



# **Assessment and retrofitting – a holistic approach**

Juraj Pojatina, dipl.ing.grad.



## Education / Expertise

- University of Zagreb / Faculty of Civil Engineering
  - SAHC - Structural Analysis of Monuments and Historical Constructions / SA5 - Repairing and Strengthening Techniques
- 
- Building Seismic Assessment Expert / U.S. Department of State
  - Research, Documenting and Renovation of Historic Structures / Croatian Ministry of Culture
  - Heritage buildings Seismic Consultant / Croatian Centre for Earthquake Engineering CCEE

## Experience

20 years of structural engineering experience:

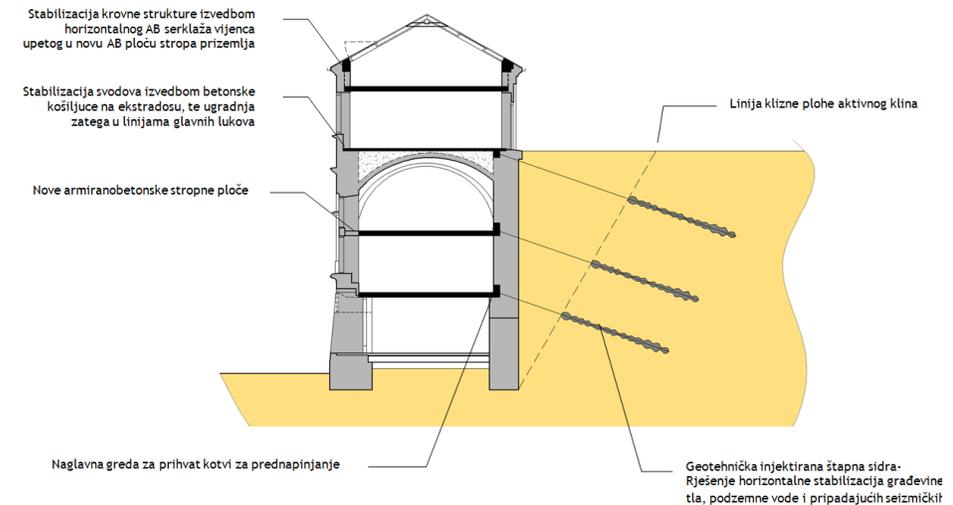
- Structural design in steelwork, concrete, timber and masonry
- Special structures
- Building performance
- Assessment & renovation
- Refurbishment, re-modelling and renovation of historic and listed structures
- Seismic assessment & rehabilitation
- Foundation design, including deep basement for urban sites

# Heritage buildings



## Specific Issues in Structural Assessment / Intervention Approach

- Interdisciplinary approach (wide range of involved competences: engineers, architects, material experts, conservators, restorers, art historians, archaeologists, lab technicians, ...)
- Historical information (sources: owner archives, conservatory department, literature, field research)
- Investigative field research (in-situ and laboratory testing): timber, masonry, steel, concrete, foundation soil / Material and geometric characterisation of the structure
- Structural Analysis / Numerical modelling  
Identification of potential vulnerabilities -> understanding of structure behaviour
- Intervention Design





When it comes to heritage building structural interventions, a thorough

**assessment is everything.**

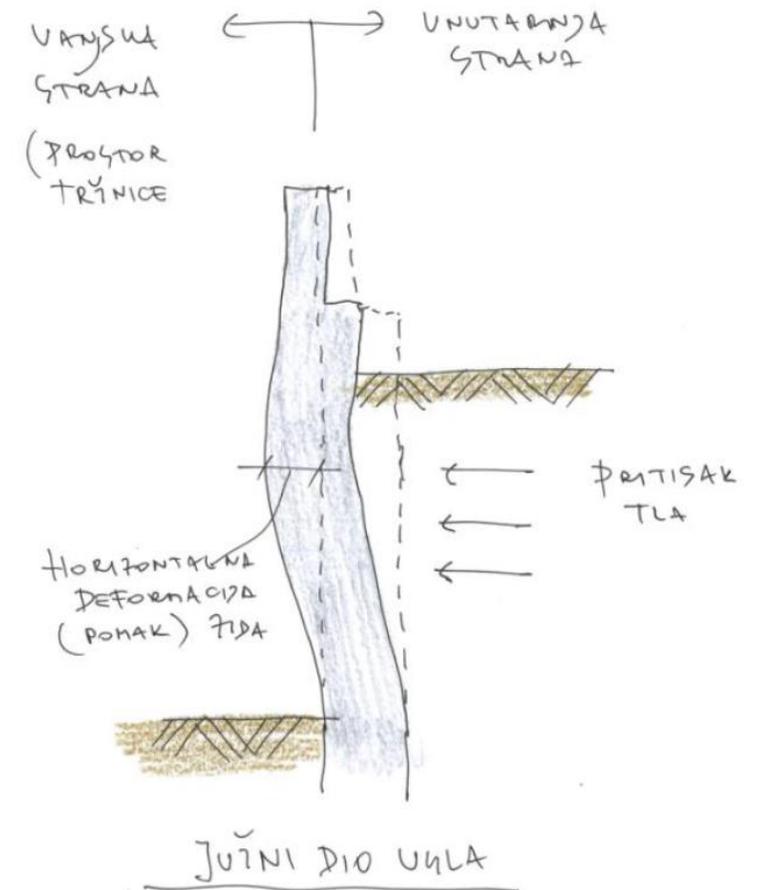
**... the retrofitting measures just follow.**

# Steps in the retrofitting process



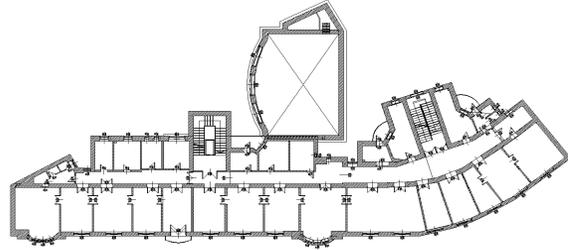
1. Earthquake or another disaster
2. Rapid assessment
3. Urgent measures
4. Assessment with investigative works
5. Retrofitting project / design
6. Construction / Execution works and supervision
7. Monitoring and maintenance ( facility management)

# 14th Century City Wall

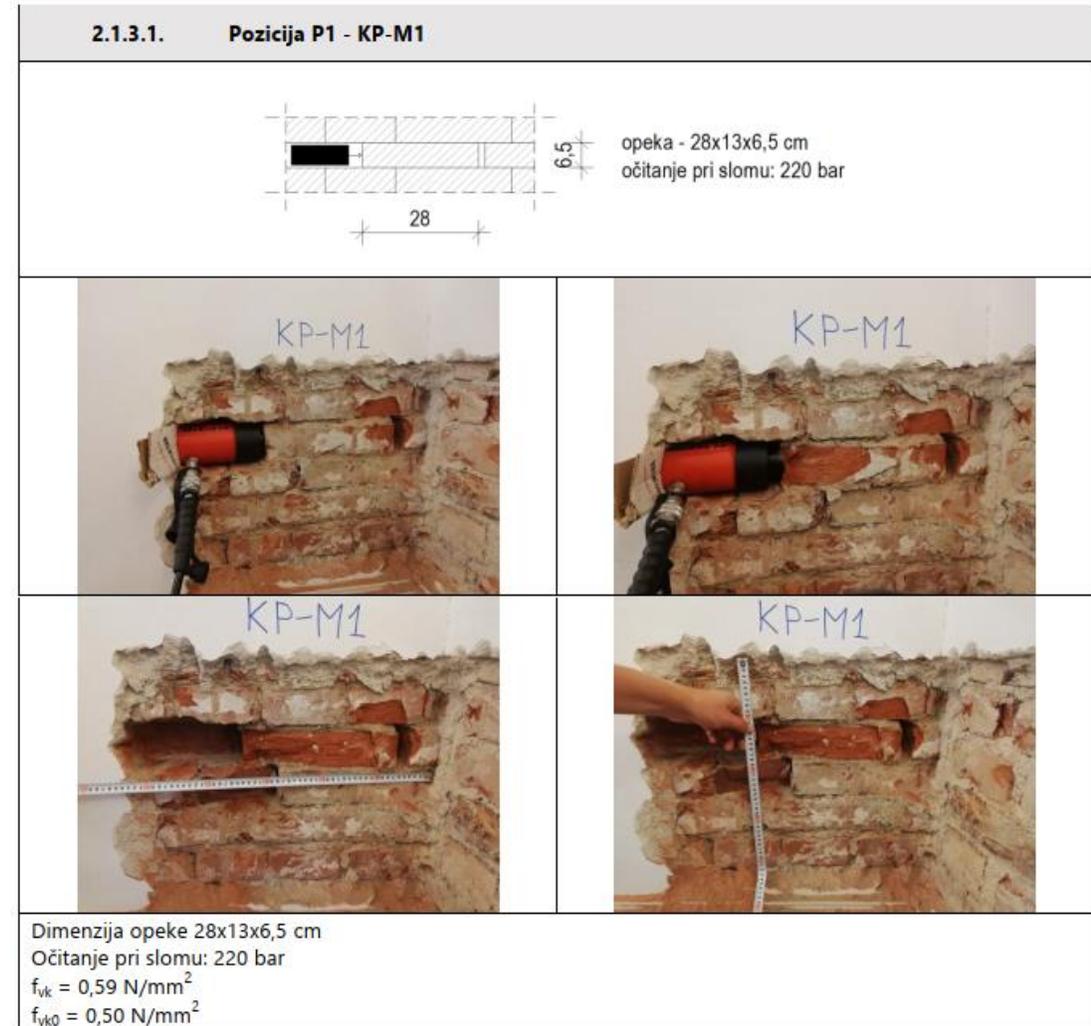
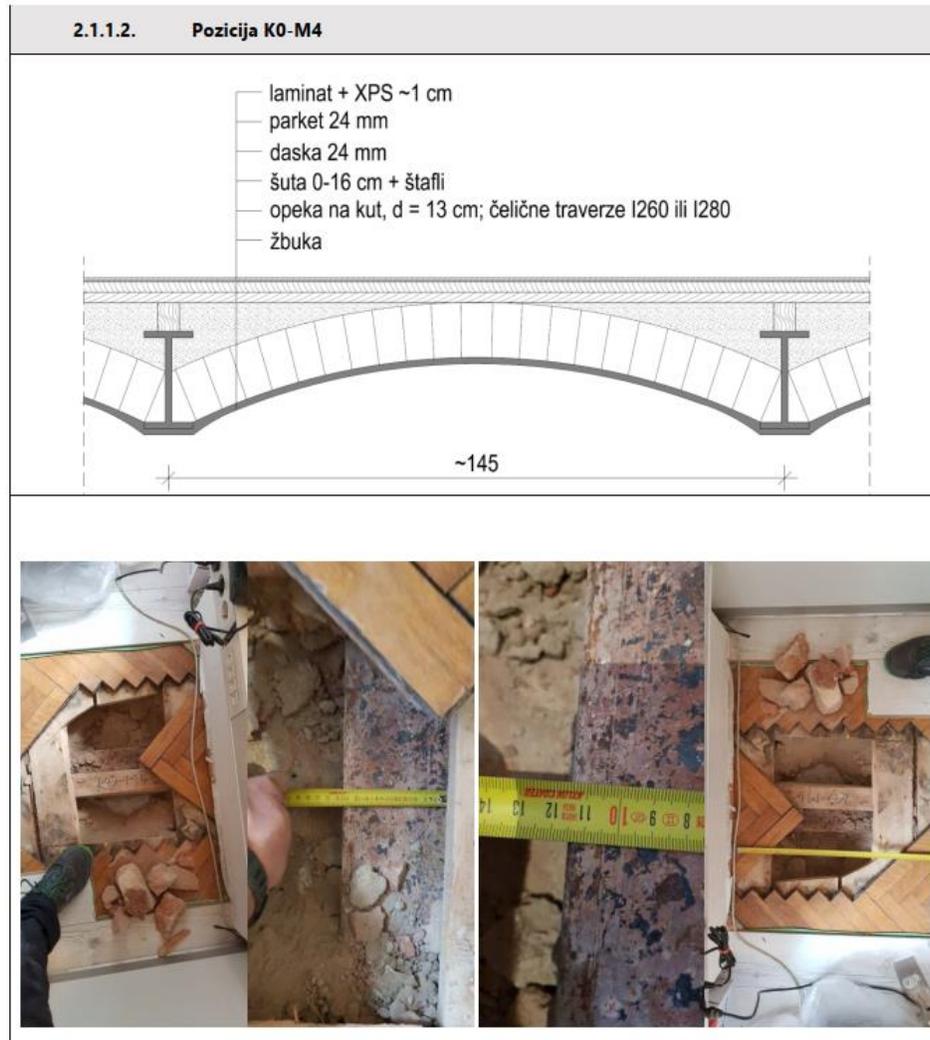




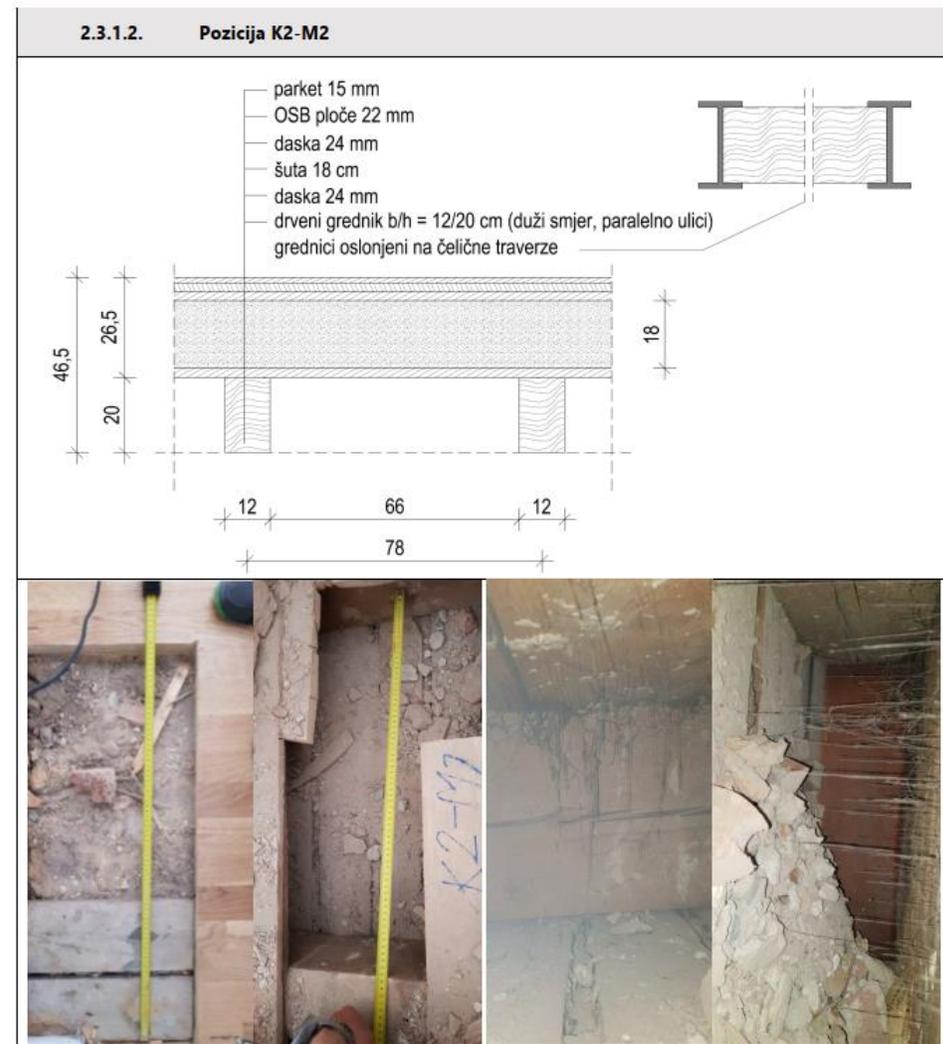
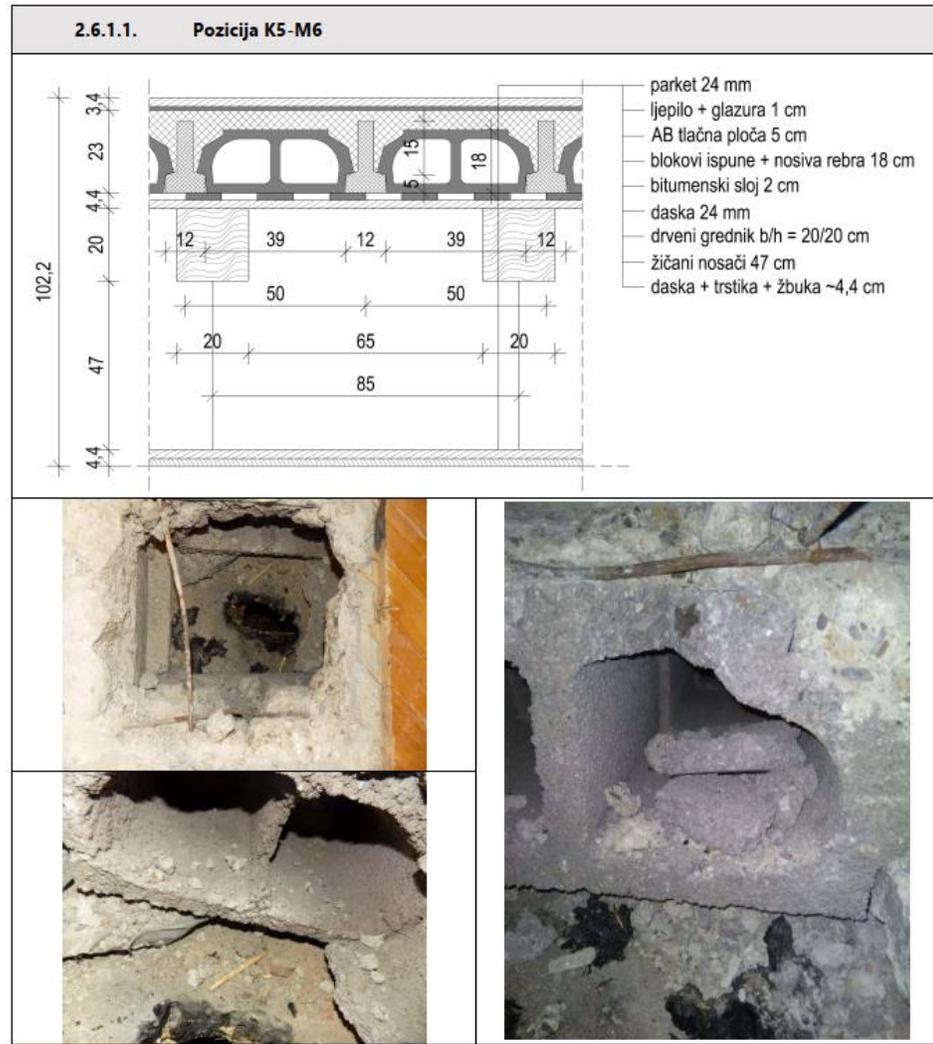
# 19th Century Public Building



