HRVATSKA KOMORA INŽENJERA GRAĐEVINARSTVA
Dani Hrvatske komore inženjera građevinarstva 2020.

Performance Based Seismic Engineering primjenjen na okvirne zidove od drveta s oblogama od GFB i OSB panela

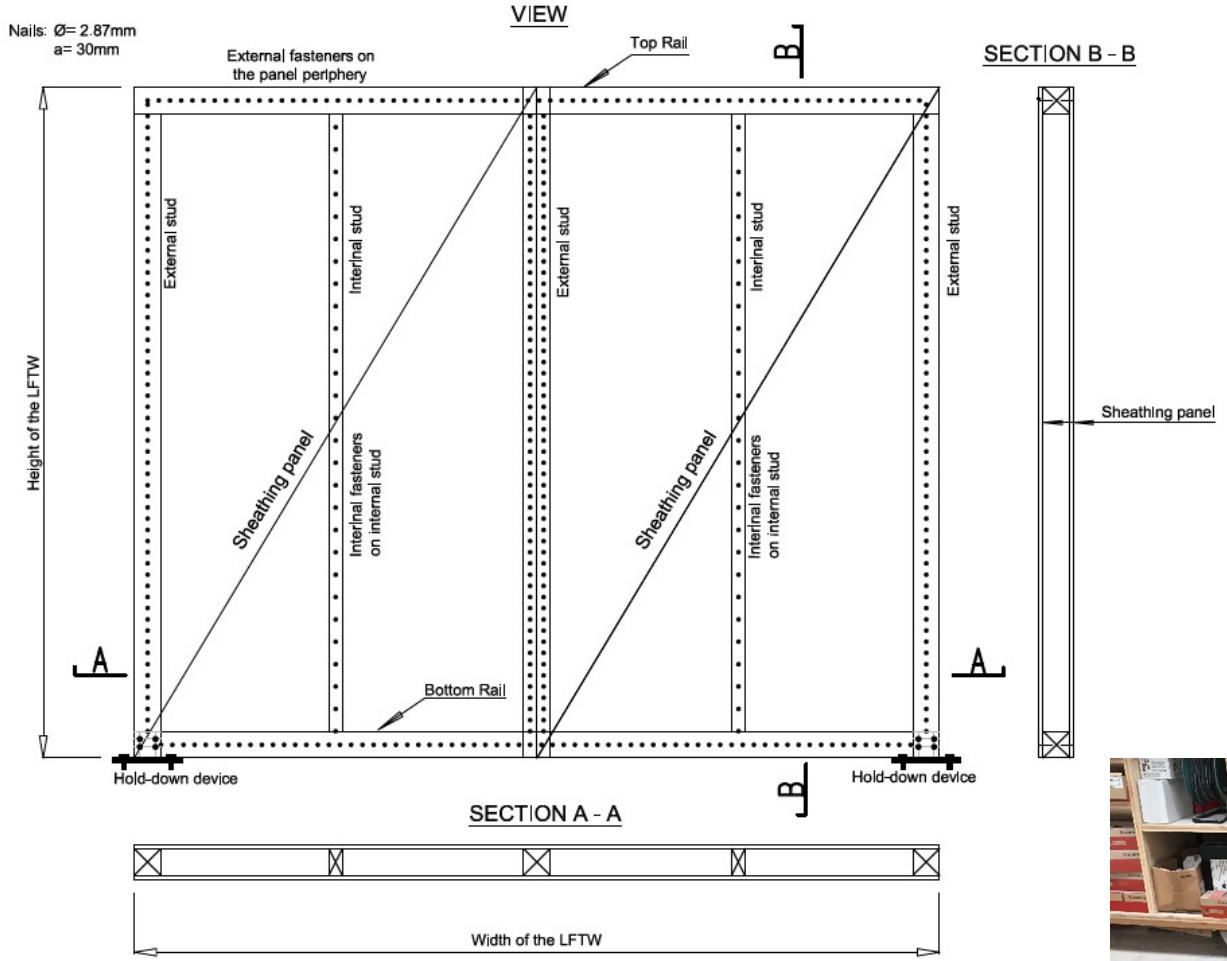
Ljupko Perić

Dr. Sc. ETH Zürich Ljupko Perić, dipl.ing.građ.,
MWV Bauingenieure AG, Baden, CH

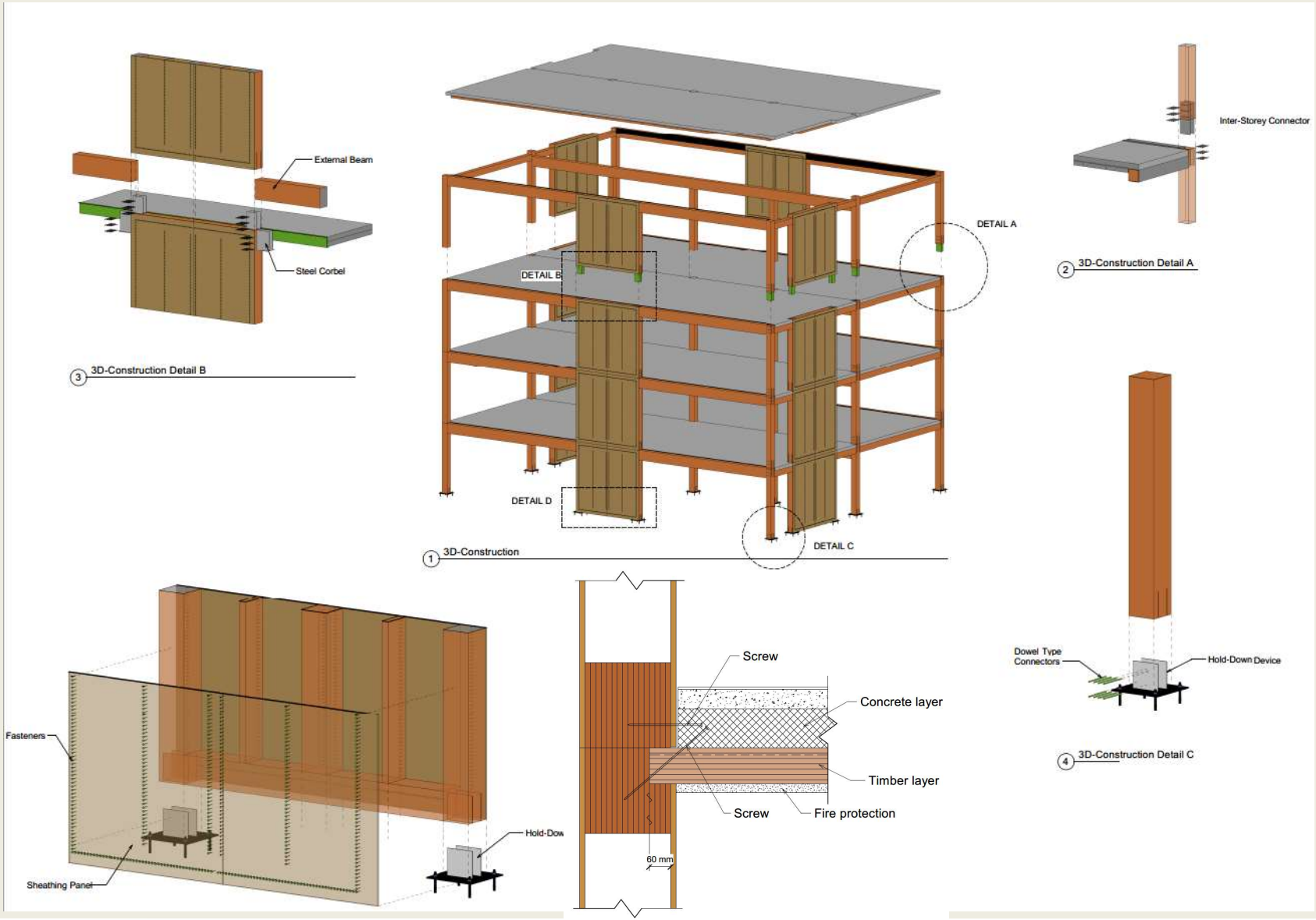
Sadržaj

1. Okvirni zidovi od drveta, svojstva i komponente
2. Metode potresnoga inženjerstva
3. Index oštećenja (Damage index **DI**)
4. Definiranje konstitutivnoga NL-modela konstrukcije
5. Pregled analiza korištenih za anlizu OZoD
6. Mehanički modeli spojnih sredstava i OZoD
7. PBSE Index oštećenja (Damage Index)
8. Nelinearni model SDOF i MDOF sistema
9. Pregled konačnih rezultata

Što su okvirni zidovi od drveta (OZoD)



Pozicija OZoD u konstrukciji



Metode potresnoga inženjerstva

- Force based design (FBD) – normiran
- Displacement based design (N 2) - normiran
- Performance based design (PBD) - normiran
- Time history analysis (THA) - normirana
- Nonlinear time history analysis (NLTHA) - normirana
- Direct displacement based design (DDBD) – normiran u NZ
- Performance based seismic engineering (PBSE) - nije normiran
- Rocking - nije normiran

PBSE – indeks oštećenja (Damage Index **DI**)

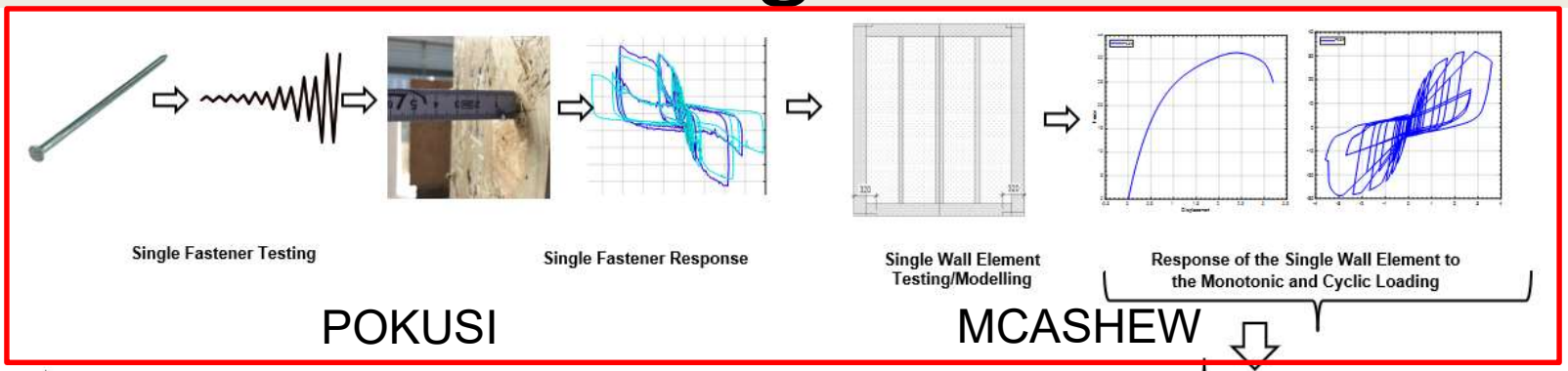
- Bazira se na **realnom mehaničkom** modelu analizirane strukture
- Zahtjeva **NLTHA**, što podrazumijeva i **skaliranje realnih potresnih zapisa**
- Zahtjeva određivanje **indeksa oštećenja (DI)**

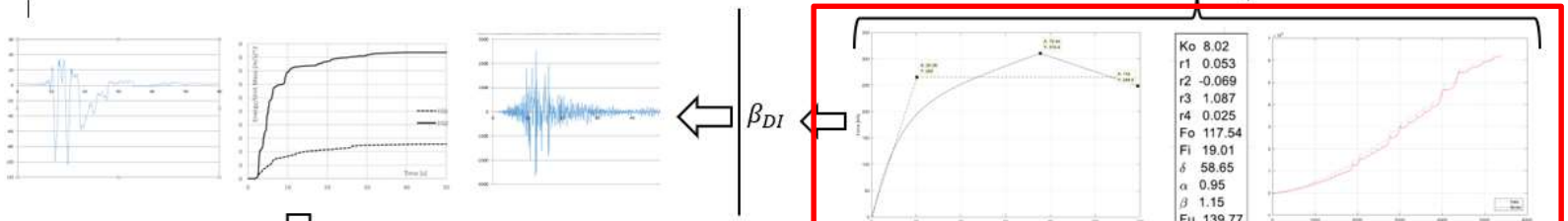
$$\mathrm{DI} = \frac{\Delta_{\mathrm{potres}}}{\Delta_{\mathrm{u,st}}} + \frac{\beta}{\mathrm{F_y} \cdot \Delta_{\mathrm{u,st}}} \cdot \int \mathrm{dE}$$

< 1.0
= 1.0 **Park & Ang (1985)**
> 1.0

- Omogućuje (pr)ocjenu troškova sanacije

Postupak u definiranju konstitutivnoga modela OZoD



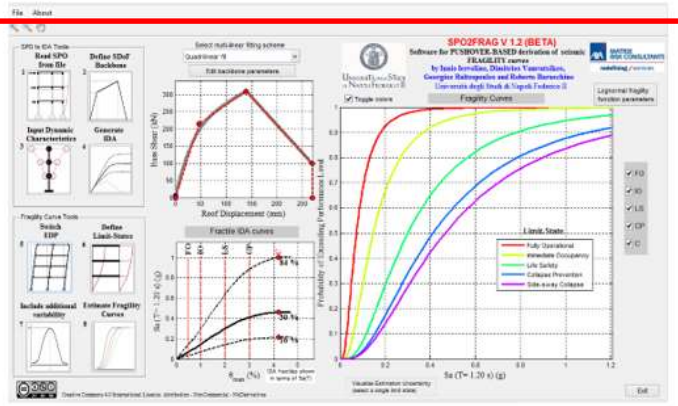


$$DI = \frac{\Delta_{resp}}{\Delta_{u,st}} + \frac{\beta_{DI}}{Q_y \cdot \Delta_{u,st}} \cdot \int dE$$

