SVEUČILIŠTE U ZAGREBU
GRAĐEVINSKI FAKULTET
UNIVERSITY OF ZAGREB
FACULTY OF CIVIL ENGINEERING

Zagrebački energetski tjedan 13.-19.05.2019.

UTJECAJ VRSTE SPONA NA TOČKASTE TOPLINSKE MOSTOVE I OPTIMIZACIJA NJIHOVA RASPOREDA ZA POVEĆANJE KRUTOSTI PREDGOTOVLJENIH ZIDNIH PANELA

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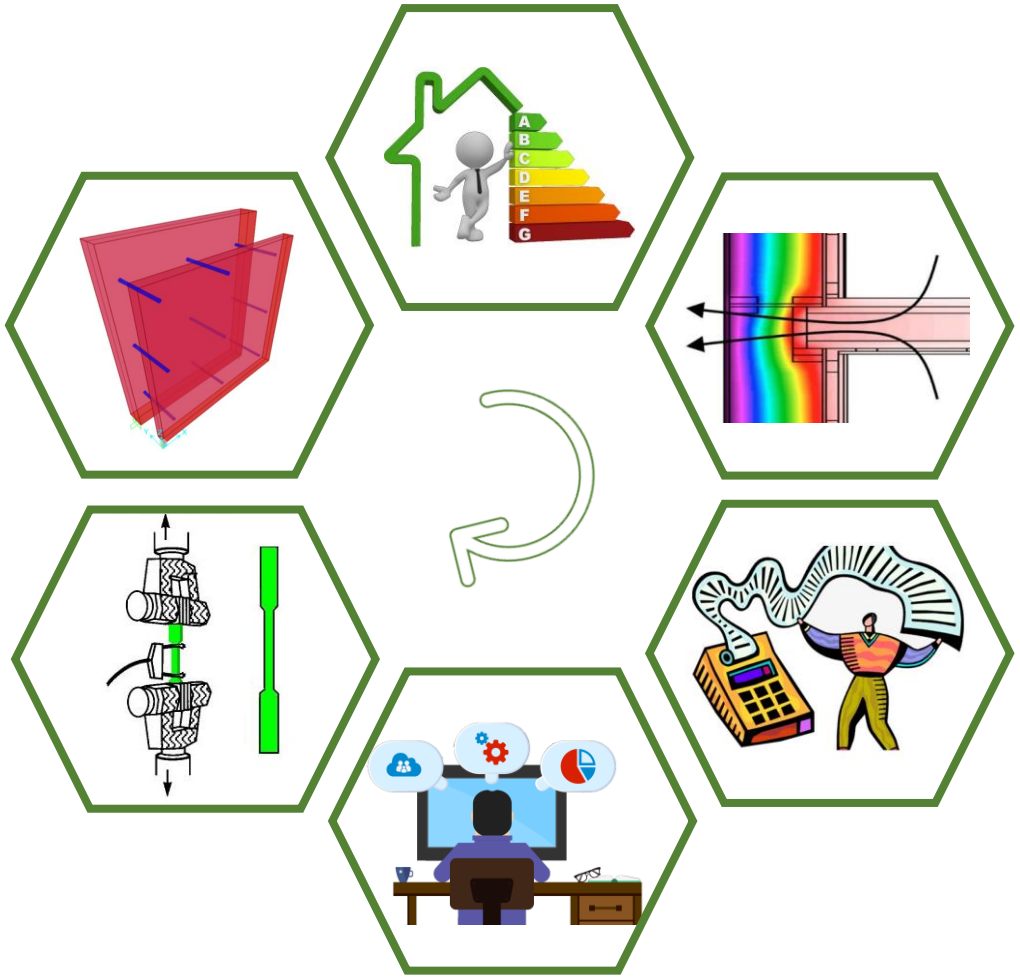
Mentori: Bojan Milovanović, Mario Uroš



- Održivost u zgradarstvu
- Toplinski mostovi
- Proračun metodom kontrolnih volumena
- Proračun u komercijalnom programu
- Laboratorijsko ispitivanje
- Optimizacija rasporeda spona

Održivost u zgradarstvu

- Zahtjevi:
  - Znatno smanjenje uporaba energije
  - Ponovna iskoristivost i recikliranje materijala
  - Zadovoljstvo čovjeka
  - Minimalni utjecaji na okoliš i minimalna ugrađena energija

- Neopasni građevinski otpad - veliki potencijal za recikliranje i ponovnu upotrebu
- Smanjenje energije od građenja do rušenja
- Zgradarstvo čini oko 40% potrošene energije, od čega 75% na zagrijavanje prostorija
- Poboljšanje toplinske ovojnice zgrade
- Toplinski mostovi čine 30% transmisijskih gubitaka energije

Toplinski mostovi

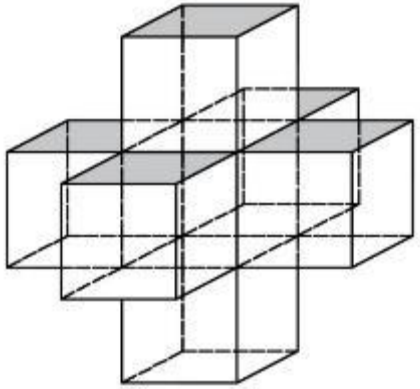
- Manje područje u ovojnici zgrade gdje je povećani gubitak topline
- Posljedice – plijesan, kondenzacija vodene pare, pukotine, povećano zadržavanje prašine, sl.
- Podjela:
  - Linijski toplinski mostovi
  - Točkasti toplinski mostovi
- Održivi proizvod:
  - Proizvodnja u kontroliranim uvjetima
  - Upotreba recikliranih materijala
  - Mala „*U*” vrijednost < 0,20 W/m^2K
- Mogućnost poboljšanja – čelične spone s polimer kompozitnim sponama

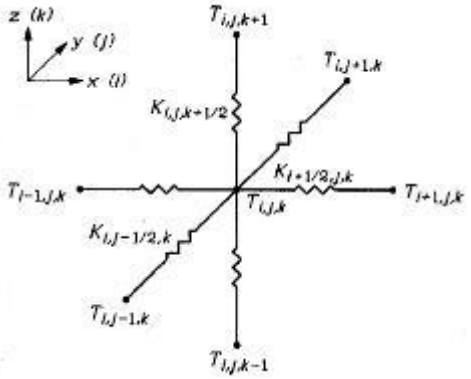
ECO-SANDWICH® – nenosivi predgotovljeni ventilirani zidni panel

Proračun metodom kontrolnih volumena

$$\frac{\partial}{\partial x}(\lambda_z \cdot \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y}(\lambda_y \cdot \frac{\partial T}{\partial y}) + \frac{\partial}{\partial z}(\lambda_z \cdot \frac{\partial T}{\partial z}) + I(x,y,z,t) = C \cdot \frac{\partial T}{\partial t}$$

- Diferencijalna jednadžba provođenja topline
- Geometrijska podjela tijela na elementarne volumene
- Diskretizacija u središnjem čvoru





$$H_{i,j,k} = K_{i-0.5,j,k} \cdot (T_{i-1,j,k} - T_{i,j,k}) + K_{i+0.5,j,k} \cdot (T_{i+1,j,k} - T_{i,j,k}) +$$
$$K_{i,j-0.5,k} \cdot (T_{i,j-1,k} - T_{i,j,k}) + K_{i,j+0.5,k} \cdot (T_{i,j+1,k} - T_{i,j,k}) +$$
$$K_{i,j,k-0.5} \cdot (T_{i,j,k+1} - T_{i,j,k}) + K_{i,j,k+0.5} \cdot (T_{i,j,k+1} - T_{i,j,k}) [W/m]$$

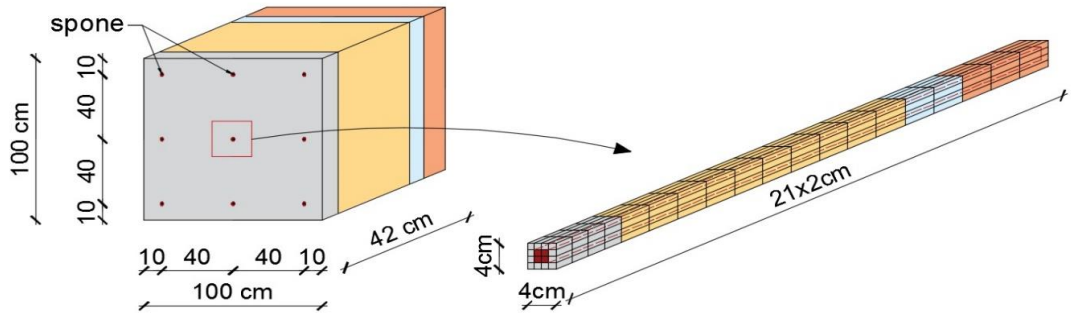
- Rezultati – temperature čvorova kontrolnih volumena

