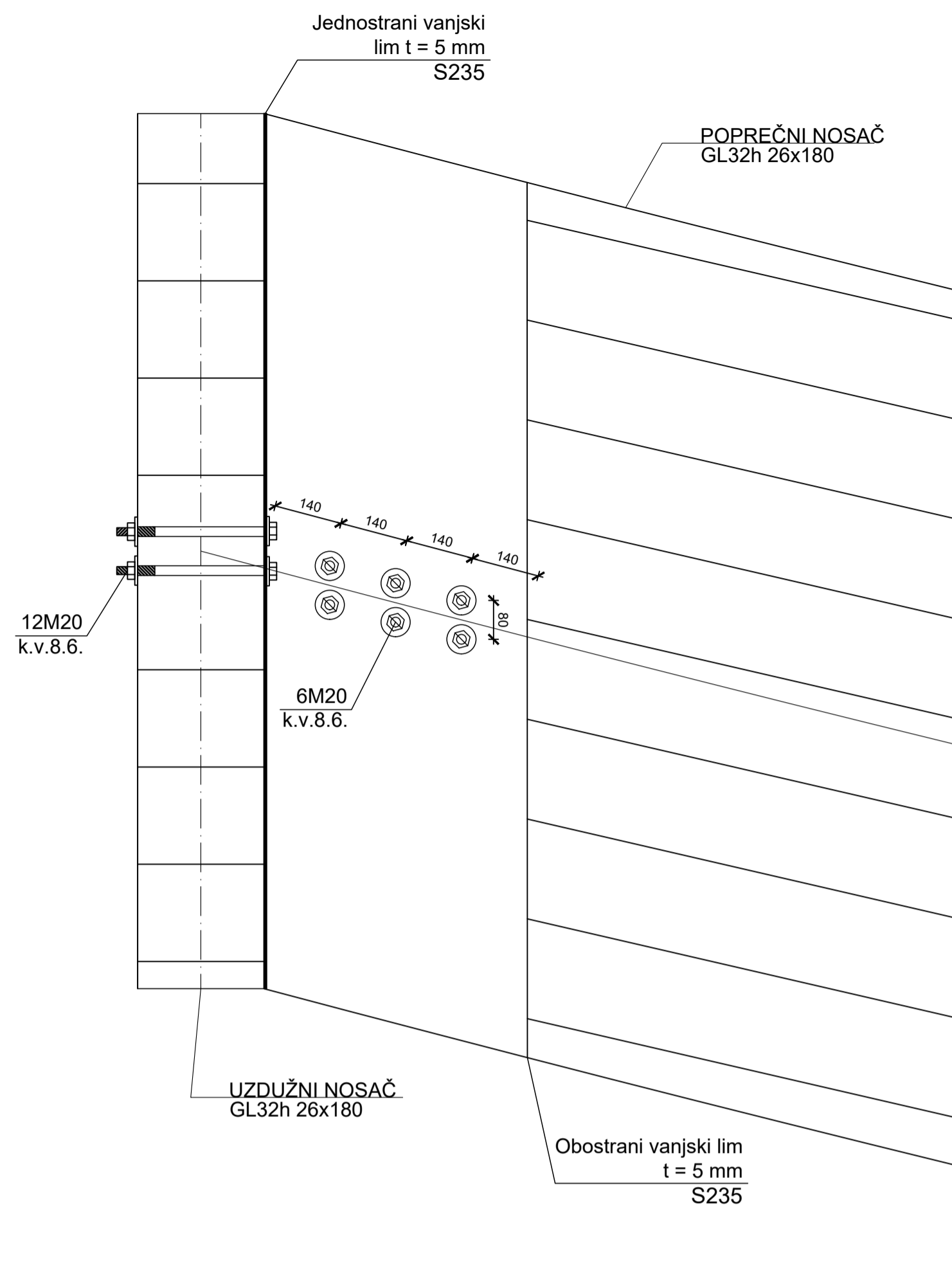
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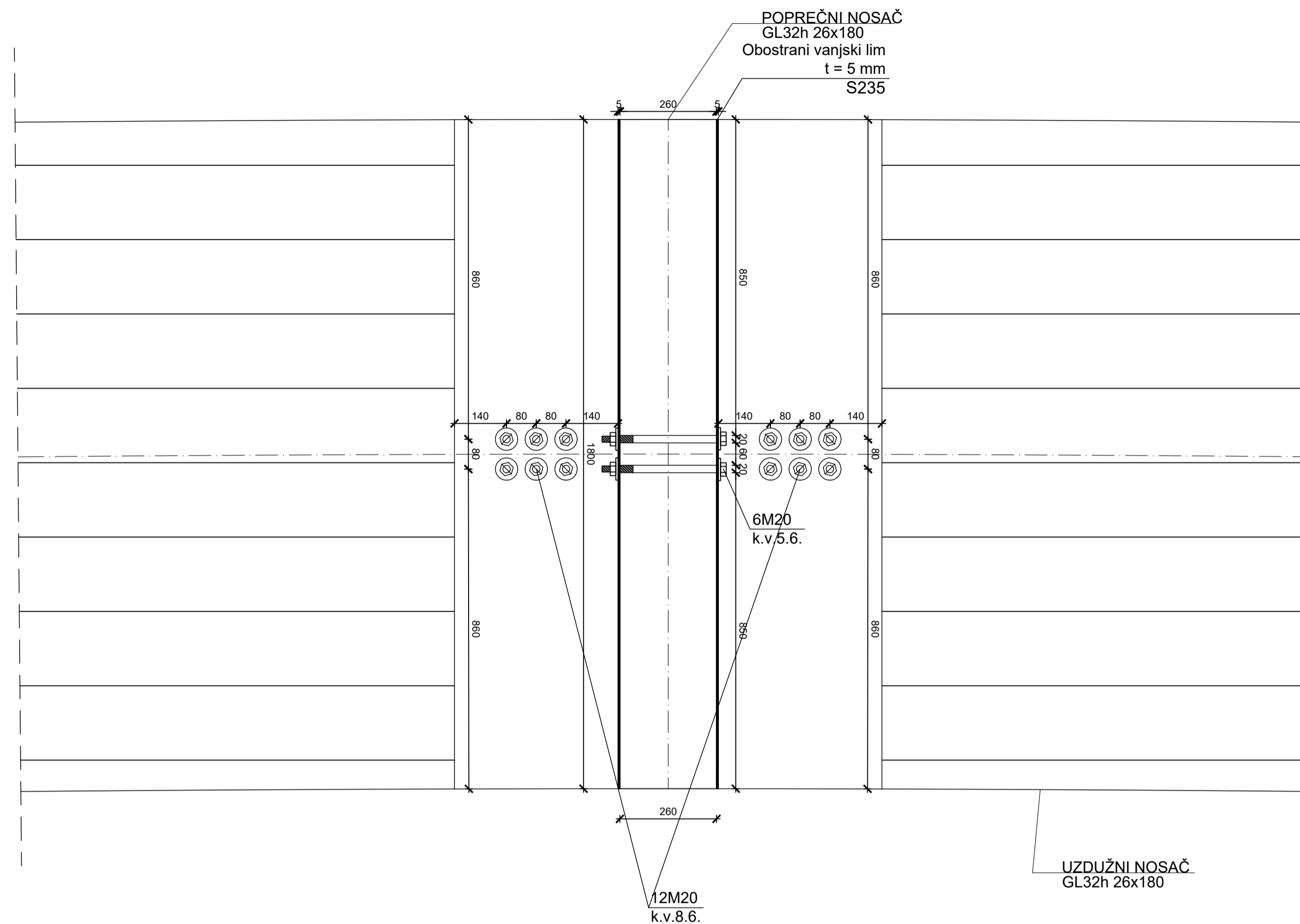