LIMIT STATE	DAMAGE INDEX
IO	D < 0.4
LS	0.4 < D < 0.7
CP	0.7 < D < 1.0

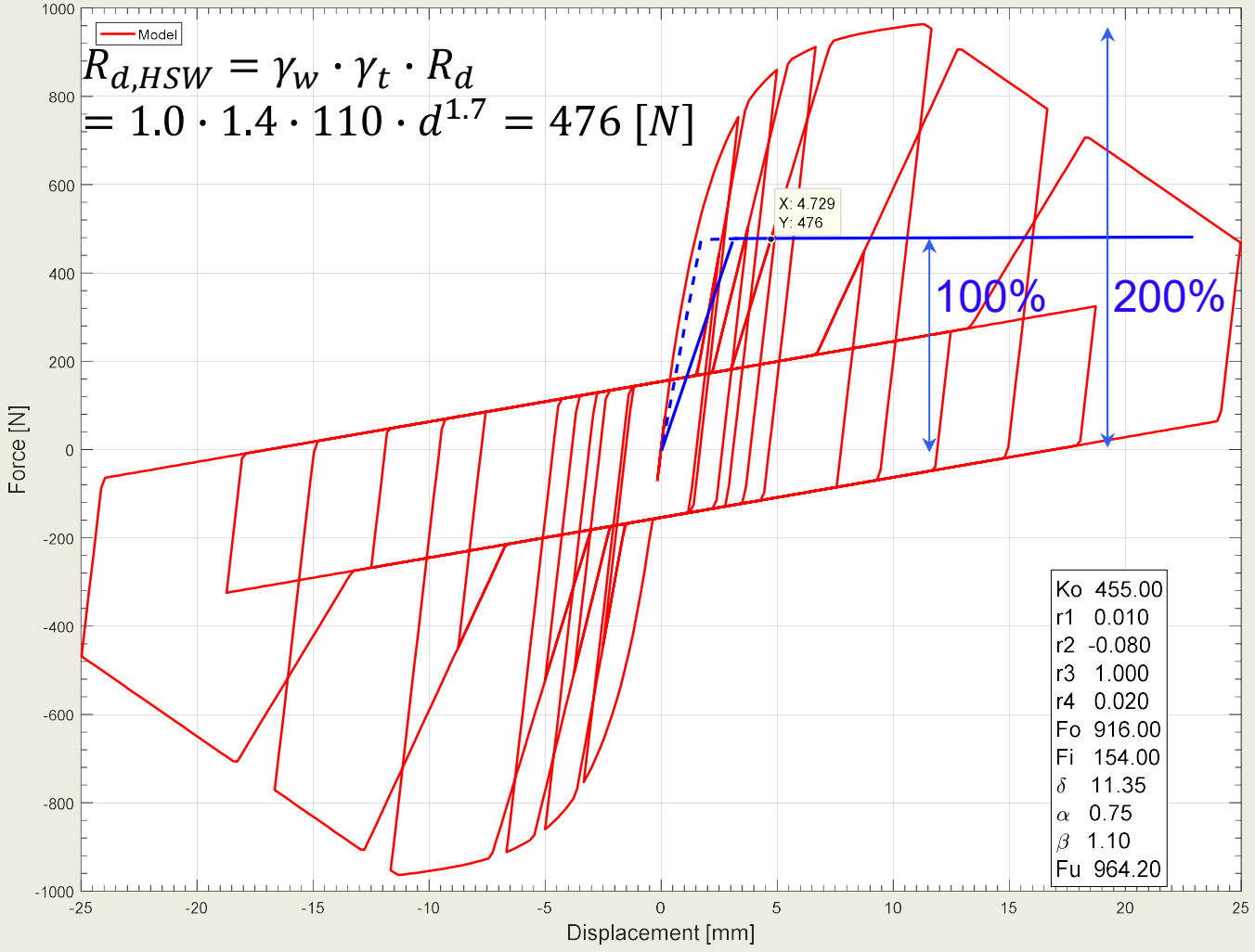
IDA

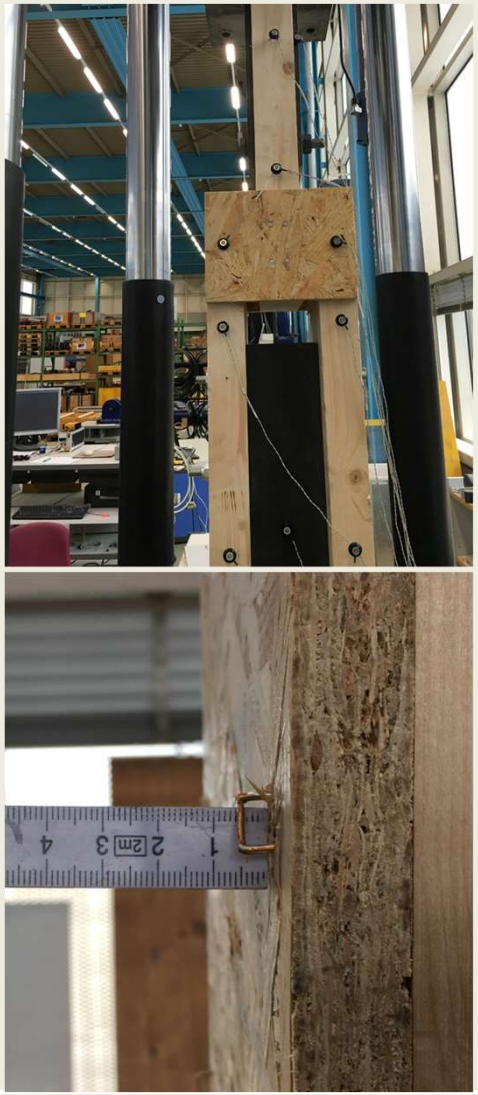
Control and Verification



Mehanički model spojnica

Stvarno ponašanje vs. računske nosivosti spojnice d=1.53 [mm]

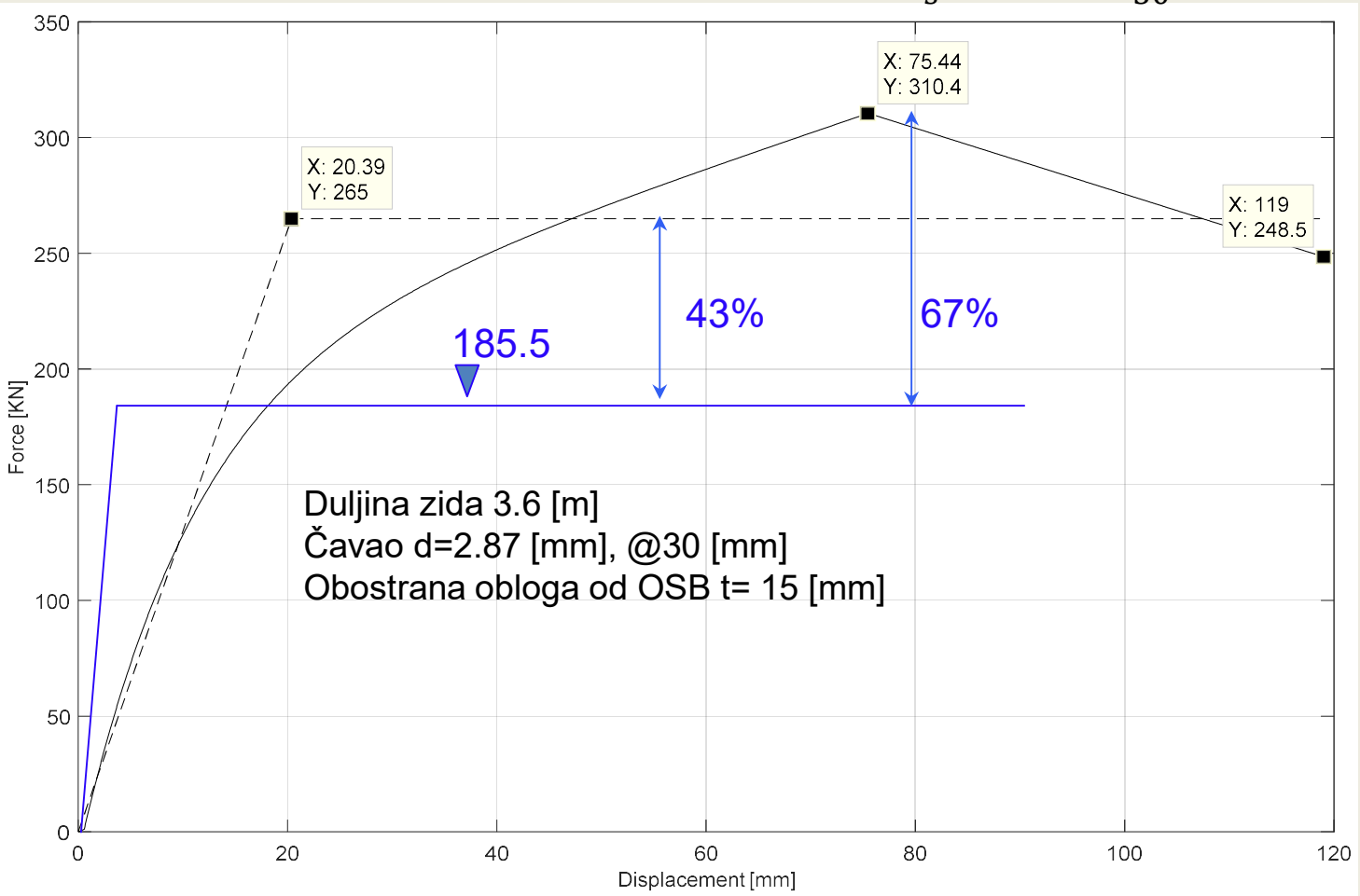




Mehanički model OZoD

Stvarno ponašanje vs. računske nosivosti OZoD jednokatnoga zida izloženoga monotonome opterećenju

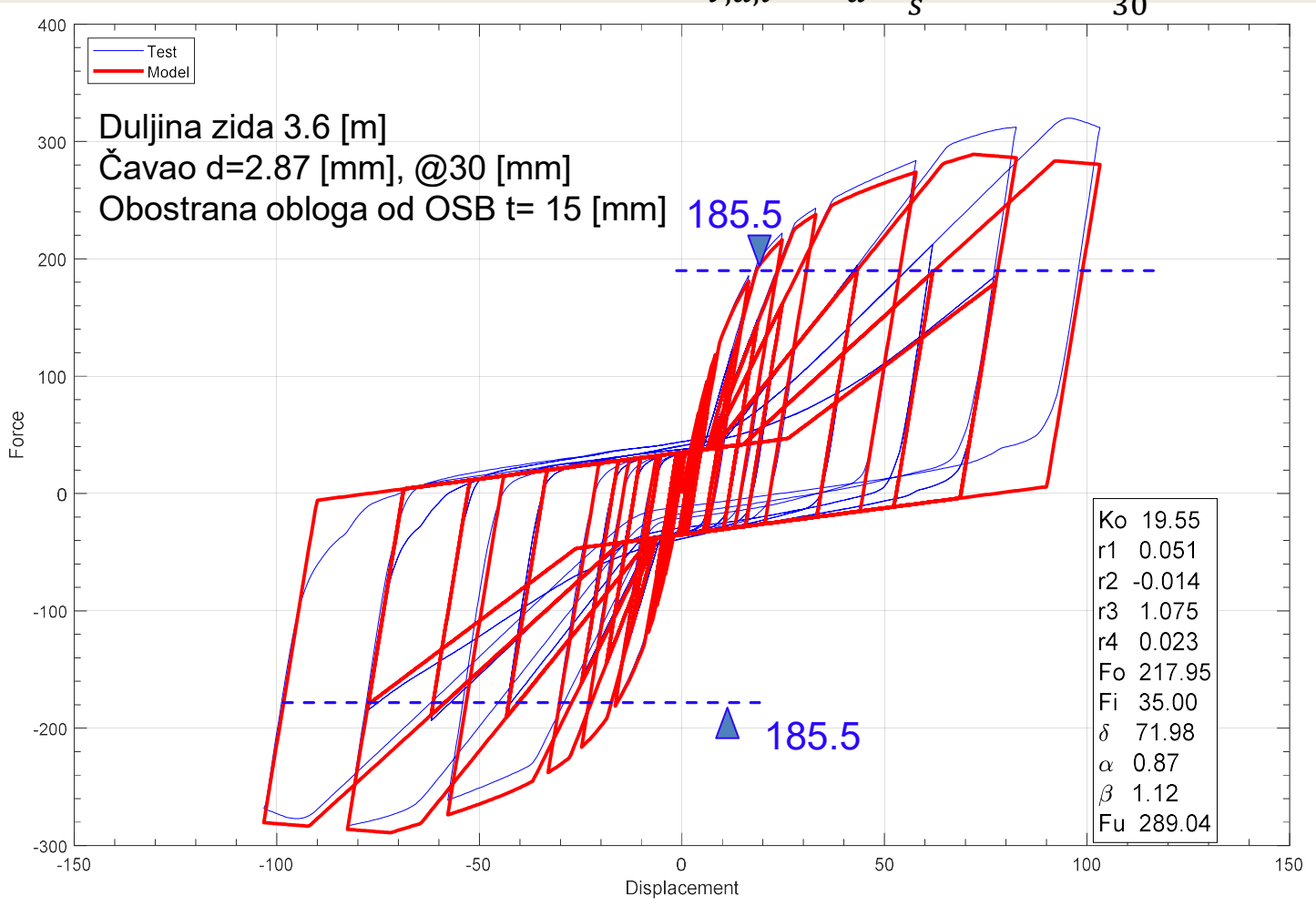
SIA 265/1, Ziffer 8.3.1.2 & 8.3.1.4 $R_{v,d,i} = R_d \cdot \frac{b_i}{s} = 773 \cdot \frac{3600}{30} \cdot 2 = 185.5\ [kN]$



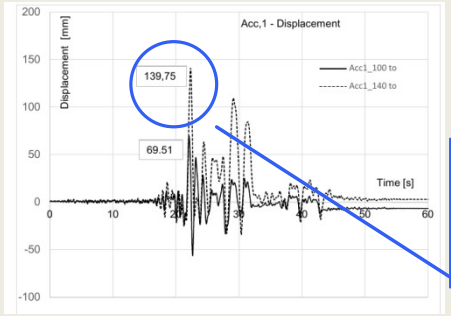
Mehanički model OZoD

Stvarno ponašanje vs. računske nosivosti OZoD jednokatnoga zida izloženoga cikličnome opterećenju

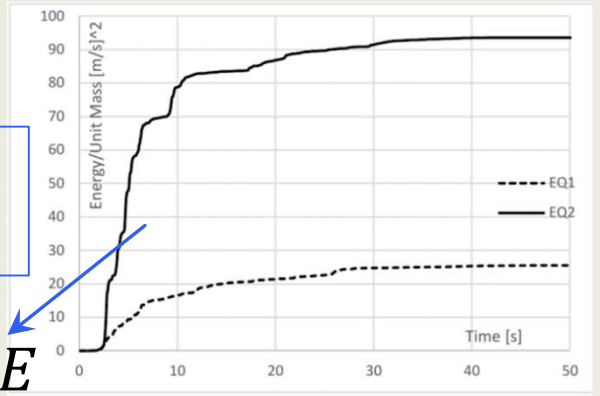
SIA 265/1, Ziffer 8.3.1.2 & 8.3.1.4 $R_{v,d,i} = R_d \cdot \frac{b_i}{s} = 773 \cdot \frac{3600}{30} \cdot 2 = 185.5\ [kN]$