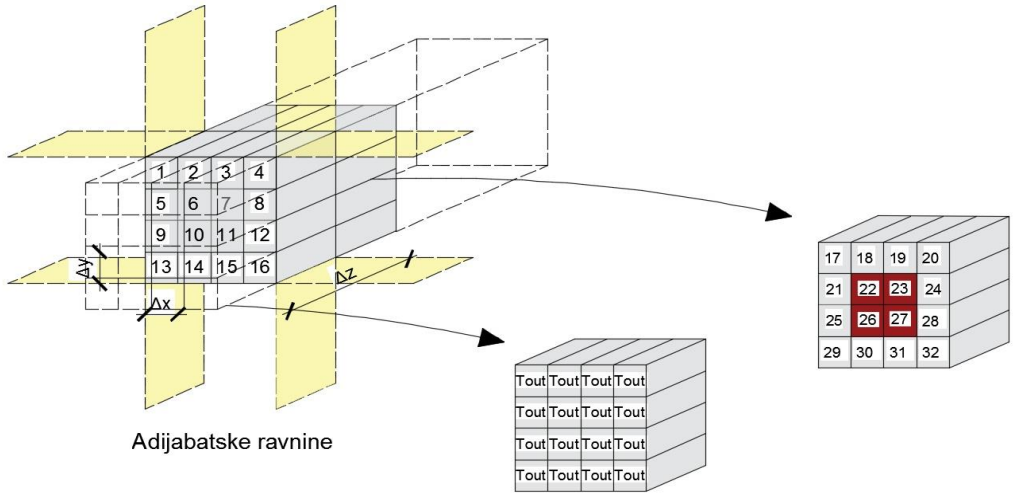
Proračun metodom kontrolnih volumena

Ukupan broj promatranih kontrolnih volumena

336

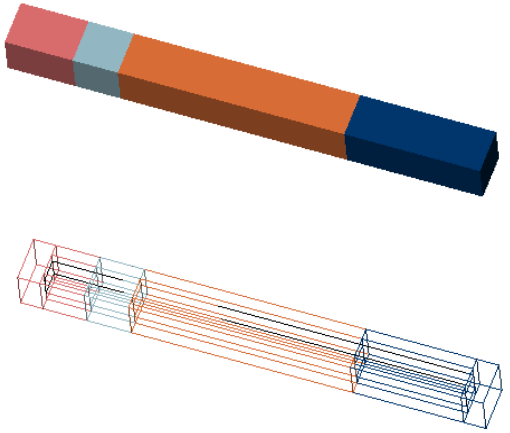
Ukupan broj jednadžbi

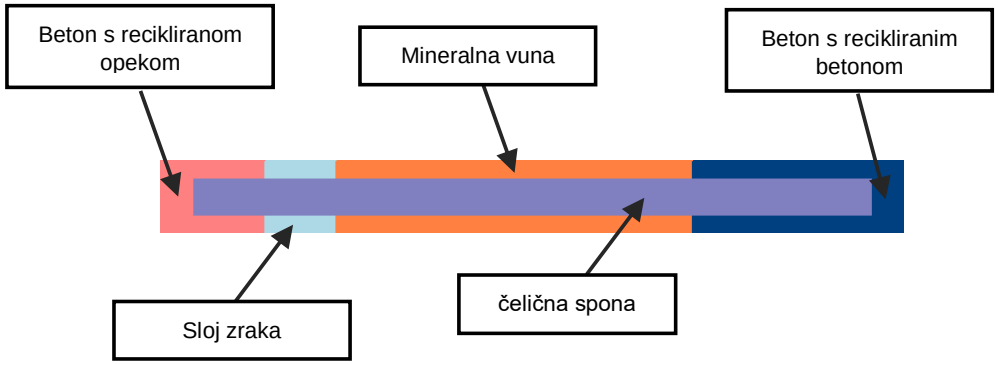


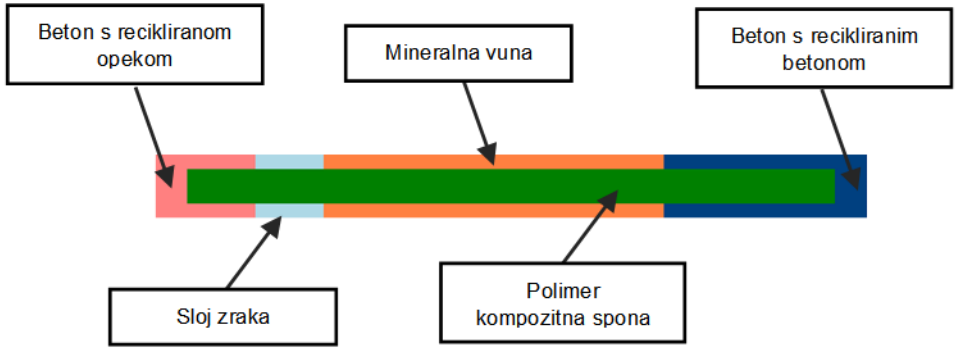


Proračun u komercijalnom programu

- Komercijalni program AnTherm
- Numerički model jednak promatranom modelu u metodi kontrolnih volumena
- Dva modela:
  - Panel s čeličnim sponama
  - Panel s polimernim kompozitnim sponama

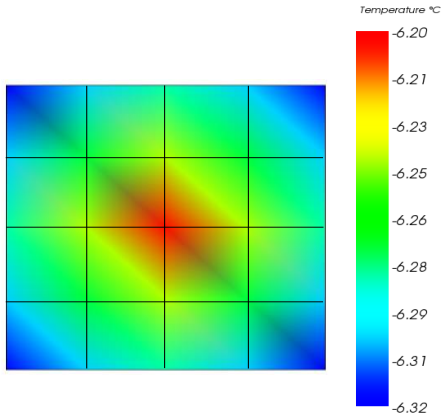


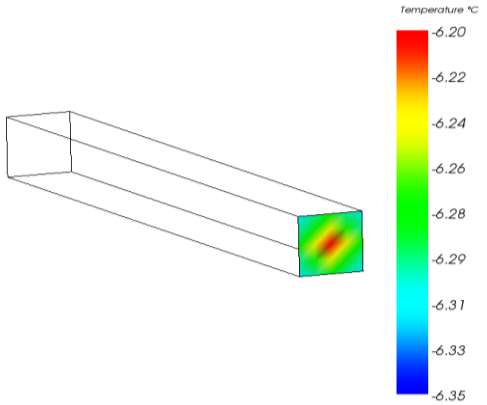




Usporedba rezultata
model s čeličnim sponama

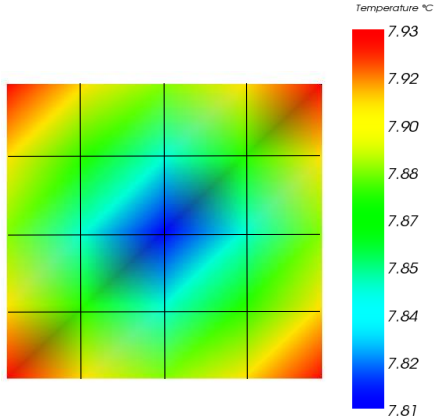
-5,17094	-5,10624	-5,10624	-5,17094
-5,10624	-4,92657	-4,92657	-5,10624
-5,10624	-4,92657	-4,92657	-5,10624
-5,17094	-5,10624	-5,10624	-5,17094

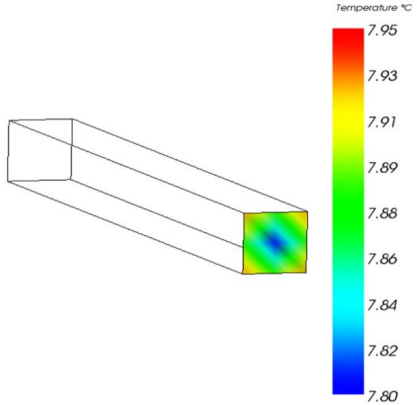




Vanjska površina

7,02588	6,96825	6,96825	7,02588
6,96825	6,81037	6,81037	6,96825
6,96825	6,81037	6,81037	6,96825
7,02588	6,96825	6,96825	7,02588