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Sadržaj nacрта: Detalj 1; detalj spoja podrožnice i glavnog poprečnog nosača			
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DETALJ 2 - Spoj glavnog uzdužnog i glavnog poprečnog nosača - M 1:10

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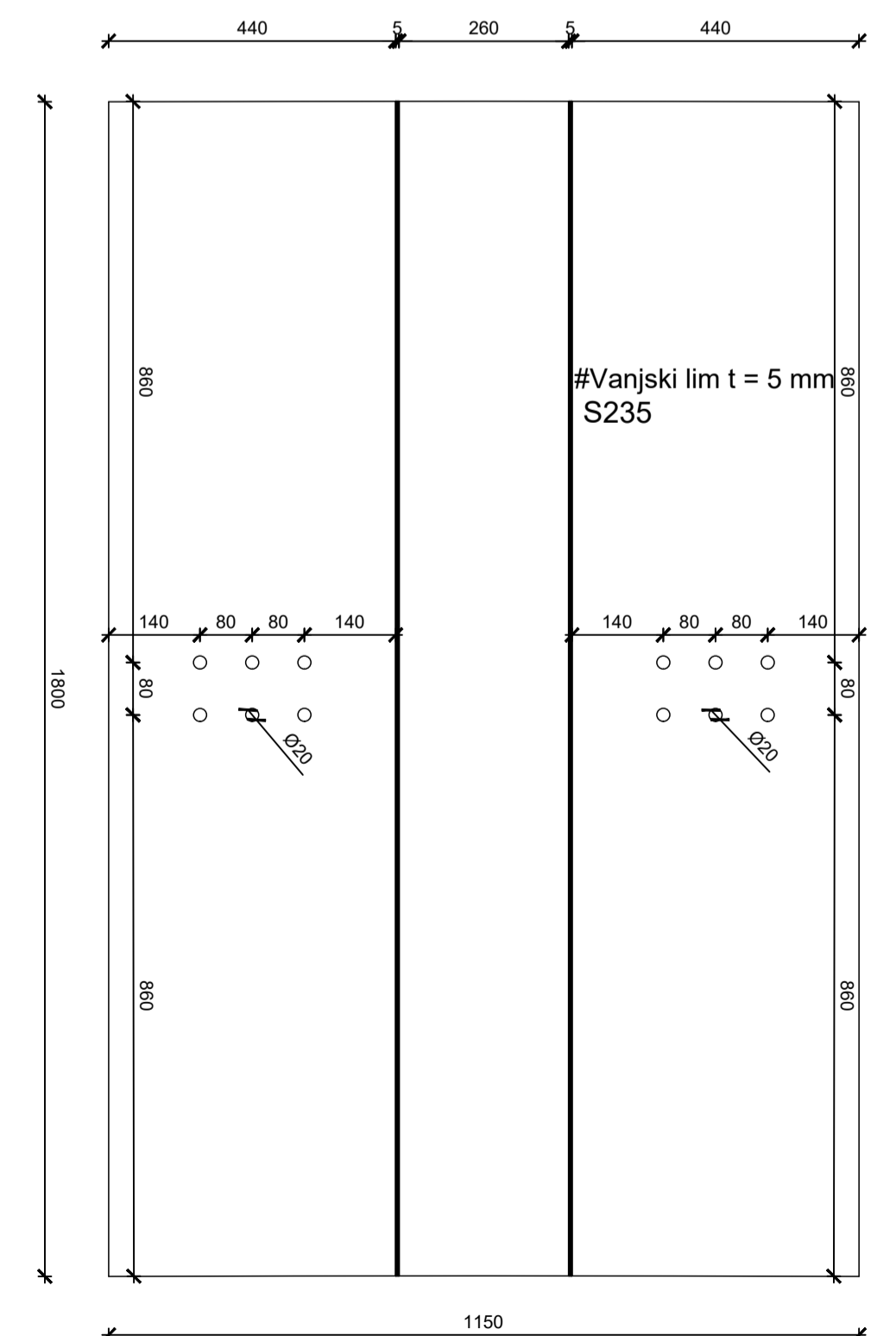
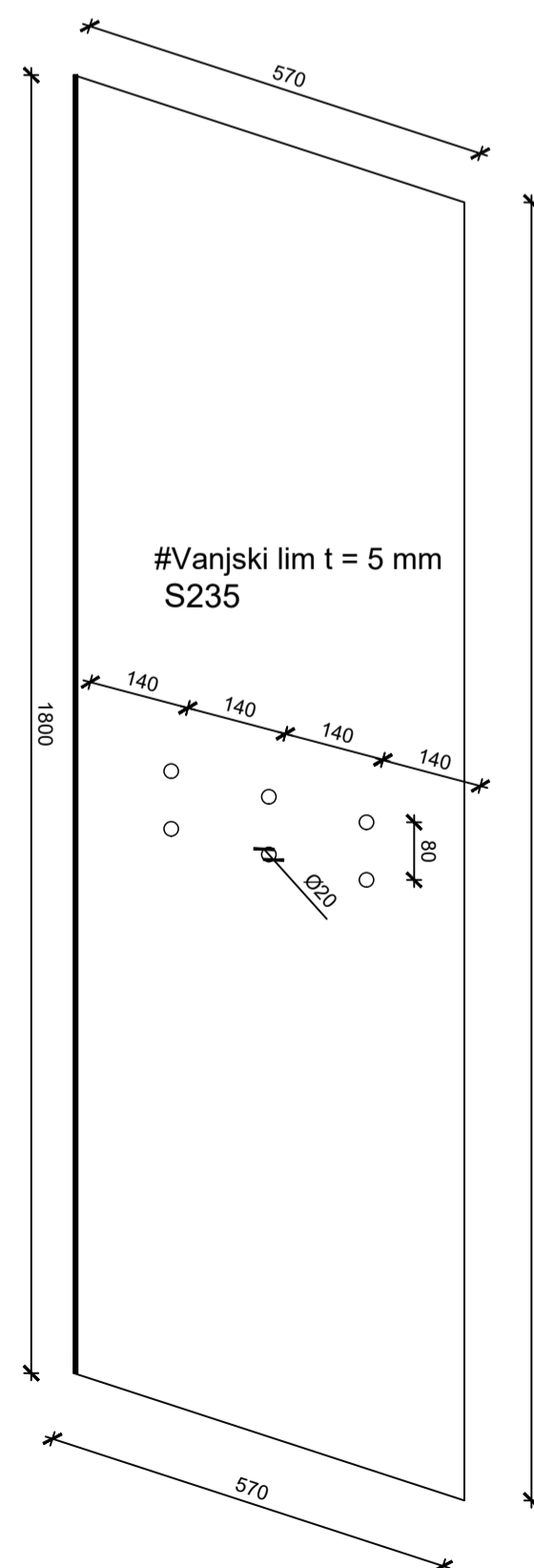
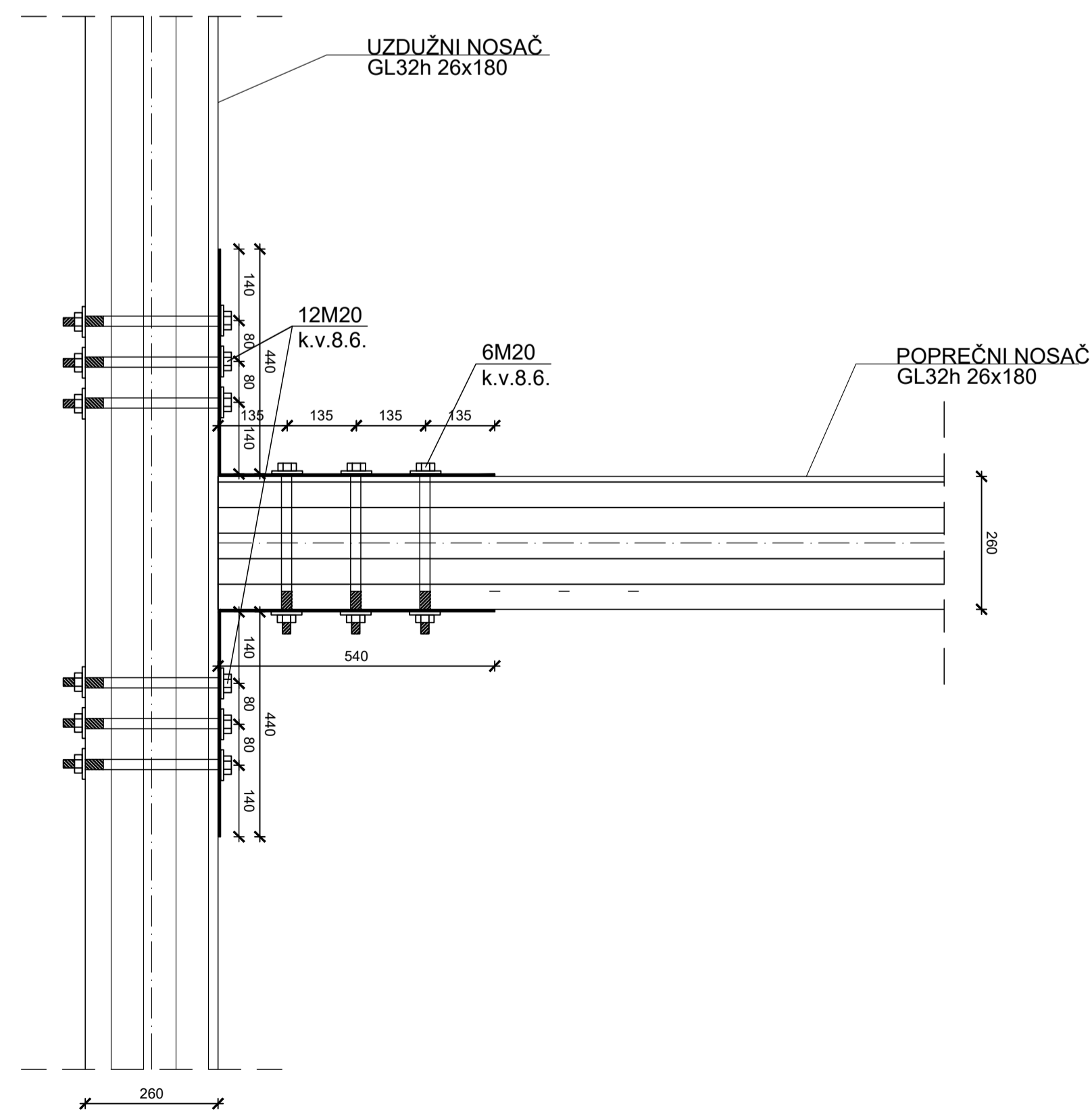
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