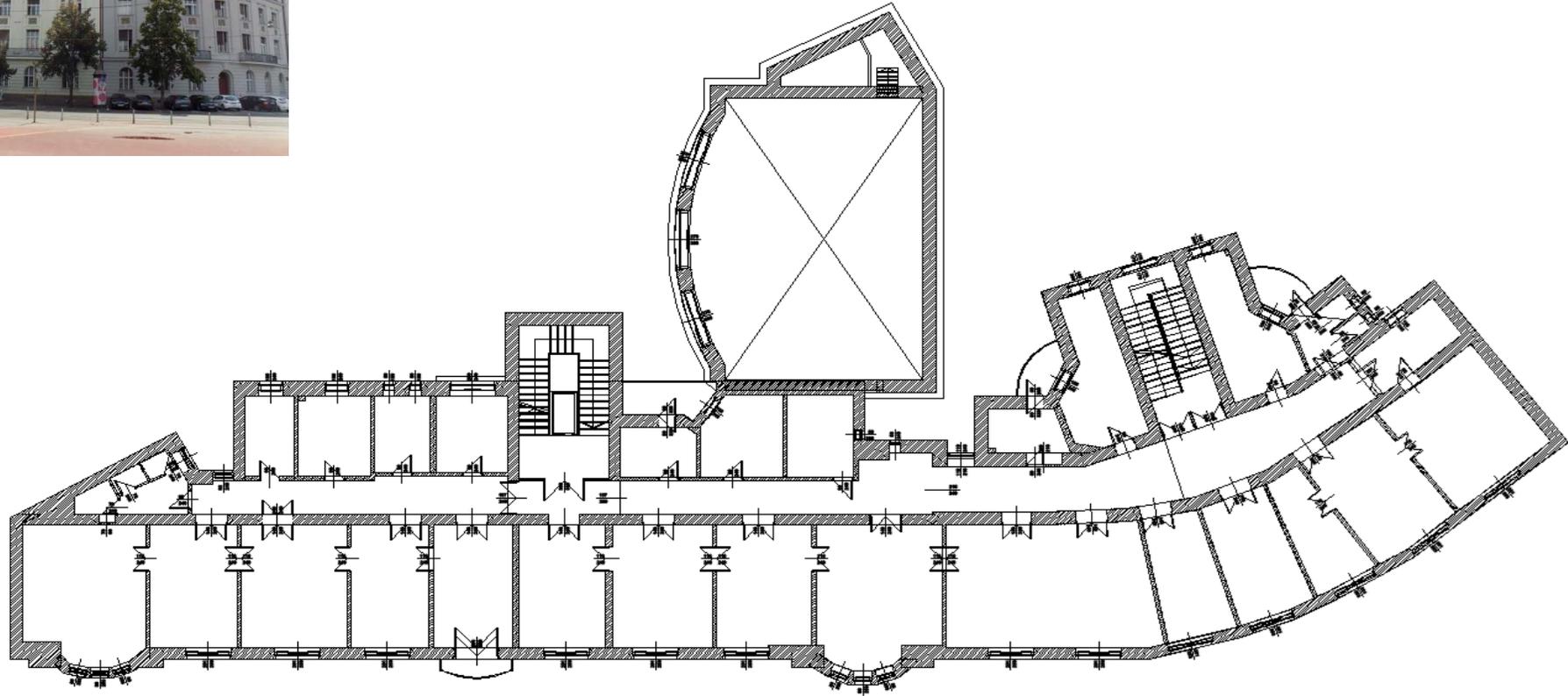
# 19th Century Public Building



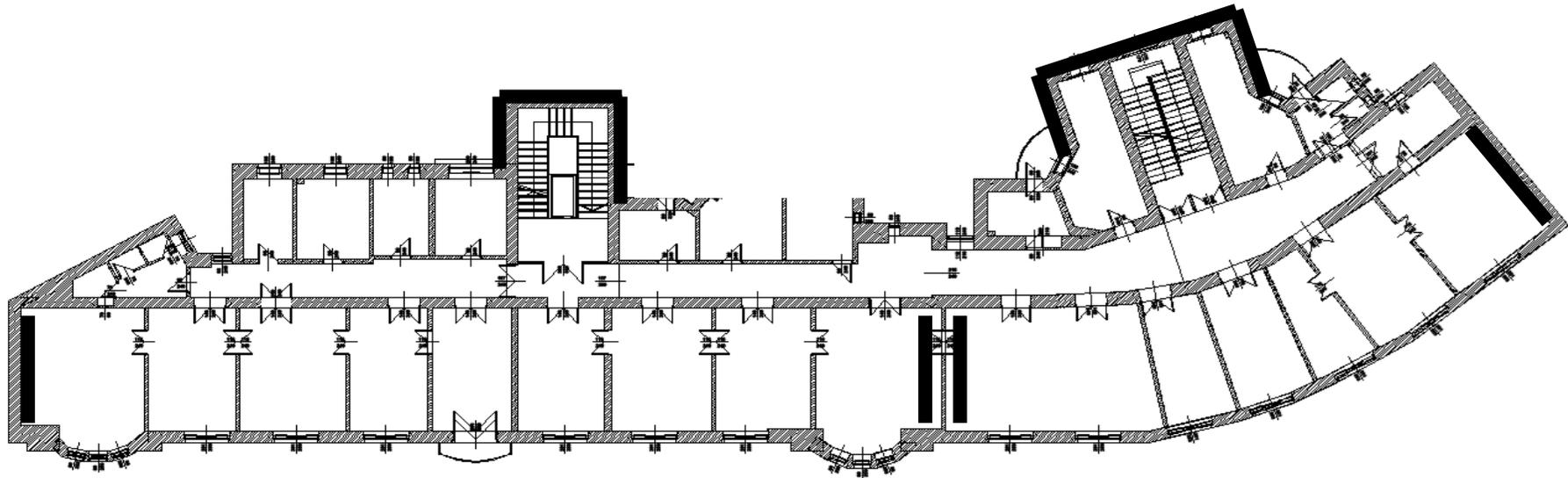
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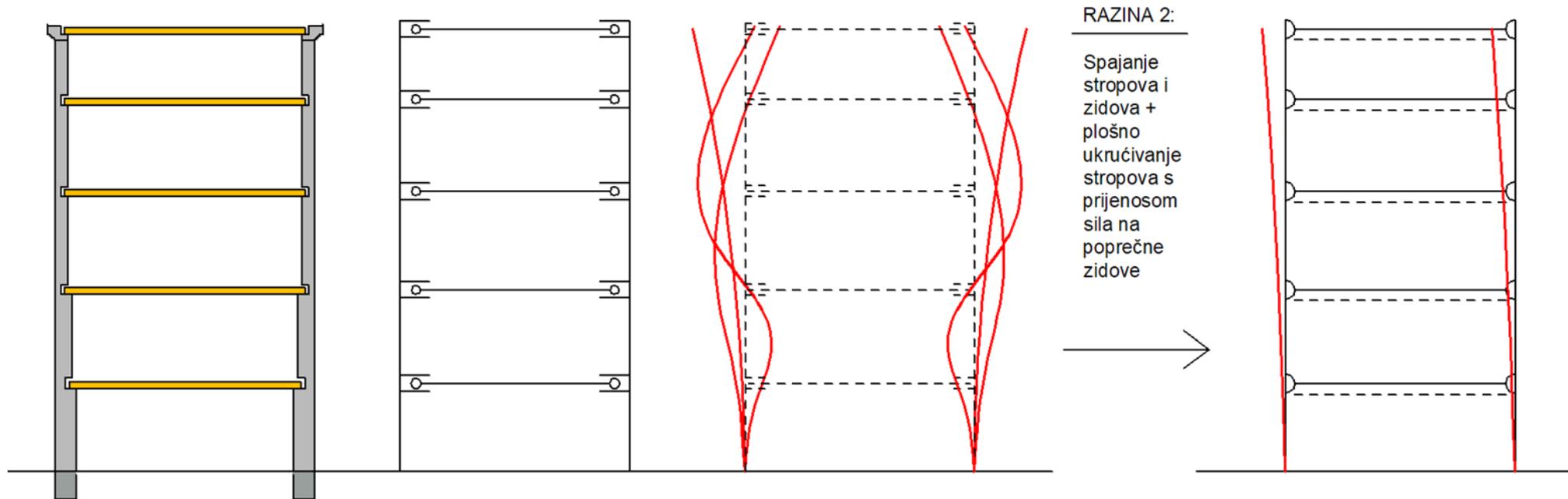
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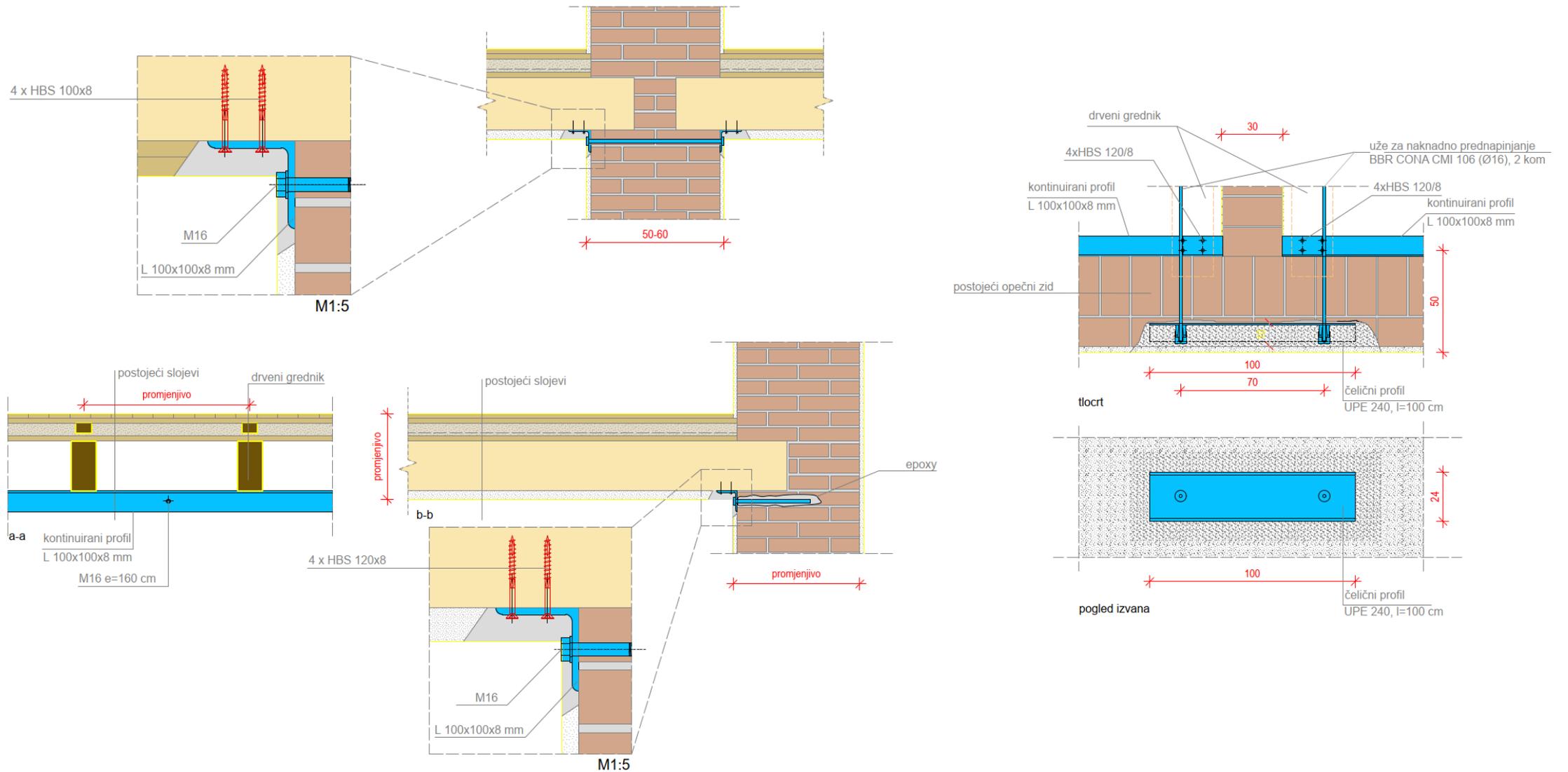


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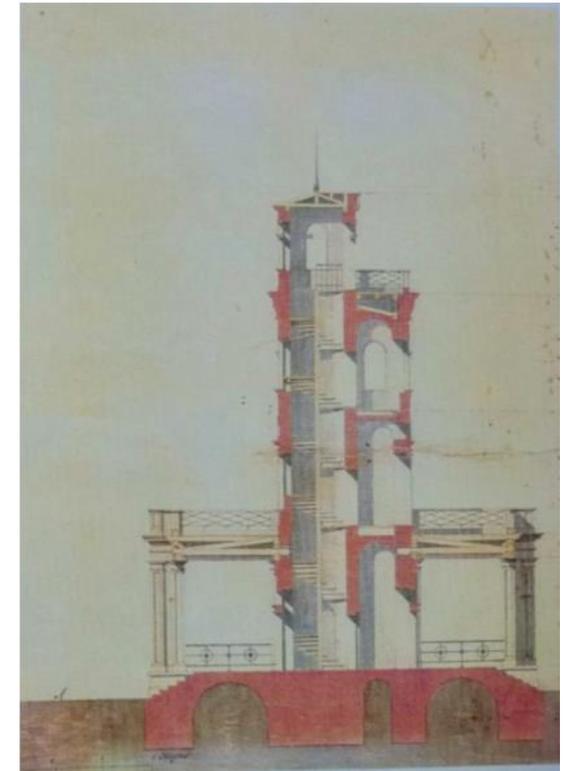
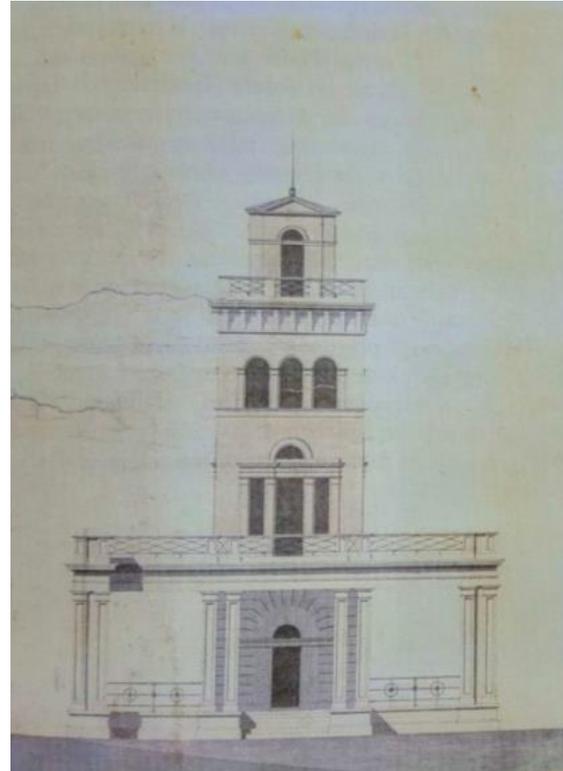
# 19th Century Public Building



# 19th Century Public Building



# 19th Century Public Building



# Early 20th Century Viewpoint Tower



STUDIO ARHING

Javna ustanova – Maksimir, Maksimirski perivoj 1, Zagreb  
Vidikovac, k.o. 3047 / 3048, k.o. Maksimir  
ELABORAT OČIGNE POSTOJEĆEG STANJA  
GRAĐEVINSKE KONSTRUKCIJE  
Zagreb, prosinac 2020.

Oznaka projekta STR  
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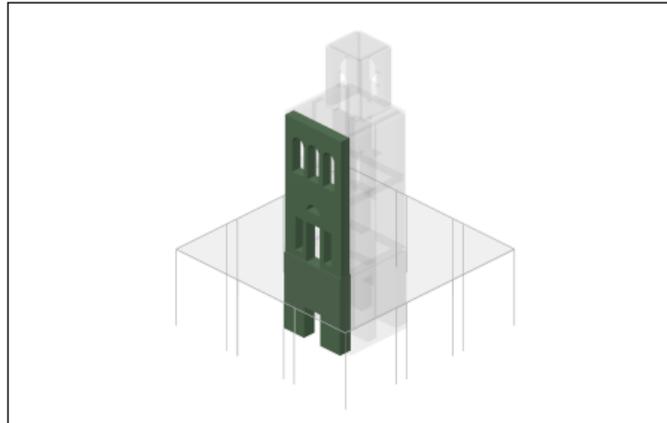
Broj slike	Oznaka oštećenja	Fotografija oštećenja
Slika 61.	052	
Opis oštećenja		Pukotine u zoni (elijepih) vrata na jugoistočnom pročelju. Vidljive su tri pukotine: pukotina uz tjemenu polukružnog luka koje se proteže preko profilacija na pročelju, horizontalna pukotina na lijevoj strani vrata na visini od otprilike 95 cm od poda prizemlja, te kosa pukotina na desnoj strani vrata.
Slika 62.	053	
Opis oštećenja		Horizontalne i vertikalne pukotine u dnu jugoistočnog zida tornja. Uz pukotine su uočena i odlamanja i odvajanja sokla zida. Pukotine se protežu od ruba zida od središnjih ulaznih vrata.

Broj slike	Oznaka oštećenja	Fotografija oštećenja
Slika 75.	066	
Opis oštećenja		Horizontalna pukotina koja se pruža u nastavku pukotine oznake 065, na sjeverozapadnom zidu tornja na 2.katu, u prostoru stubišta, te se nastavlja u prostor kuhinje.
Slika 76.	067	
Opis oštećenja		Kosa i vertikalna pukotina na unutrašnjem zidu tornja na strani stubišta koje vodi s 2. na 3. kat.

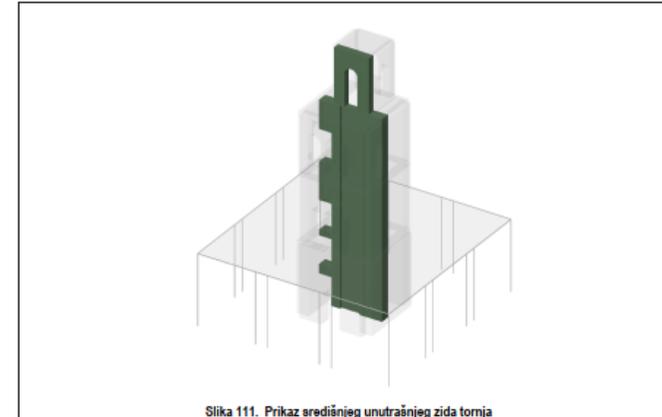
Broj slike	Oznaka oštećenja	Fotografija oštećenja
Slika 85.	076	
Opis oštećenja		Horizontalne i vertikalne pukotine u dnu jugozapadnog zida tornja, s obje strane vrata i prozora. Uočene su i kose i horizontalne pukotine u razinama nadvoja, te dvije pukotine blizu tjemena polukružnog luka malog prozora iznad vrata, koje se protežu do profilacija na vrhu etaže.
Slika 86.	077	
Opis oštećenja		Poprečna pukotina u parapetu prozora na stubištu između 2. i 3. kata, na sjeveroistočnom zidu tornja.

Broj slike	Oznaka oštećenja	Fotografija oštećenja
Slika 63.	054	
Opis oštećenja		Pukotine u vrhu zapadnog ugaonog stupa. Pukotine se pojavljuju s dvije unutrašnje strane stupa, kreću od vrha udubljene pruge na stupu, dijagonalno preko pilastera prema ležaju glavnih greda.
Slika 64.	055	
Opis oštećenja		Pukotina na unutrašnjoj strani jugozapadnog zida tornja koje se proteže od gornjeg ugla ulaznih vrata do stropa.