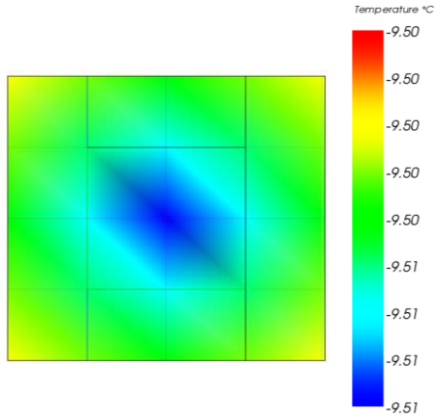


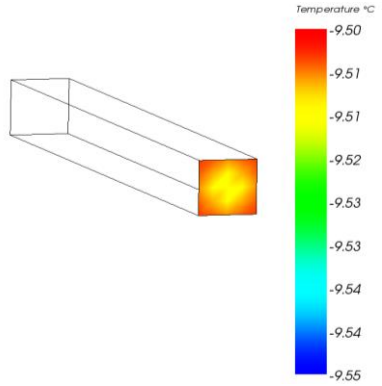


Unutarnja površina

Usporedba rezultata
model s polimernim kompozitnim sponama

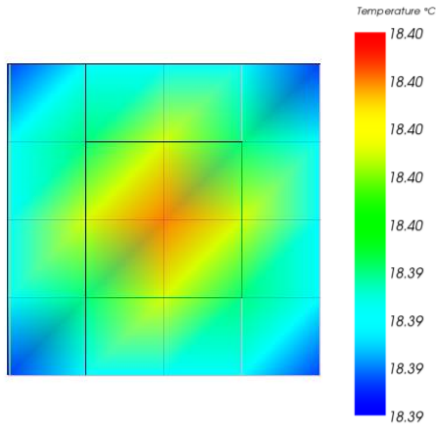
-9,33586	-9,33934	-9,33934	-9,33586
-9,33934	-9,35077	-9,35077	-9,33934
-9,33934	-9,35077	-9,35077	-9,33934
-9,33586	-9,33934	-9,33934	-9,33586

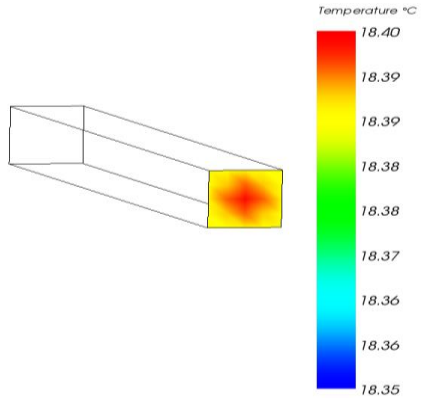




Vanjska površina

18,24690	18,25078	18,25078	18,24690
18,25078	18,26306	18,26306	18,25078
18,25078	18,26306	18,26306	18,25078
18,24690	18,25078	18,25078	18,24690

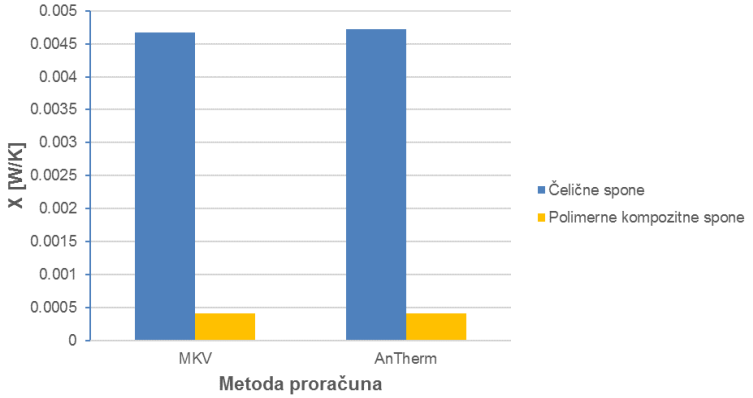


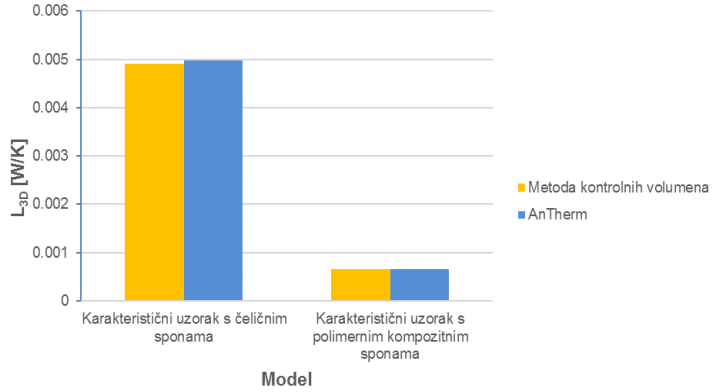


Unutarnja površina

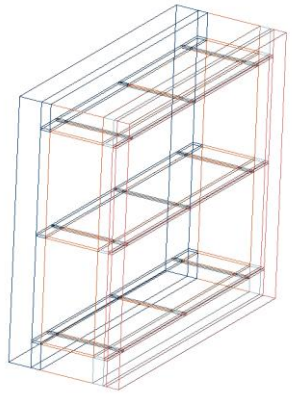
Usporedba rezultata

	Spone	U [W/(m² K)]	A [m²]	L_{3D} [W/K]	X [W/K]
MKV	Čelične	0,155087	0,0016	0,004916	0,004668
	Polimerne kompozitne	0,155087	0,0016	0,000658	0,0004098
AnTherm	Čelične	0,155662	0,0016	0,004974	0,004725
	Polimerne kompozitne	0,155662	0,0016	0,000659	0,00041

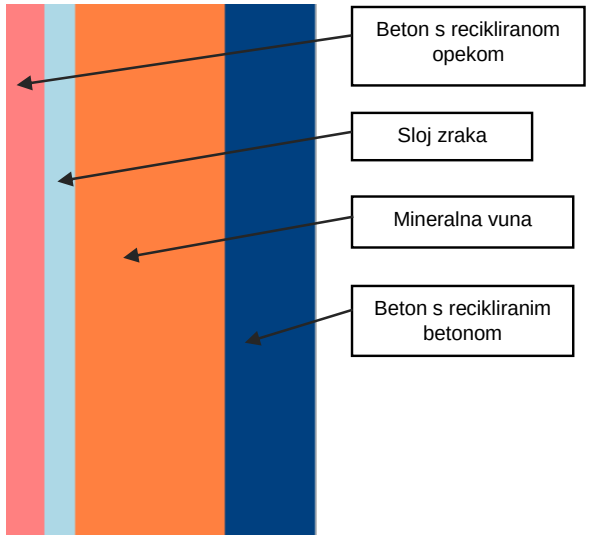


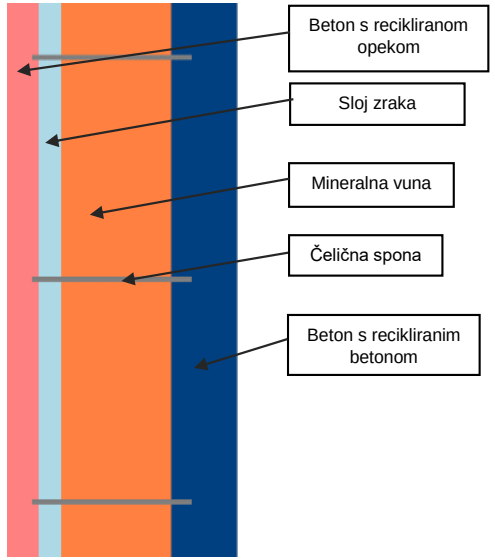


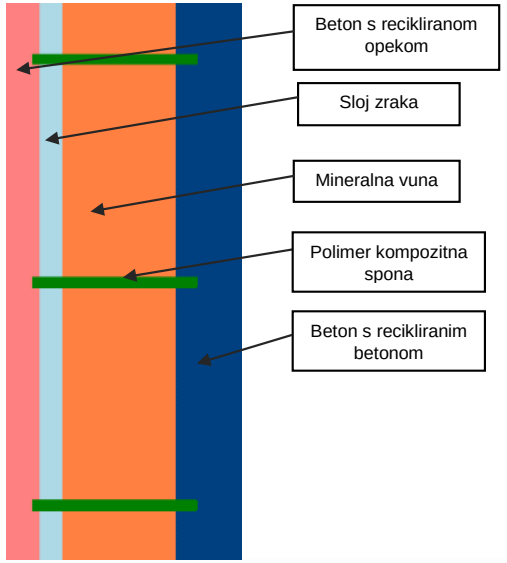
Proračun u komercijalnom programu



- Tri modela cijelog panela:
  - Panel bez spona
  - Panel s čeličnim sponama
  - Panel s polimernim kompozitnim sponama