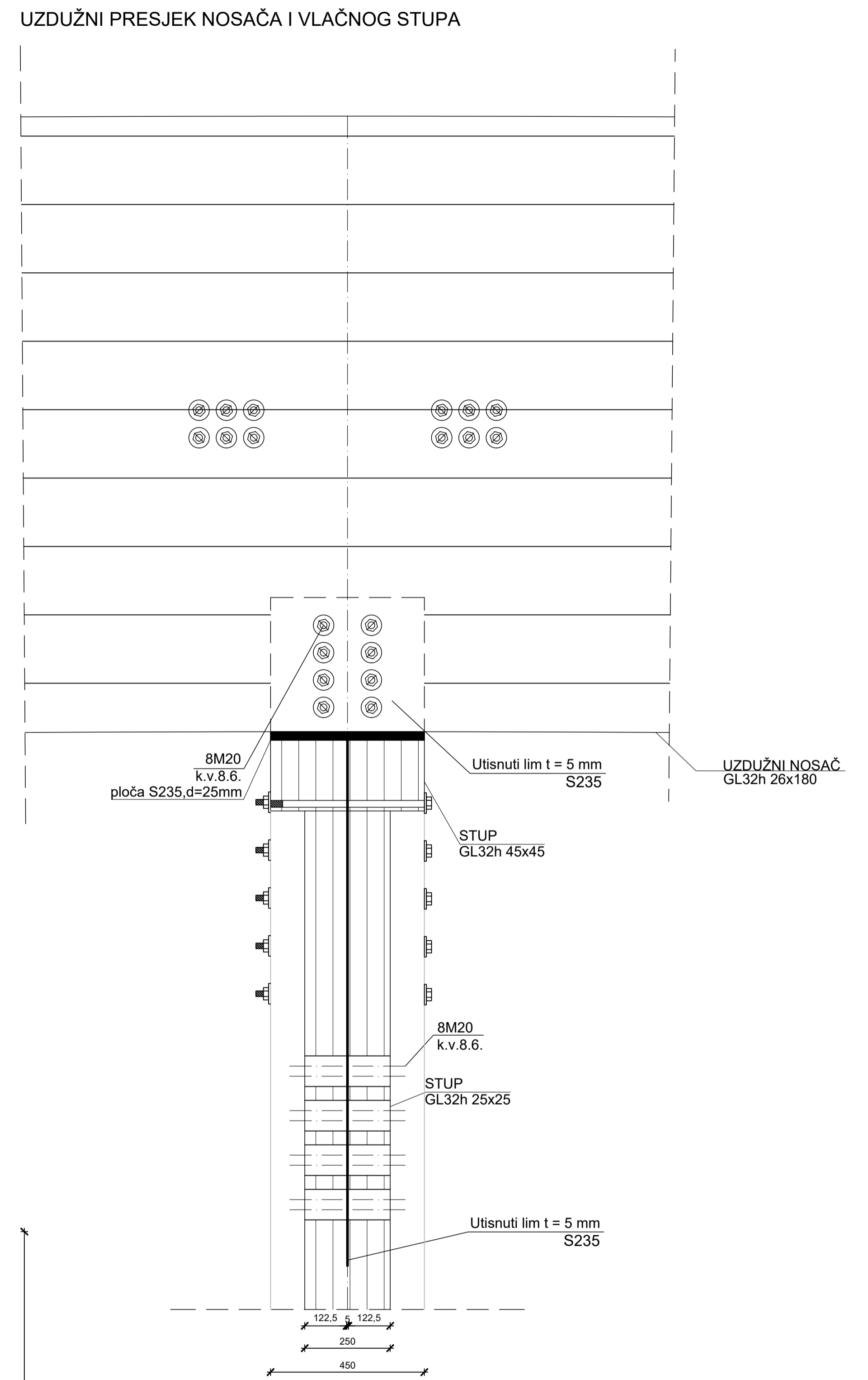
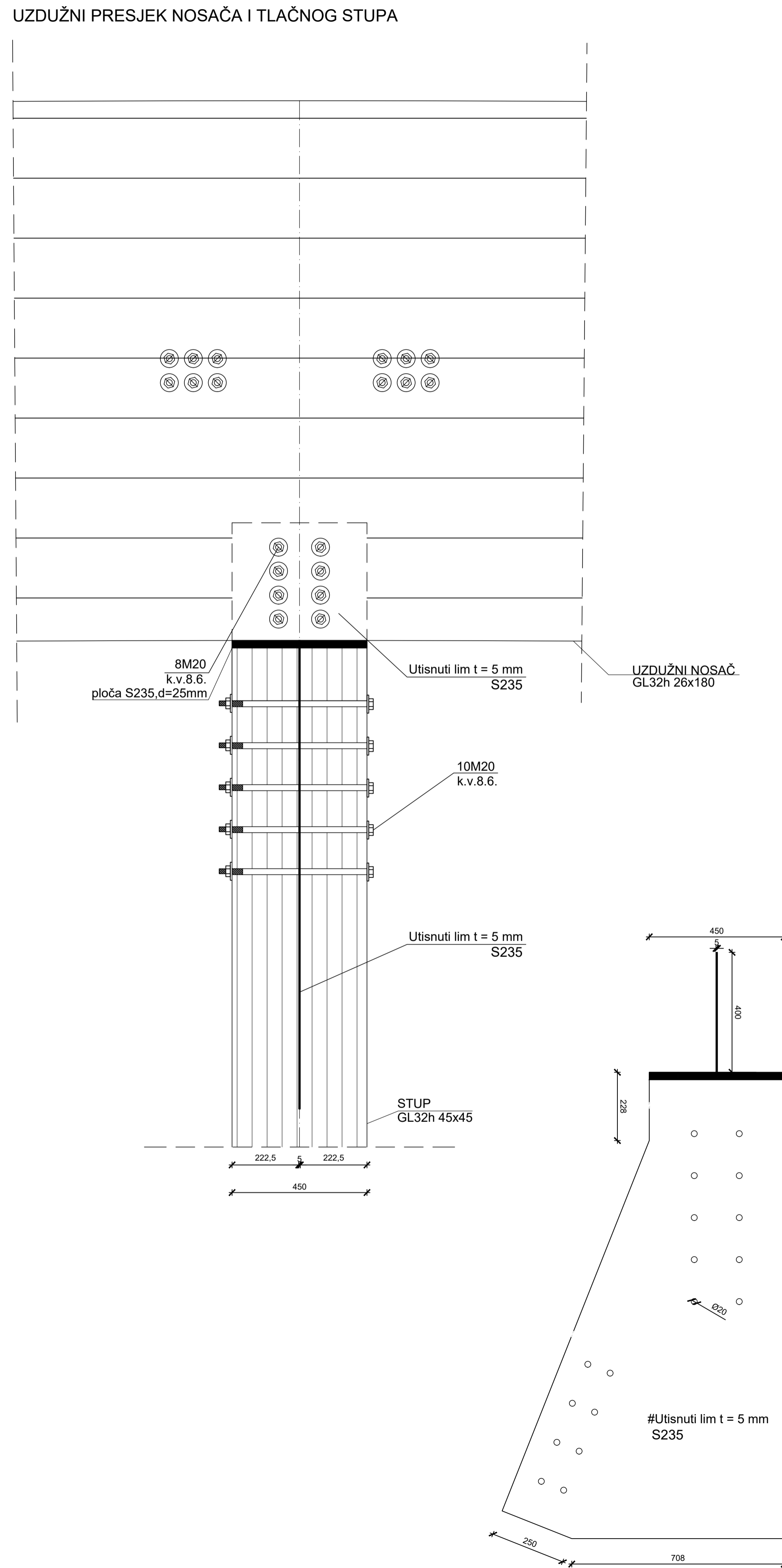
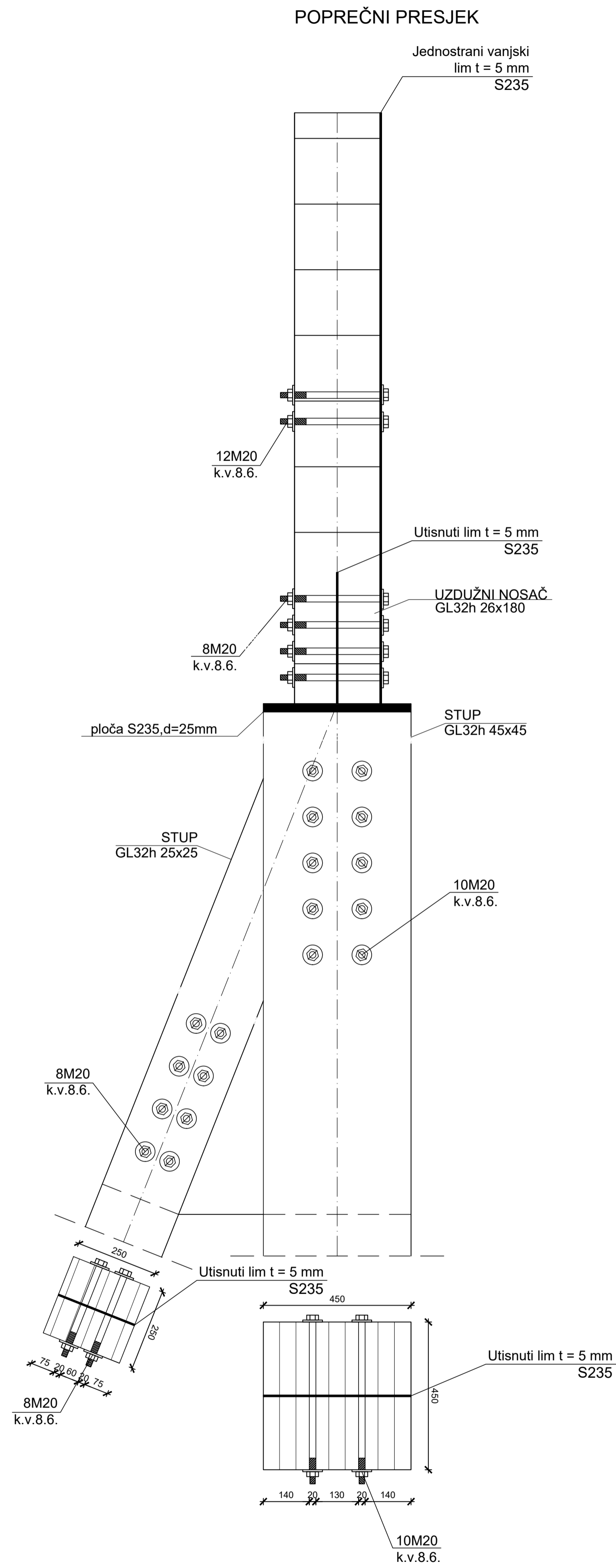