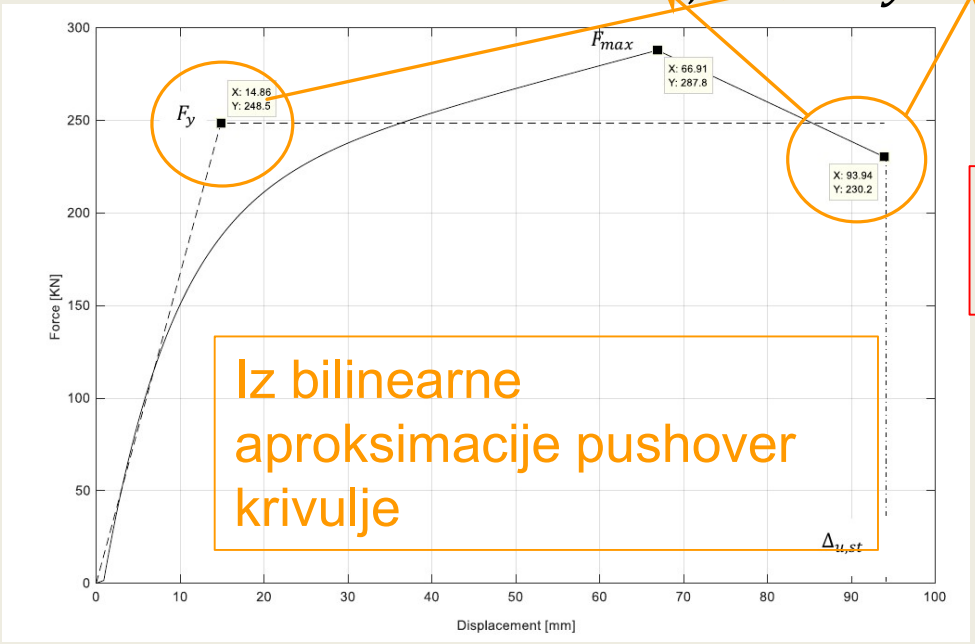
PBSD – indeks oštećenja



rezultat analize za djelovanje specifičnoga potresa



$$DI = \frac{\Delta_{potres}}{\Delta_{u,st}} + \frac{\beta}{F_y \cdot \Delta_{u,st}} \cdot \int dE$$

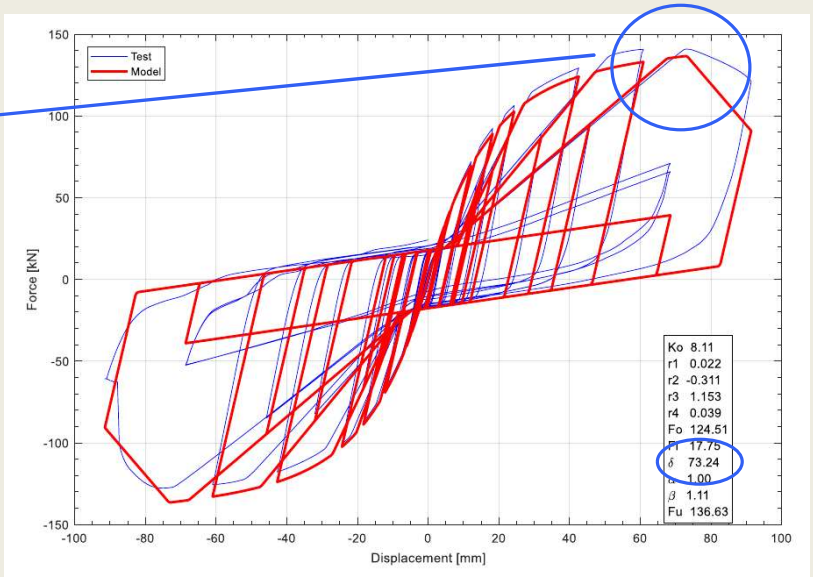


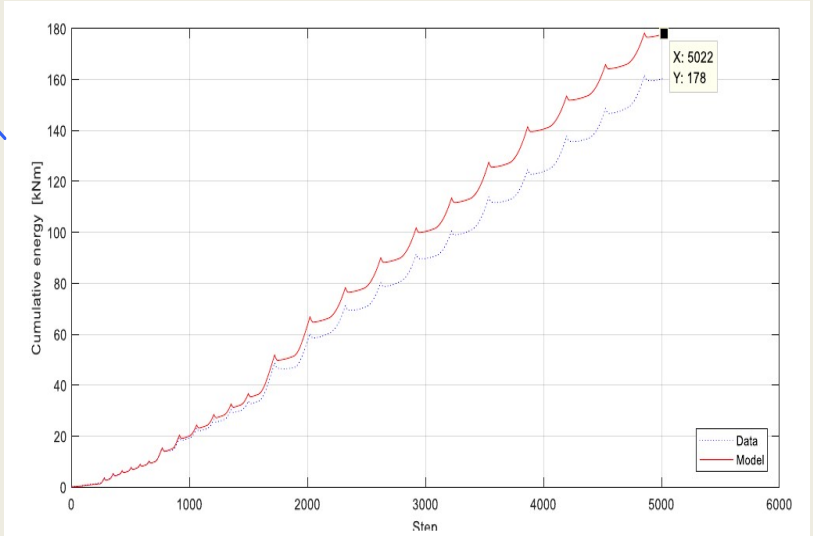
Iz bilinearne aproksimacije pushover krivulje

Treba biti određen numerički ili eksperimentalno (pokusima)

PBSD – indeks oštećenja

$$\beta = \frac{F_y \cdot (\Delta_{U,st} - \Delta_{"potres"})}{\int \mathrm{dE}}$$





Parametar β predstavlja opadanje nosivosti u funkciji inkrementalnoga prirasta $\frac{d\Delta_{EB}}{\Delta_{u,st}}$

i inkrementa disipirane energije $\frac{d\int dE}{\Delta_{u,st}}$

(Park, Kunnath, 1988)

PBSD – indeks oštećenja

Indeks oštećenja OZoD s oblogom od GFB, određivanje parametra β

Tab. 5.5: Estimation of coefficient β_{DI} from the CASHEW hysteretic and static pushover analysis of shear walls sheathed with GFB

GFB	L_w	$\Delta_{u,st}$	F_y	$\Delta_{respISO}$	Δ_{respMB}	$\int dE_{ISO}$	$\int dE_{MB}$	β_{ISO}	β_{MB}	β_{DI}
#	[m]	[mm]	[kN]	[mm]	[mm]	[kNm]	[kNm]	[-]	[-]	[-]
1	2.4	29.75	47.71	21.25	22.52	10.038	8.85	0.038	0.039	0.039
2		31.25	85.74	26.25	22.8	15.98	17.92	0.027	0.04	0.033
1	3.0	31.06	60.75	21.5	22.23	11.79	10.92	0.049	0.049	0.049
2		39.52	119.2	28.71	28.65	16.83	11.55	0.077	0.112	0.095
1	3.6	33.3	70.1	20.65	21.5	17.8	12.48	0.05	0.066	0.058
2		38.31	140.5	22.2	26.67	25.96	18.63	0.087	0.0878	0.087
1	4.2	31.2	87.92	21.65	22.86	15.92	13.94	0.053	0.053	0.053
2		29.3	167.9	24.13	24.93	37.32	28.53	0.023	0.026	0.024
1	4.8	39.88	95.62	21.25	24.08	20.53	15.16	0.087	0.099	0.093
2		37.53	179.1	27.41	26.62	34.9	26.58	0.052	0.074	0.063

Korelacija IDR i DI

DI (Park & Ang) za OZoD obložene s GFB

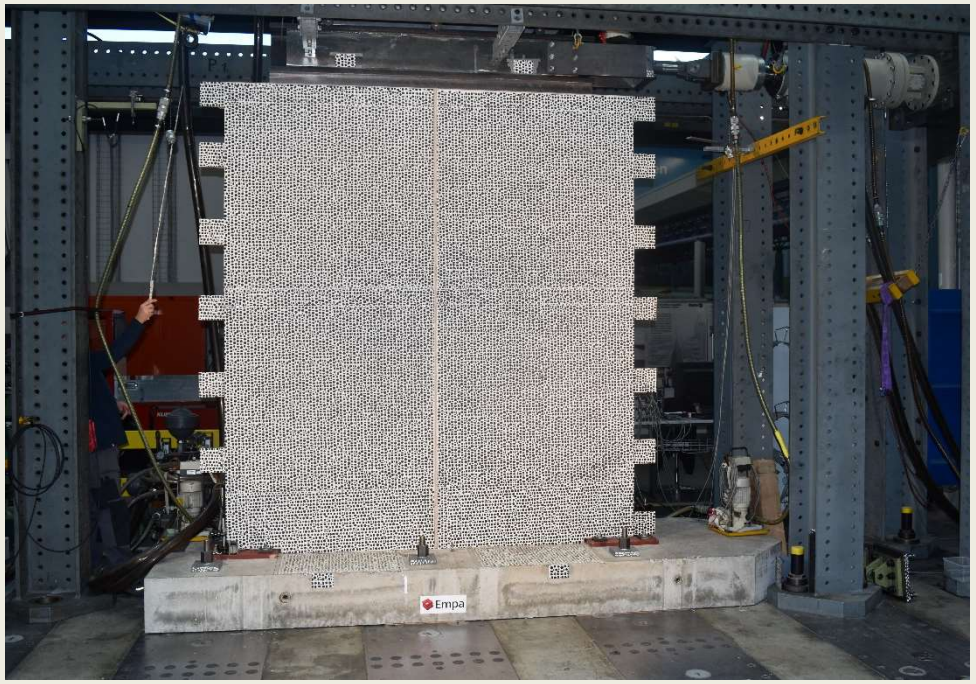
Tab. 4.6: Damage Index Estimation for a three-storey structure. Constitutive wall element of length 3.6 m with displacement capacity $\Delta_{u,st} = 38.8[mm]$, yield force $F_y = 140.5[kN]$ and parameter $\beta_{DI} = 0.087$ for an earthquake sute scaled in such way to produce average IDR of 0.45%, 0.65%, 0.85% and 1.1% corresponding to the IO, LS and CP limit states

EQ	IDR 0.45%			IDR 0.65%			IDR 0.85%			IDR 1.1%		
No.	Δ_{resp} [mm]	$\int dE$ [kNm]	DI [-]	Δ_{resp} [mm]	$\int dE$ [kNm]	DI [-]	Δ_{resp} [mm]	$\int dE$ [kNm]	DI [-]	Δ_{resp} [mm]	$\int dE$ [kNm]	DI [-]
1	18.36	19.11	0.77	22.07	3.56	0.62	9.87	3.53	0.31	18.48	6.67	0.58
2	15.85	8.12	0.54	6.31	1.22	0.18	36.66	16.59	1.20	21.74	19.1	0.87
3	10.76	1.49	0.30	13.2	5.45	0.43	24.44	10.57	0.80	15.43	15.16	0.64
4	12.41	4.9	0.40	12.61	3.22	0.38	22.36	15.12	0.82	19.51	6.06	0.60
5	11.27	4.75	0.37	27.42	8.35	0.84	13.87	9.96	0.52	26.201	6.05	0.77
6	11.29	5.75	0.38	33.17	37.87	1.46	43.91	28.18	1.58	41.05	9.48	1.21
7	12.72	4.96	0.41	12.98	5.94	0.43	18.46	13.47	0.69	93.83	27.14	> 2.85
8	9.95	2.71	0.30	14.82	6.651	0.49	20.03	23.37	0.89	26.82	21.68	1.04
9	15.0	6.85	0.50	27.78	40.25	1.36	18.98	10.09	0.65	19.56	8.82	0.64
10	10.32	3.24	0.32	13.15	7.92	0.46	25.66	20.46	0.99	18.56	11.48	0.66
average	12.79	6.19		18.35	12.04		23.42	15.13		30.12	13.17	
Average Damage Index			0.43			0.67			0.85			0.99

Verifikacija

ETH zürich

OZoD obloženi s GFB izloženi monotonom i cikličnom opterećenju



OZoD **jednostrano i obostrano** obloženi

Loading protocols:

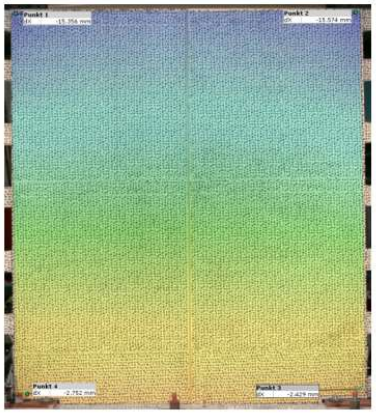
- Monotonic
- ISO 21581:210

Verifikacija

OZoD s jednostranom oblogom

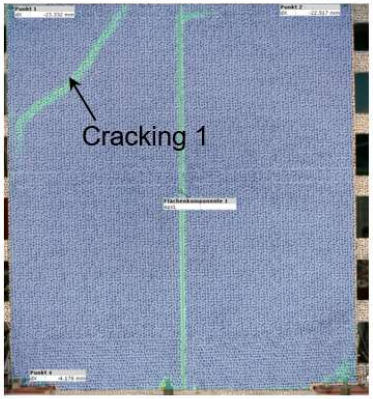
ETH zürich

IDR = 0.53
Δmax = 17.5 mm



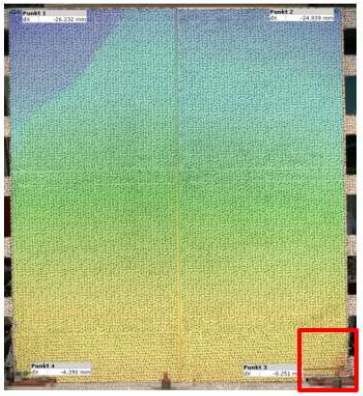
No cracking visible

IDR = 0.9
Δmax = 25.0 mm



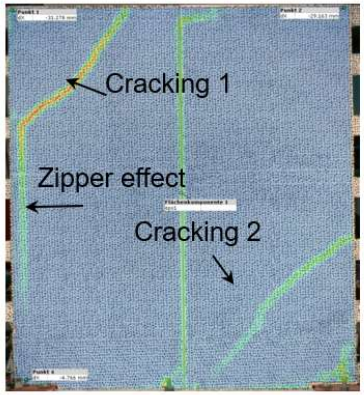
Sudden cracking onset in the GB panel corner

