STUDIO
ARHING

Studio Arhing / Structural Engineering Office

Founded in 1991. in Zagreb, Croatia

33 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

Expertise:

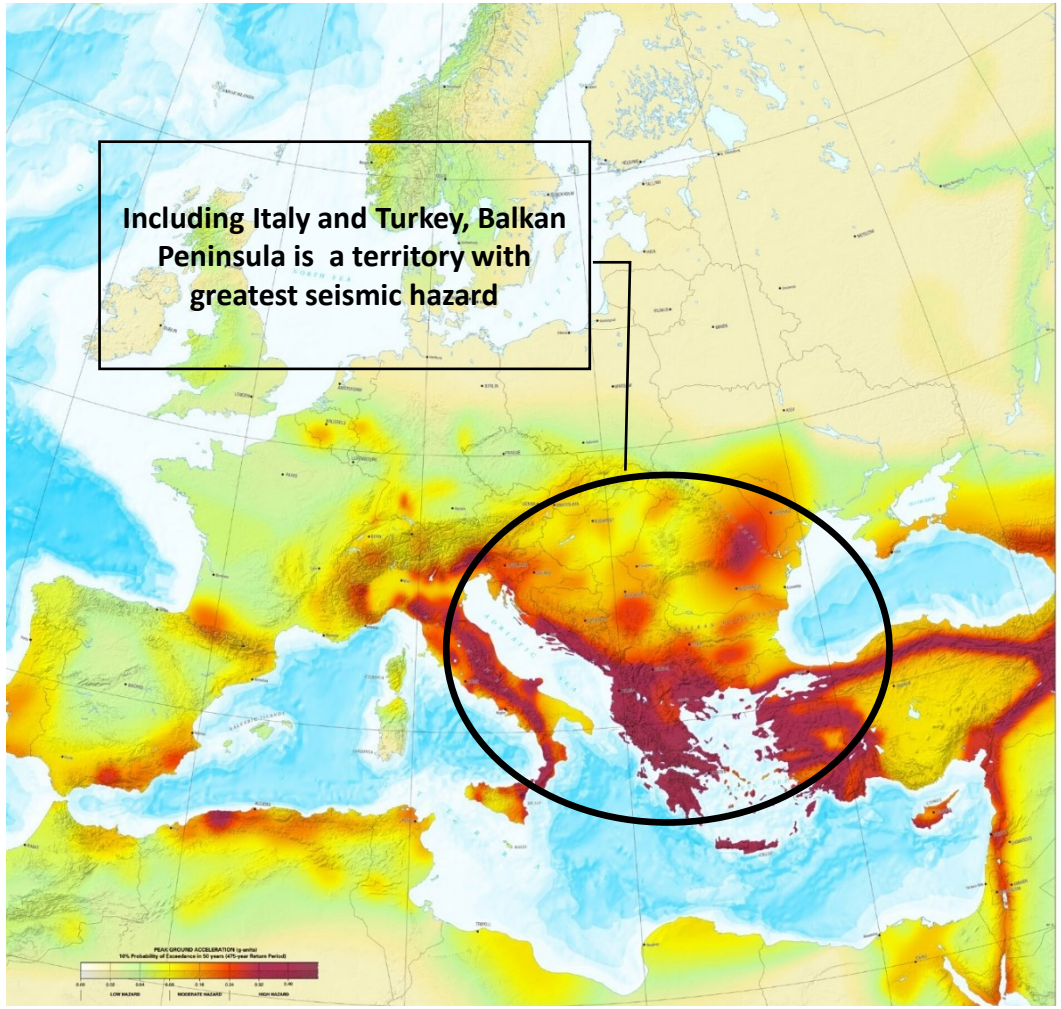
- Building Seismic Assessment Expert / U.S. Department of State
- Research, Documenting and Renovation of Historic Structures / Croatian Ministry of Culture
- Heritage buildings Seismic Consultants / Croatian Centre for Earthquake Engineering CCEE

Content:

1. Introduction – damage to sacral and heritage buildings after the earthquake
2. Urgent measures
3. Documentation and Research / ANAMNESIS - HISTORY
4. Assessment of the condition of the building structure / DIAGNOSIS
5. Technical solutions for repair and reinforcement / THERAPY