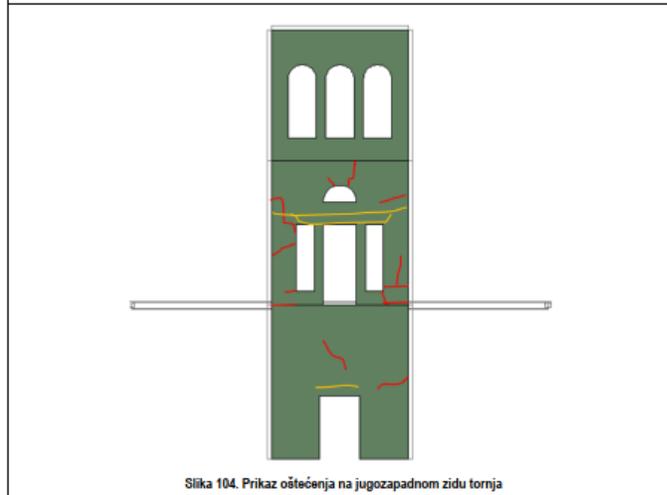
# Early 20th Century Viewpoint Tower



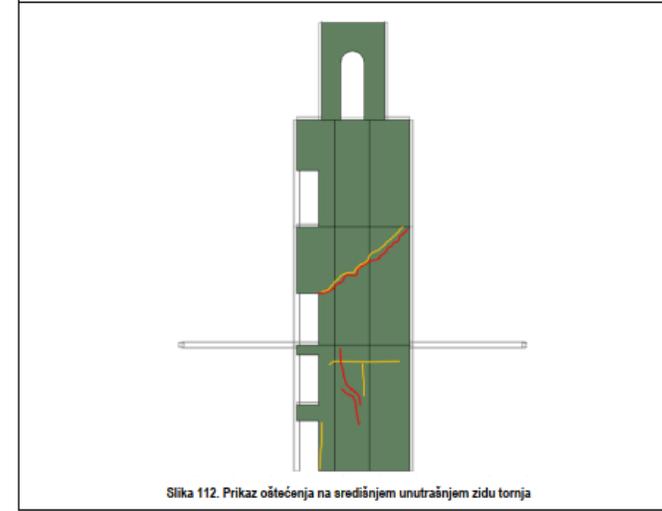
Slika 103. Prikaz jugozapadnog zida tornja



Slika 111. Prikaz središnjeg unutrašnjeg zida tornja

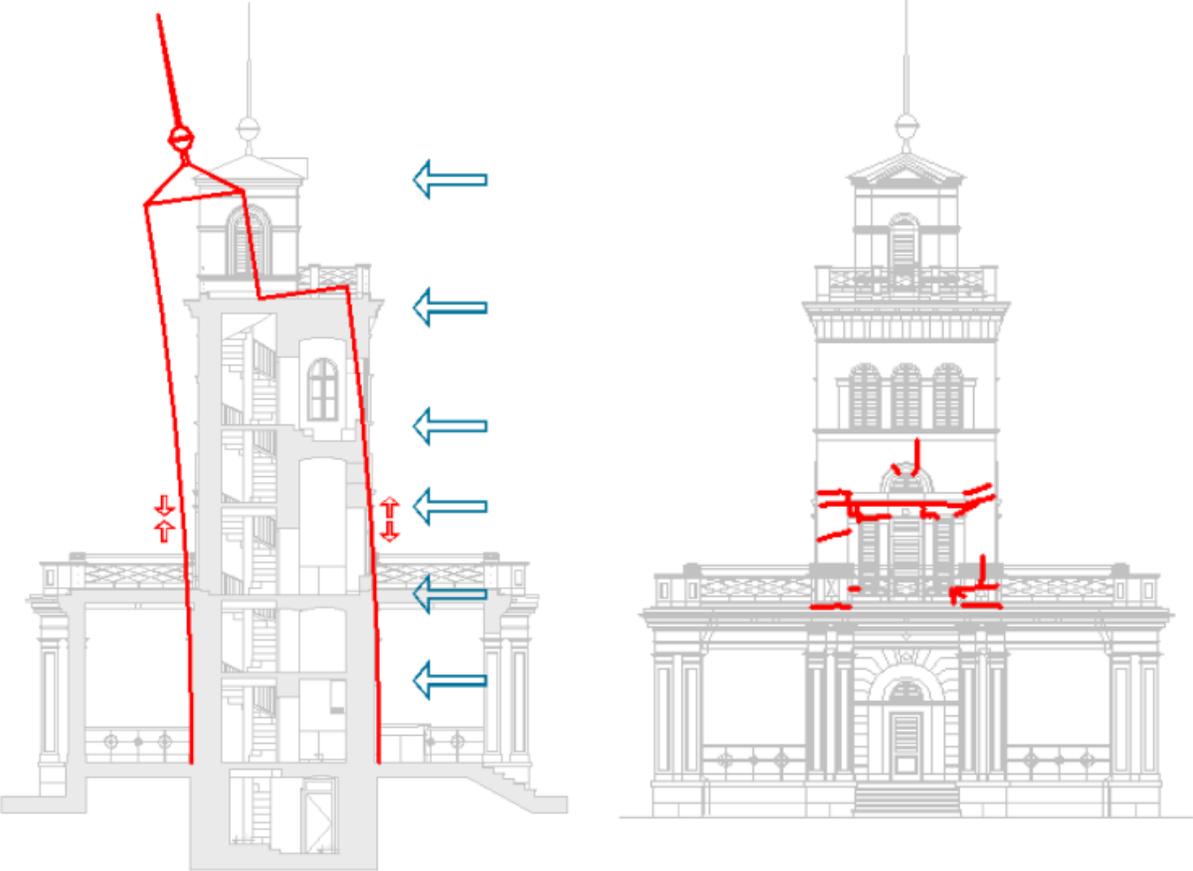


Slika 104. Prikaz oštećenja na jugozapadnom zidu tornja

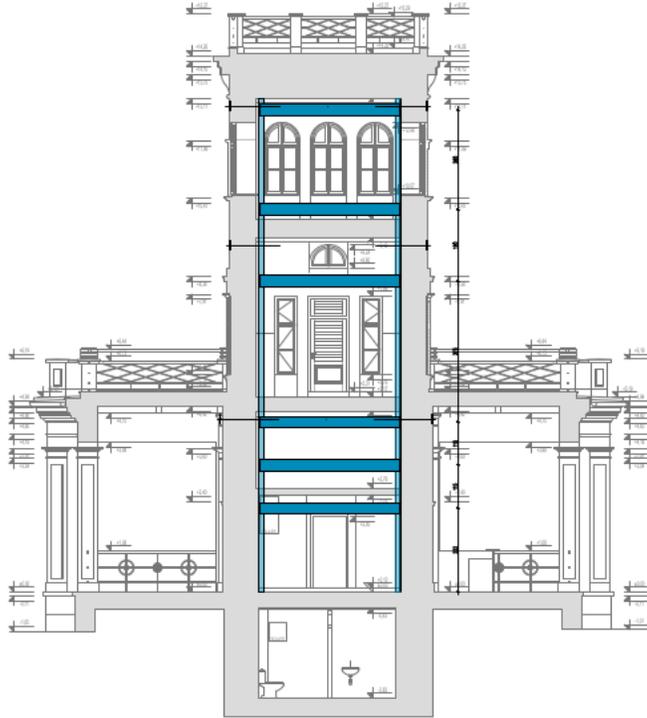


Slika 112. Prikaz oštećenja na središnjem unutrašnjem zidu tornja

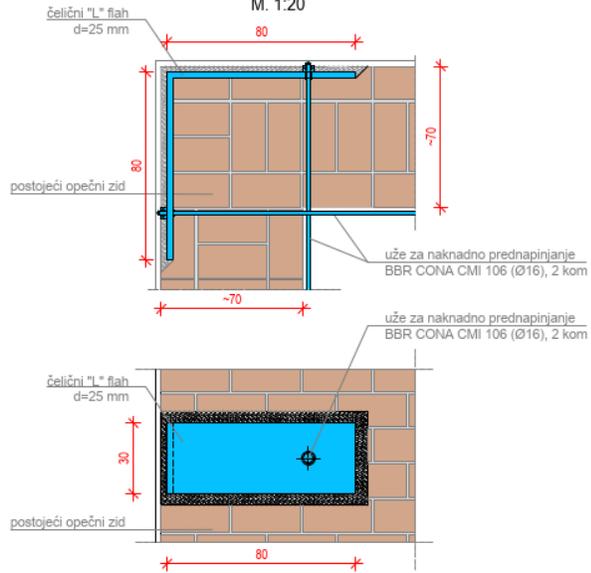
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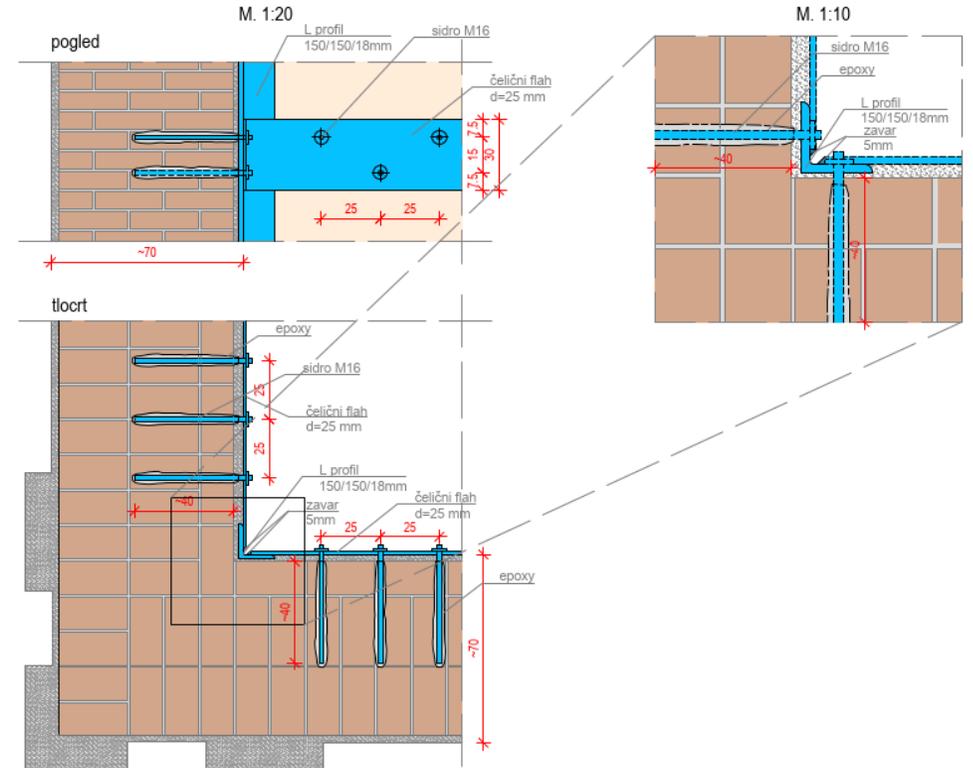
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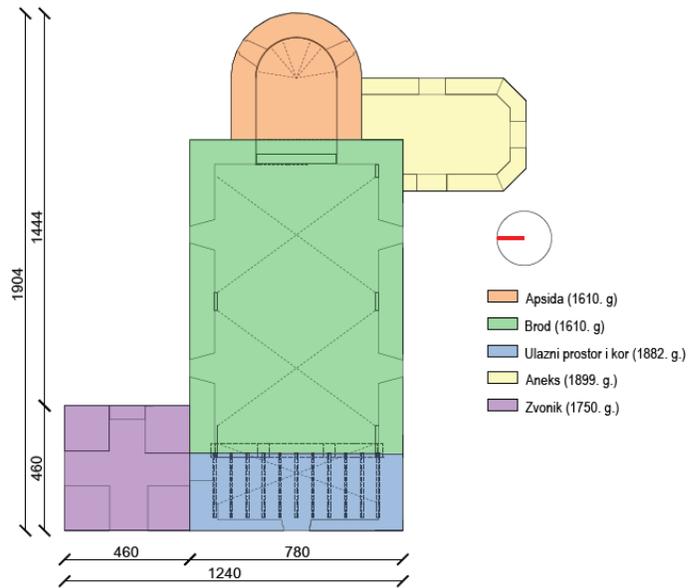
DETALJ SIDRENJA UŽETA ZA NAKNADNO PREDNAPINJANJE  
M. 1:20



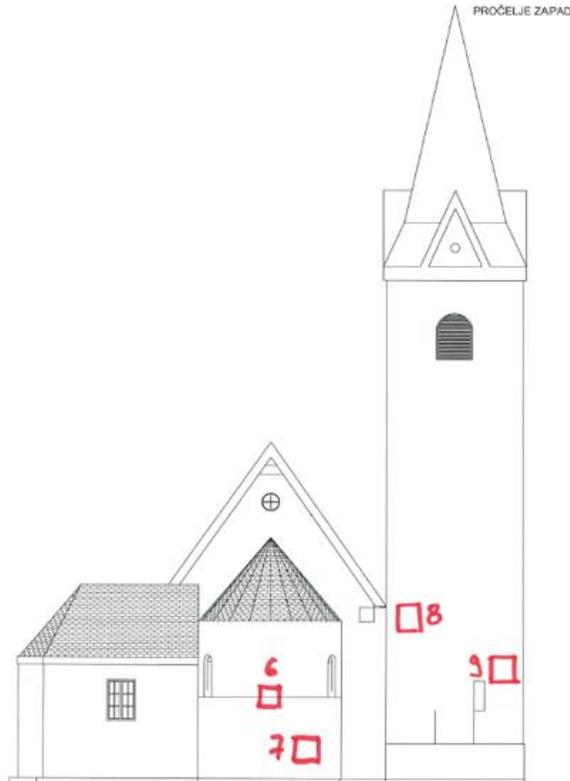
DETALJ SIDRENJA ČELIČNIH FLAHOVA I L PROFILA  
M. 1:10



# 18th Century Church Tower

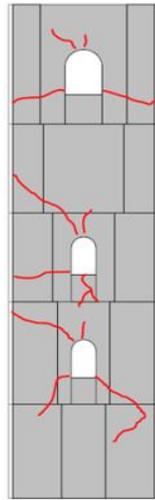
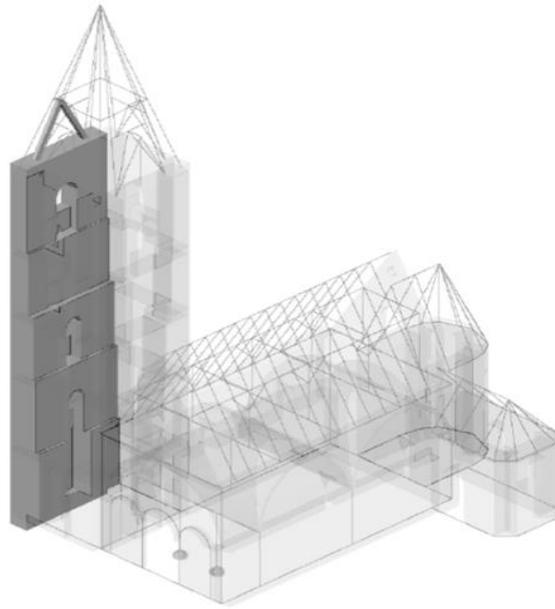


# 18th Century Church Tower

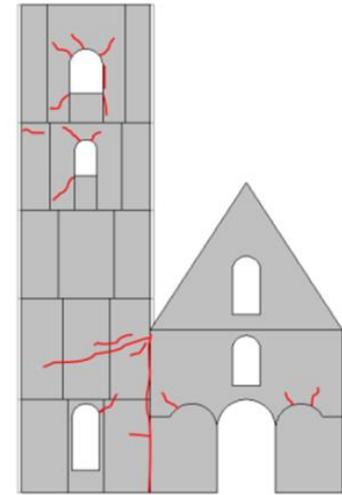
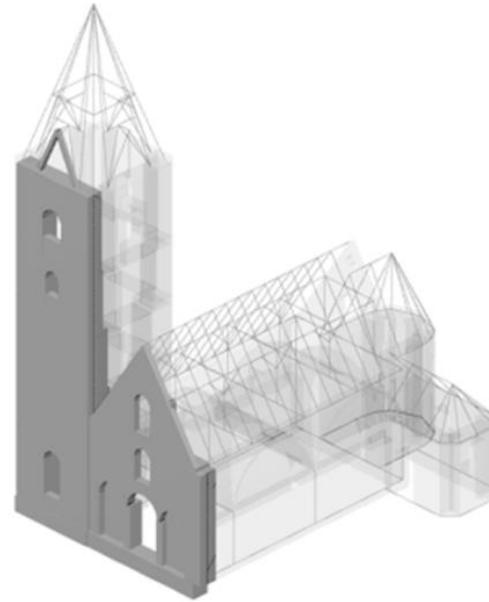


				FOTOGRAFIE							
				PRESJEK							
Pogled		Presjek									
<p>Nepravilan kameni zid Zide se sastoji od kamenih elemenata različitih dimenzija. Elementi manjih dimenzija koriste se za popunjavanje praznina između većih elemenata. Uzorak spajanja, vertikalni i horizontalni većim dijelom nepravilan.</p>											
<p>Kamen – prirodni kamen Mort – vapnени mort</p>											
<p>Dimenzije elemenata s=20 - 30 cm h=20 - 35 cm t=6 - 22 cm</p>											
WC	MM	SS	VJ	SM	HJ	SD		Vertikalno	Van ravnine	U ravnini	
NF	NF	NF	NF	PF	NF	PF	Kategorija	C	C	C	
								M			
								MCI	1,4	1,05	1,05
								Meh karakteristike (min-max)	f <sub>m</sub> (MPa) 1,2-2,15	E (MPa) 600-800	f <sub>1</sub> (MPa) 0,034-0,036
ANALIZA											

# 18th Century Church Tower



— Pukotina u zidu



— Pukotina u zidu

# 18th Century Church Tower



$f_{kd} = 0,05 \text{ N/mm}^2$       $\sigma_d = N_{Ed}/A$       $V_{Rd} = t L_c f_{td}$       $f_{td} = f_{yk}/\gamma_M$       $\gamma_M = 1,5$       $KL = 2$   
 $f_{tk} = 0,08 \text{ N/mm}^2$       $\tau_{Rd} = (f_{td}/1,5)(1 + \sigma_d/f_{td})^{0,5}$       $V_{RHd} = C_r A_m \tau_{Rd}$       $f_{td} = f_{yk}/\gamma_M$       $C_r = 0,9$       $CF = 1,2$

$R_z = \min(V_{Rd}, V_{RHd}) / V_{Ed}$

zid	L <sub>w</sub> [cm]	t [cm]	A [cm <sup>2</sup> ]	V <sub>Ed</sub> [kN]	N <sub>Ed</sub> [kN]	M <sub>Ed</sub> [kNm]	σ <sub>d</sub> [N/mm <sup>2</sup> ]	0,4σ <sub>d</sub>	f <sub>yk</sub> [N/mm <sup>2</sup> ]	τ <sub>Rd</sub> [N/mm <sup>2</sup> ]	L <sub>c</sub> [cm]	V <sub>Rd</sub> [kN]	V <sub>Ed</sub> /V <sub>Rd</sub>	V <sub>RHd</sub> [kN]	V <sub>Ed</sub> /V <sub>RHd</sub>	ΔV <sub>Ed</sub> [kN]
X1	290	39	11310	210,6	162,3	168,5	0,144	0,057	0,107	0,061	124	28,7	7,33	62,0	3,40	181,8
X2	290	39	11310	199,0	185,9	151,3	0,164	0,066	0,116	0,064	191	47,9	4,16	65,4	3,04	151,1
X3	240	90	21600	215,5	265,1	146,2	0,123	0,049	0,099	0,057	195	96,4	2,24	111,7	1,93	119,1
X4	240	90	21600	224,1	274,7	124,2	0,127	0,051	0,101	0,058	224	113,2	1,98	113,2	1,98	110,9
X5	150	90	13500	105,9	229,7	77,7	0,170	0,068	0,118	0,065	124	73,0	1,45	79,1	1,34	32,9
X6	150	90	13500	138,6	212,6	66,3	0,157	0,063	0,113	0,063	131	74,2	1,87	76,7	1,81	64,3
X7	210	60	12600	163,4	167,1	45,1	0,133	0,053	0,103	0,059	210	72,1	2,27	67,1	2,44	96,4
X8	200	60	12000	147,7	139,9	57,6	0,117	0,047	0,097	0,056	177	56,9	2,60	60,9	2,42	90,8
X9	70	60	4200	73,5	75,2	19,7	0,072	0,072	0,122	0,066	26	10,7	6,86	25,1	2,92	62,7
X10	200	60	12000	194,4	129,2	115,0	0,108	0,043	0,093	0,055	33	10,3	18,90	59,2	3,28	184,1

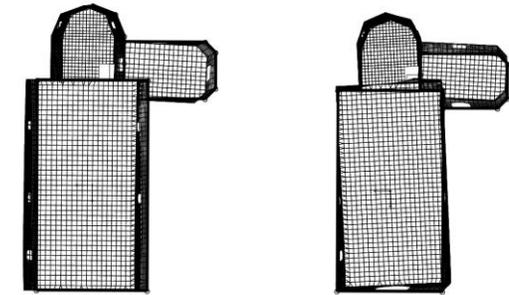
R <sub>z</sub>	R <sub>z</sub> × A
0,137	1543,85
0,241	2721,11
0,447	9659,68
0,505	10908,94
0,689	9304,50
0,536	7231,59
0,410	5170,57
0,385	4621,02
0,146	162,15
0,053	634,91