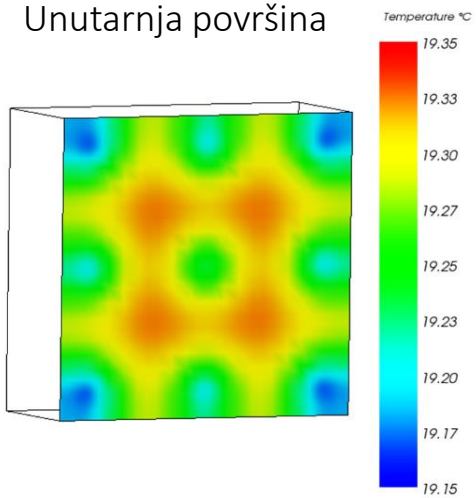




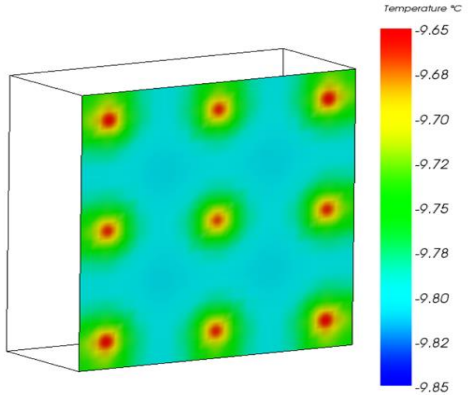


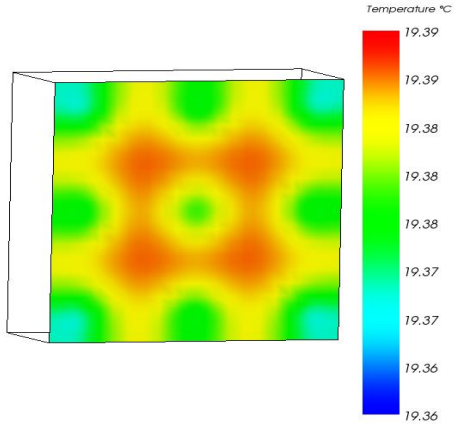
Proračun u komercijalnom programu

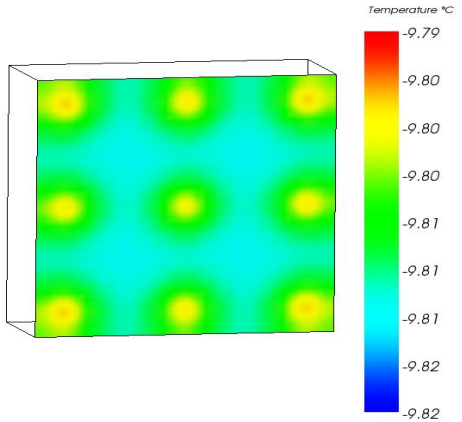
Unutarnja površina



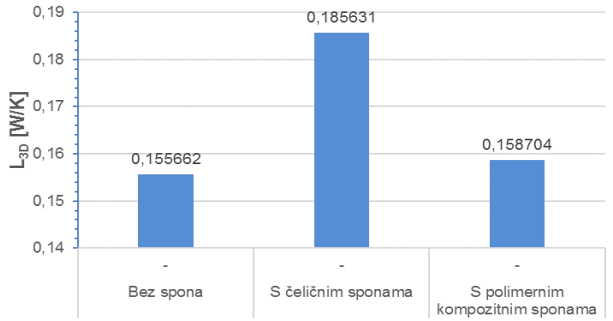
Vanjska površina



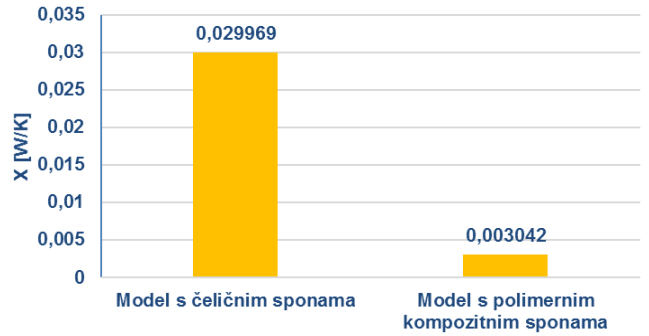




Model s čeličnim sponama

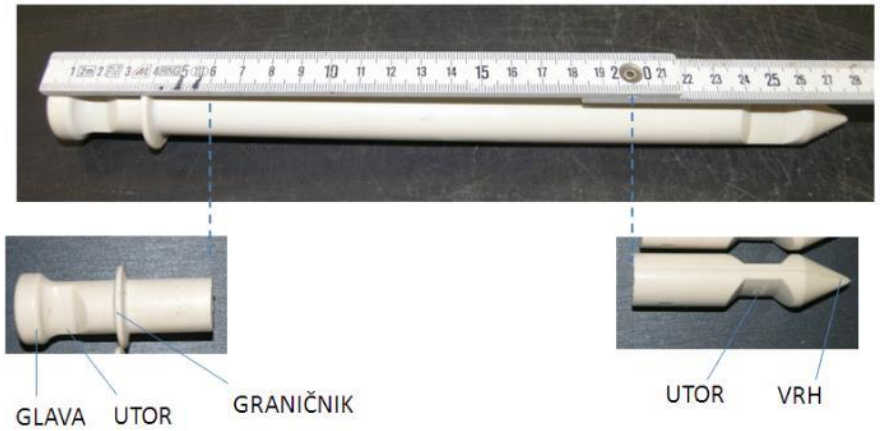


Model s polimer kompozitnim sponama



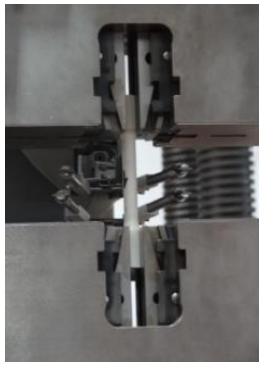
Laboratorijsko ispitivanje

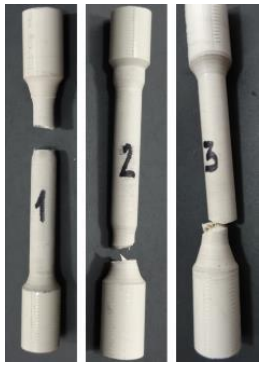
- Kalibracija numeričkog modela
- Spone tvrtke HK Composites – ST200
- Obuhvaćena ispitivanja polimernih kompozitnih spona:
  - Vlačna čvrstoća
  - Odrez
  - Sila čupanja
  - Nosivost zidnog panela:
    - Dinamičko opterećenje
    - Cikličko opterećenje