2020 Earthquakes

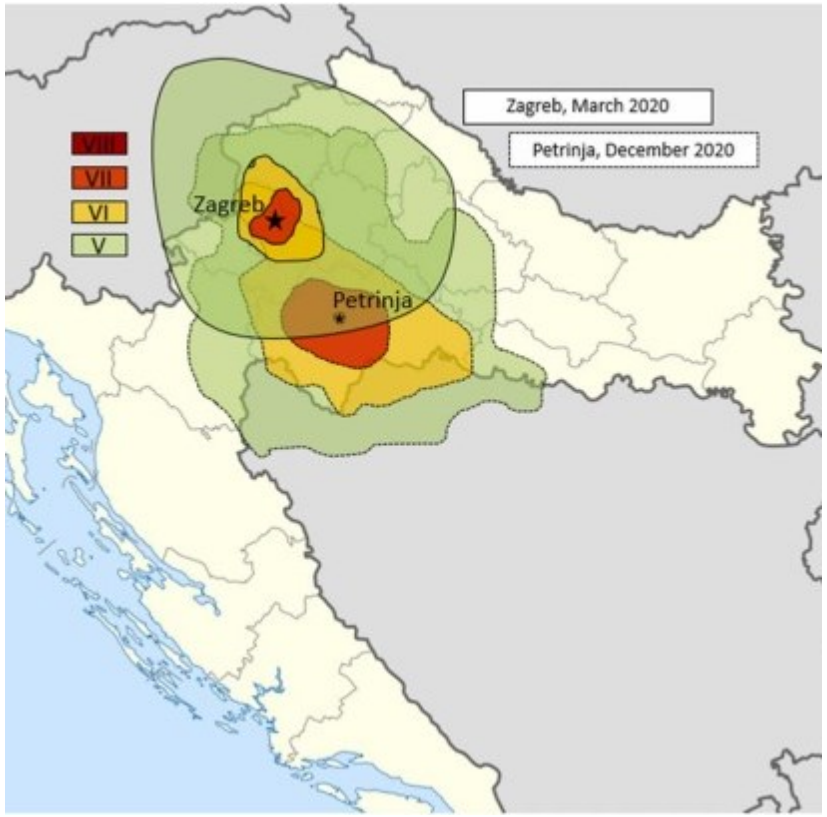
Damage to heritage buildings



Peak Ground Acceleration on Reference (Type A) Bedrock (a_{gR}) with a 10 % probability of being exceeded in 50 years (475 year return period) – LIFE SAFETY for important cities in our region:

ZAGREB	**~ 0.26g – 0.29g**
SKOPJE	**~ 0.24g**
SARAJEVO	**~ 0.20g**
DUBROVNIK	**~ 0.31g**

Damage to heritage buildings



Zagreb M_L = 5,5

Petrinja M_L = 6,3

Tablica. Stupnjevi oštećenja za zidane građevine prema EMS-98 klasifikaciji

Kategorija	Skica	Detaljan opis
I		**Neznatno do blago oštećenje** **- zanemarivo konstruktivno oštećenje** **- blago nekonstruktivno oštećenje** Vrlo tanke pukotine u ponekim zidovima Otpadanje malih komada žbuke Vrlo rijetko otpadanje pojedinačnih odvojenih dijelova zida
II		**Umjereno oštećenje** **- blago konstruktivno oštećenje** **- umjereno nekonstruktivno oštećenje** Pukotine u brojnim zidovima Otpadanje većih komada žbuke Djelomično otkazivanje dimnjaka
III		**Značajno do teško oštećenje** **- umjereno konstruktivno oštećenje** **- teško nekonstruktivno oštećenje** Velike, razvedene pukotine u većini zidova Otpadanje crijepa Otkazivanje dimnjaka u razini krova Otkazivanja pojedinačnih nekonstruktivnih elemenata (pregradni, zabatni zidovi)
IV		**Vrlo teško oštećenje** **- teško konstruktivno oštećenje** **- vrlo teško nekonstruktivno oštećenje** Značajno otkazivanje zidova Djelomično otkazivanje konstrukcija krovova i međukatnih konstrukcija
V		**Otkazivanje** **- vrlo teško konstruktivno oštećenje** Potpuno ili gotovo potpuno rušenje