$\Sigma(R_z \times A) / \Sigma A = 0,392 \quad 39,2\% \quad 19,6\%$

zid	L <sub>w</sub> [cm]	t [cm]	A [cm <sup>2</sup> ]	V <sub>Ed</sub> [kN]	N <sub>Ed</sub> [kN]	M <sub>Ed</sub> [kNm]	σ <sub>d</sub> [N/mm <sup>2</sup> ]	0,4σ <sub>d</sub>	f <sub>yk</sub> [N/mm <sup>2</sup> ]	τ <sub>Rd</sub> [N/mm <sup>2</sup> ]	L <sub>c</sub> [cm]	V <sub>Rd</sub> [kN]	V <sub>Ed</sub> /V <sub>Rd</sub>	V <sub>RHd</sub> [kN]	V <sub>Ed</sub> /V <sub>RHd</sub>	ΔV <sub>Ed</sub> [kN]
Y1	185	90	16650	107,7	365,4	61,9	0,219	0,088	0,138	0,072	185	127,5	0,85	108,2	1,00	
Y2	268	90	24120	142,1	487,4	13,5	0,202	0,081	0,131	0,070	268	175,3	0,81	151,5	0,94	
Y3	400	90	36000	151,9	632,2	44,0	0,176	0,070	0,120	0,066	400	240,5	0,63	213,6	0,71	
Y4	300	90	27000	106,5	454,7	29,6	0,168	0,067	0,117	0,065	300	176,0	0,60	157,6	0,68	
Y5	380	90	34200	153,0	658,7	106,0	0,193	0,077	0,127	0,068	380	241,4	0,63	210,6	0,73	
Y6	190	90	17100	179,6	394,5	64,7	0,231	0,092	0,142	0,074	190	135,2	1,33	113,5	1,58	66,1
Y7	130	90	11700	43,9	93,2	11,3	0,080	0,032	0,082	0,050	130	53,2	0,82	52,1	0,84	
Y8	115	60	6900	30,3	68,4	4,4	0,099	0,040	0,090	0,053	115	34,4	0,88	33,1	0,92	
Y9	80	60	4800	20,8	41,9	1,9	0,087	0,035	0,085	0,051	80	22,6	0,92	22,0	0,94	
Y10	80	60	4800	19,4	44,2	1,5	0,092	0,037	0,087	0,052	80	23,2	0,84	22,4	0,86	
Y11	115	60	6900	54,1	73,3	12,9	0,106	0,043	0,093	0,055	115	35,5	1,53	33,9	1,60	20,3
Y12	320	90	28800	207,4	428,9	124,8	0,149	0,060	0,110	0,062	320	175,3	1,18	160,2	1,29	47,2
Y13	430	90	38700	247,3	639,8	33,9	0,165	0,066	0,116	0,064	430	249,7	0,99	224,2	1,10	23,1
Y14	570	90	51300	293,1	877,5	109,6	0,171	0,068	0,118	0,065	570	337,5	0,87	301,2	0,97	

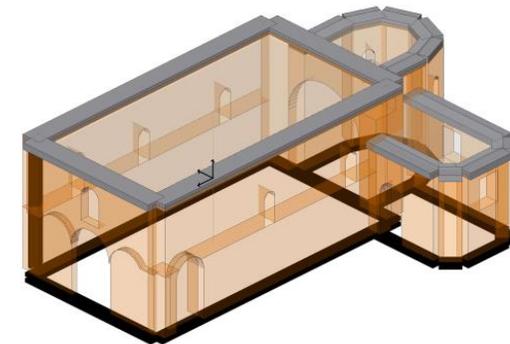
R <sub>z</sub>	R <sub>z</sub> × A
1,004	16720,12
1,066	25715,69
1,406	50611,37
1,480	39954,50
1,377	47076,78
0,632	10803,53
1,188	13904,47
1,093	7540,61
1,060	5089,16
1,157	5553,18
0,626	4318,42
0,772	22240,99
0,907	35091,66
1,028	52720,42

$\Sigma(R_z \times A) / \Sigma A = 1,092 \quad 109,2\% \quad 54,6\%$

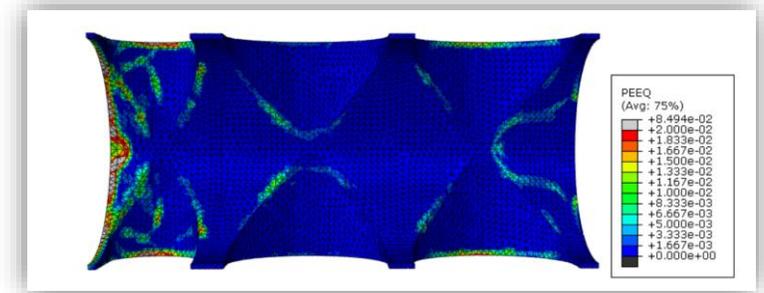
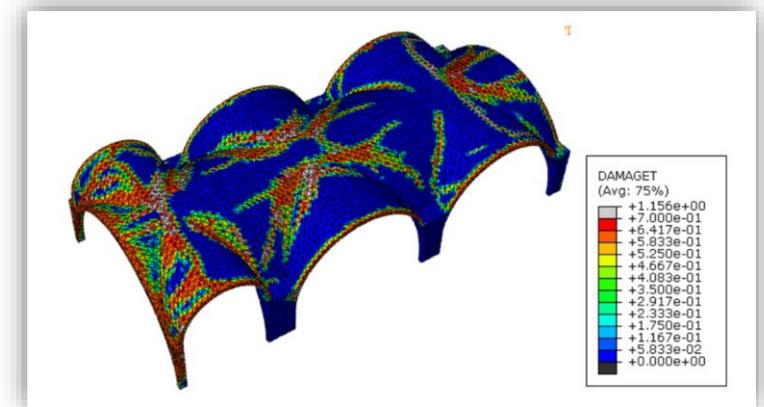
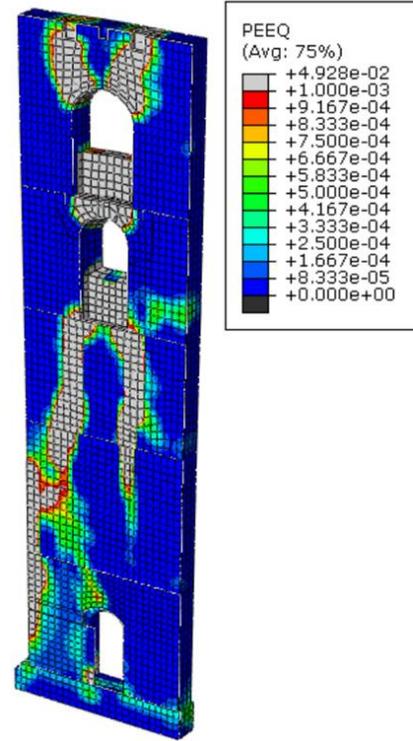
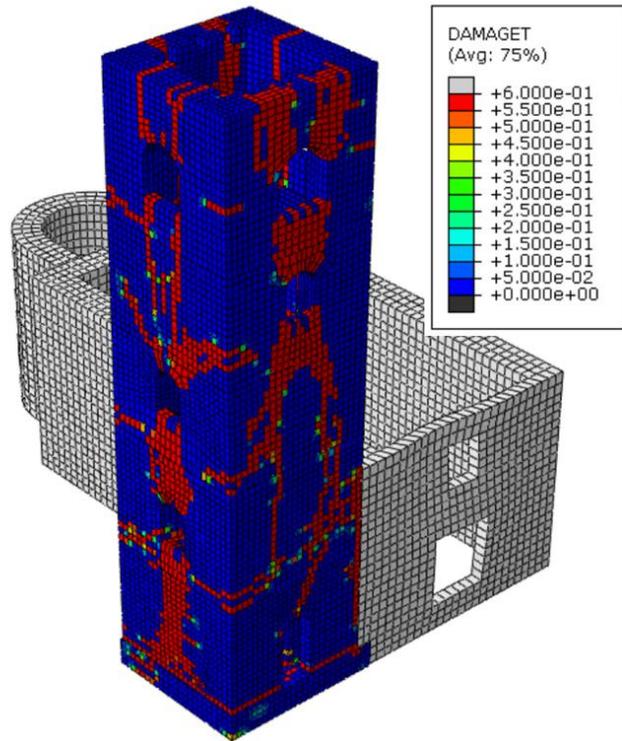


Izometrija  
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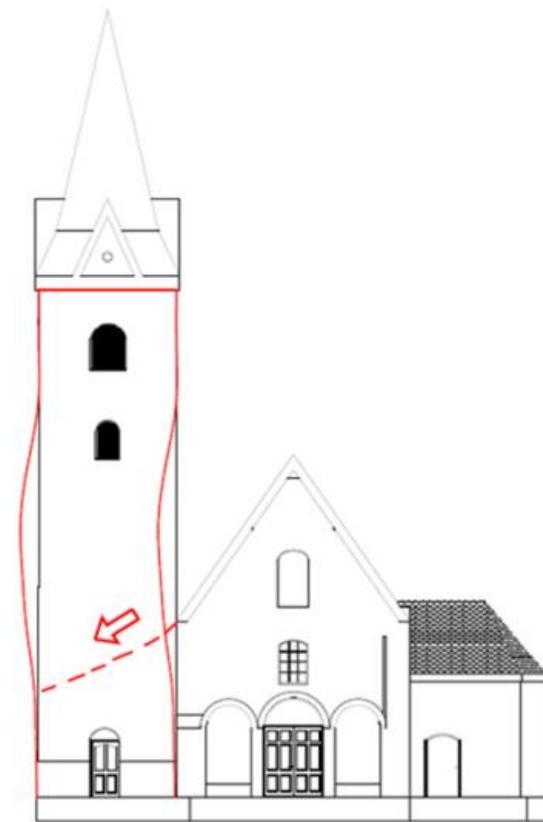
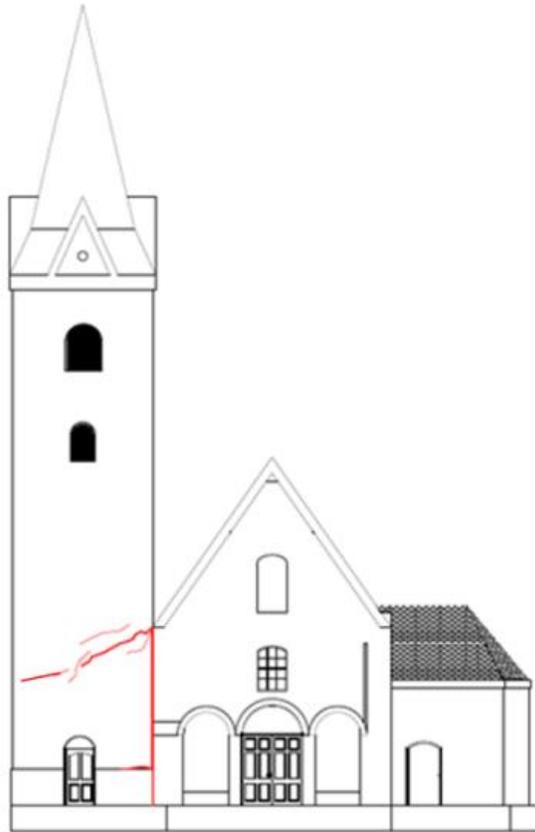
Izometrija  
Forma osciliranja: 2/5 [T=0.2700sec / f=3.70Hz]



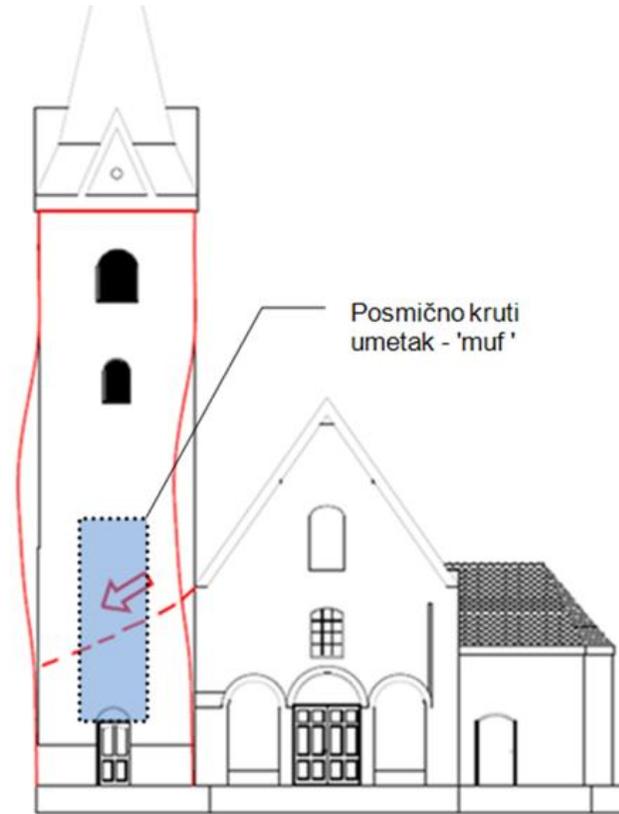
# 18th Century Church Tower



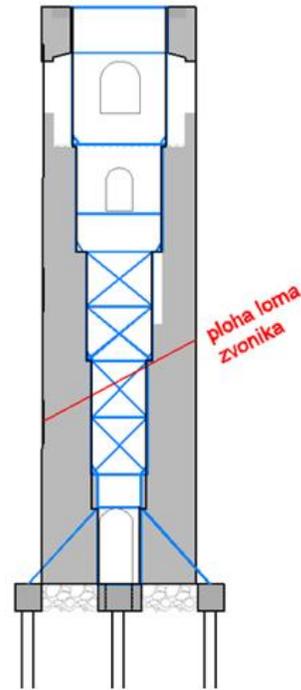
# 18th Century Church Tower



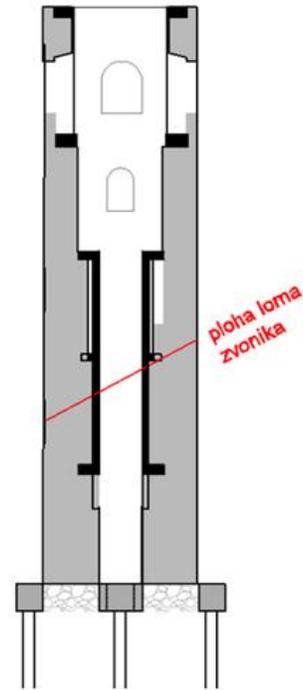
# 18th Century Church Tower



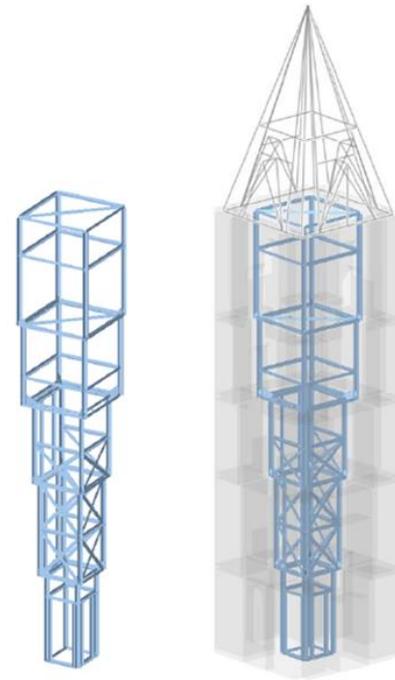
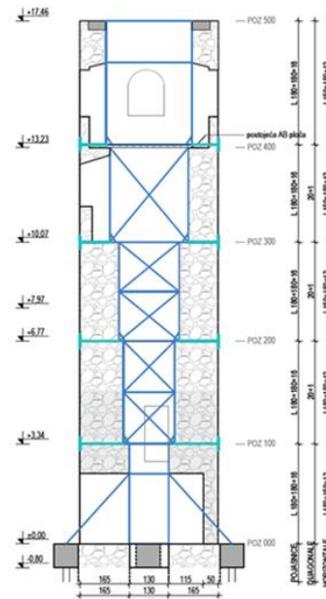
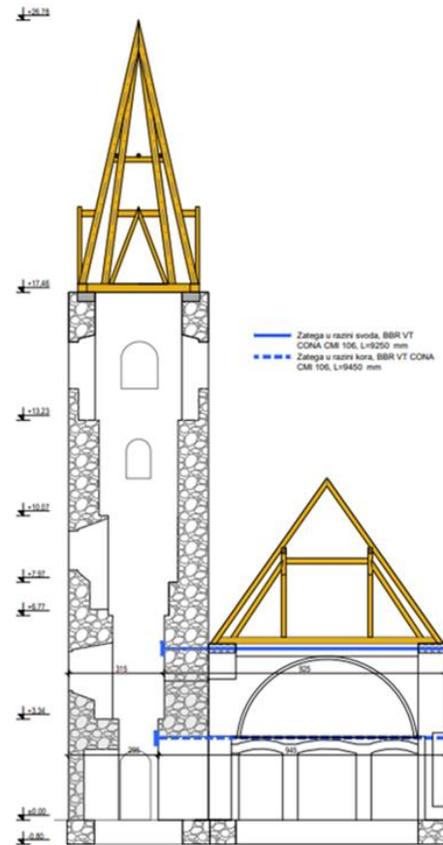
Varijanta 1.  
Interpolirana  
čelična rešetka



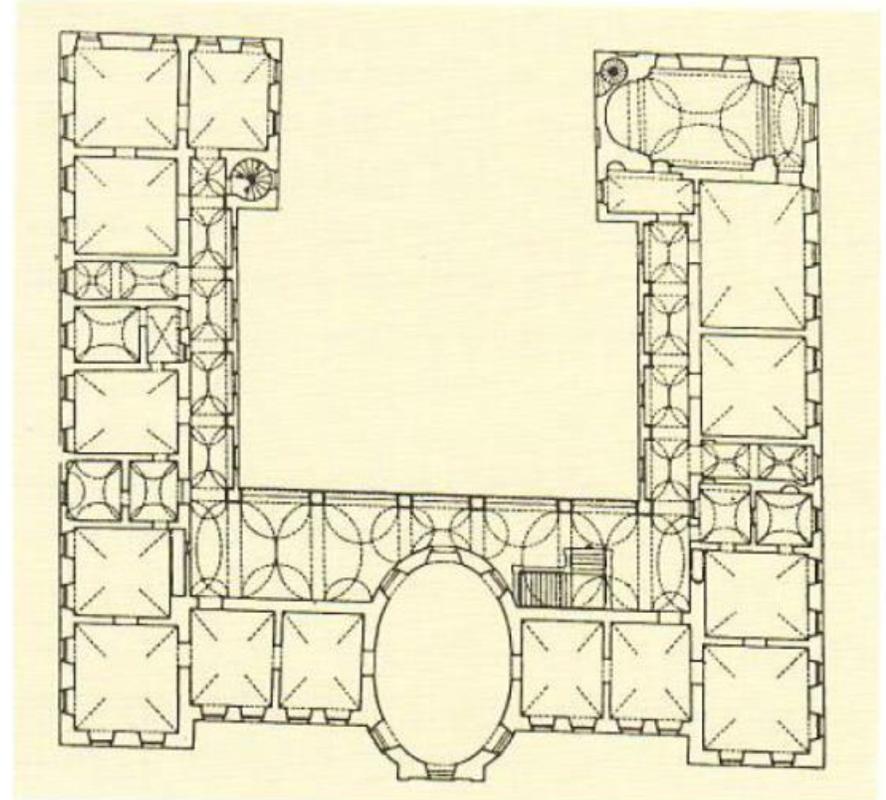
Varijanta 2.  
Interpolirani  
armiranobetonski  
zidovi i grede