IDR ≈ 1.0
Δmax = 28.5 mm

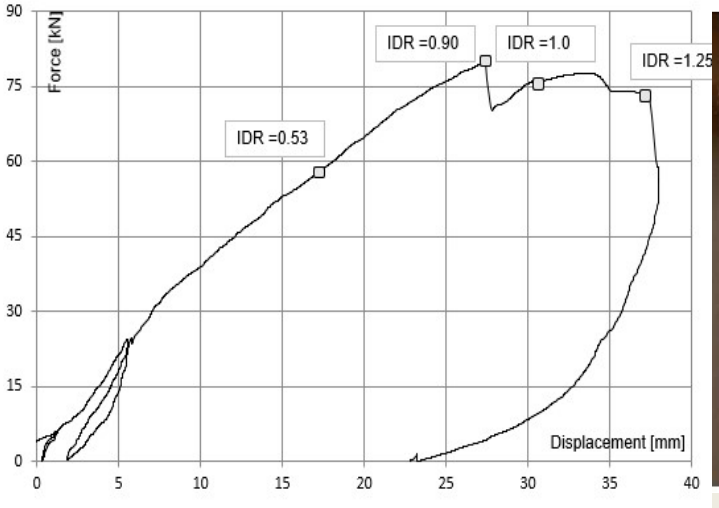


Cracking onset in the right GB panel corner

IDR ~ 1.25
Δmax = 35.0 mm



Cracking in the GB panel corner and zipper effect



IDR = 0.90

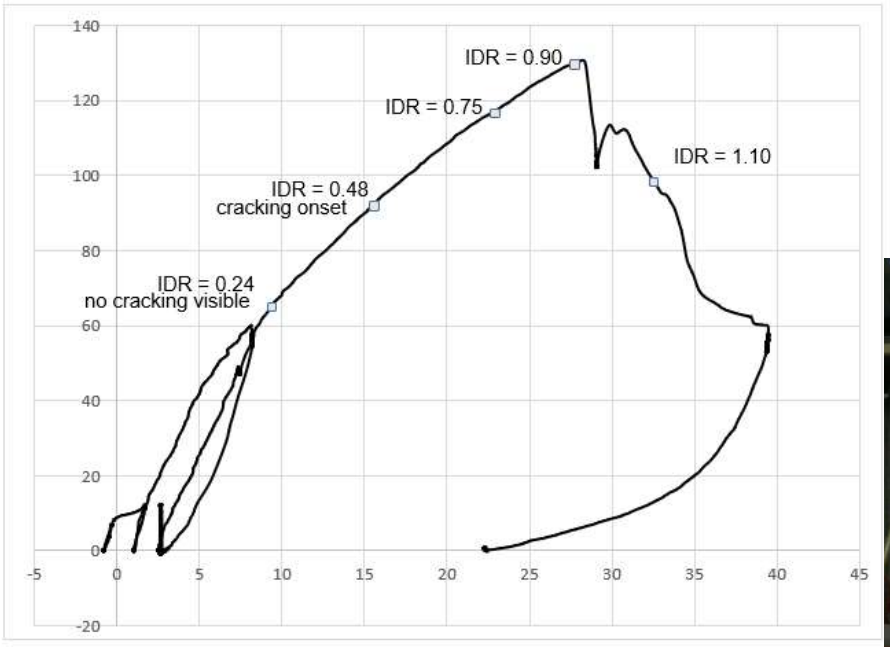
IDR = 1.0

IDR =1.25

HKIG 2020.

Verifikacija

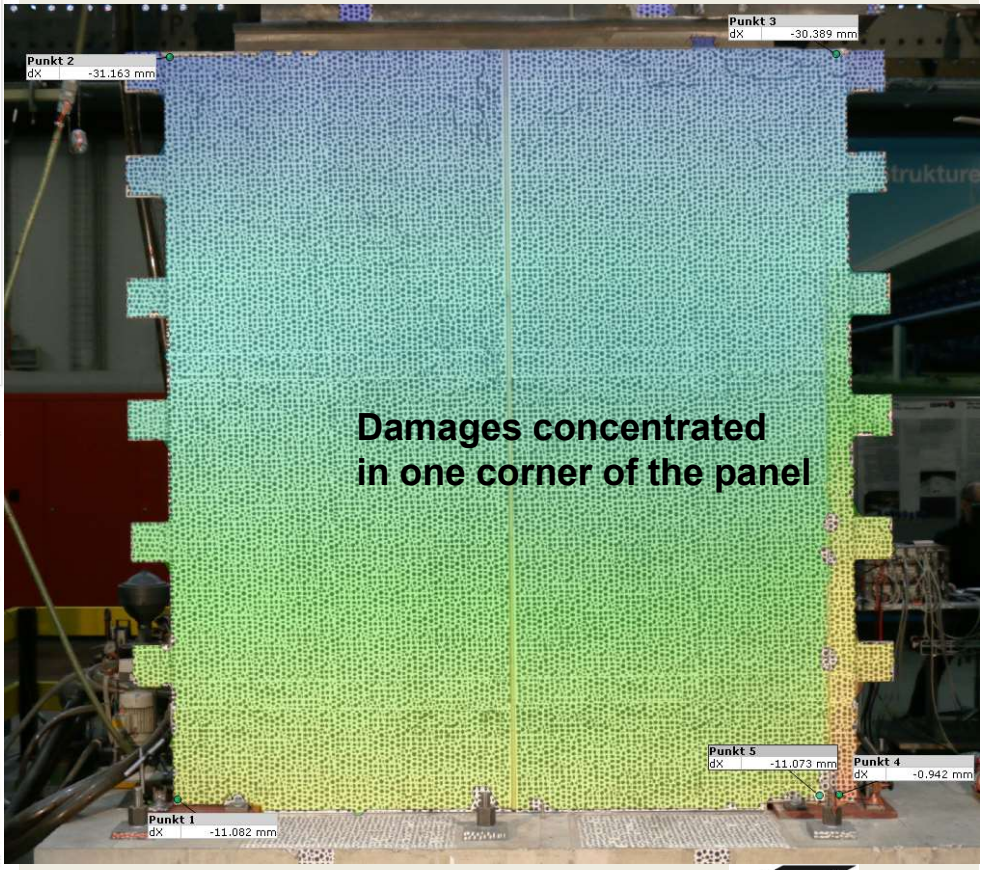
OZoD s dvostranom oblogom



IDR = 0.75

IDR = 0.90

IDR = 1.10

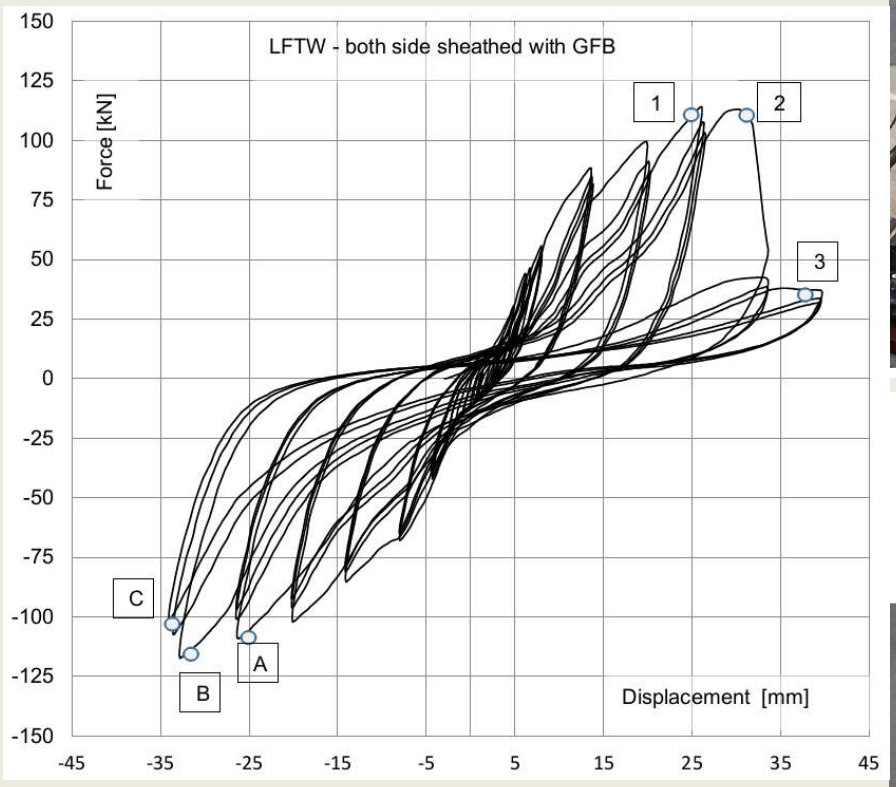


Damages concentrated in one corner of the panel

HKIG 2020.

Verifikacija

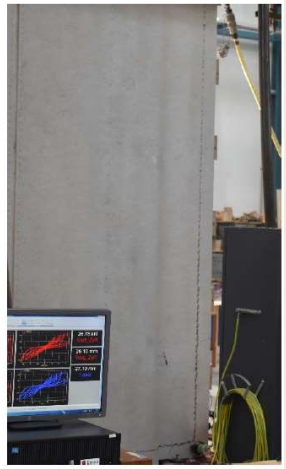
OZoD s dvostranom oblogom



Point 1
Displacement 22.6 [mm]
IDR = 0.83

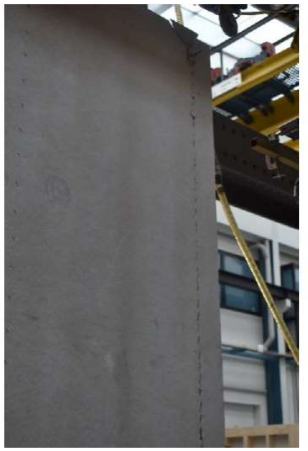
Point 2
Displacement 29.4 [mm]
IDR = 1.09

Point 3
Displacement 38.8 [mm]
IDR = 1.43



Point A
Displacement -25 [mm]
IDR = 0.92

Point B
Displacement -30.6 [mm]
IDR = 1.13



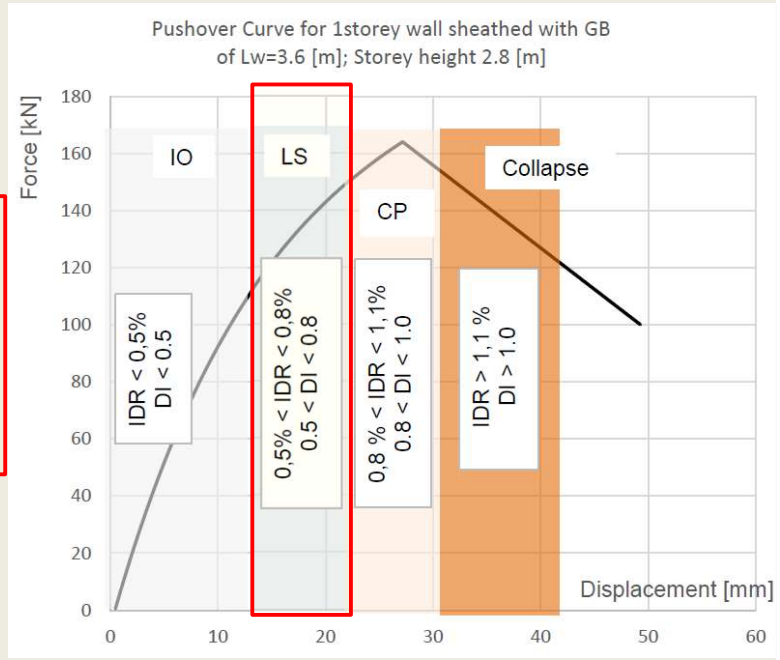
Point C
Displacement -37.9 [mm]
IDR = 1.4

Prijedlog DI za granična stanja IO, LS i CP

Tab. 5.8: Performance Expectations Proposal for Light Frame Shear Timber Walls Sheathed with GFB

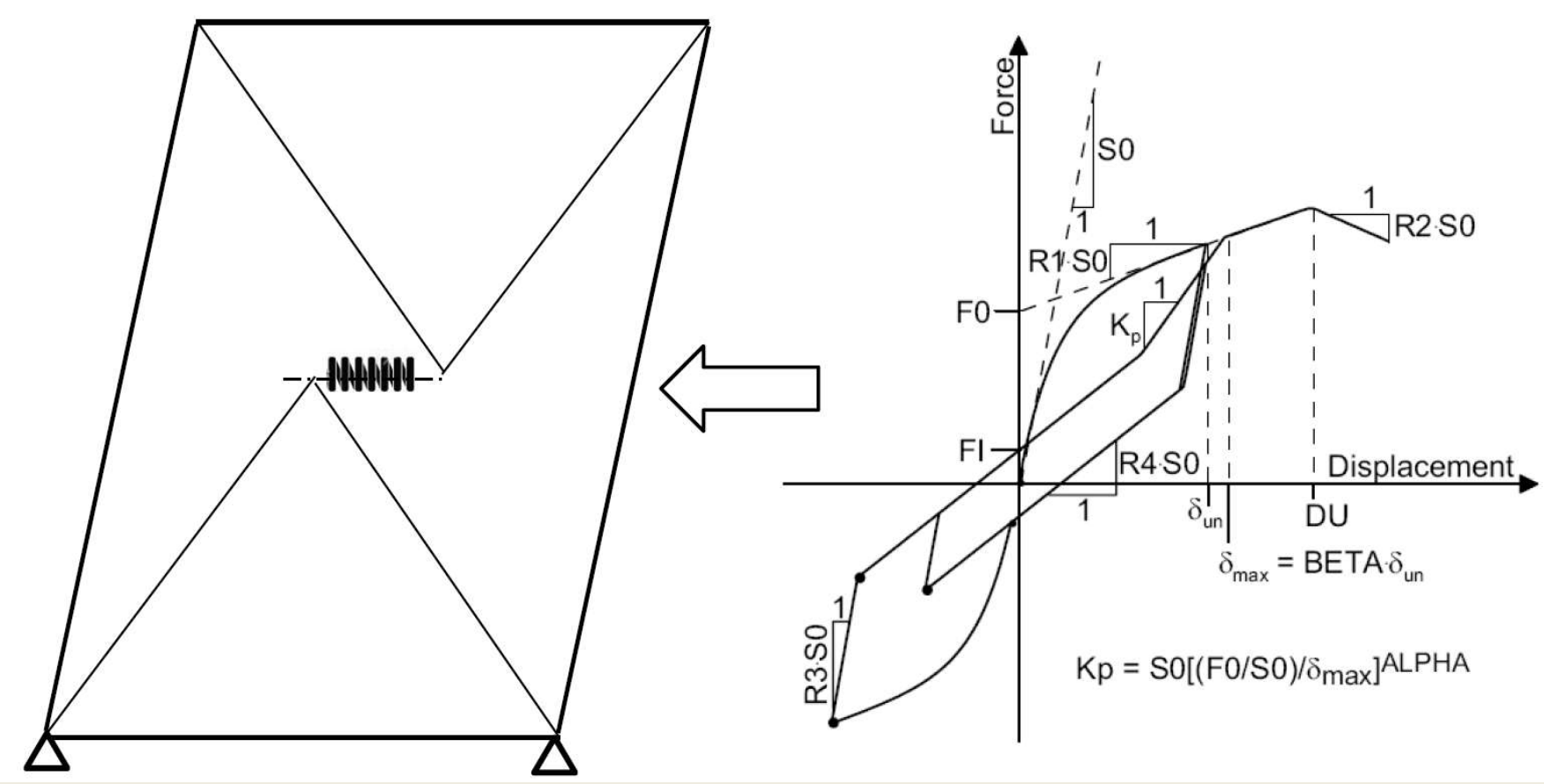
Design level	EC8 nomenclature	Seismic hazard PoE	Return Period	Performance Expectations: Inter-storey Drift Limit	Performance Expectations: Non-exceedance Probabaility	Performance Expectations: Damage Index
IO	Damage control	50% in 50Y	72Y	< 0.5%	50%	
	Description	The structure is lightly damaged. The structural elements preserve their strength and stiffness. The damages are reparable in an economic way.				≤ 0.5
LS	Life safety	10% in 50Y	475Y	(0.5 – 0.8)%	50%	
	Description	The structure is moderate to significantly damaged. Moderate permanent drifts are present. The damages are likely to be reparable.				$0.5 < DI \leq 0.8$
CP	Collapse prevention	2% in 50Y	2475Y	(0.8 – 1.1)%	50%	
	Description	The structure is heavily damaged. Large permanent drifts are present. The damages are likely not to be reparable. The structure could probably not survive an another earthquake, even of moderate intensity.				$0.8 < DI \leq 1.0$