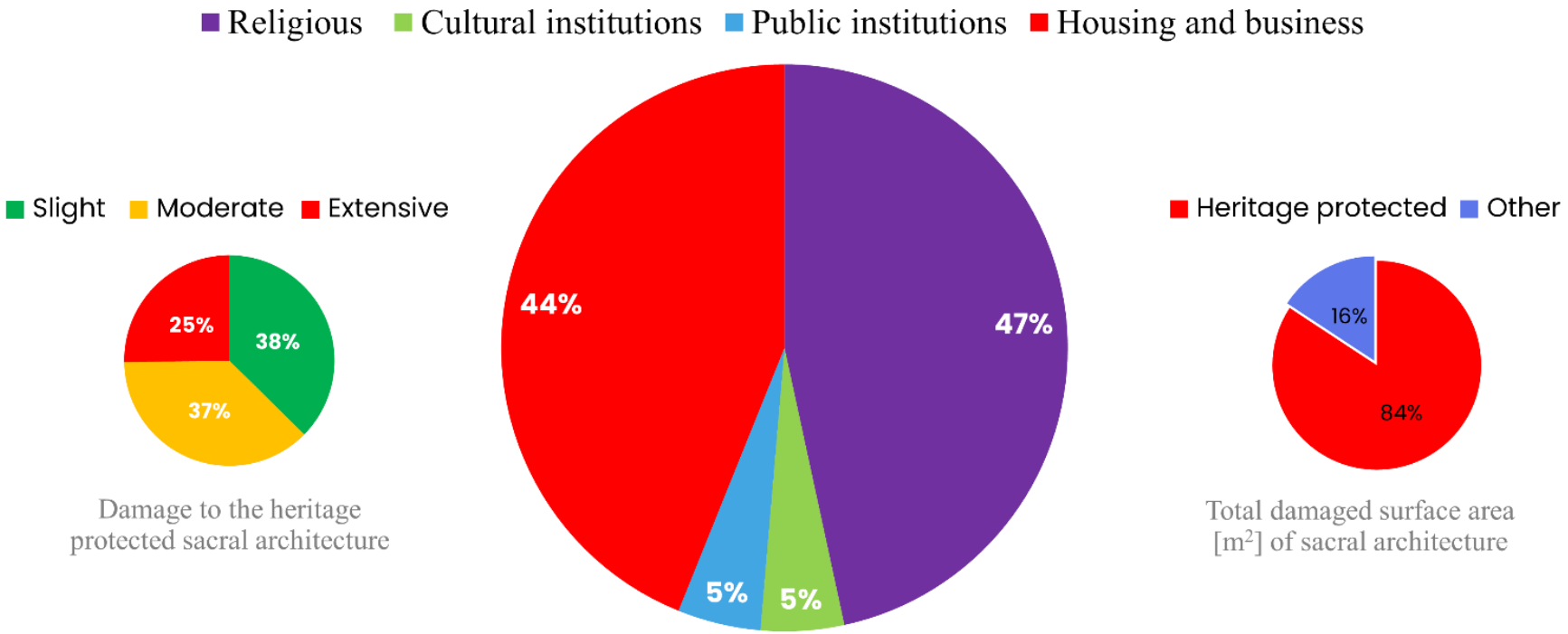
57 000 damaged buildings

206 damaged sacral buildings

... out of which 52 severly damaged

Izvor:
1. World Bank Report: Croatia December 2020 Earthquake—Rapid Damage And Needs Assessment; Government of Croatia: Zagreb, Croatia, 2021.
2. The Database of Usability Classification, Croatian Centre of Earthquake Engineering (HCPI—Hrvatski Centar za Potresno Inženjerstvo); Faculty of Civil Engineering, University of Zagreb: Zagreb, Croatia, 2020.
3. M. Stepinac, P.B. Lourenço, J. Atalić, T. Kišiček, M. Uroš, M. Baniček, M. Šavor Novak, Damage classification of residential buildings in historical downtown after the ML5.5 earthquake in Zagreb, Croatia in 2020 Int. J. Disaster Risk Reduct., vol. 56 (. 2021), 10.1016/j.ijdrr.2021.102140

Damage to heritage buildings



Izvor:
1. World Bank Report: Croatia December 2020 Earthquake—Rapid Damage And Needs Assessment; Government of Croatia: Zagreb, Croatia, 2021.
2. The Database of Usability Classification, Croatian Centre of Earthquake Engineering (HCPI—Hrvatski Centar za Potresno Inženjerstvo); Faculty of Civil Engineering, University of Zagreb: Zagreb, Croatia, 2020.
3. M. Stepinac, P.B. Lourenço, J. Atalić, T. Kišiček, M. Uroš, M. Baniček, M. Šavor Novak, Damage classification of residential buildings in historical downtown after the ML5.5 earthquake in Zagreb, Croatia in 2020 Int. J. Disaster Risk Reduct., vol. 56 (. 2021), 10.1016/j.ijdrr.2021.102140