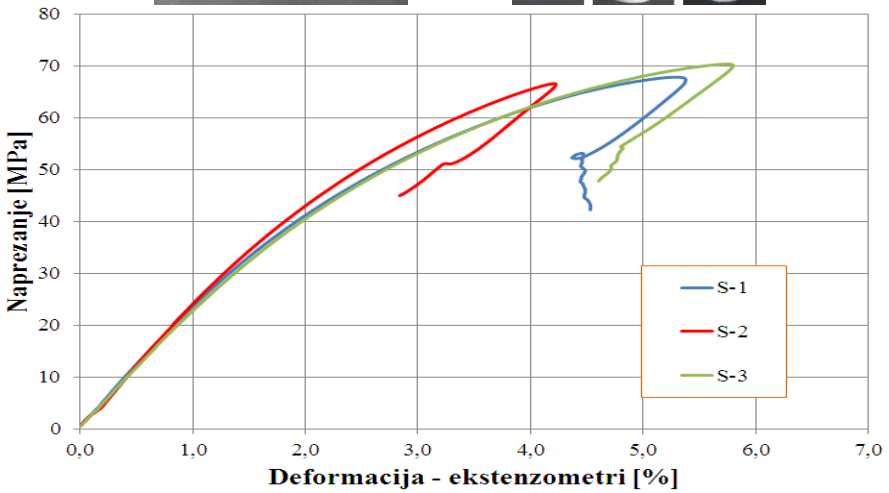


Laboratorijsko ispitivanje

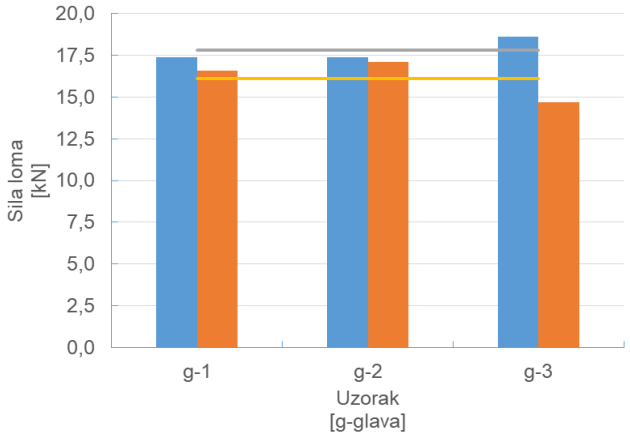
Vlačna čvrstoća

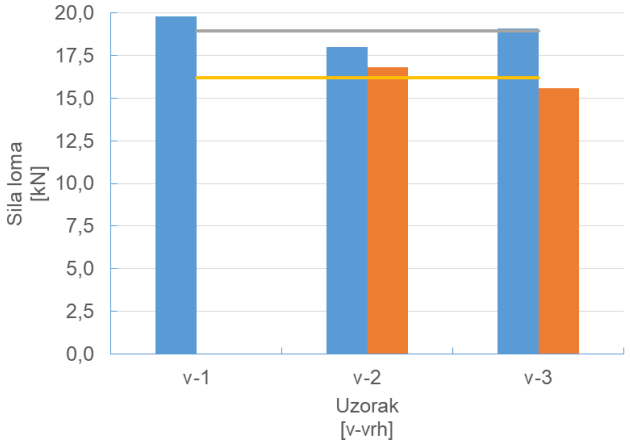


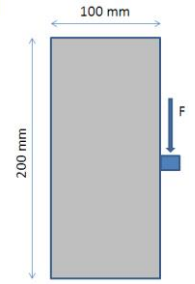


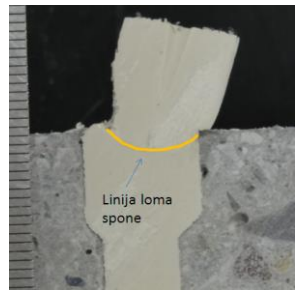


Odrez



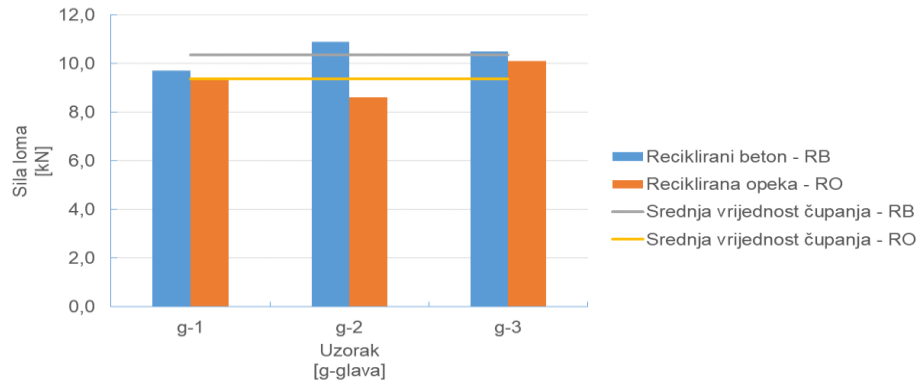


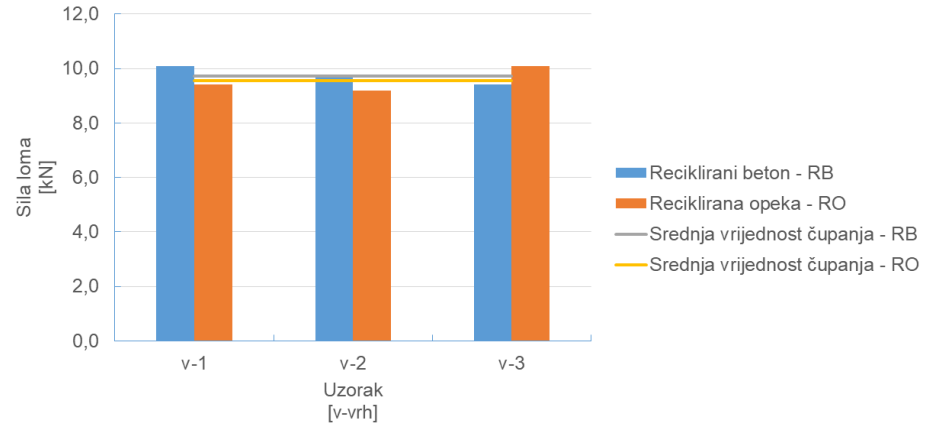


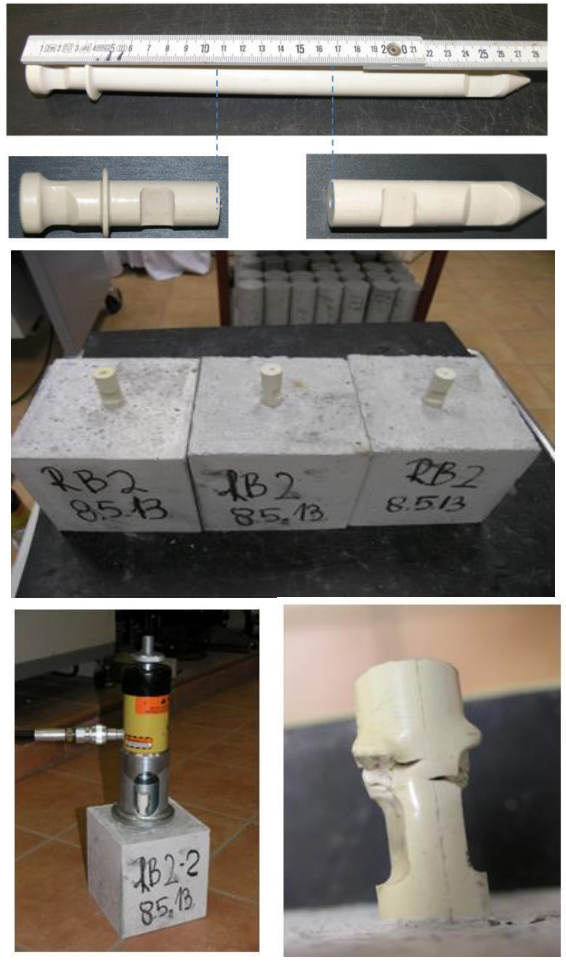


Laboratorijsko ispitivanje

Sila čupanja

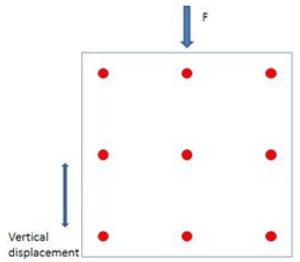


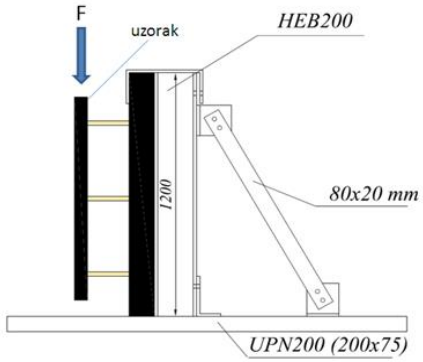


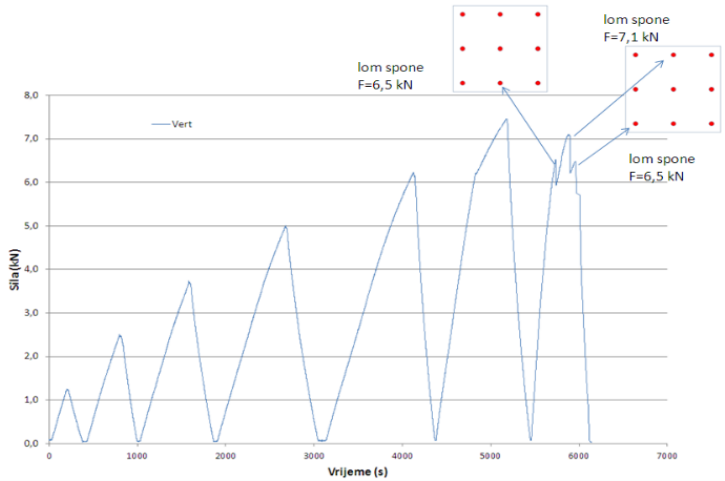


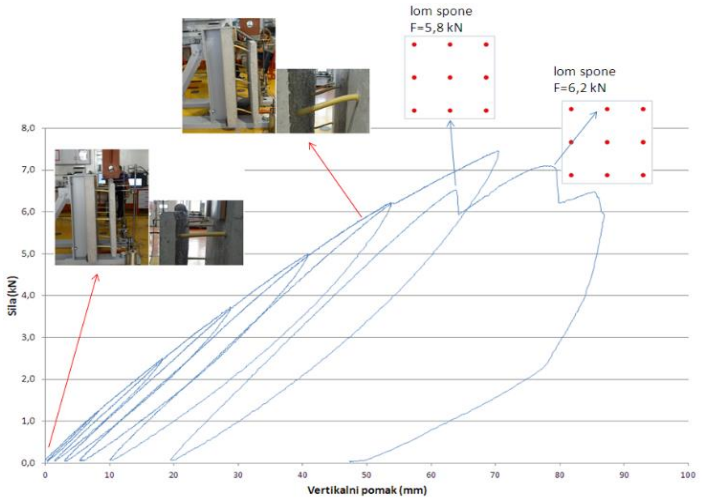
Laboratorijsko ispitivanje

- 3 uzorka – nosivi sloj, vanjski sloj, polimer kompozitne spone
- Dimenzije panela 1,2x1,0 m
- Beton s 50% agregata recikliranog betona
- Problem – početni progib od 1 cm





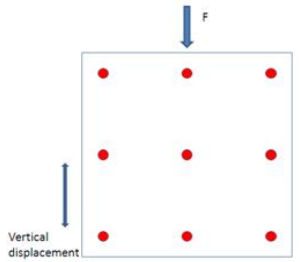


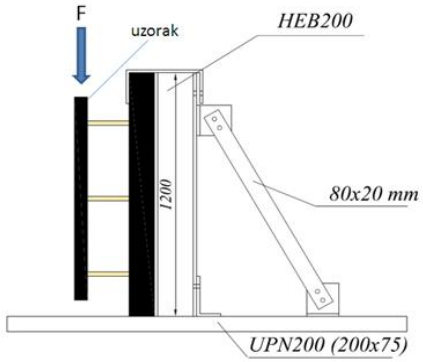