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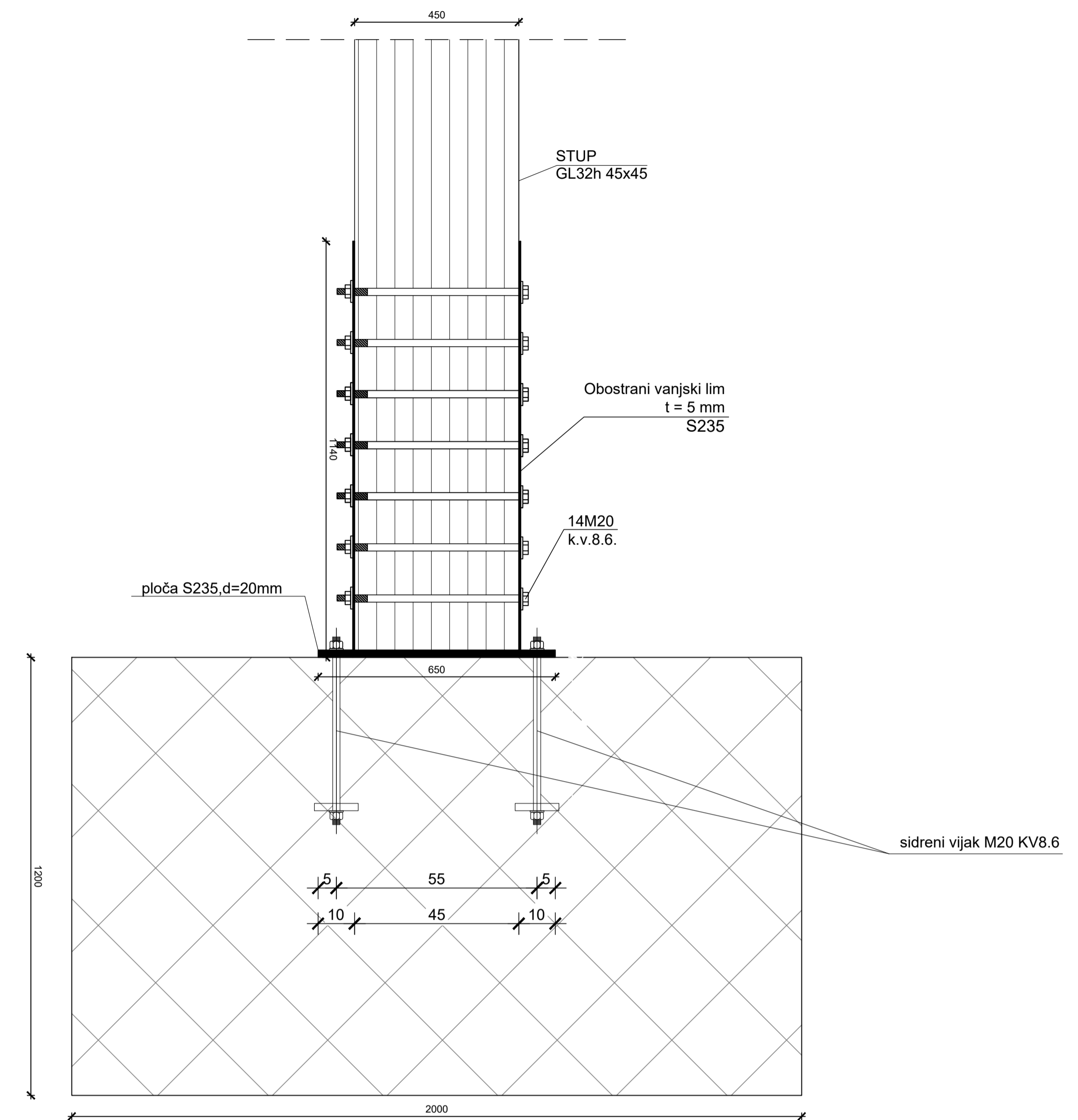
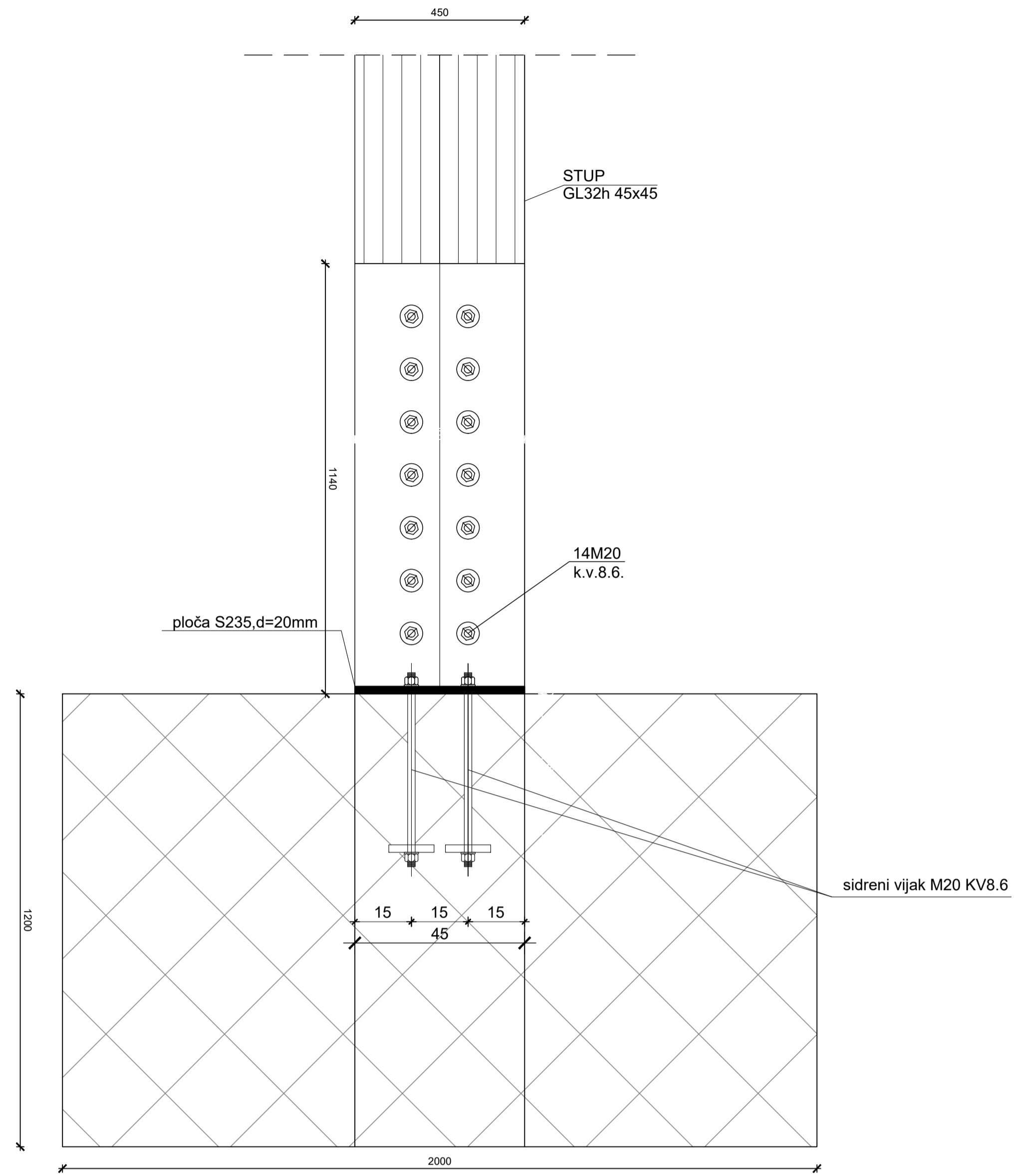
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