Damage to heritage buildings

Damage to heritage buildings

Damage to heritage buildings

Damage to heritage buildings

Damage to heritage buildings

Damage to heritage buildings

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

ICOMOS CHARTER- PRINCIPLES FOR THE ANALYSIS, CONSERVATION AND STRUCTURAL RESTORATION OF ARCHITECTURAL HERITAGE (2003)

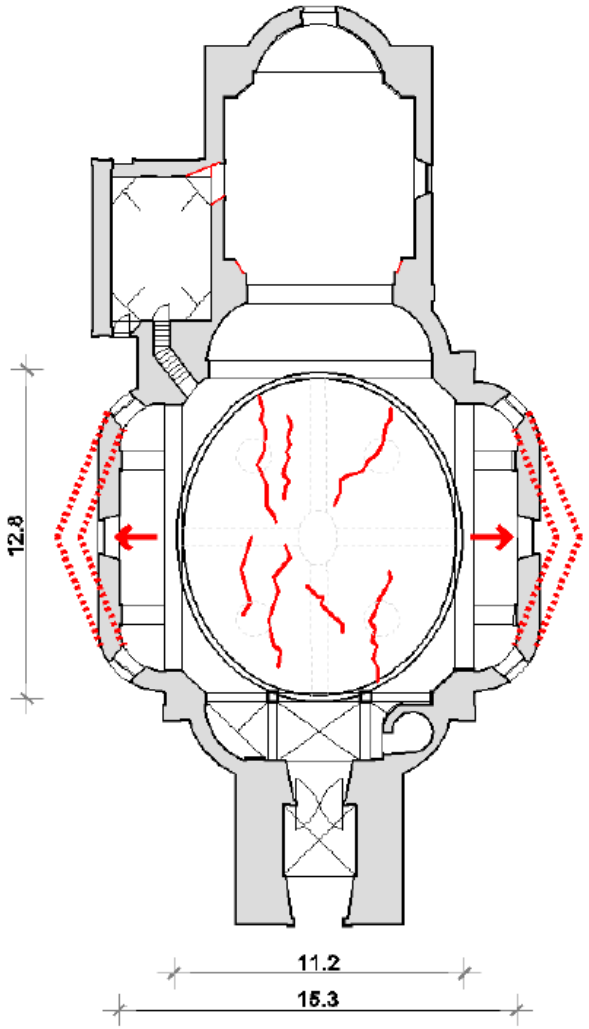
ICOMOS
international council on monuments and sites

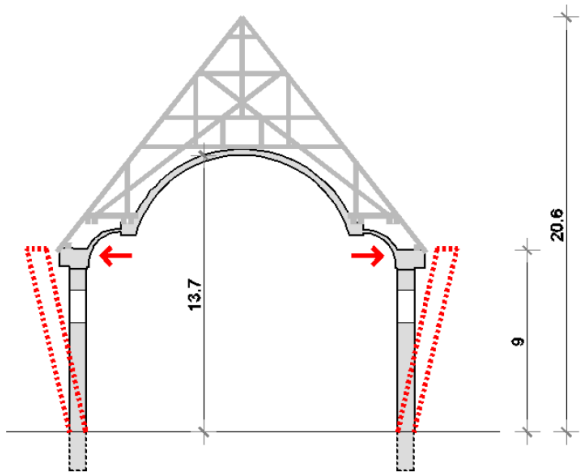
The peculiarity of heritage structures, with their complex history, requires the organisation of studies and proposals in precise steps that are similar to those used in medicine. Anamnesis, diagnosis, therapy and controls, corresponding respectively to the searches for significant data and information, individuation of the causes of damage and decay, choice of the remedial measures and control of the efficiency of the interventions.