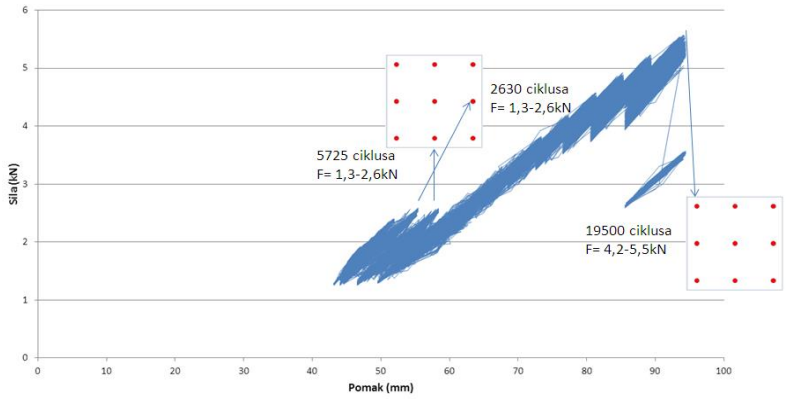
Dinamičko opterećenje

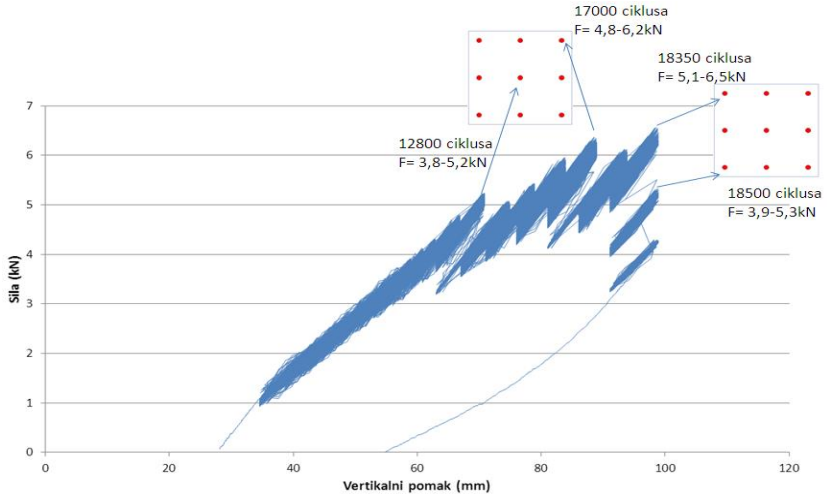
Laboratorijsko ispitivanje

- Frekvencija osciliranja 2 Hz
- Amplituda pomaka 4-4,5 mm – promjena sile u granicama vrijednosti jedne vlastite težine vanjskog sloja
- Povećanje opterećenja svakih 1000 ciklusa za 2-4 mm





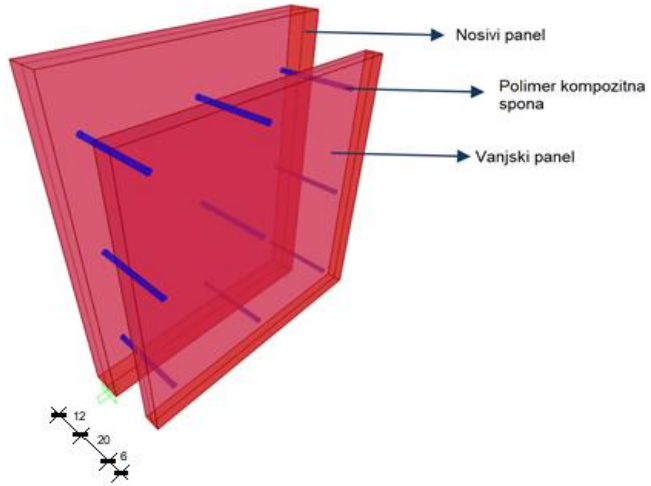


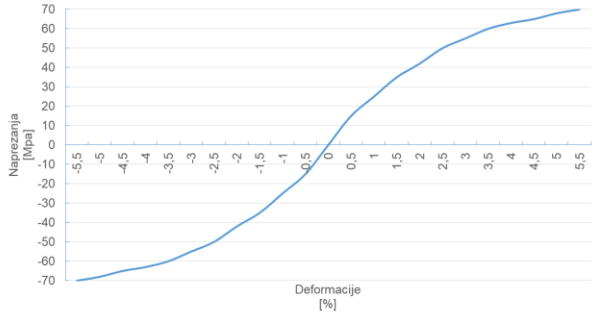


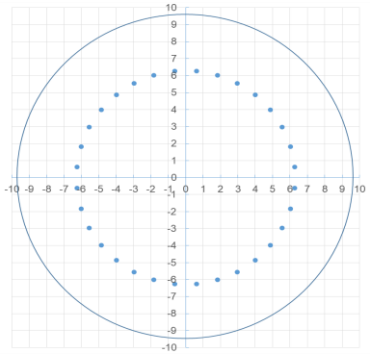
Cikličko opterećenje

Optimizacija rasporeda spona

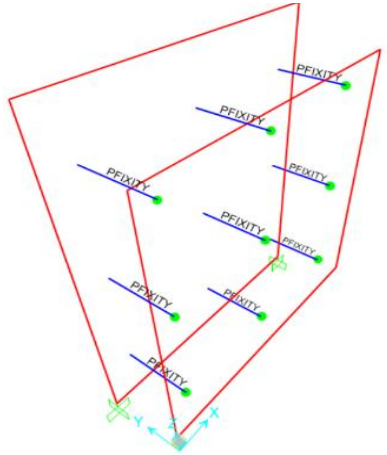
- Motivacija – početni progib uslijed vlastite težine vanjskog panela
- Mehaničke karakteristike elemenata - prema poznatim podacima dobivenim iz laboratorijskog ispitivanja
- Rubni uvjeti – jednaki onima u laboratoriju
- Proračuni:
  - Linearni – početni progib, dinamičko opterećenje i varijante ojačanja
  - Nelinearni – početni progib