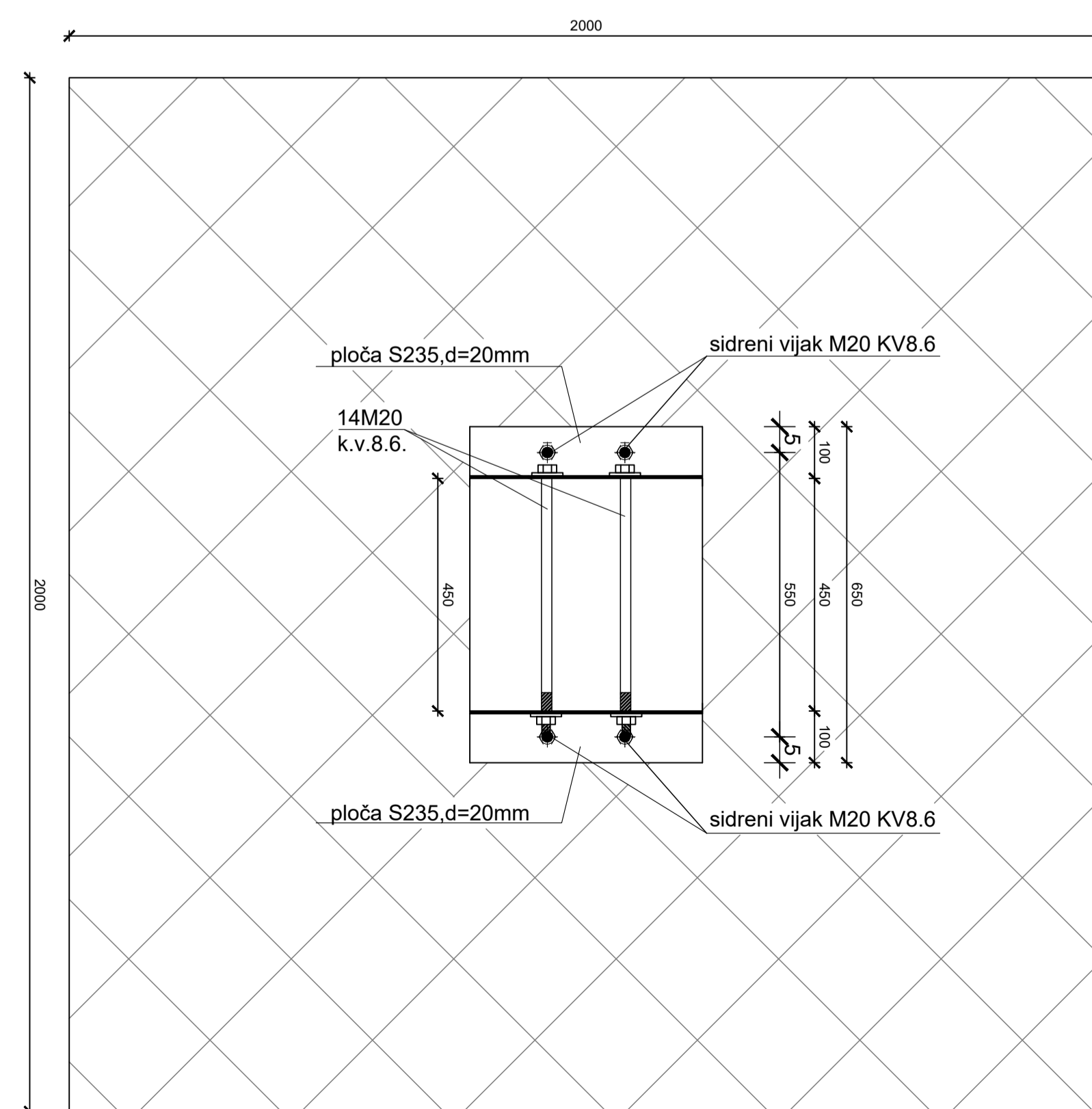
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Mentor: prof.dr.sc. Vlatka Rajčić		Broj nacrt: 4	