IO - Immediate Occupancy
LF - Life Safety
CP - Collapse Prevention
PoE - Probability of Exceedance



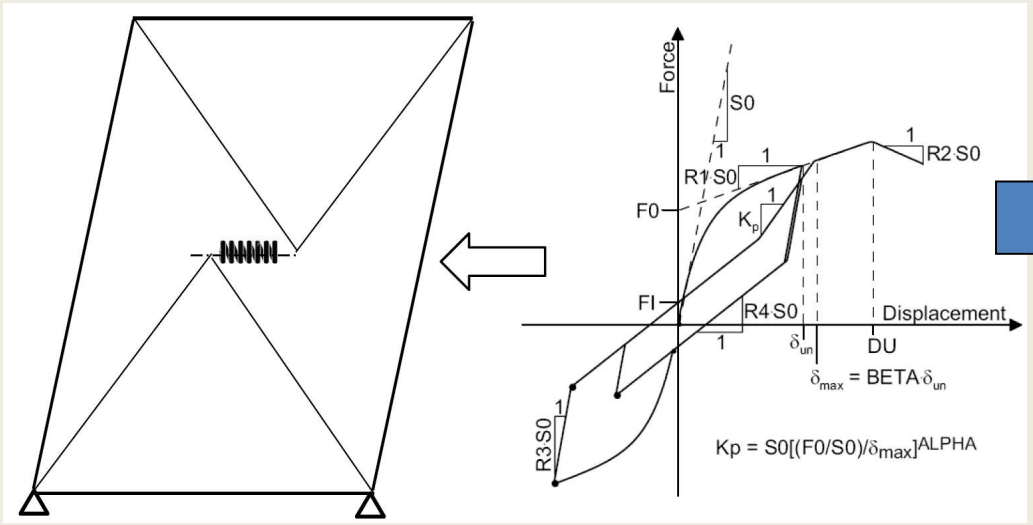
Modeliranje u OPENSEES

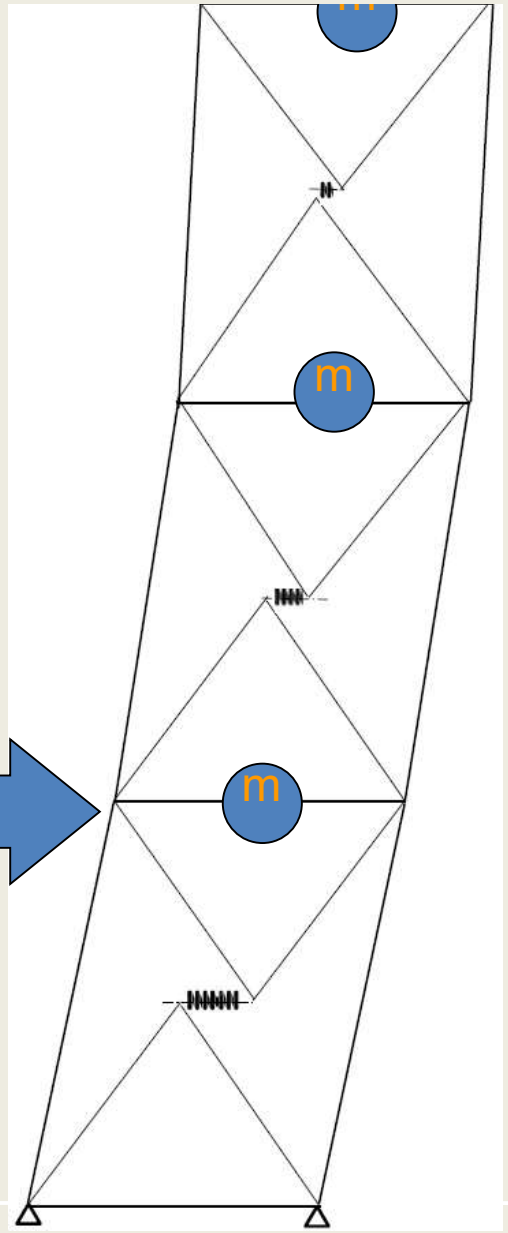
- 10-parametarska histereza kao SAWS–materijal u OPENSEES
- element sa zadanim svojstvima je koncentriran u jednoj točci (tzv. *zero length element*)



Modeliranje u OPENSEES

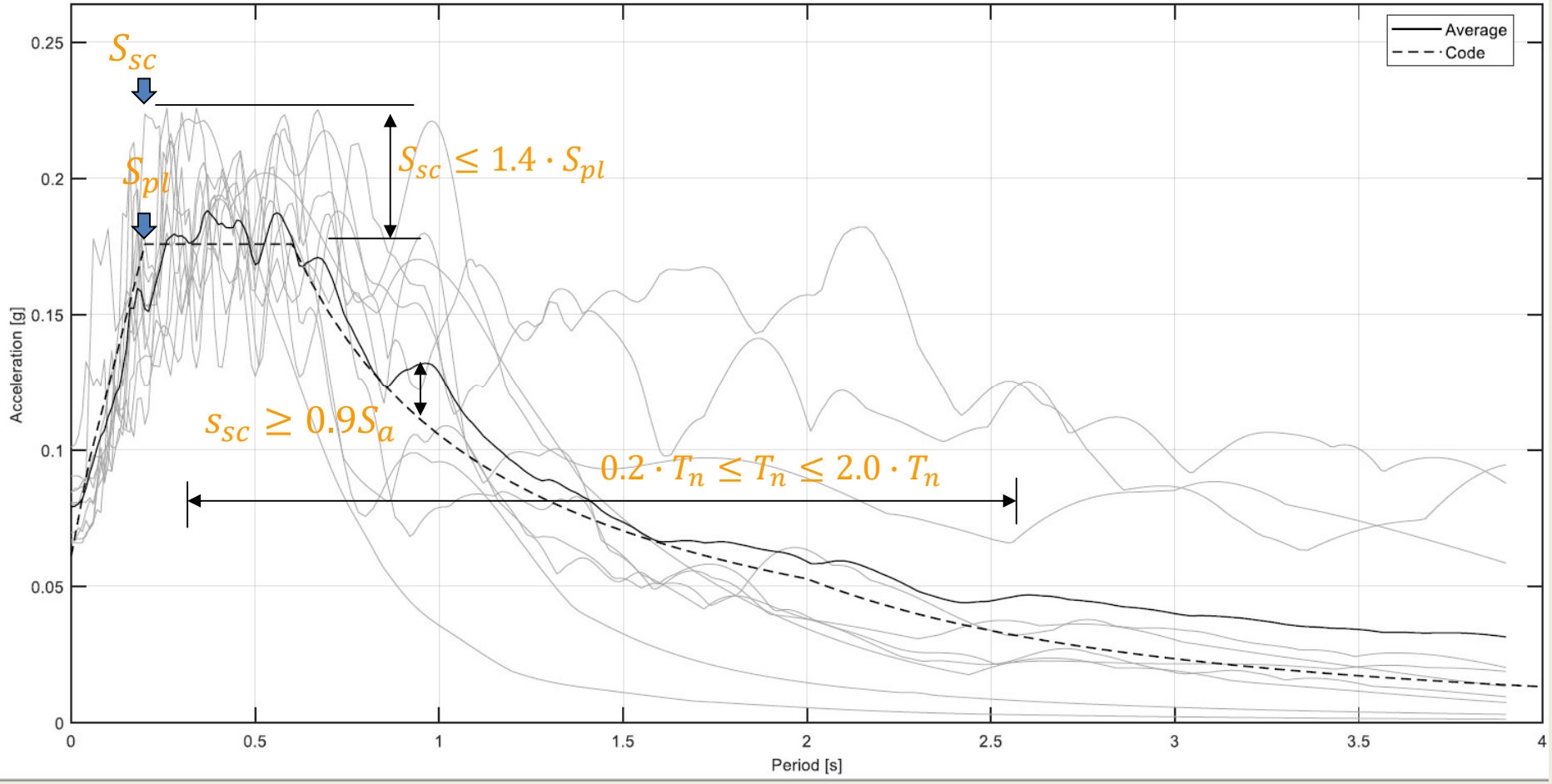
Od SDOFS do MDOFS



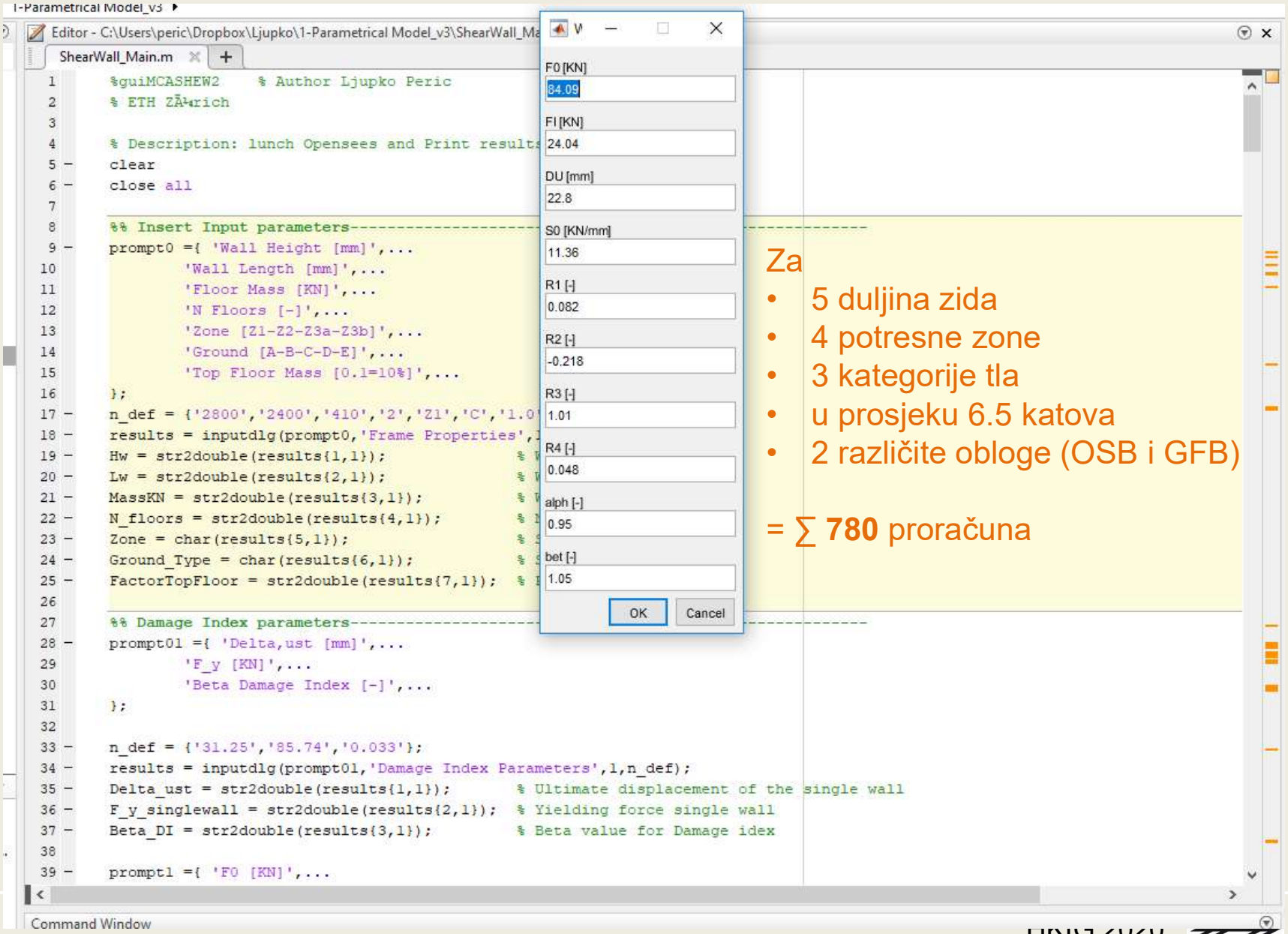


Modeliranje u OPENSEES

Izbor i skaliranje realnih potresnih zapisa
(10 od 3510 iz NGA baze podataka) za svaku potresnu zonu



Modeliranje u OPENSEES



Za

- 5 duljina zida
- 4 potresne zone
- 3 kategorije tla
- u prosjeku 6.5 katova
- 2 različite obloge (OSB i GFB)

= ∑ **780** proračuna

Pregled konačnih rezultata

Tab. A.7: Results of the parameter study of a LFTW with a length of 3.0 [m] sheathed on both sides with GFB