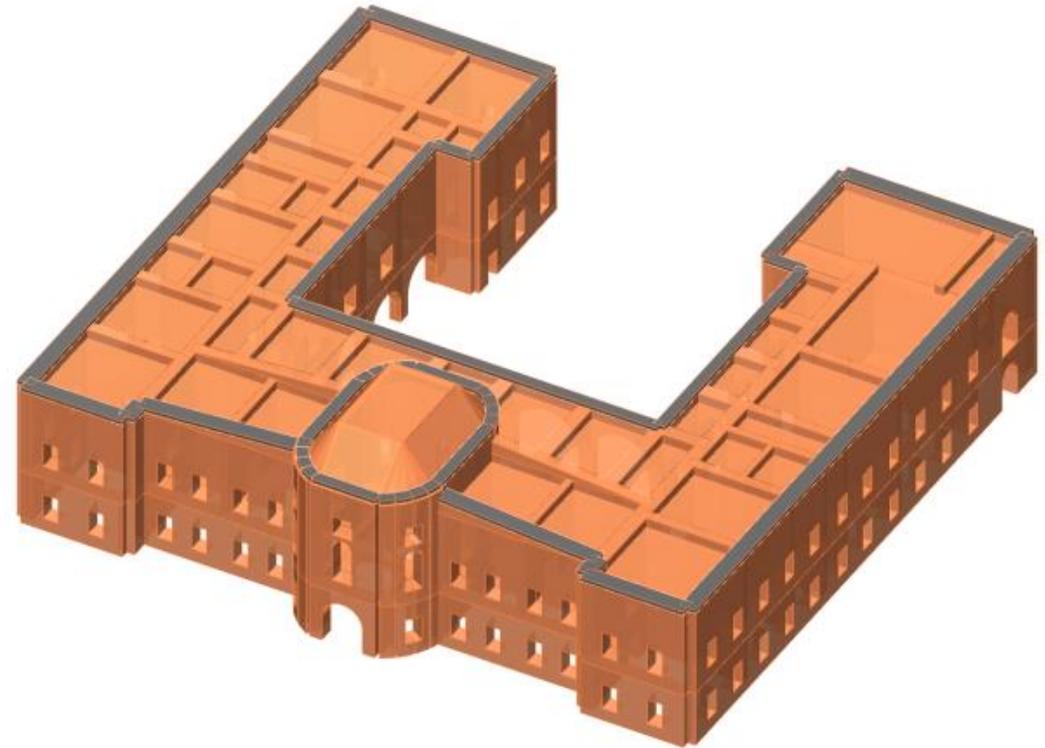
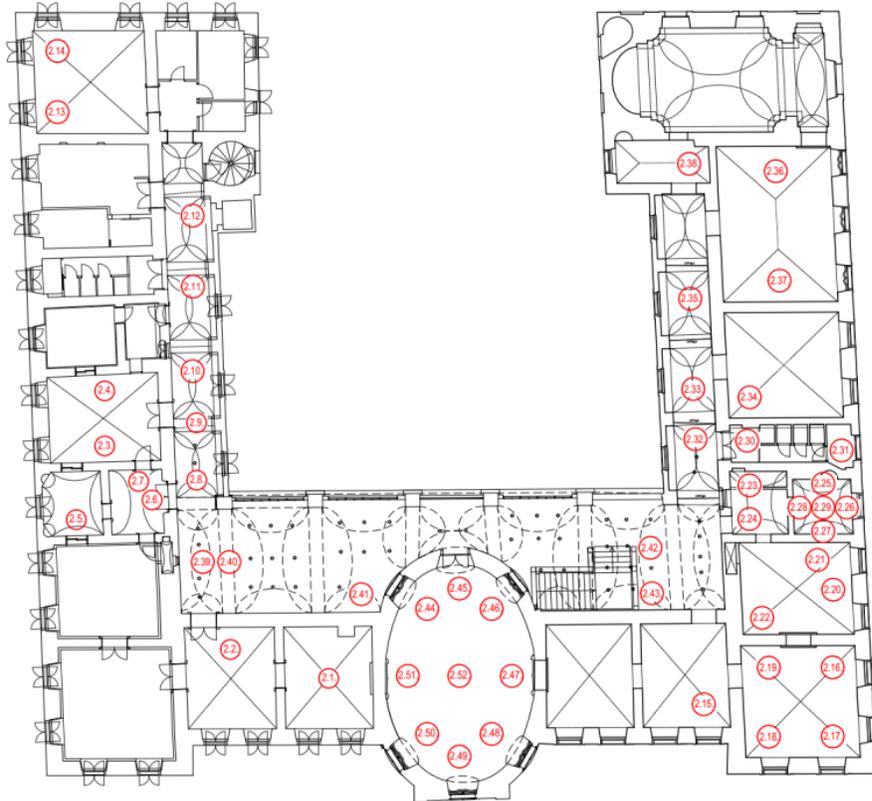
# 18th Century Church Tower



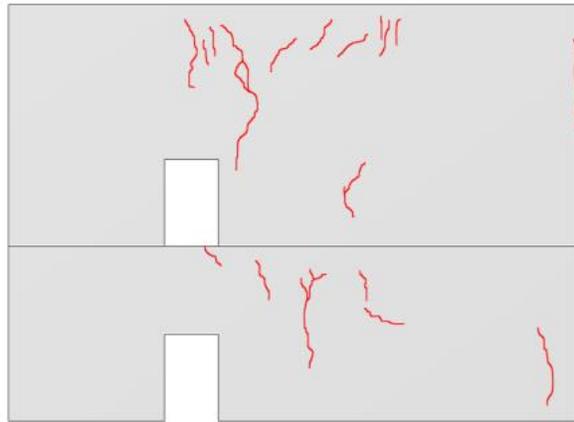
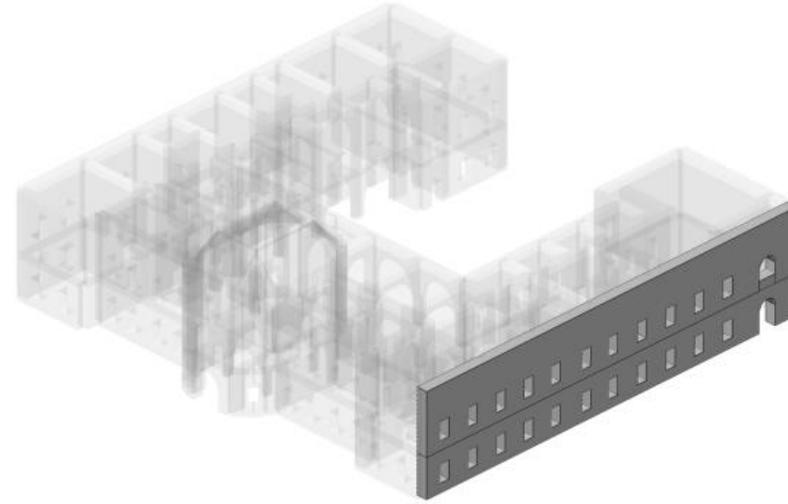
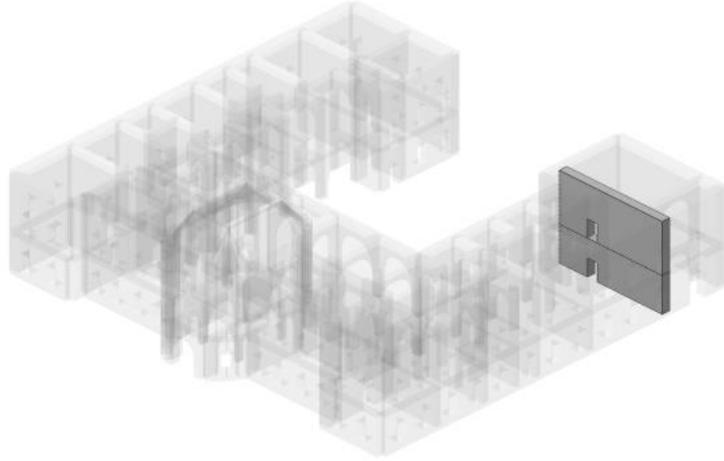
# 18th Century Castle



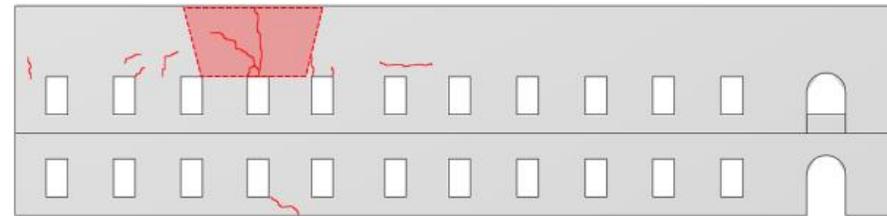
# 18th Century Castle



# 18th Century Castle

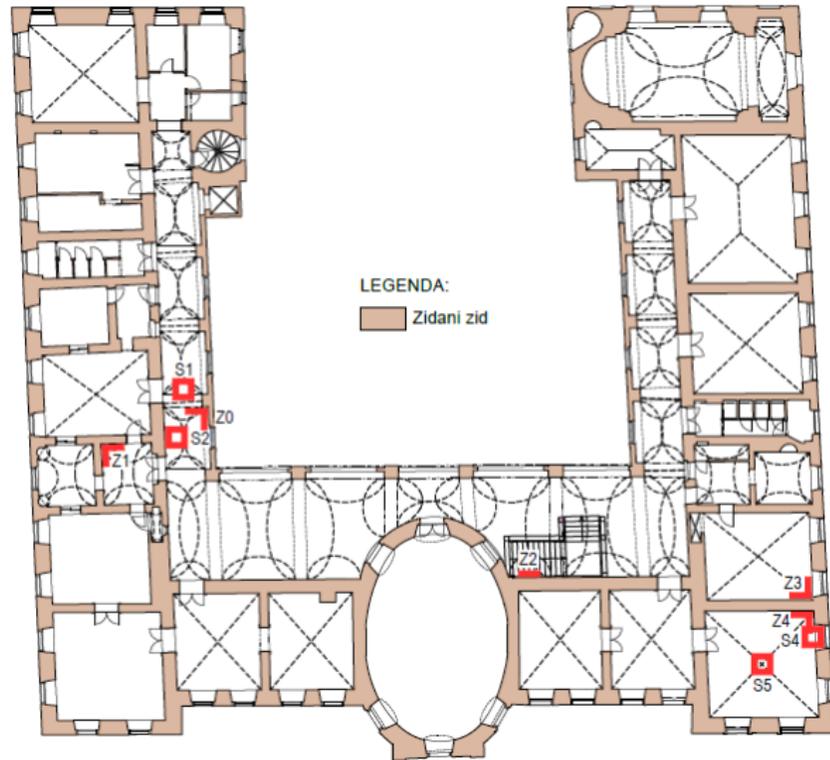


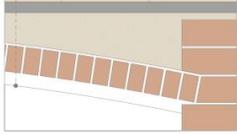
— Pukotina u zidu

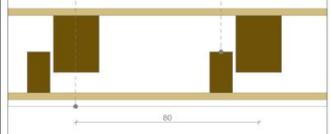


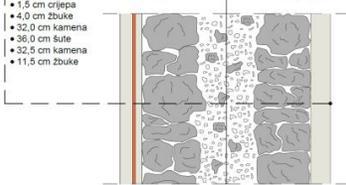
— Pukotina u zidu  
▭ Izbočavanje izvan ravnine

# 18th Century Castle



Broj istražne bušotine	Pozicija istražne bušotine	Prikaz
P1	Pod hodnika na katu.	 <p><b>P1</b> Detalj presjeka međukatne konstrukcije pozicija P1</p> <ul style="list-style-type: none"> <li>• 5,0 cm kamene ploče</li> <li>• 5,0 cm glazura</li> <li>• max 27,0 cm šuta</li> <li>• 12,0 cm opeka</li> <li>• 5,0 cm zbučke</li> </ul> 

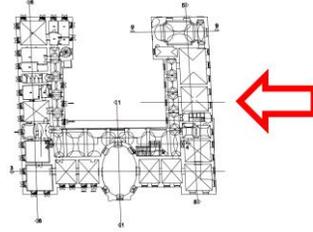
Broj istražne bušotine	Pozicija istražne bušotine	Prikaz
P2	Pod sobe na katu.	 <p><b>P2</b> Detalj presjeka međukatne konstrukcije pozicija P2</p> <ul style="list-style-type: none"> <li>• 3,0 cm daske</li> <li>• štit=20/25 cm grada</li> <li>• 3,0 cm daske</li> <li>• 3,0 cm zbučke</li> </ul> <p style="text-align: right;">štit=10/18 cm</p> <p style="text-align: center;">80</p> 

Broj istražne bušotine	Pozicija istražne bušotine	Prikaz
Z17	Zapadno pročelje – kod ulaza u podrum.	 <p style="text-align: center;">vanjska ploha ← → unutarnja ploha</p> <ul style="list-style-type: none"> <li>• 7,5 cm zbučke</li> <li>• 1,5 cm crijeva</li> <li>• 4,0 cm zbučke</li> <li>• 32,0 cm kamena</li> <li>• 36,0 cm šute</li> <li>• 32,5 cm kamena</li> <li>• 11,5 cm zbučke</li> </ul> 

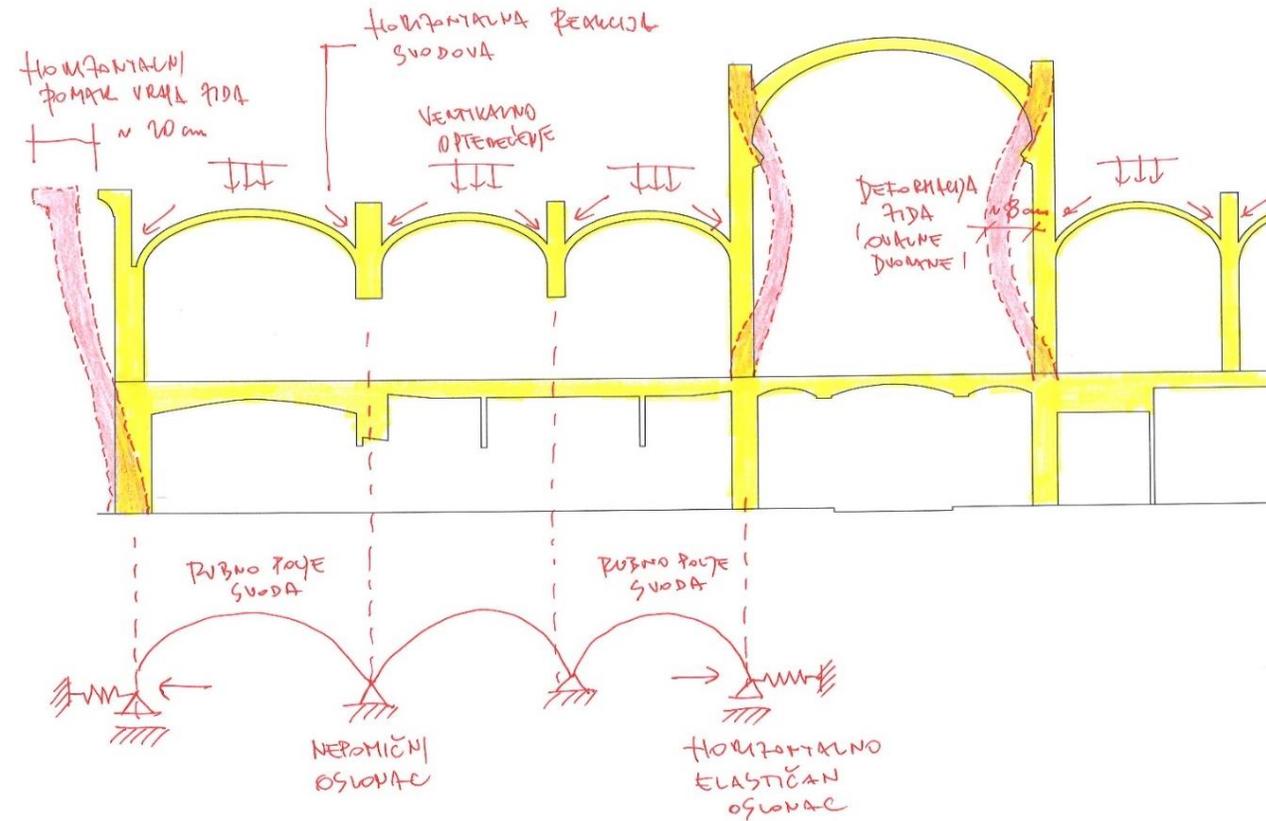
Broj istražne bušotine	Pozicija istražne bušotine	Prikaz
Z18	Sjeverno pročelje – istočno krilo – zid kapele.	 

Broj istražne bušotine	Pozicija istražne bušotine	Prikaz
Z19	Sjeverno pročelje – zapadno krilo	 

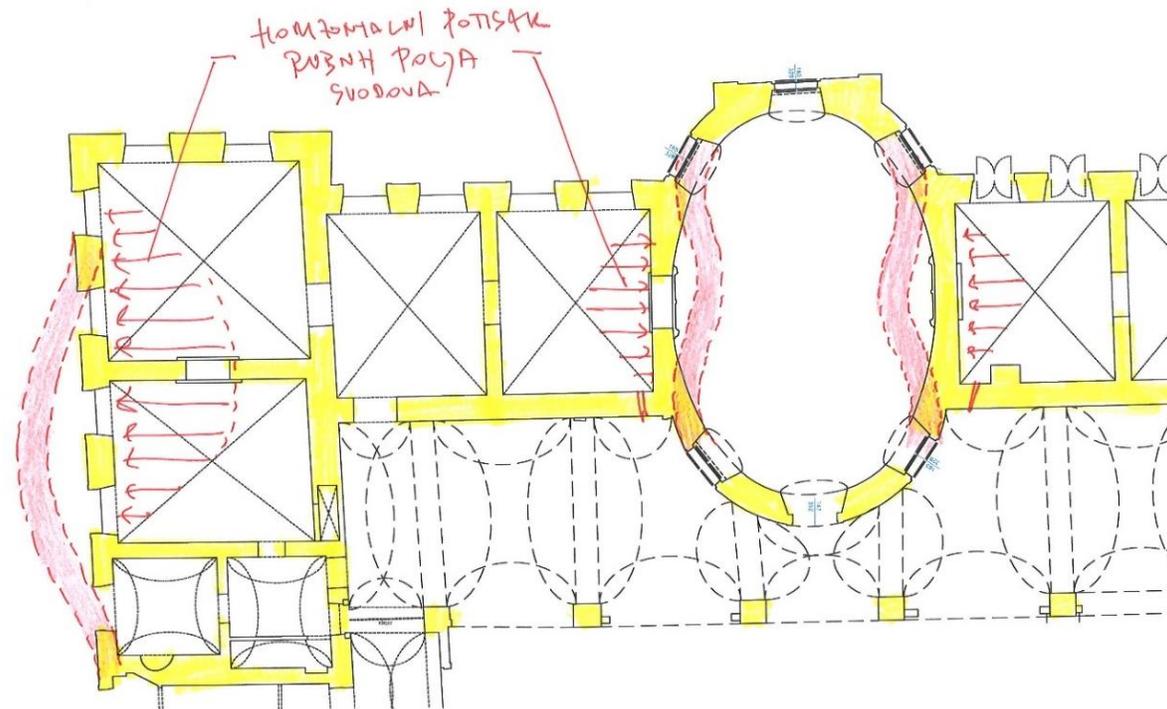
# 18th Century Castle



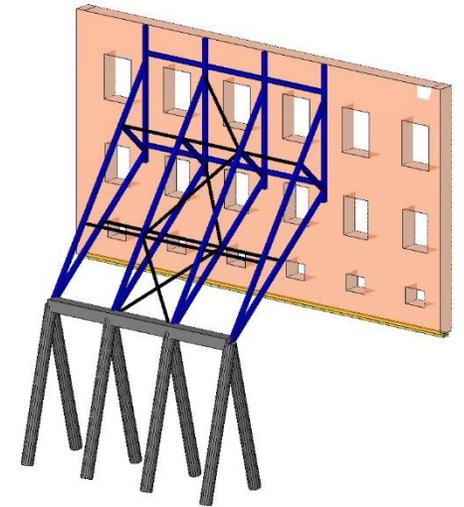
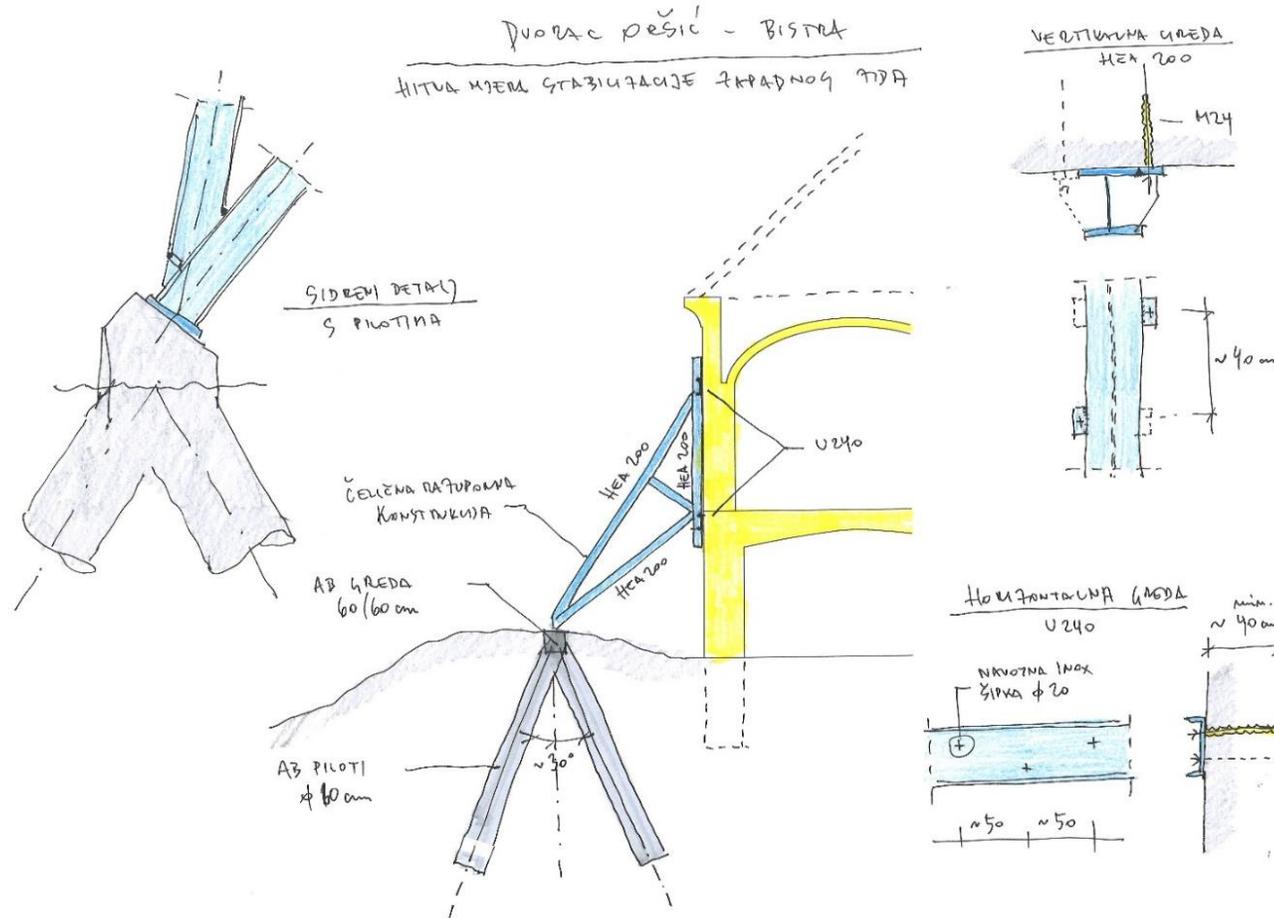
# 18th Century Castle