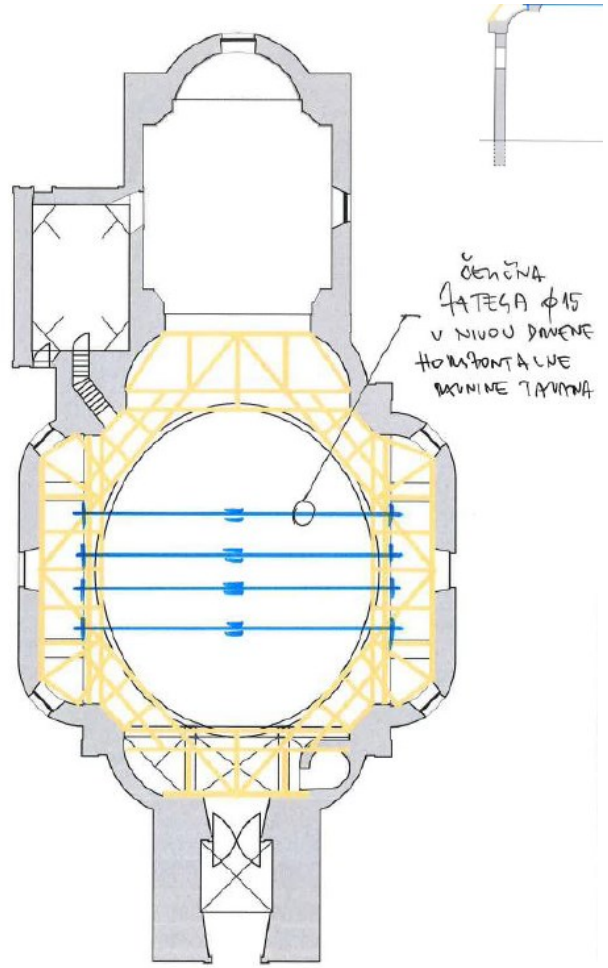
Structural safety (EUROCODE)