Zone	Mass	IDA	Modal analysis			Pushover analysis				NLTH analysis			
a_g	m	check	T	T^*	Γ	Δ_y	F_y	μ	$\Delta_{u,st}$	HD force	Δ_{roof}	IDR	DI
$\frac{m}{s^2}$	[t]		[s]	[s]	[-]	[mm]	[kN]	[-]	[mm]	[kN]	[mm]	[-]	[-]
			1- storey structure										
0.6	173.0	✓	0.83	1.0	1.0	17.37	119.6	1.52	40.66	123.16	25.0	0.86	0.80
1.0	78.5	✓	0.55	0.64				1.77		128.8	26.67	0.92	0.80
1.3	50.0	✓	0.45	0.50				1.9		130.0	27.54	0.95	0.80
1.6	37.5	✓	0.39	0.43				1.76		130.3	27.64	0.95	0.80
			2- storey structure										
0.6	120.0	✓	1.15	1.27	1.181	25.53	118.1	1.57	53.01	183.6	33.41	0.81	0.80
1.0	52.5	✓	1.76	1.14				1.74		207.5	39.92	0.92	0.80
1.3	30.5	✓	0.59	0.64				1.73		208.5	40.82	0.95	0.8
1.6	20.0	✓	0.47	0.5				208.5	40.39	0.95	0.8		
			3- storey structure										
0.6	92.0	✓	1.46	1.60	1.25	38.17	115.1	1.39	64.6	207.0	41.21	0.75	0.80
1.0	45.5	✓	1.03	1.12				1.64		273.6	56.18	0.87	0.80
1.3	28.5	✓	0.8	0.89				1.70		300.7	59.82	0.87	0.8
1.6	16.5	✓	0.62	0.67				1.58		277.1	55.14	0.86	0.69
			4- storey structure										
0.6	60.0	✓	1.60	1.70	1.295	54.6	116.4	1.08	89.41	212.2	42.44	0.53	0.57
1.0	32.0	✓	1.17	1.25				1.3		286.0	61.09	0.79	0.71
1.3	25.0	✓	1.03	1.10				1.5		351.0	78.42	0.82	0.79
1.6	18.5	✓	0.88	0.94				1.59		339.60	73.44	0.81	0.77
			5- storey structure										
0.6	36.5	✓	1.61	1.70	1.331	75.95	116.1	1.0	119.6	208.8	44.25	0.44	0.44
1.0	36.5	✓	1.61	1.70				1.32		333.2	79.96	0.70	0.66
1.3	26.5	✓	1.37	1.44				1.46		284.0	94.88	0.81	0.8
1.6	17.5	✓	1.11	1.17				1.46		388.8	91.5	0.77	0.79
			6- storey structure										
0.6	23.75	✓	1.64	1.70	1.36	103.4	116.1	1.0	157.0	195.6	46.0	0.38	0.35
1.0	23.75	✓	1.64	1.70				1.0		326.0	75.98	0.63	0.52
1.3	23.75	✓	1.64	1.70				1.29		389.5	107.9	0.78	0.78
1.6	14.0	✓	1.26	1.31				1.22		419.1	111.2	0.77	0.78

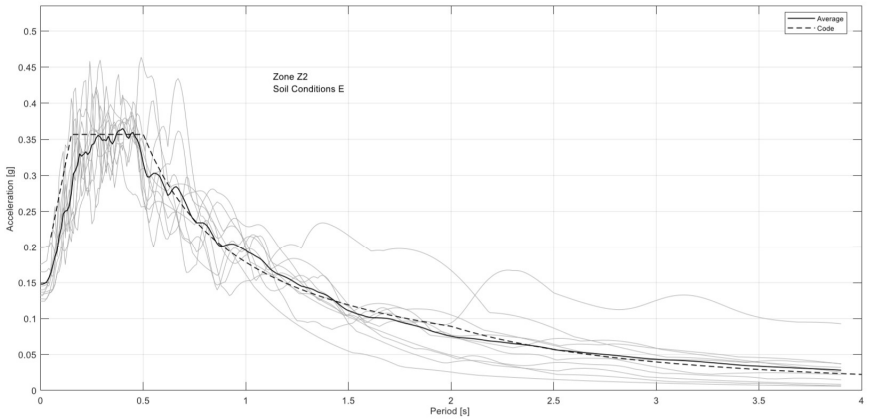


Fig. A.11: Resultant average of 10 earthquake records selected and scaled to the hazard level of Zone $Z2$ for soil conditions E superimposed on elastic RS..

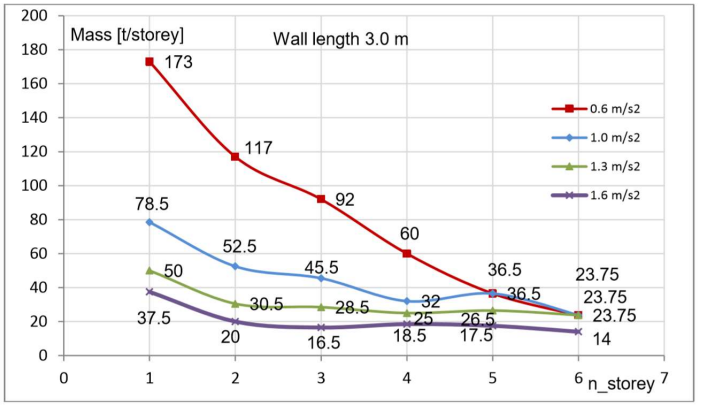
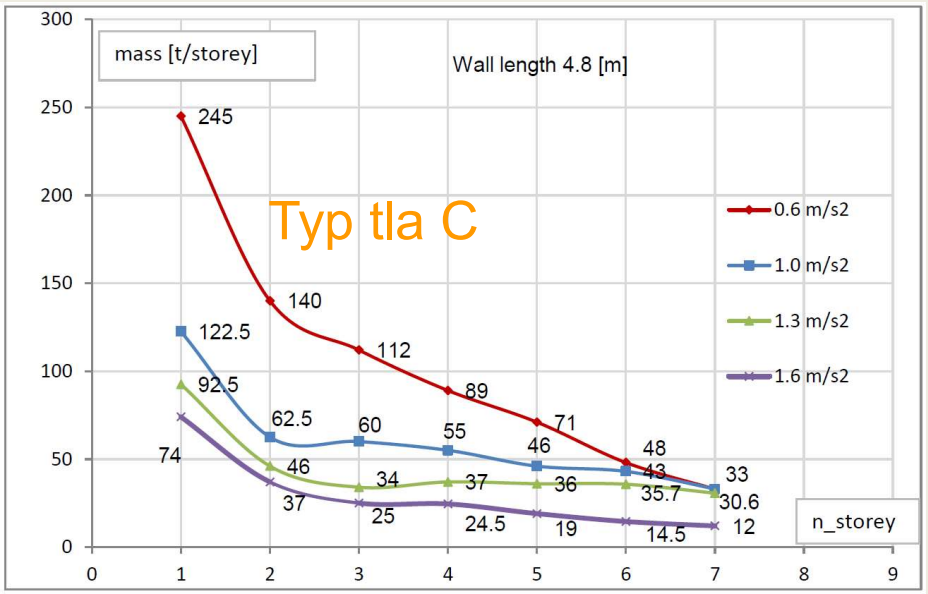
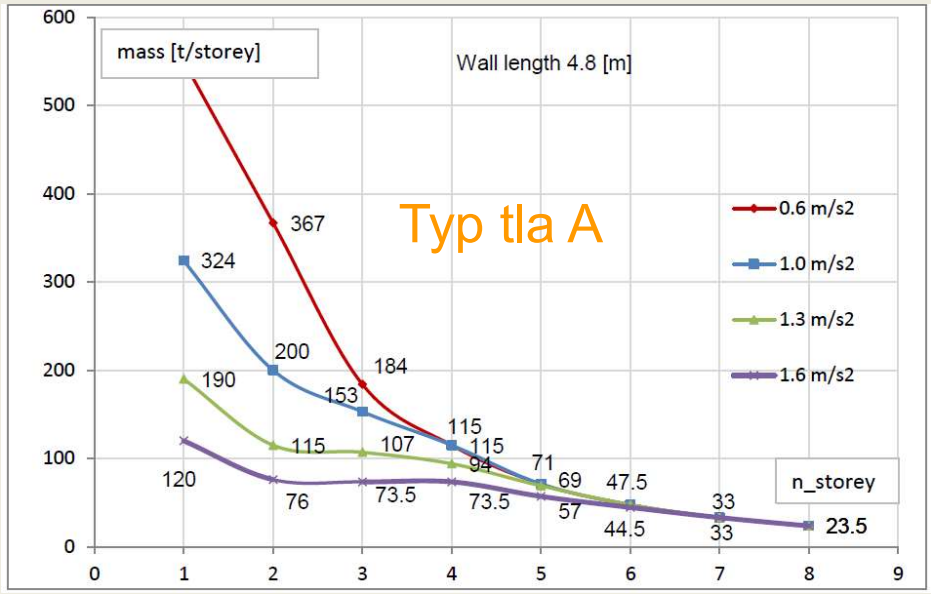


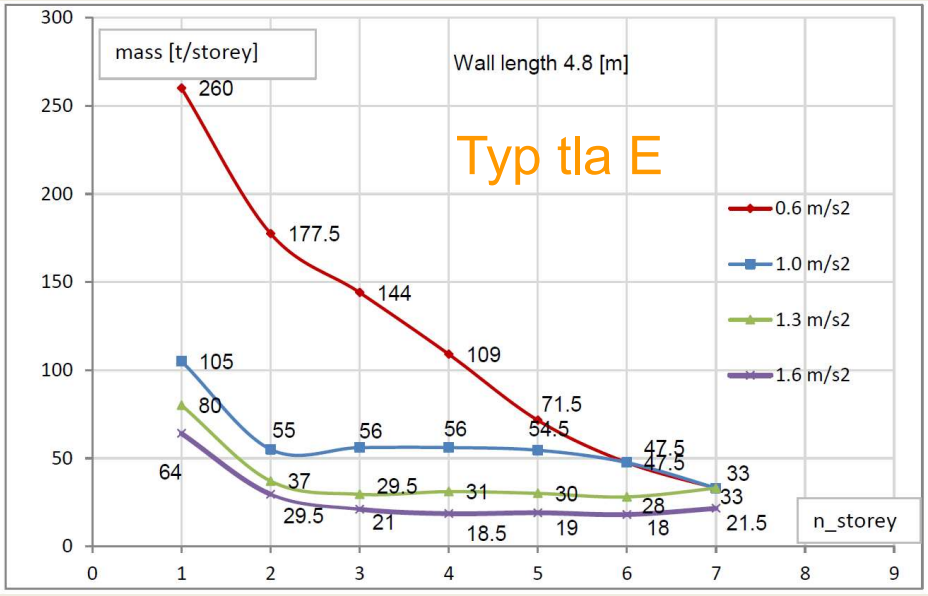
Fig. A.15: Outcome of the parameter study of the LFTW sheathed on both sides with GFB with a length of 3.0 [m], see also Table A.7

Rezultati





OZoD obloženi s GFB
(PoE 10% in 50Y)

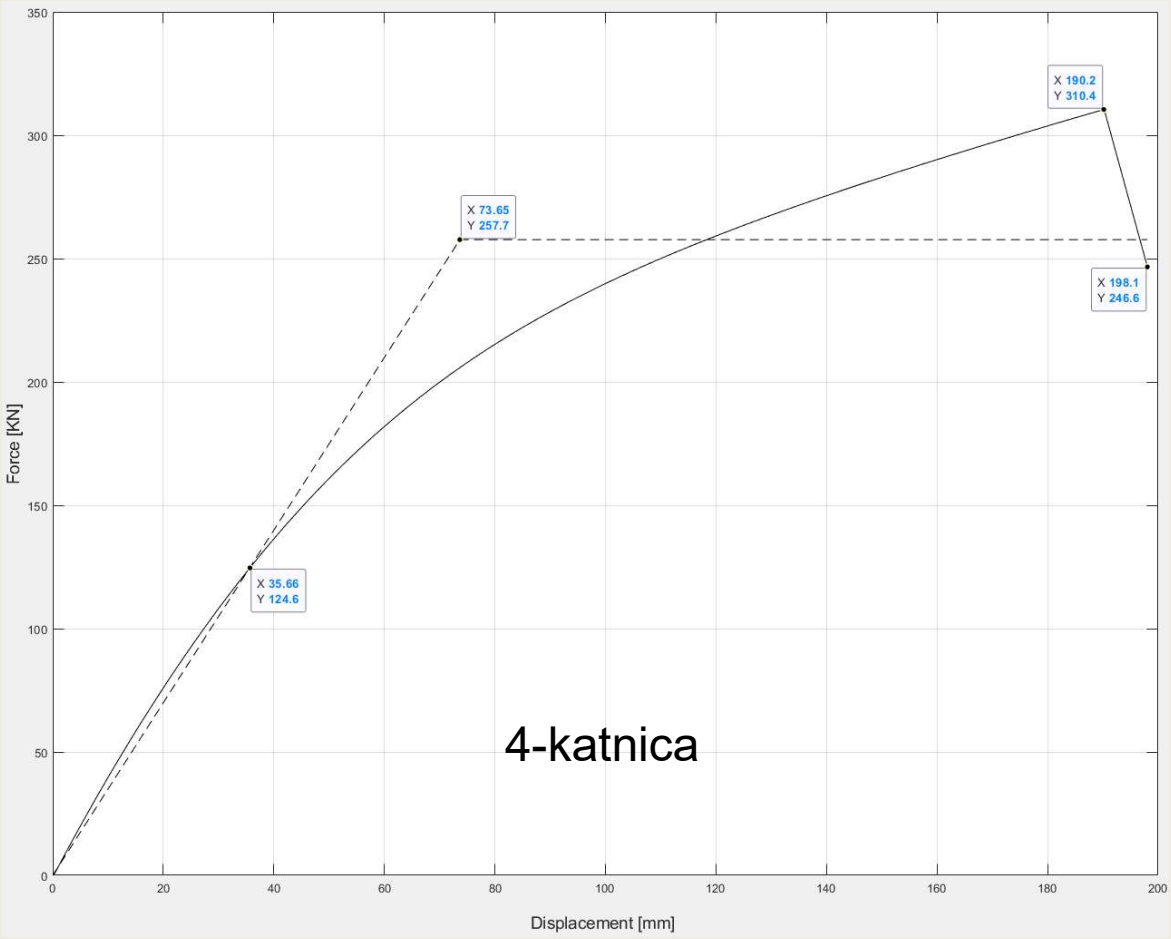


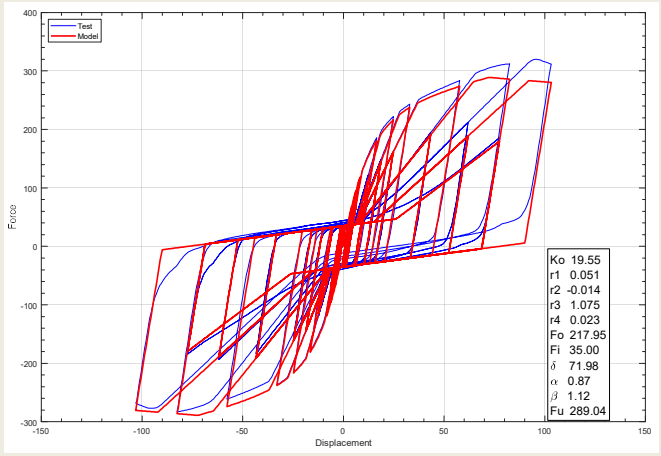
Hvala na pozornosti

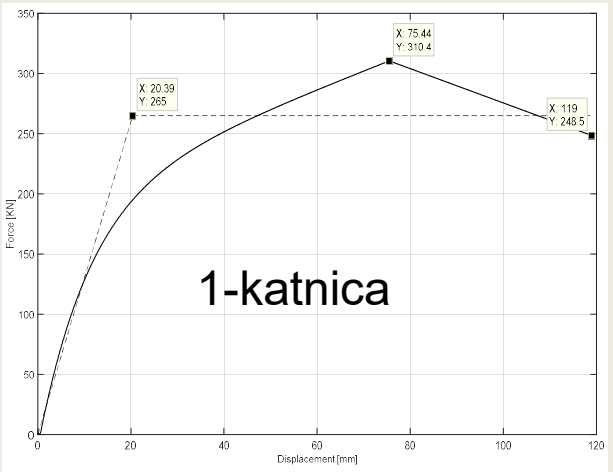
Mehanički model OZoD

Stvarno ponašanje vs. računske nosivosti OZoD jednokatnoga zida izloženoga monotonome opterećenju