# 18th Century Castle



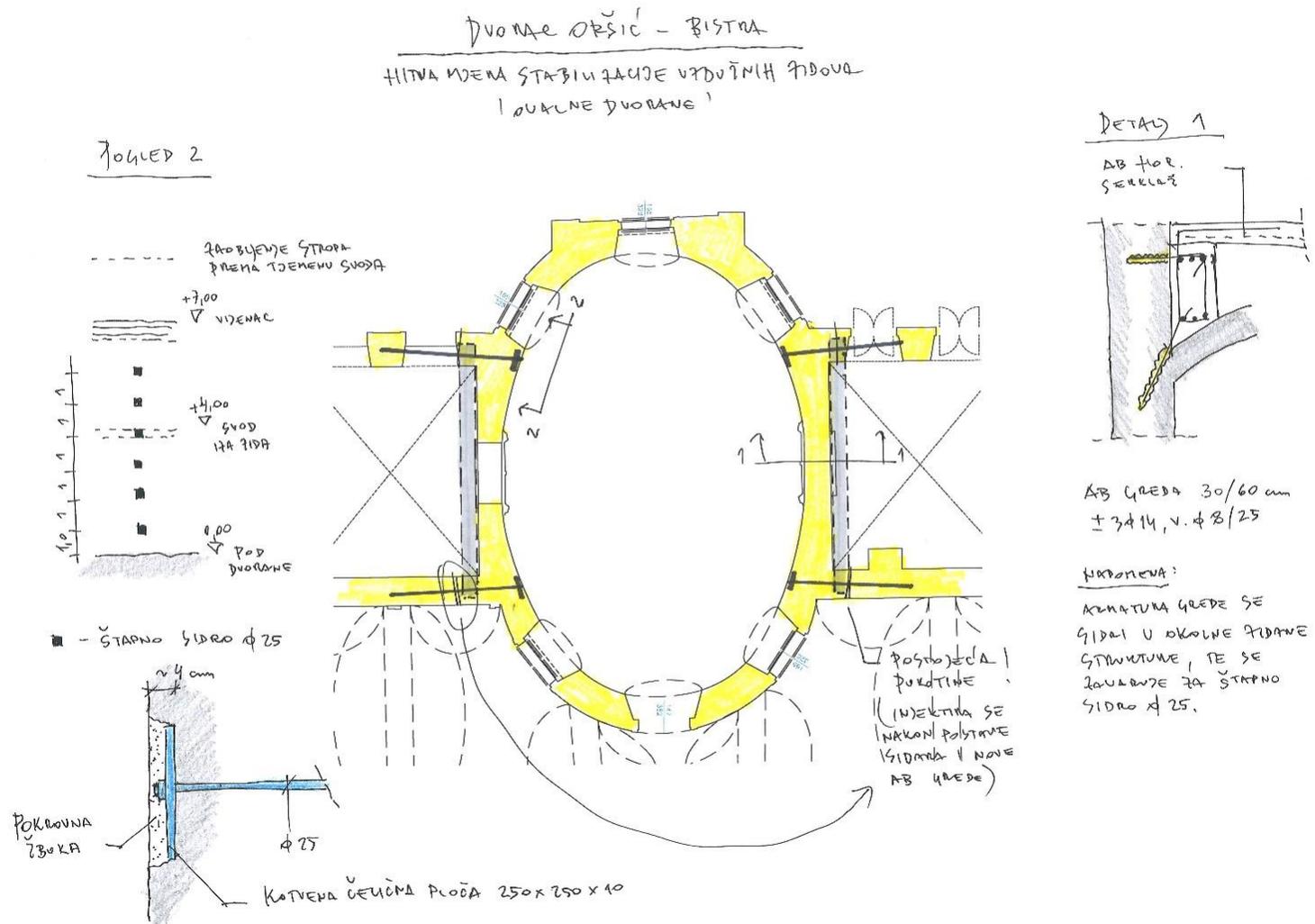
# 18th Century Castle



# 18th Century Castle



# 18th Century Castle



# 18th Century Castle



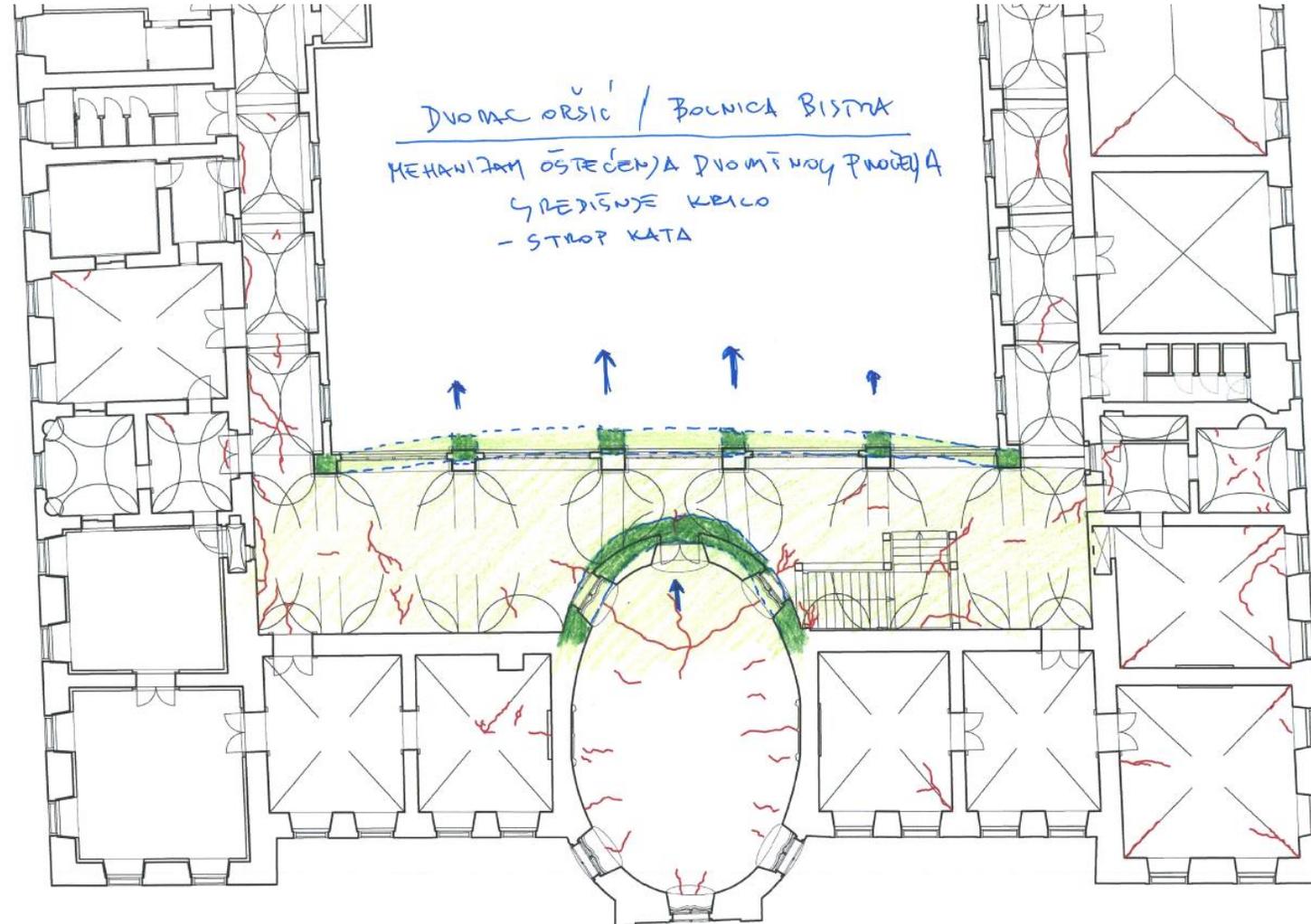
LEGENDA SIMBOLA:



SMJER DEFORMACIJE  
TIDONA USLIJED NEDOSTATKA  
ZATEZA U LINIJAMA  
GLAVNIH LUKOVA



ZONA UTJECAJA  
OSTEĆENJA (SVOZONI)



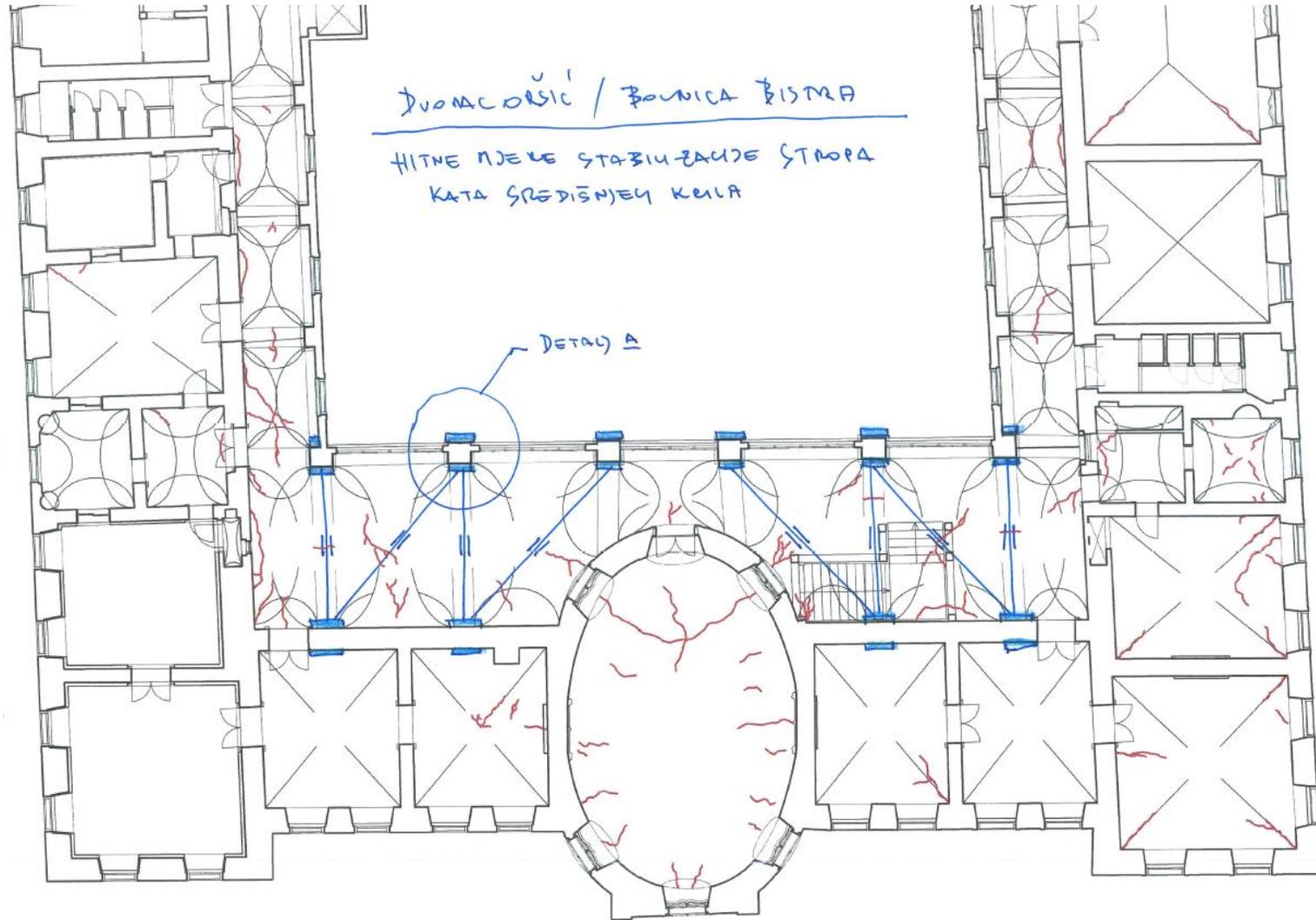
# 18th Century Castle



## LEGENDA SIMBOLA:

  
ČEŇŇM OKOV ZA  
PŘIHNAT ZATEŽE U  
PĚTANA LUKOVA

  
ČEŇČKA ZATEŽA  
Ø 20 mm S 235  
Š PŘI PÁDÁNÍM ŽELEZEM



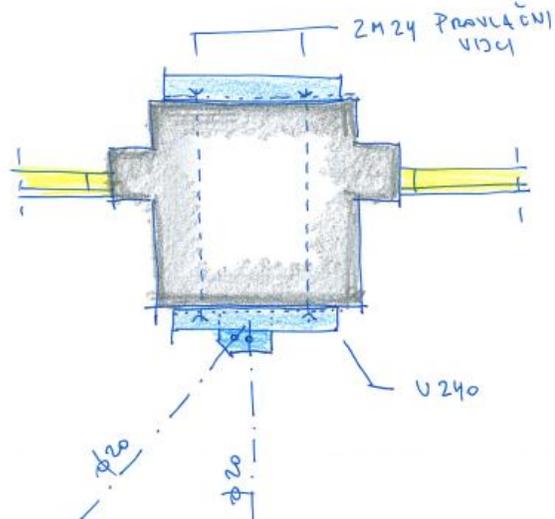
# 18th Century Castle



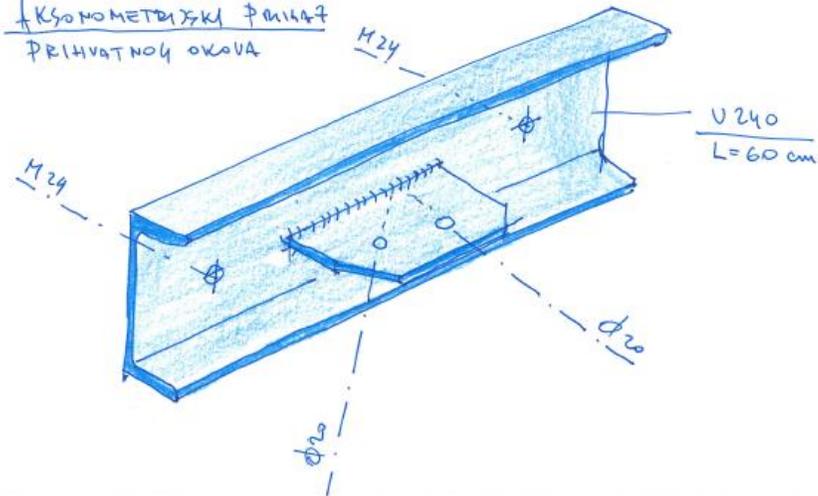
ДВОКЉИШНО ПРОЦЕЉЕ  
ПОЗИЦИЈЕ ДЕМЧИВИХ  
ОКОВА



ЈЕТАУ А



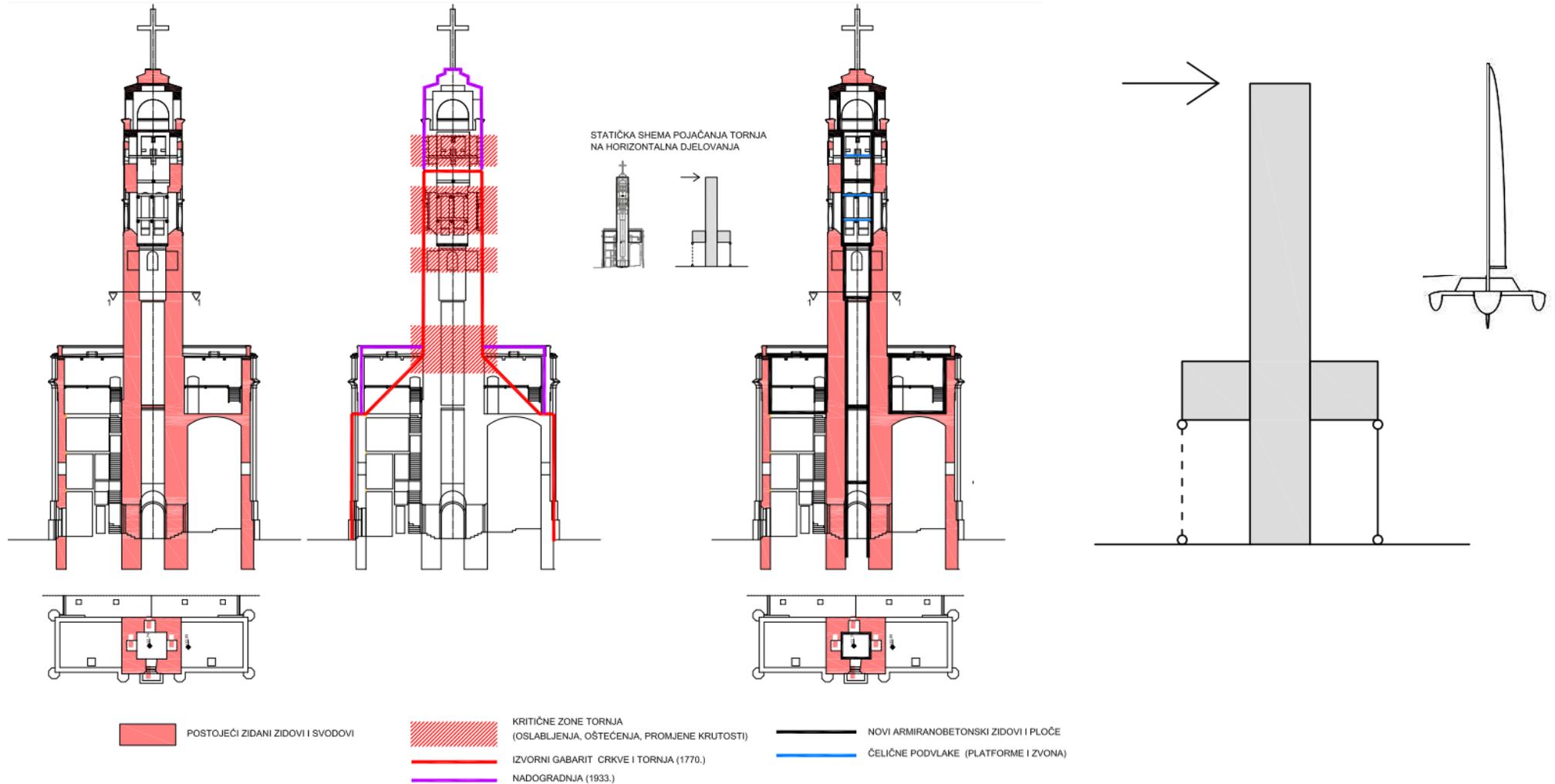
АКСОНОМЕТРИСКИ ПРИКАЗ  
ПРИХВАТНОГ ОКОВА