Preservation of cultural property

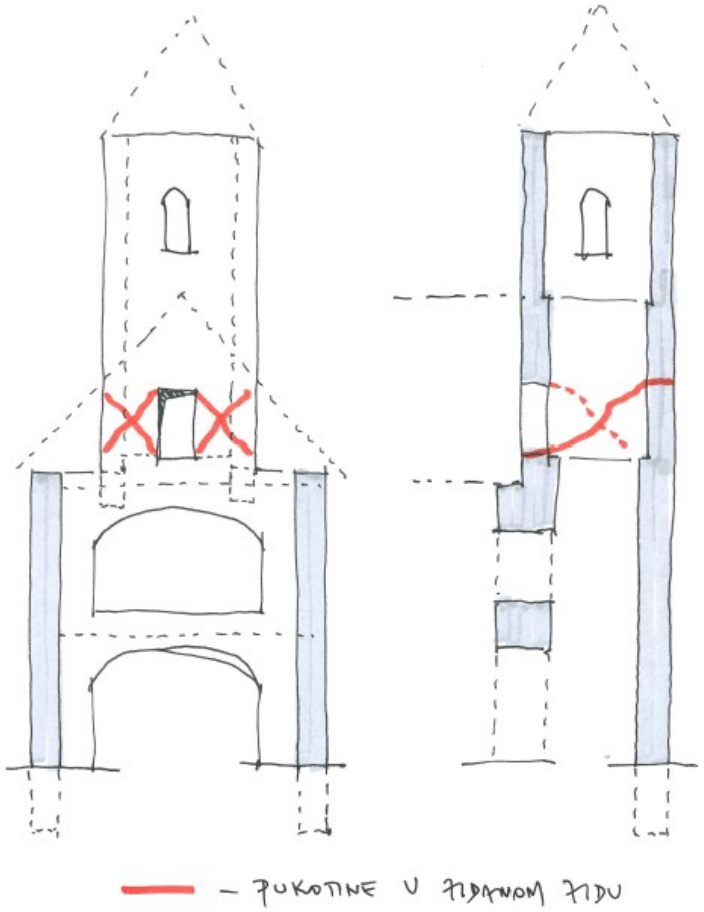
Urgent measures



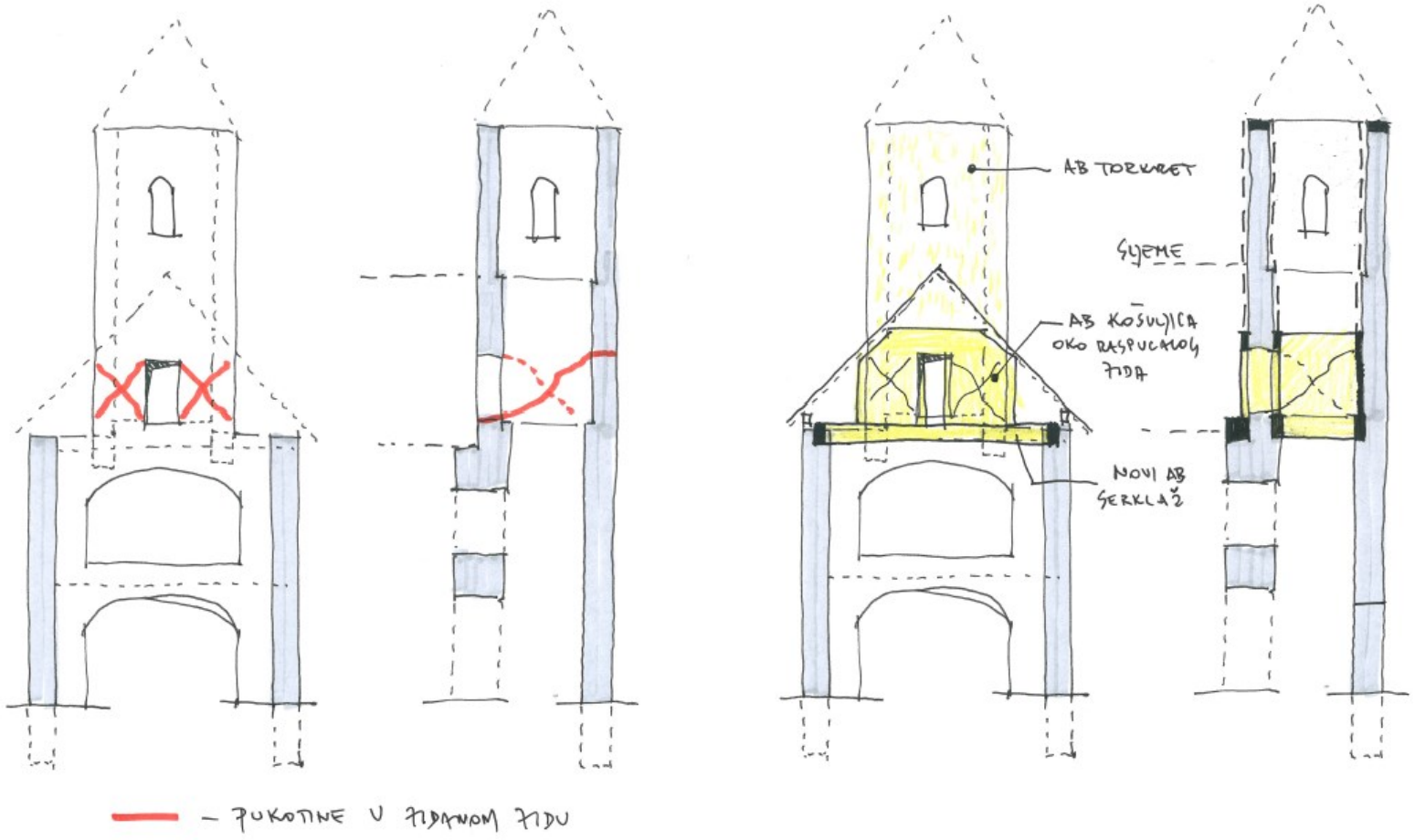