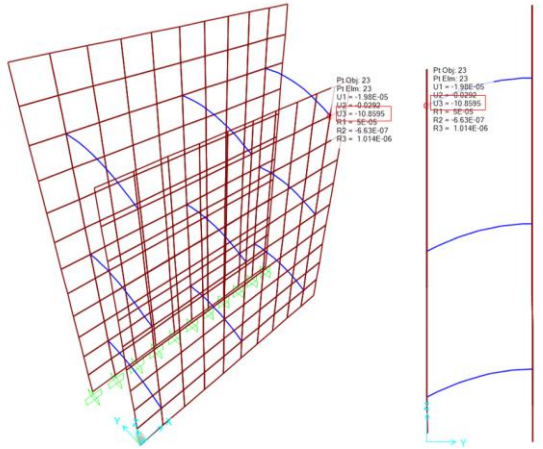




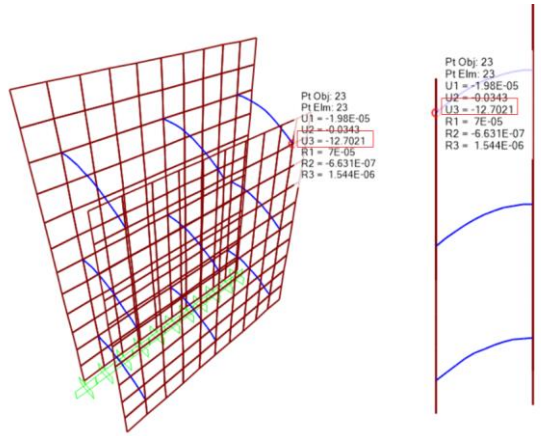
Ulazni parametri za nelinearni proračun



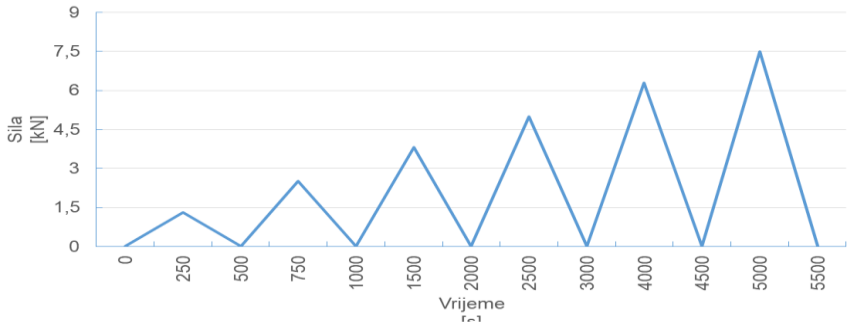
Optimizacija rasporeda spona – usporedba rezultata