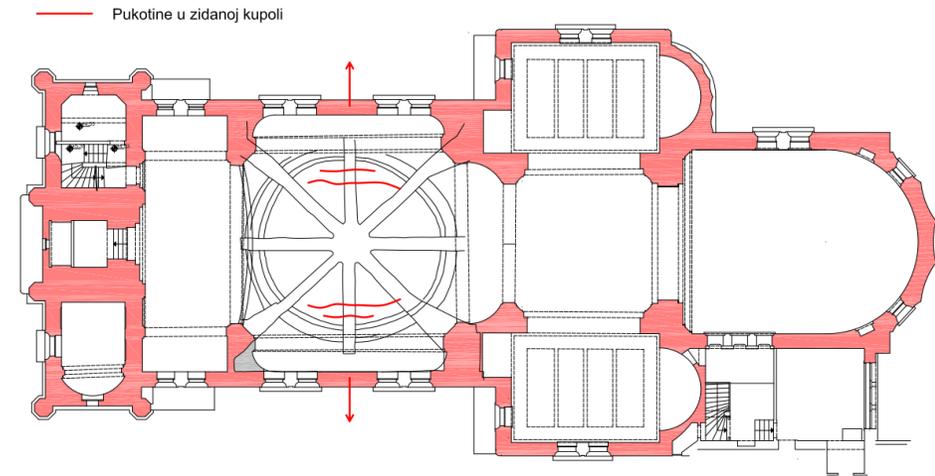
# 19th Century Church



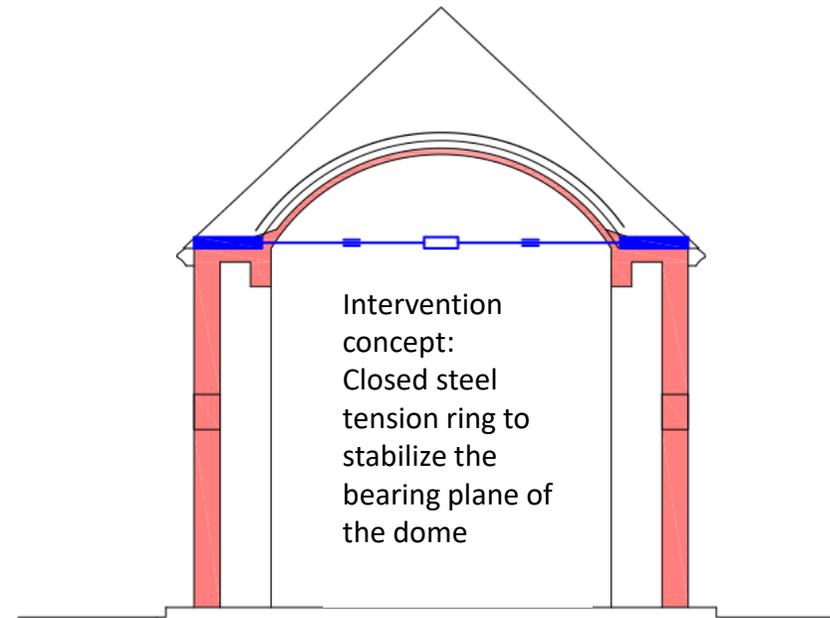
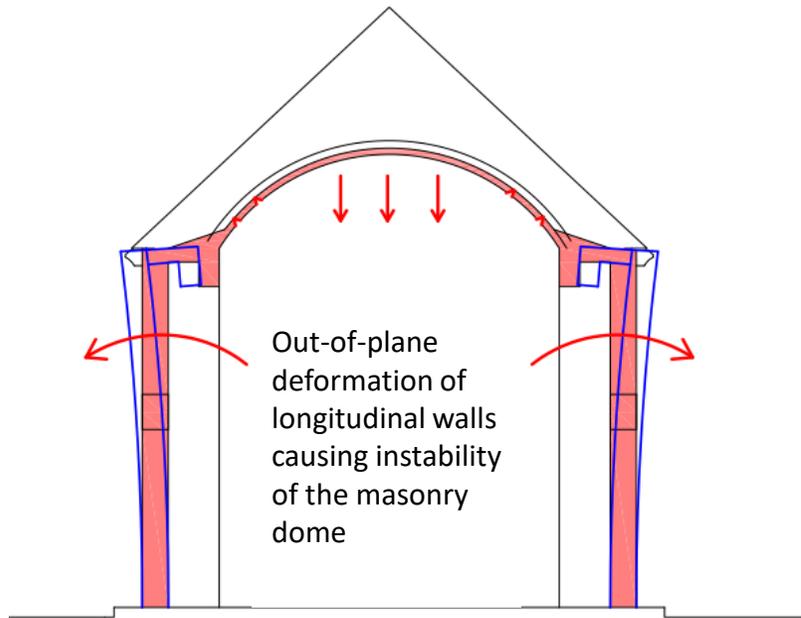
# 19th Century Church



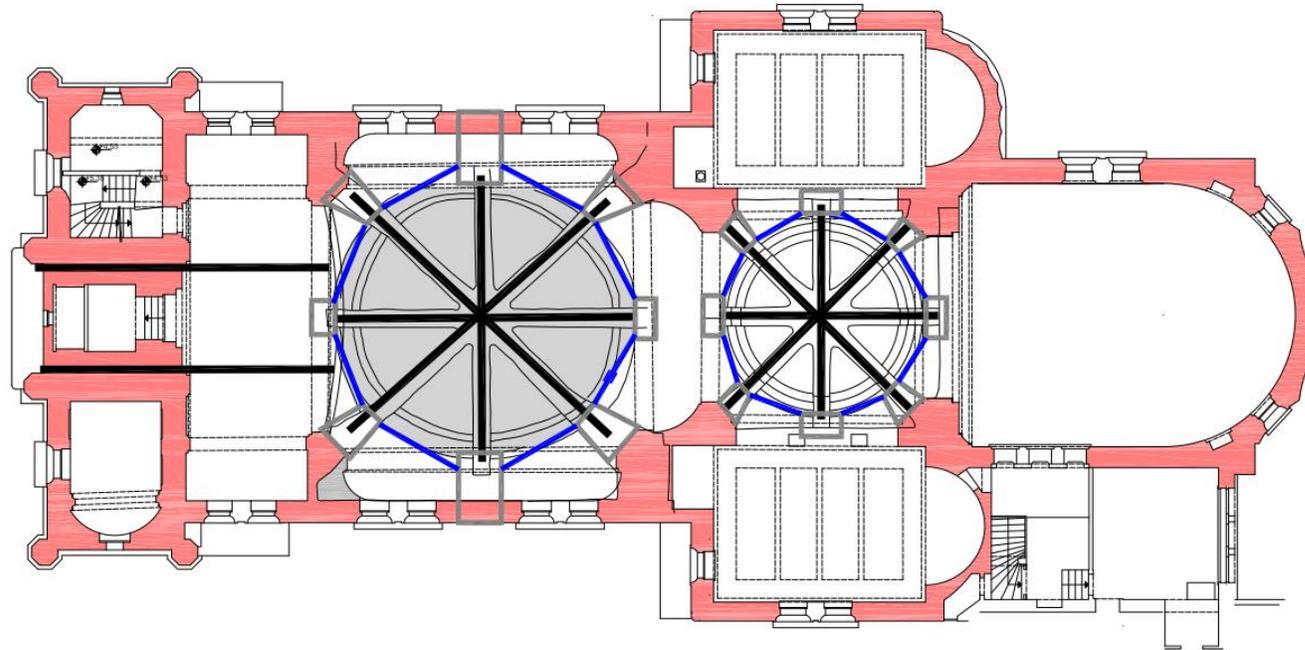
# 19th Century Church



# 19th Century Church



# 19th Century Church



-  Sustav čeličnih zatega sa sidrenim blokovima
-  čelične trake debljine 8 mm na ekstradosu kupole
-  Pojačanje FRCM (na dijelu velike kupole)

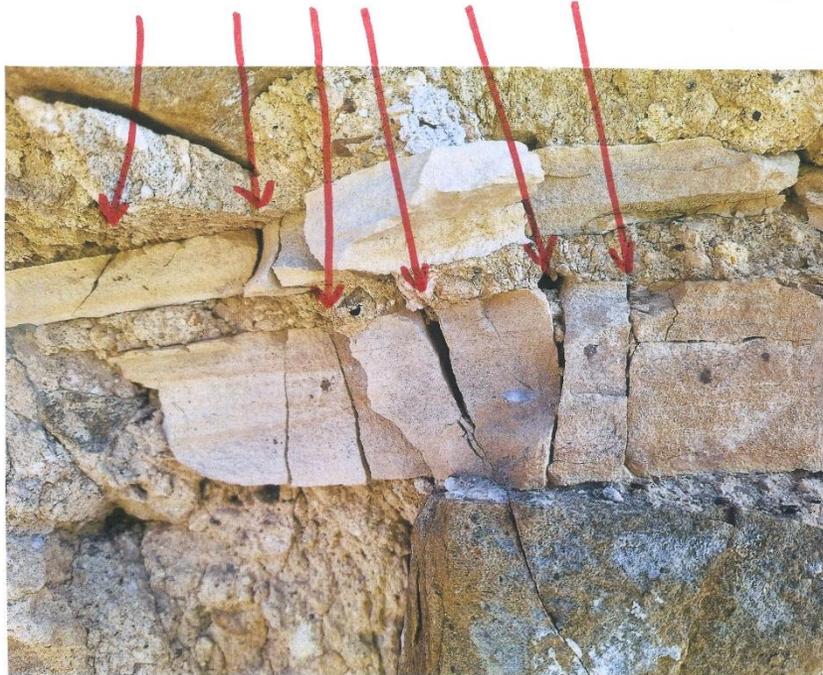
# 18th Century Church Tower





# 18th Century Church Tower

VERTICAL CRACKS - STONE CRUSHING

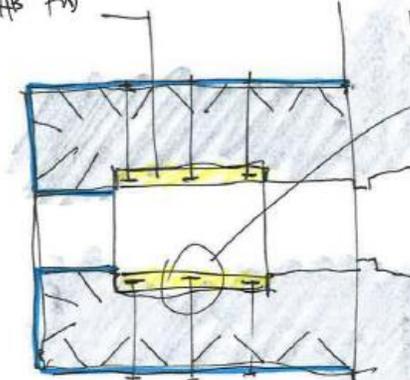


COMPRESSIBLE LAYER ON THE BOTTOM  
OF THE WESTERN BELL TOWER FACADE !

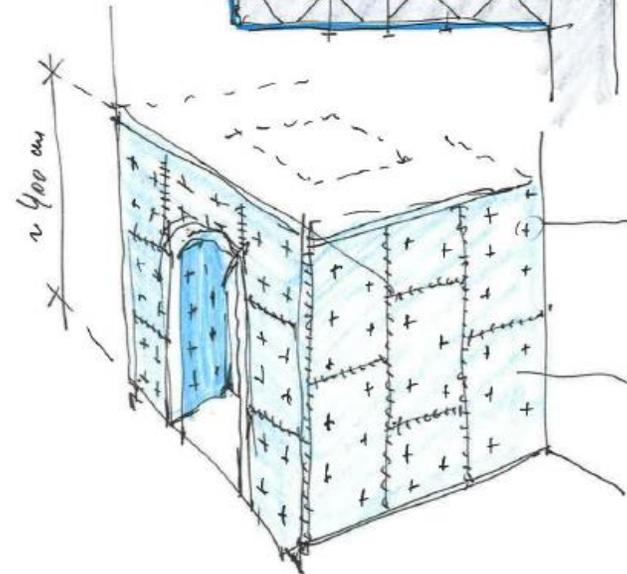
ŘÍZAROVINA POZÁČERNĚ

řídová pronika - čelové ploče

Nový AB 70



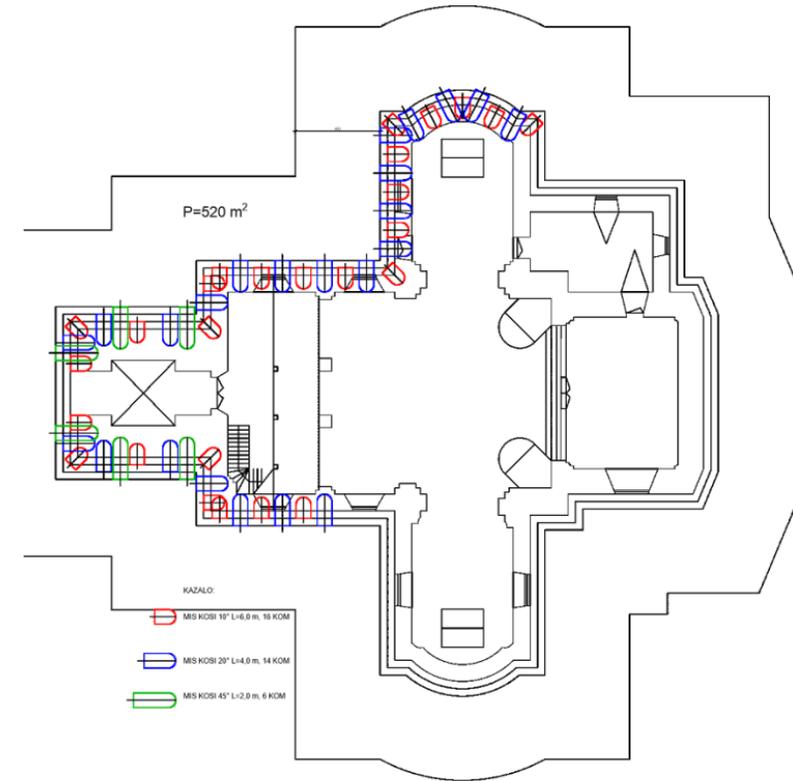
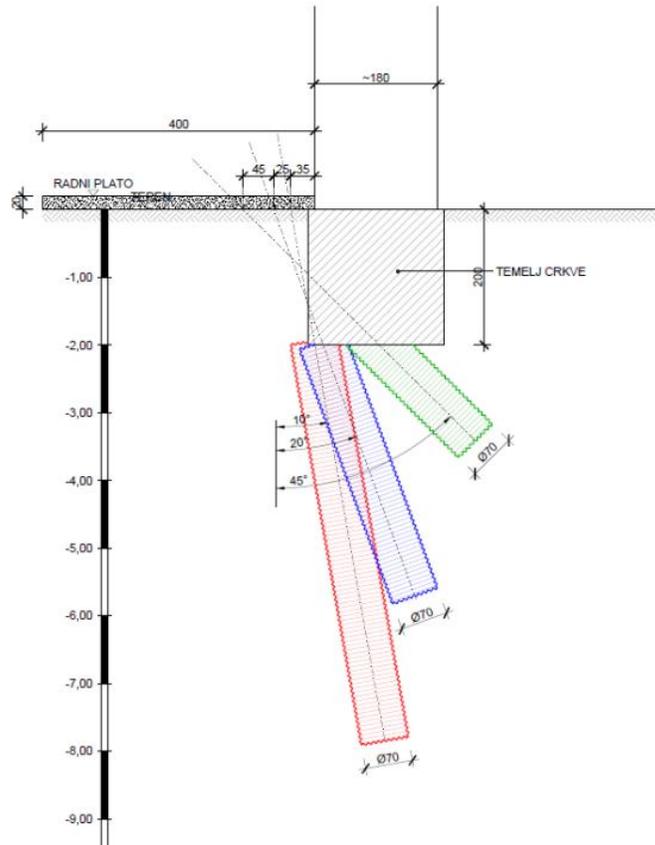
čel. plocha  
800 x 200 x 200  
(řídová a  
armatura nov)



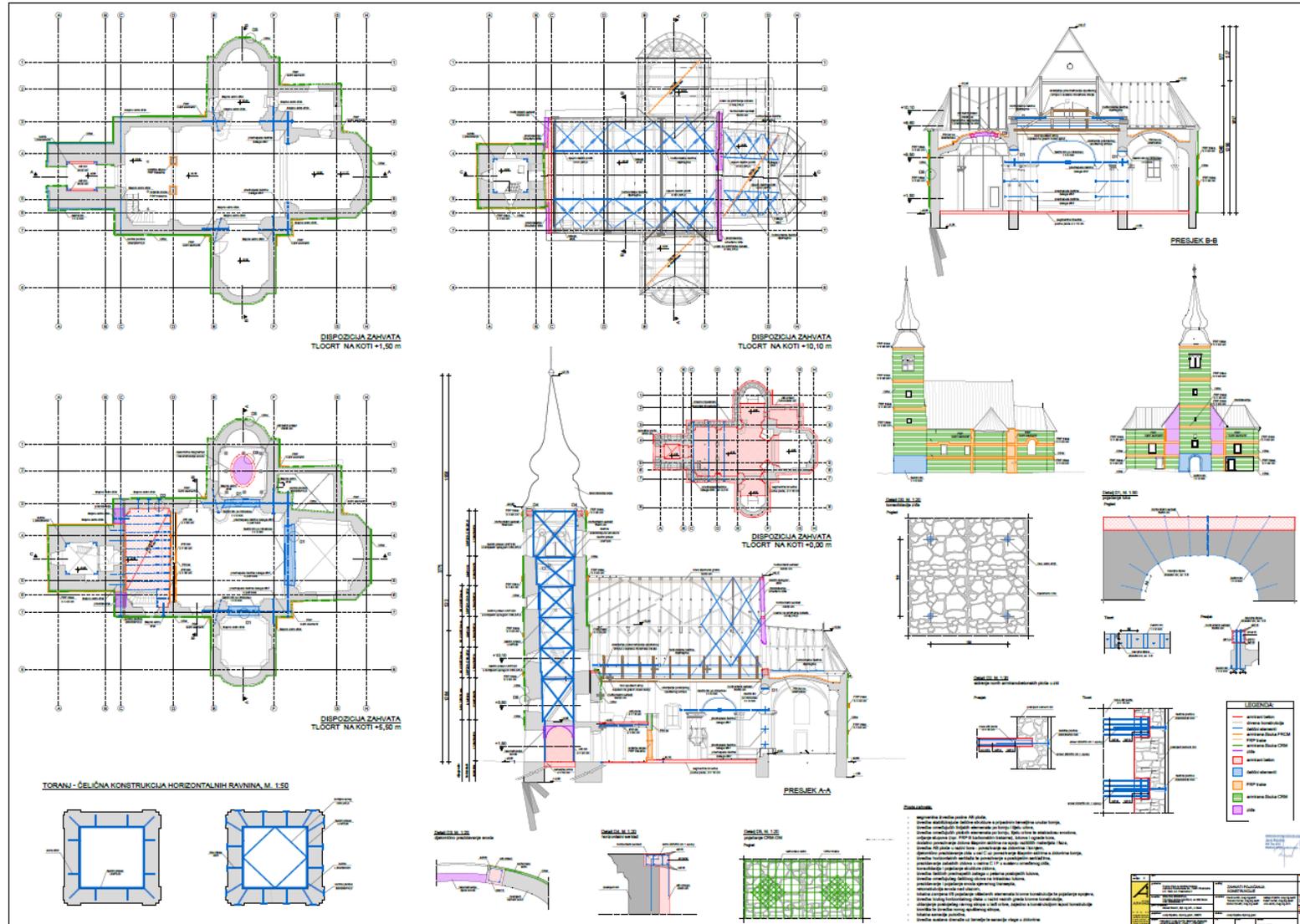
ANKER  $\phi 20$   
(RUPA  $d 25$  + EPOXY)