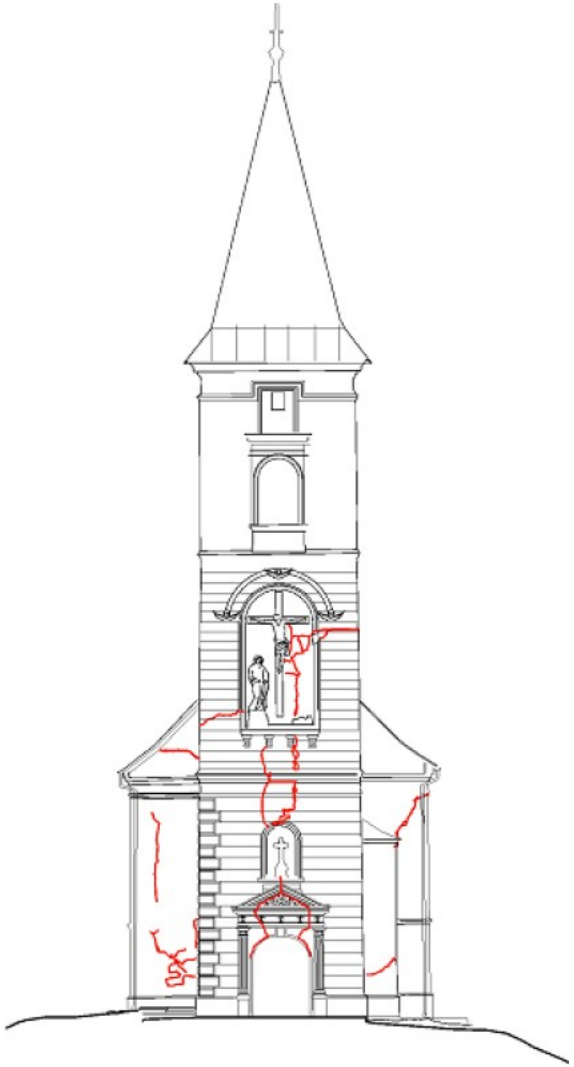
Urgent measures

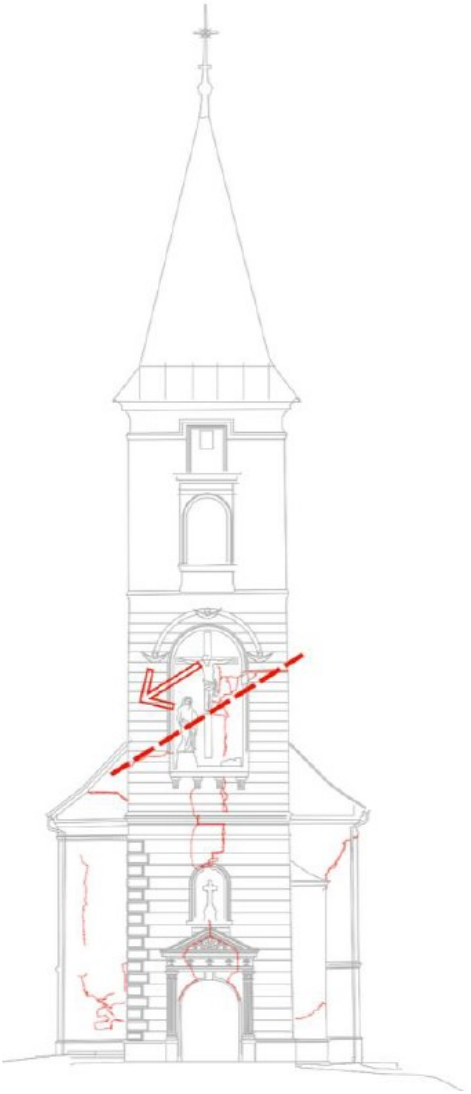


Urgent measures

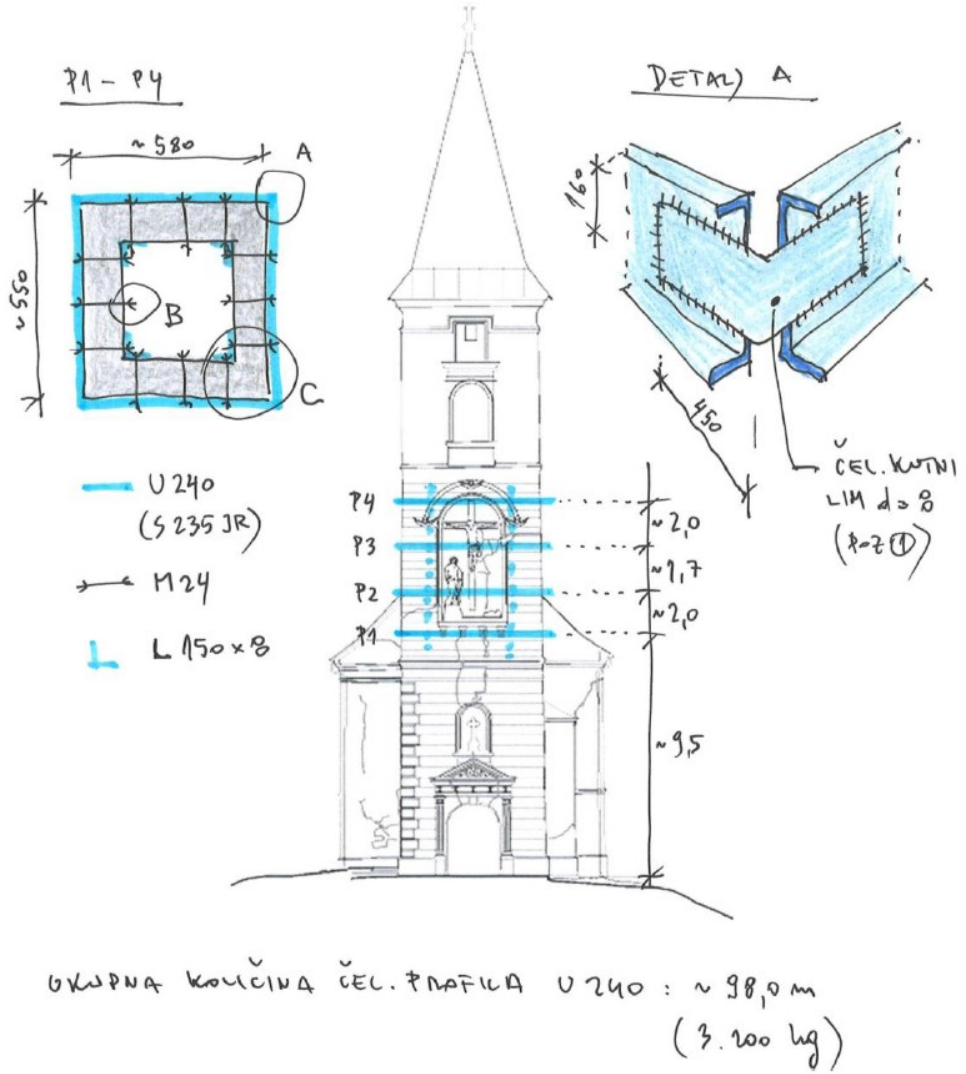