SIA 265/1, Ziffer 8.3.1.2 & 8.3.1.4 $R_{v,d,i} = R_d \cdot \frac{b_i}{s} = 773 \cdot \frac{3600}{30} \cdot 2 = 185.5\ [kN]$

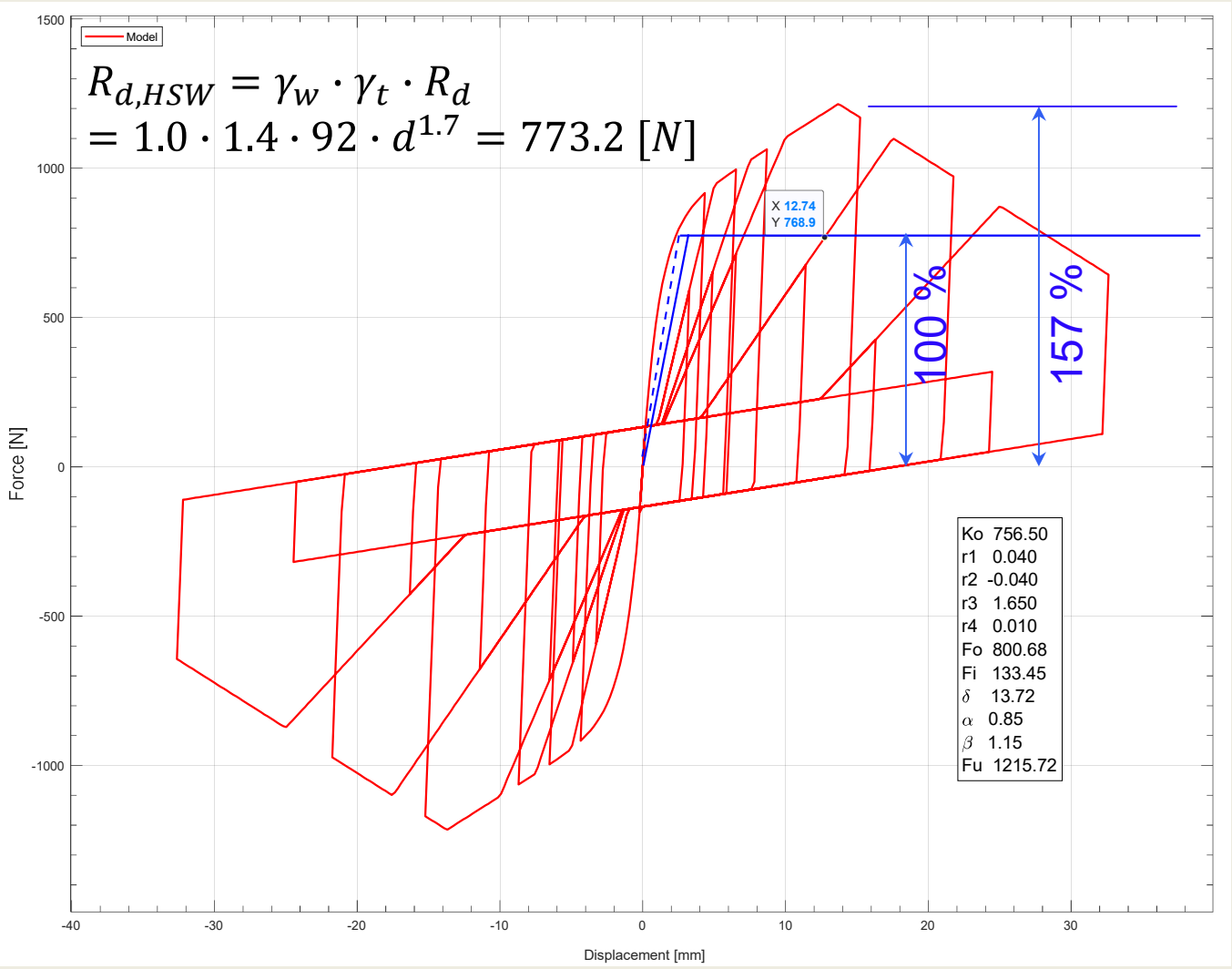






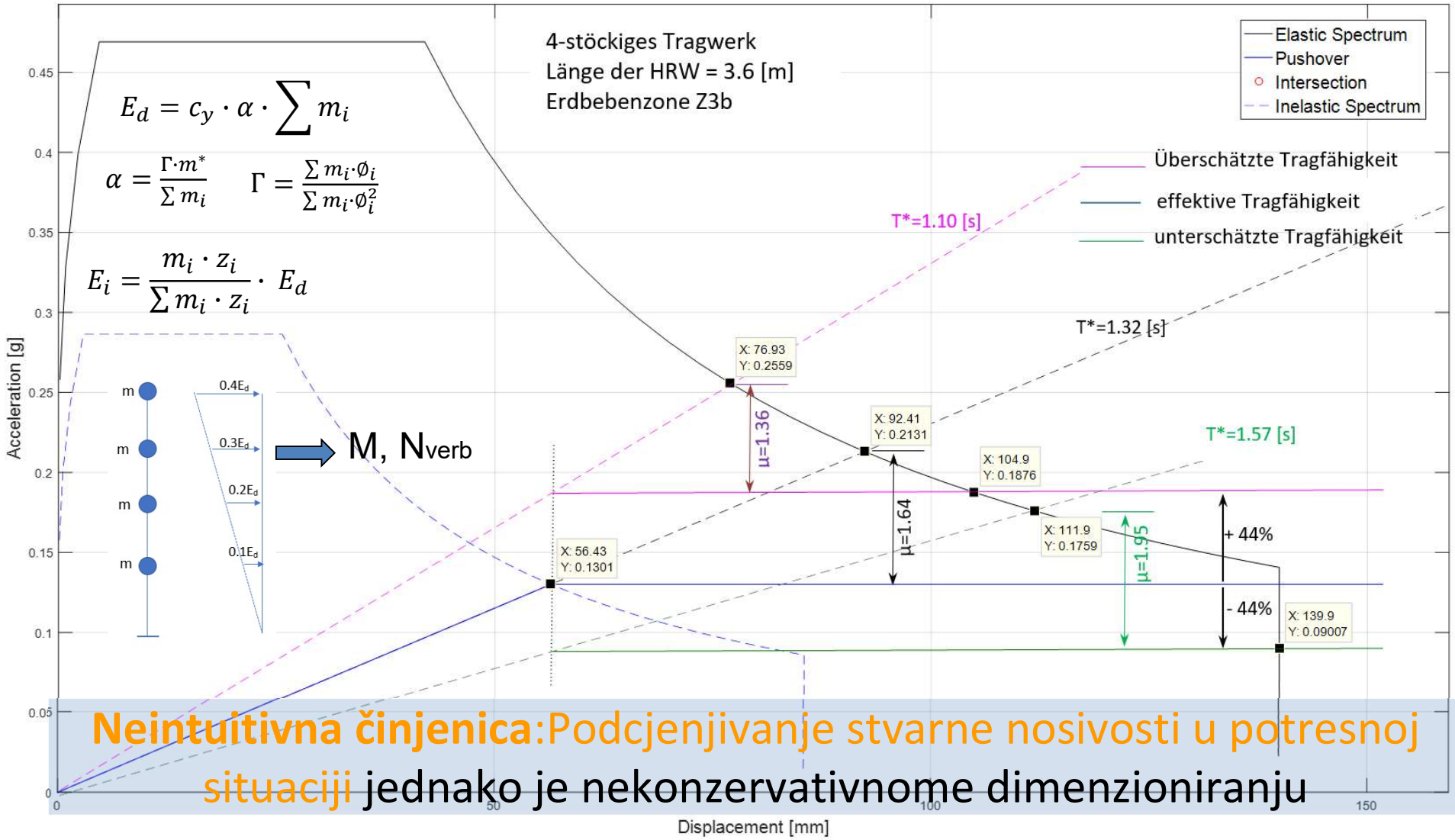
Mehanički model čavla

Stvarno ponašanje spajalice vs. računske nosivosti čavla d=2.87 [mm]



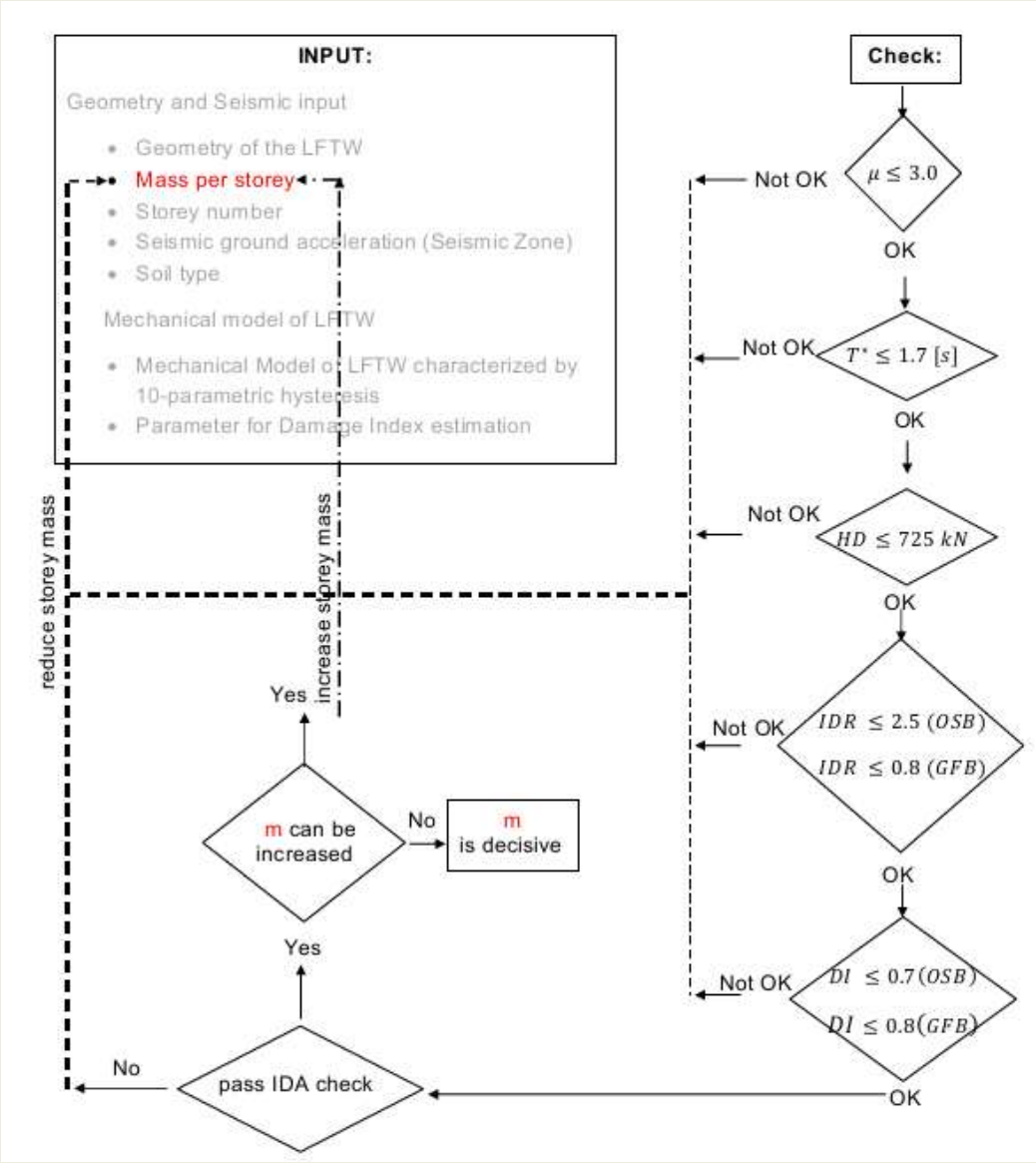
Stvarno vs. računsko ponašanje OZoD

Exkurs

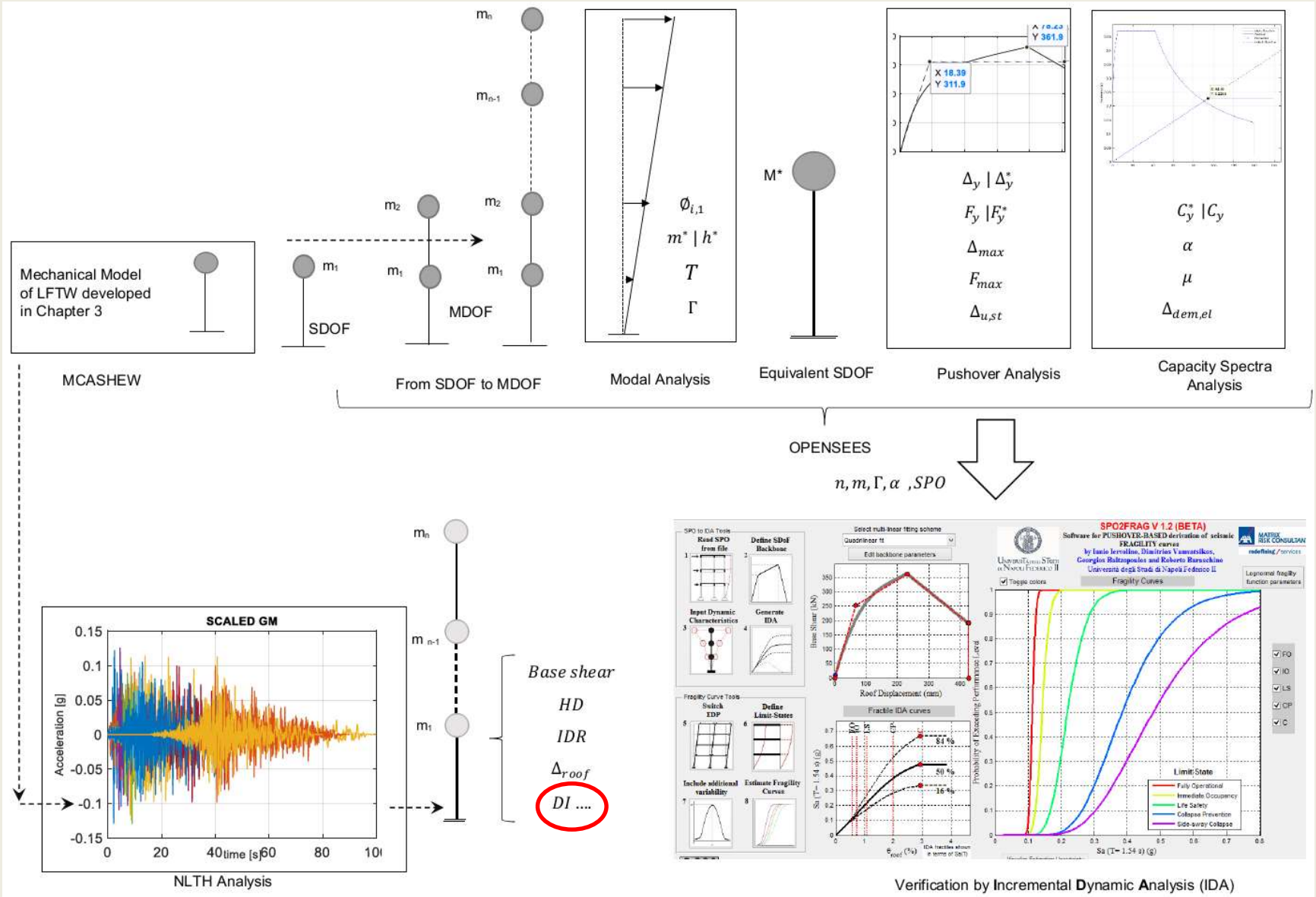


Neintuitivna činjenica:Podcjenjivanje stvarne nosivosti u potresnoj situaciji jednako je nekonzervativnome dimenzioniranju