čel. VIM  
 $d = 8 \text{ mm}$   
řídová a  
LICU MĚSTA

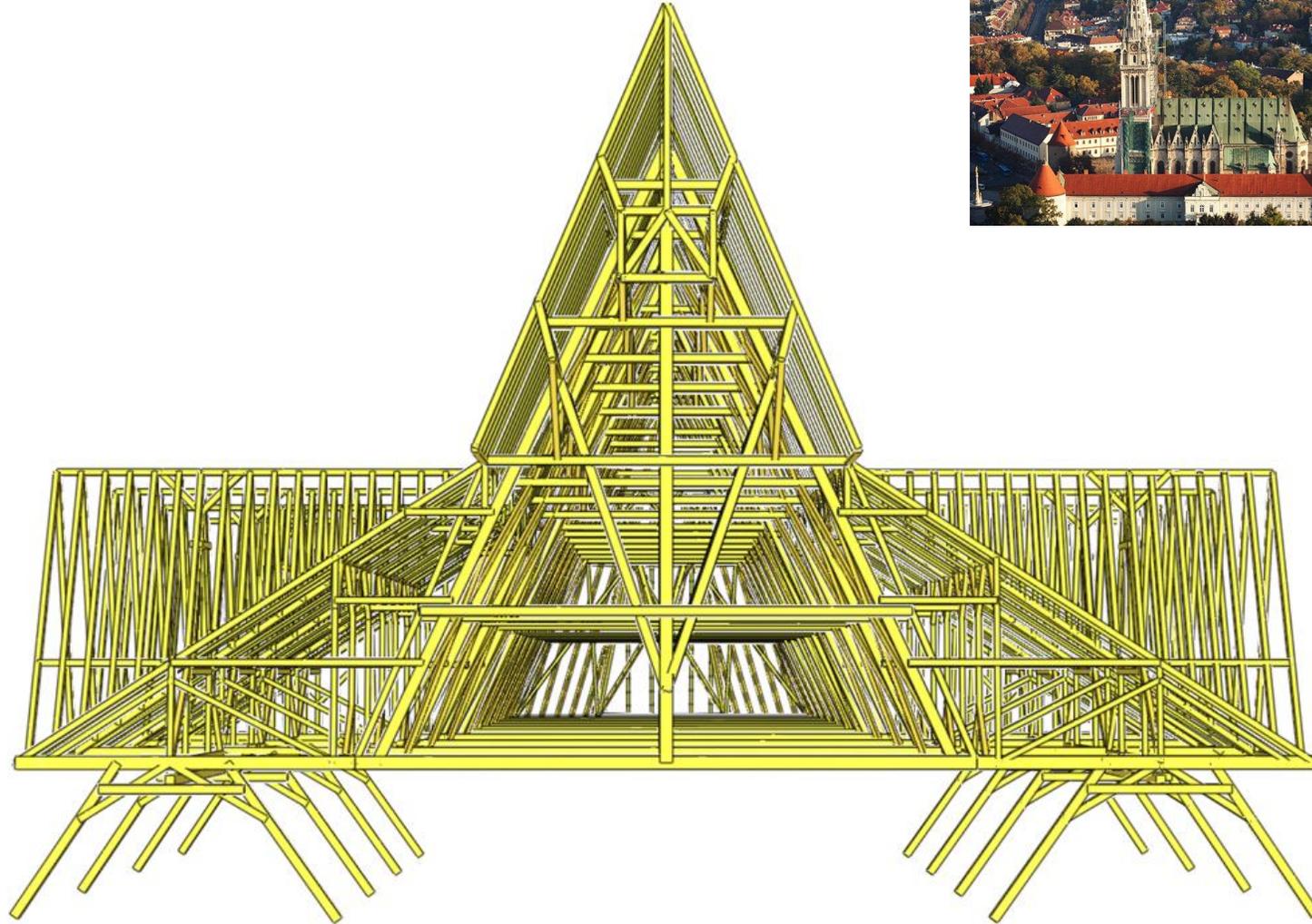
# 18th Century Church Tower



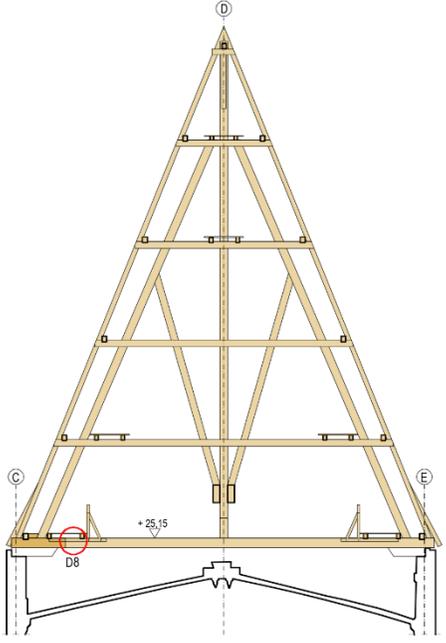
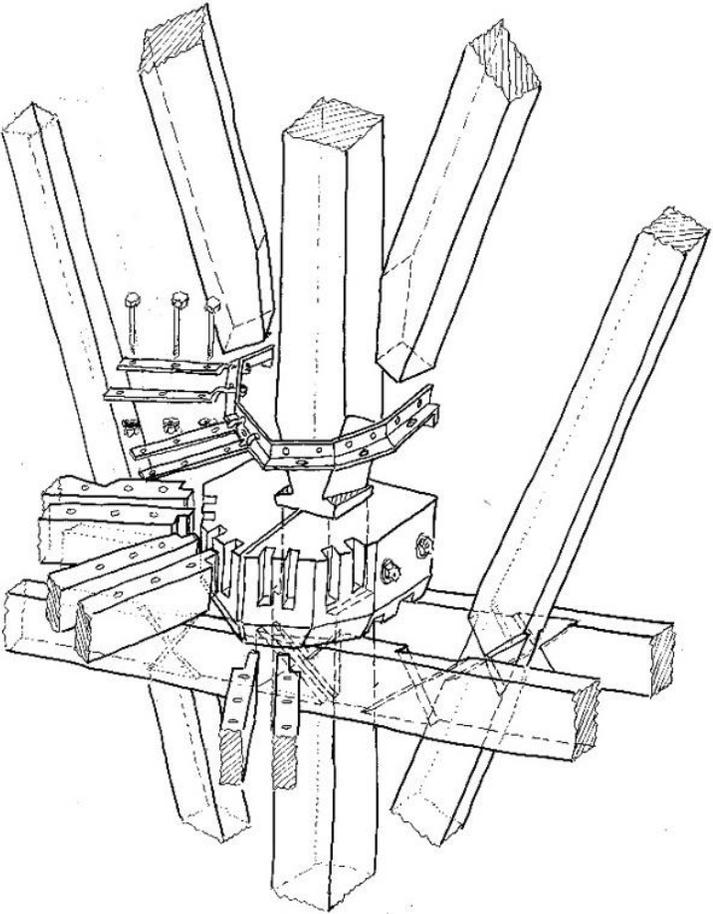
# 18th Century Church Tower



# Zagreb Cathedral



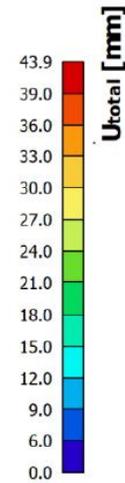
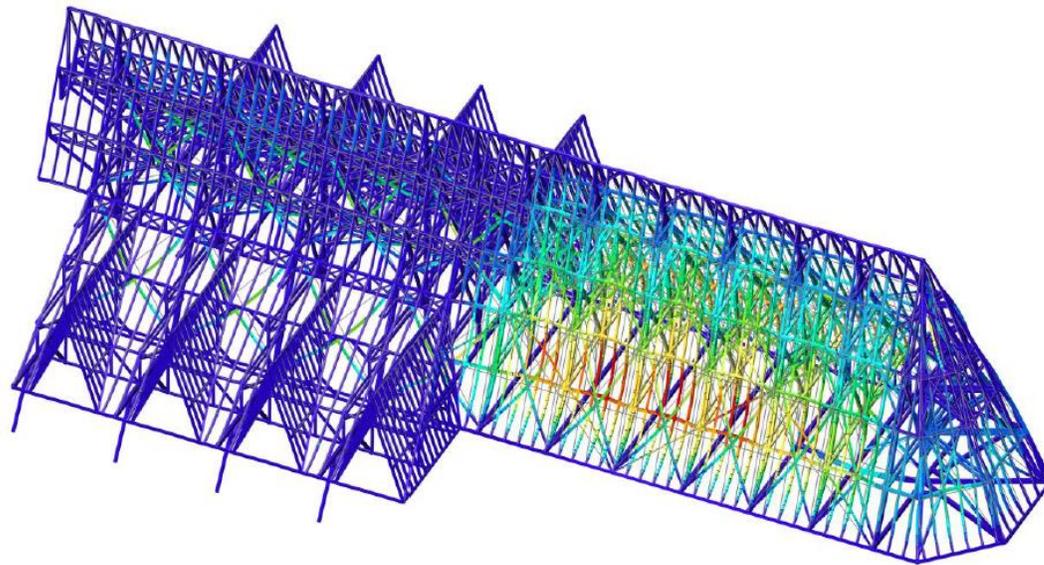
# Zagreb Cathedral



# Zagreb Cathedral

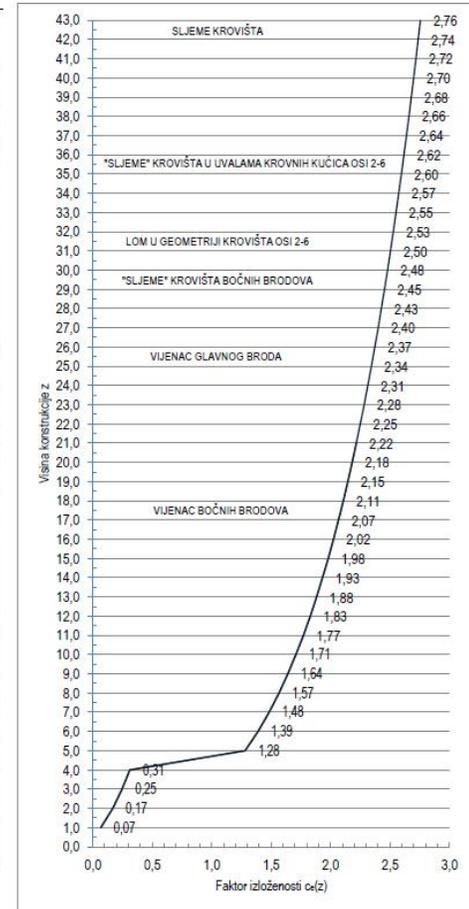


GSU 2 (1,0 · stalno + 1,0 · vjetar pritisak Y)

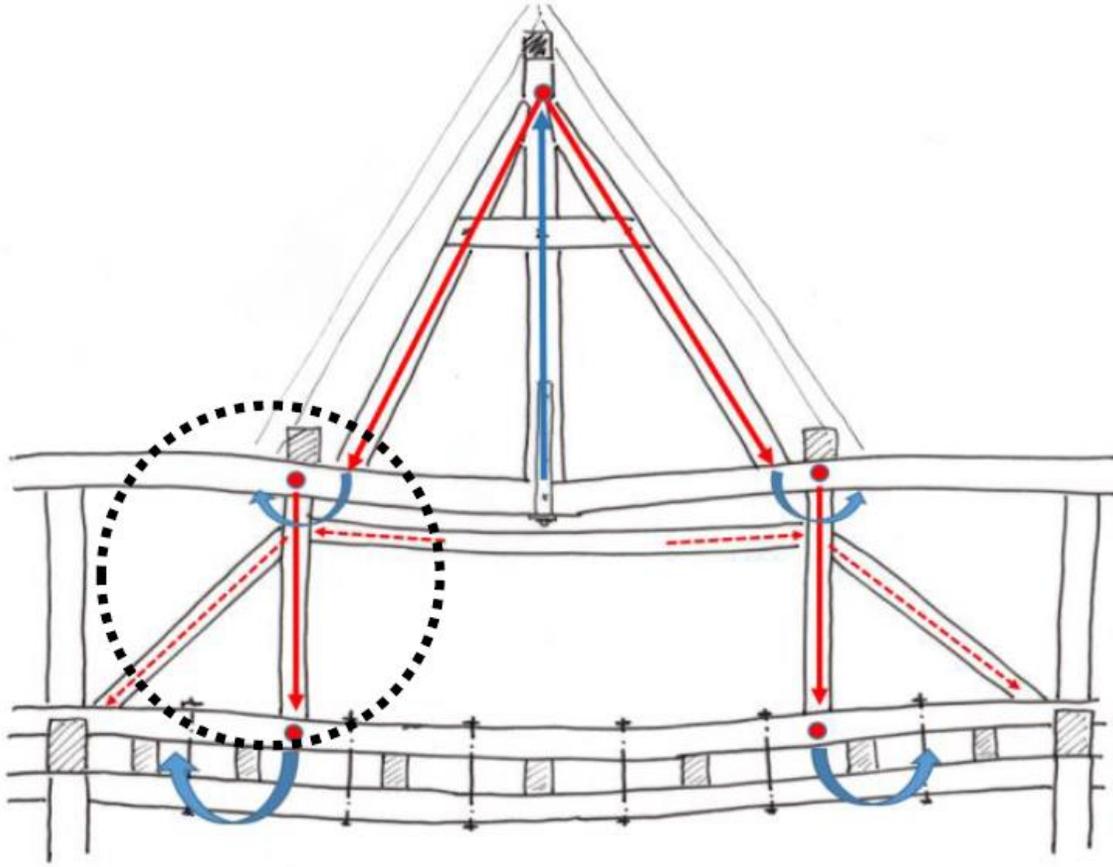


U nastavku dan tablični i grafički prikaz ovisnosti faktora izloženosti o visini konstrukcije.

z	c <sub>e</sub> (z)	l <sub>v</sub>	c <sub>e</sub> (z)
1,0	0,259	0,000	0,07
2,0	0,409	0,000	0,17
3,0	0,496	0,000	0,25
4,0	0,558	0,000	0,31
5,0	0,606	0,355	1,28
6,0	0,645	0,334	1,39
7,0	0,678	0,317	1,48
8,0	0,707	0,305	1,57
9,0	0,733	0,294	1,64
10,0	0,755	0,285	1,71
11,0	0,776	0,278	1,77
12,0	0,795	0,271	1,83
13,0	0,812	0,265	1,88
14,0	0,828	0,260	1,93
15,0	0,843	0,256	1,98
16,0	0,857	0,251	2,02
17,0	0,870	0,248	2,07
18,0	0,882	0,244	2,11
19,0	0,894	0,241	2,15
20,0	0,905	0,238	2,18
21,0	0,915	0,235	2,22
22,0	0,925	0,233	2,25
23,0	0,935	0,230	2,28
24,0	0,944	0,228	2,31
25,0	0,953	0,226	2,34
26,0	0,961	0,224	2,37
27,0	0,969	0,222	2,40
28,0	0,977	0,220	2,43
29,0	0,985	0,219	2,45
30,0	0,992	0,217	2,48
31,0	0,999	0,216	2,50
32,0	1,006	0,214	2,53
33,0	1,012	0,213	2,55
34,0	1,019	0,211	2,57
35,0	1,025	0,210	2,60
36,0	1,031	0,209	2,62
37,0	1,037	0,208	2,64
38,0	1,043	0,207	2,66
39,0	1,048	0,205	2,68
40,0	1,054	0,204	2,70
41,0	1,059	0,203	2,72
42,0	1,064	0,202	2,74
43,0	1,069	0,201	2,76



# Zagreb Cathedral

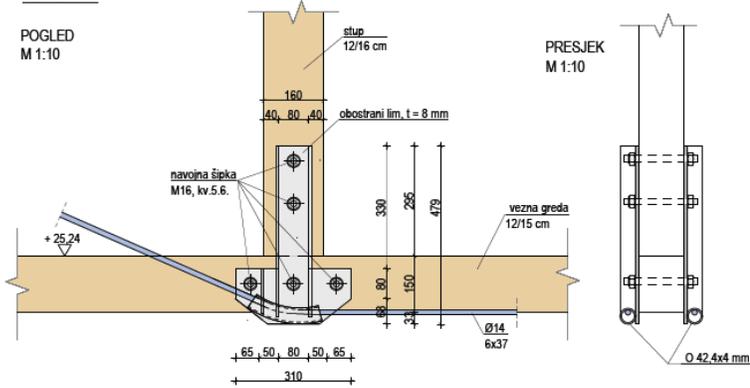


# Zagreb Cathedral



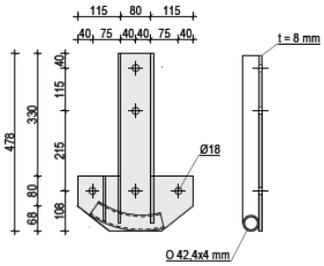
DETALJ D11

POGLED  
M 1:10



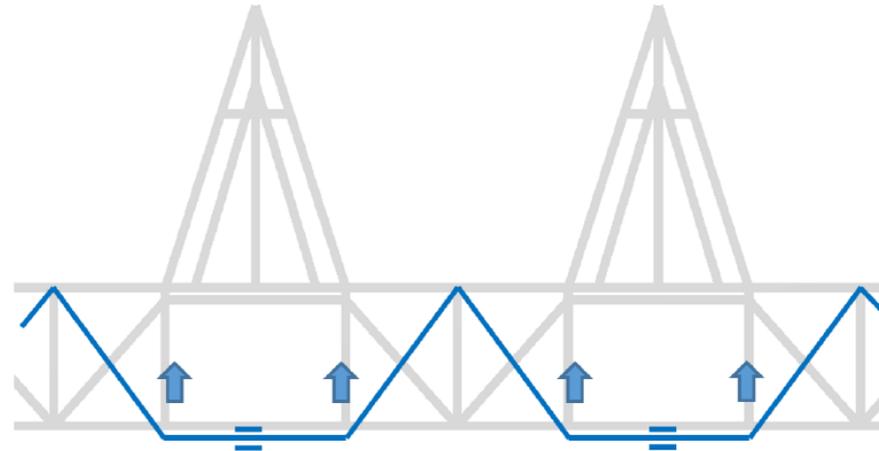
PRESJEK  
M 1:10

SKLOP OKOVA  
M 1:10



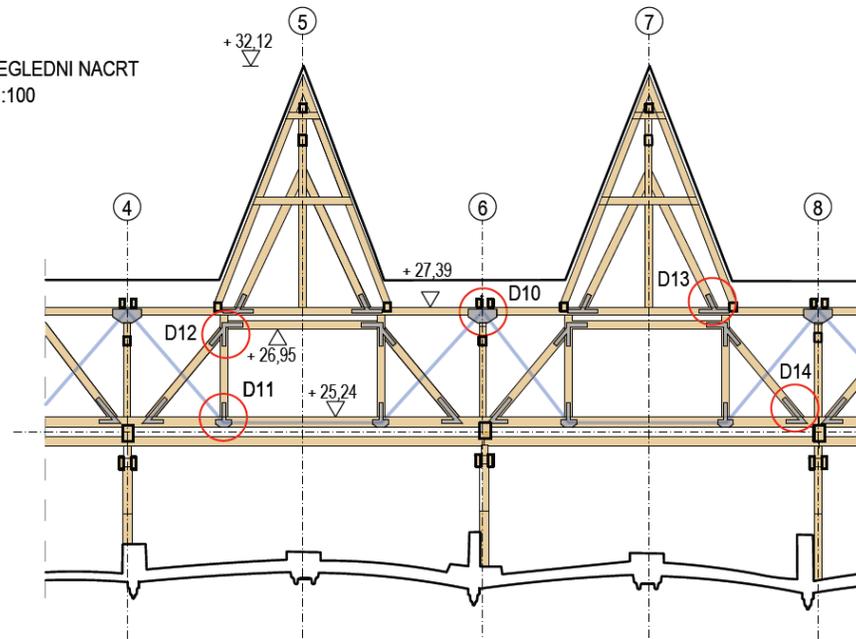
DETALJ D14

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Slika 2- 15 Shematski prikaz pojačanja dvostruke visulje zone krovnih kućica

PREGLEDNI NACRT  
M 1:100





**Thank you for your  
attention**