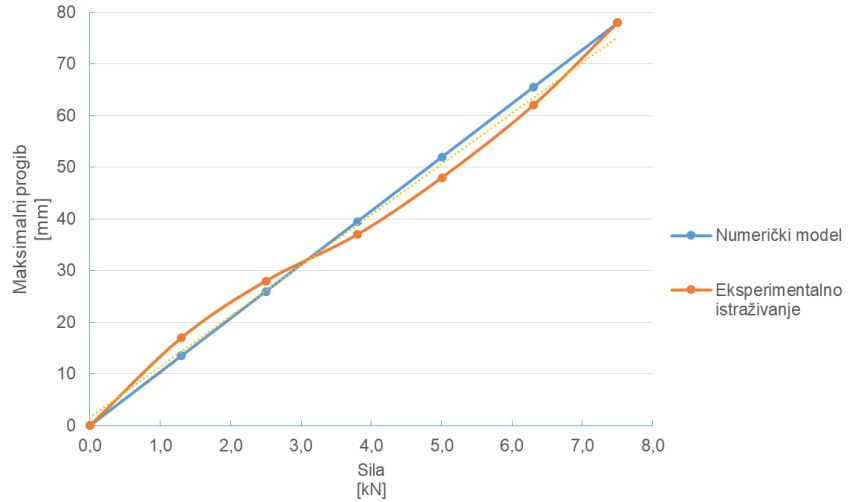


Linearni proračun
10,85 mm



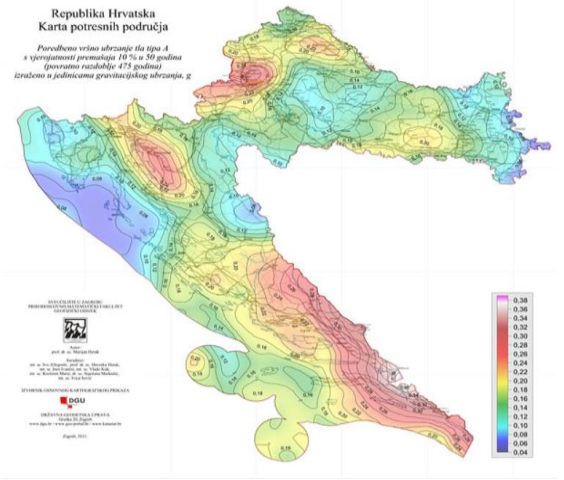
Nelinearni proračun
12,70 mm





Dinamički
proračun - 2,38 %

Optimizacija rasporeda spona

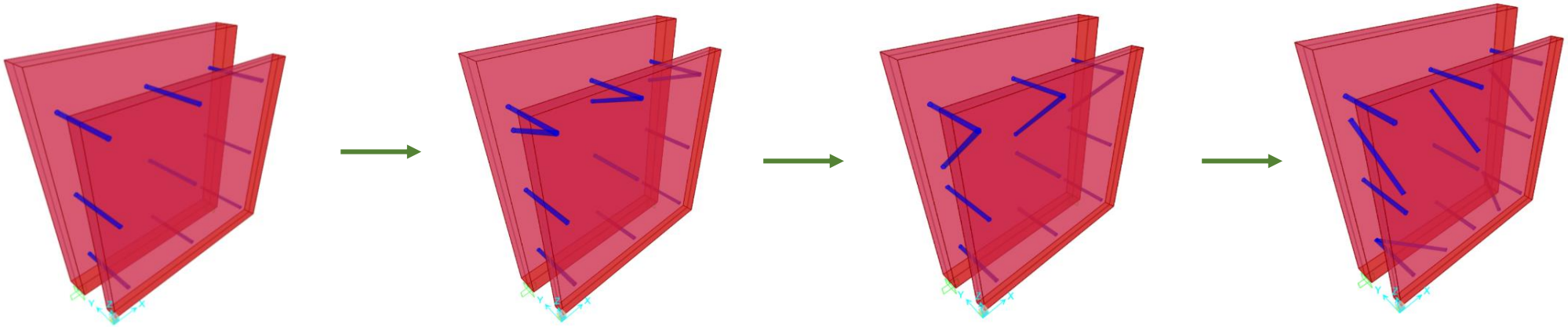


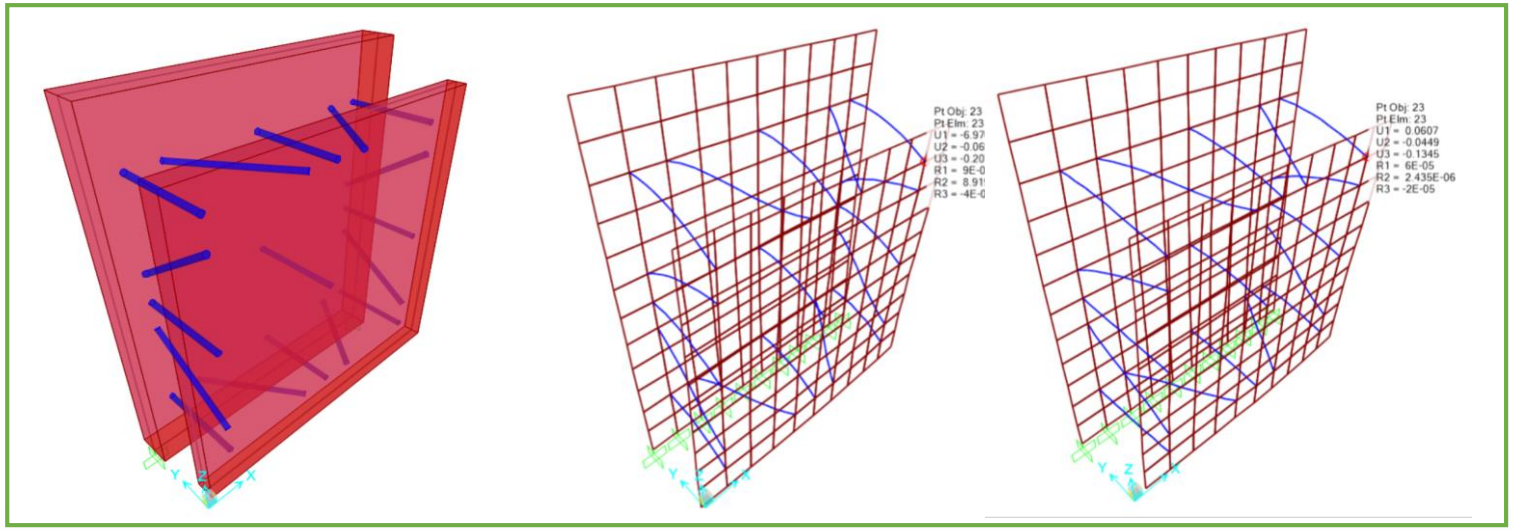
$$F_a = \frac{S_a \cdot W_a \cdot \gamma_a}{q_a}$$

- Republika Hrvatska - seizmički aktivno područje
- Eurokod 8 – HRN EN 1998-1:2004+AC:2009
- Vršno ubrzanje temeljnog tla obzirom na odabranu lokaciju – Dubrovnik
- Povratno razdoblje od 475 godina
- Određivanje potresne sile u smjeru osi x i z za zamišljenu zgradu definirane geometrije

Numerički model		Period [s]	Potresna sila [kN]
Bez ojačanja	Potres X – smjer	0,205	1,155
	Potres Z - smjer	0,209	1,666
br. 1	Potres X – smjer	0,191	1,120
	Potres Z - smjer	0,049	0,769
br. 2	Potres X – smjer	0,181	1,094
	Potres Z - smjer	0,027	0,720
br. 3	Potres X – smjer	0,049	0,769
	Potres Z - smjer	0,208	0,722
br 4	Potres X – smjer	0,021	0,706
	Potres Z - smjer	0,026	0,716

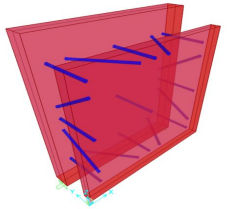
Optimizacija rasporeda spona – varijante ojačanja

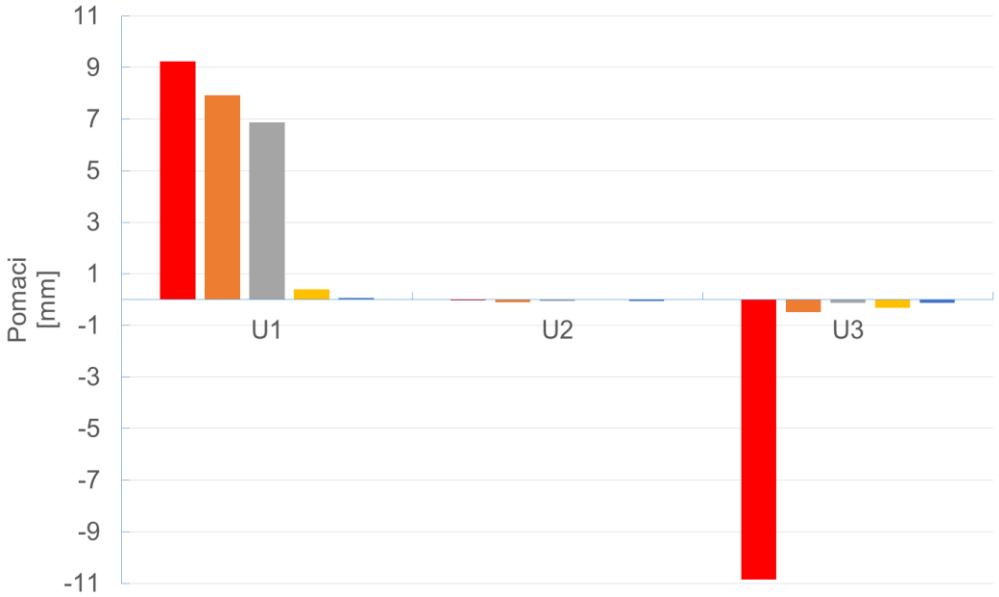




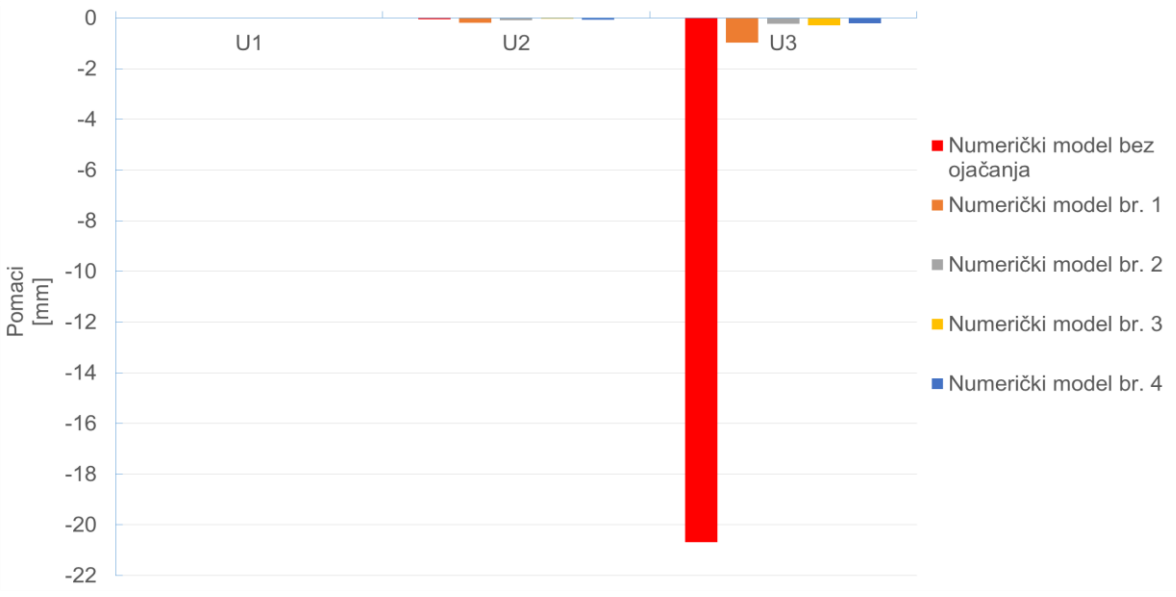
Konačni prijedlog rješenja

Optimizacija rasporeda spona – usporedba rezultata

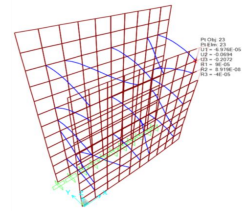


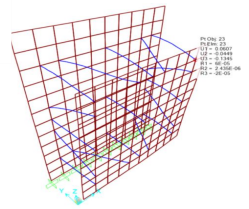


Pomaci X smjer



Pomaci Z smjer





Zaključak

- Održiv proizvod = održiva gradnja
- Zamjena čeličnih spona s polimer kompozitnim sponama:
  - smanjen utjecaj točkastih toplinskim mostova
  - Smanjena *„U”* vrijednost zidnog panela
- Laboratorijska ispitivanja – pomoć pri definiranju mehaničkih karakteristika materijala pri izradi numeričkog modela
- Krutost zidnog panela s polimernim kompozitnim sponama – ostvarena optimizacijom rasporeda spona

Hvala na pažnji ☺