Postupak određivanja mj. mase



Pregled korištenih analiza



Parametri kojima se osigurava željeno ponašanje konstrukcije

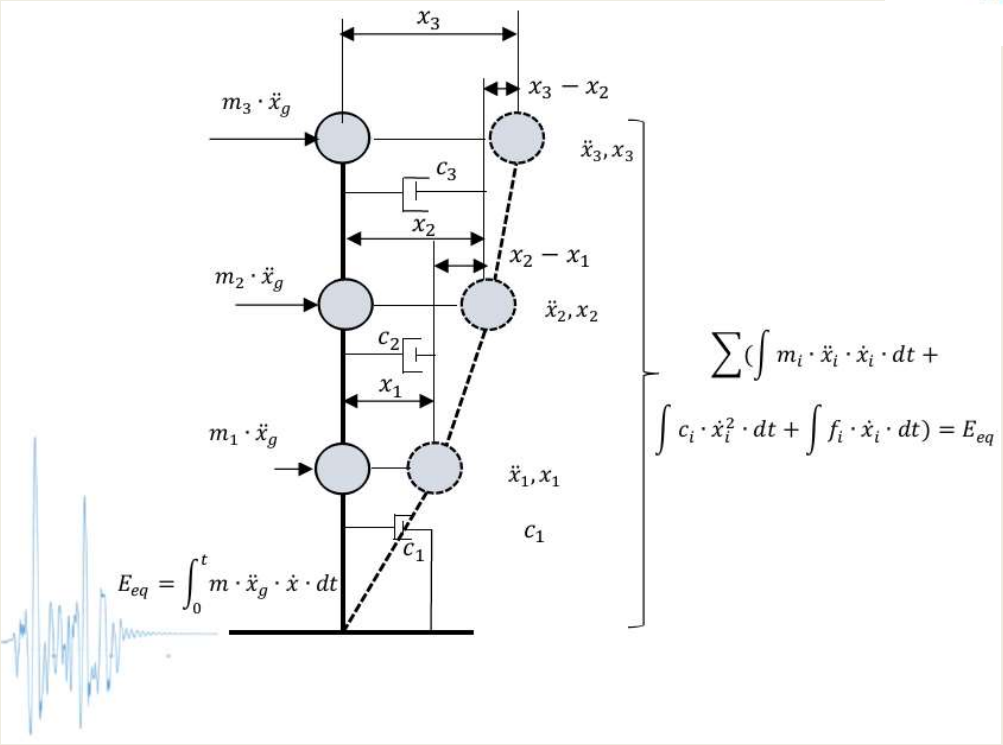
- Zahtjevana duktilnost $\mu < 3.0$ za OZoD obložene OSB panelima
- Zahtjevana duktilnost $\mu < 2.0$ za OZoD obložene GFB panelima
- Period titranja $T^* < 1.7\ s$
- Sile u temeljnoj spojnici < 725 kN
- Relativni katni pomak (IDR) i
- Indeks oštećenja posebno za OZoD $\mathrm{DI} = \frac{\Delta_{\mathrm{potres}}}{\Delta_{\mathrm{u,st}}} + \frac{\beta}{\mathrm{F_y} \cdot \Delta_{\mathrm{u,st}}} \cdot \int \mathrm{dE}$

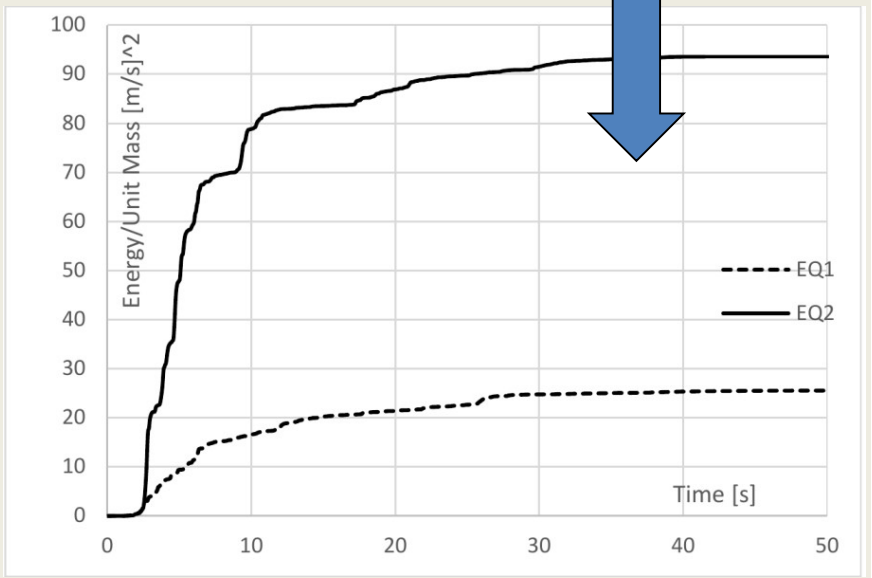
} određuju se obložene sa GFB i OSB

PBS – indeks oštećenja

Indeks oštećenja za OZoD s oblogom od GFB, određivanje enegrgije disipirane $\int \mathrm{dE}$

$$\frac{E_{in,r,1}}{m_{total}} = -\int \ddot{x}_g \cdot \dot{x}_1 \cdot dt = \ddot{x}_g \cdot x_1 \cdot \frac{\Delta_t^2}{2}$$





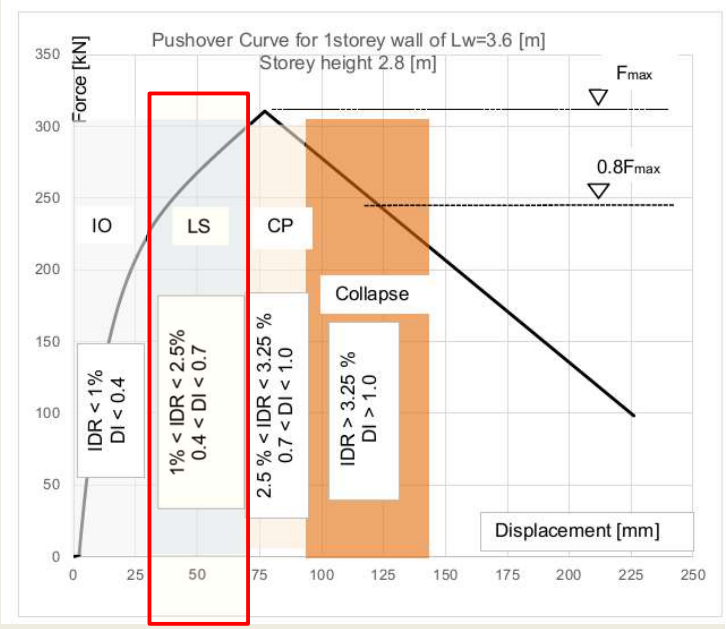
Integral nesene energije u sustav $\int dE$, kao i maksimalni pomaci izazvani potresom Δ_{potres} dobiju se iz NLTHA za svaki potres i za svaki kat posebno

6. Verhaltensgrenzen der HRW beplankt mit OSB für den Fall eines Bemessungsbebens

ETH zürich

Tab. 5.7: Performance expectations and drift limits for LFTW sheathed with OSB

Design level	EC8 nomenclature	Seismic hazard PoE	Return Period	Performance expectations: Inter-storey Drift Limit	Performance expectations: Non-exceedance Probabaility	Performance expectations: Damage Index
IO	Damage control	50% in 50Y	72Y	1%	50%	
	Description	The structure is slightly damaged. The structural elements preserve their strength and stiffness. Damages are reparable in an economic way.				≤ 0.4
LS	Life safety	10% in 50Y	475Y	$(1.0 - 2.5)\%$	50%	
	Description	The structure is moderately to significantly damaged. Moderate permanent drifts are present. Damages are likely to be reparable.				$0.4 < DI \leq 0.7$
CP	Collapse prevention	2% in 50Y	2475Y	$(2.5 - 3.25)\%$	50%	
	Description	The structure is heavily damaged. Large permanent drifts are present. Damages are likely irreparable. The structure could probably not survive another earthquake, even of a moderate intensity.				$0.7 < DI \leq 1.0$

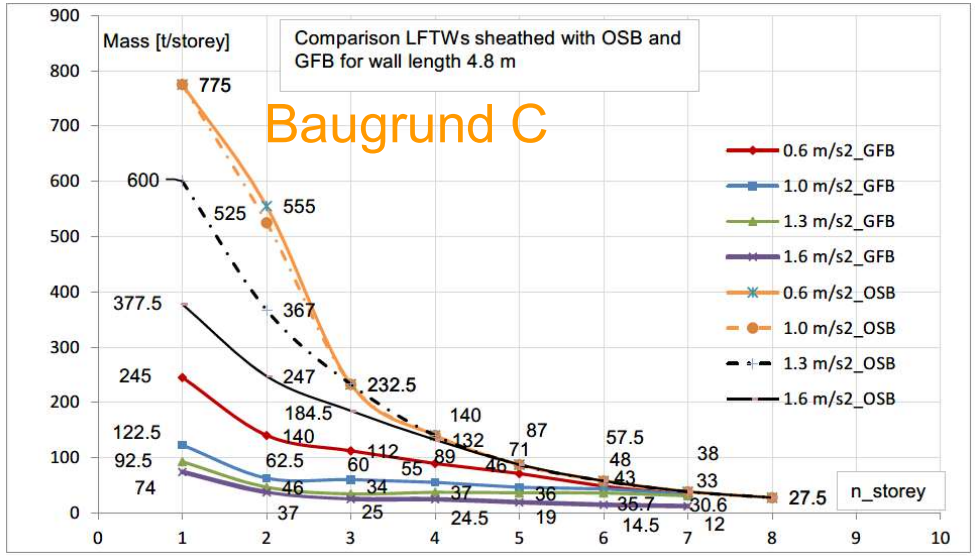


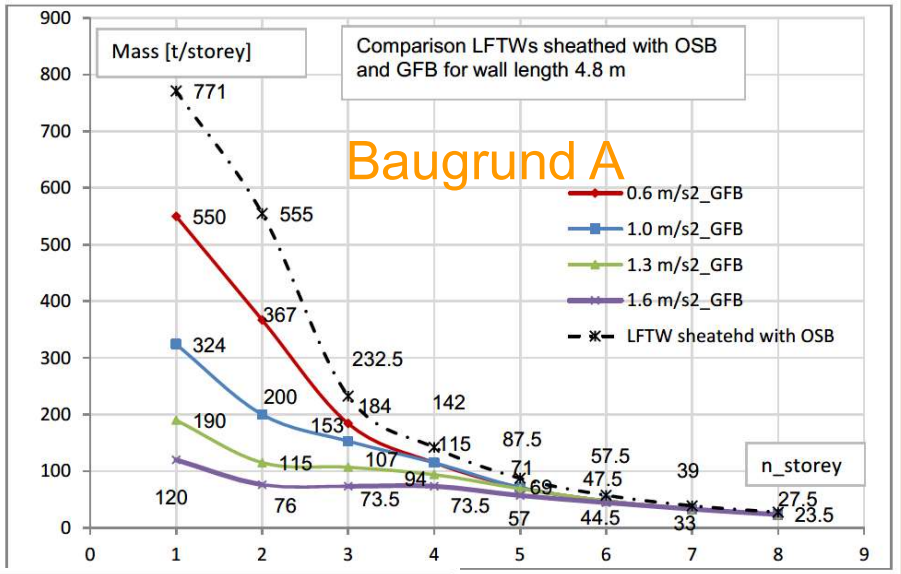
HKIG 2020.

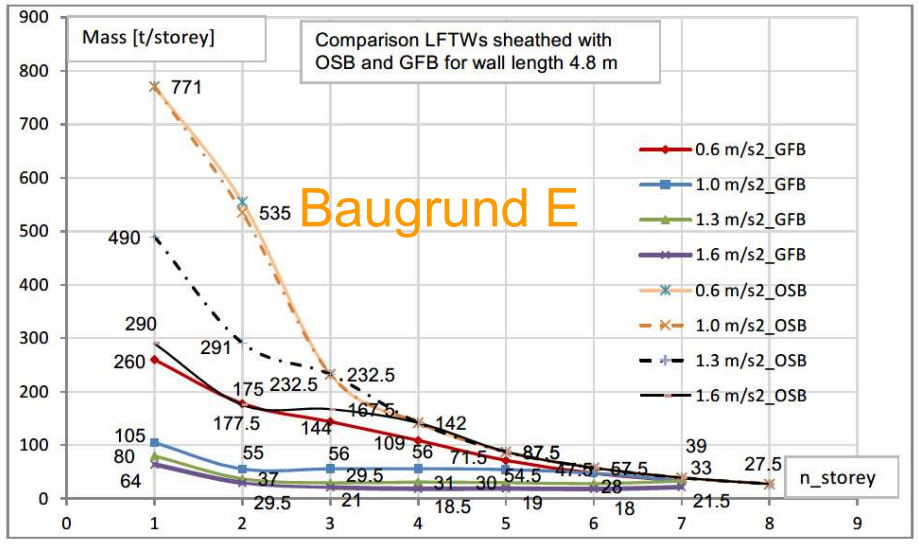
8. Resultate

ETH zürich

Vergleich der Ergebnisse für eine HRW beplankt mit GFB und OSB







HKIG 2020.