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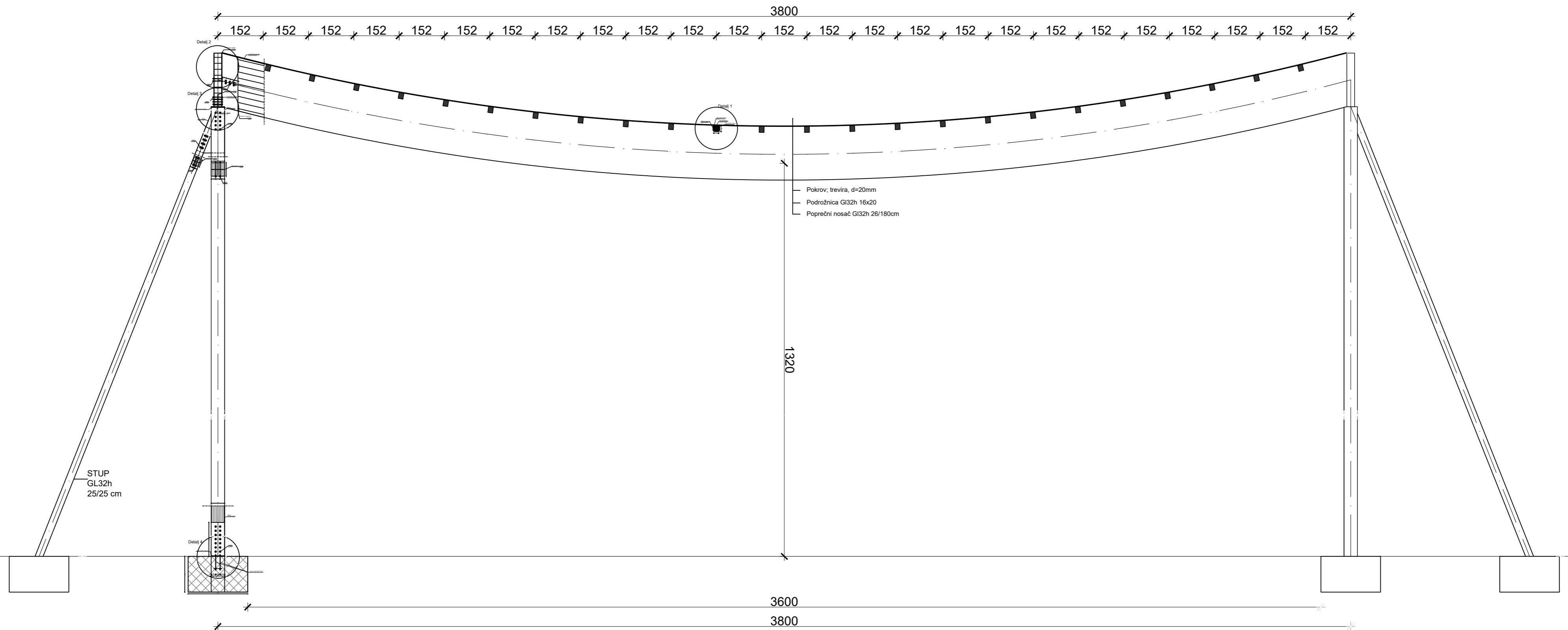


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