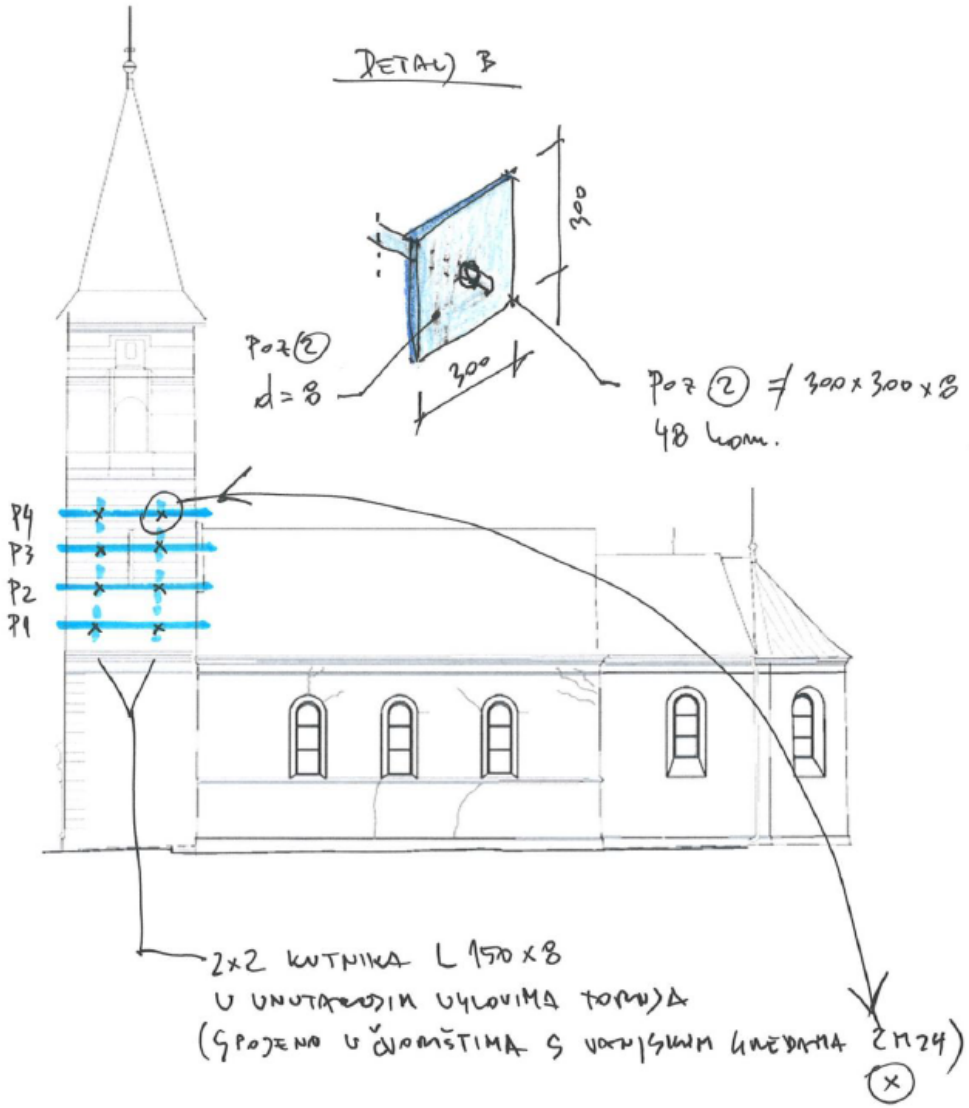
Urgent measures





Urgent measures





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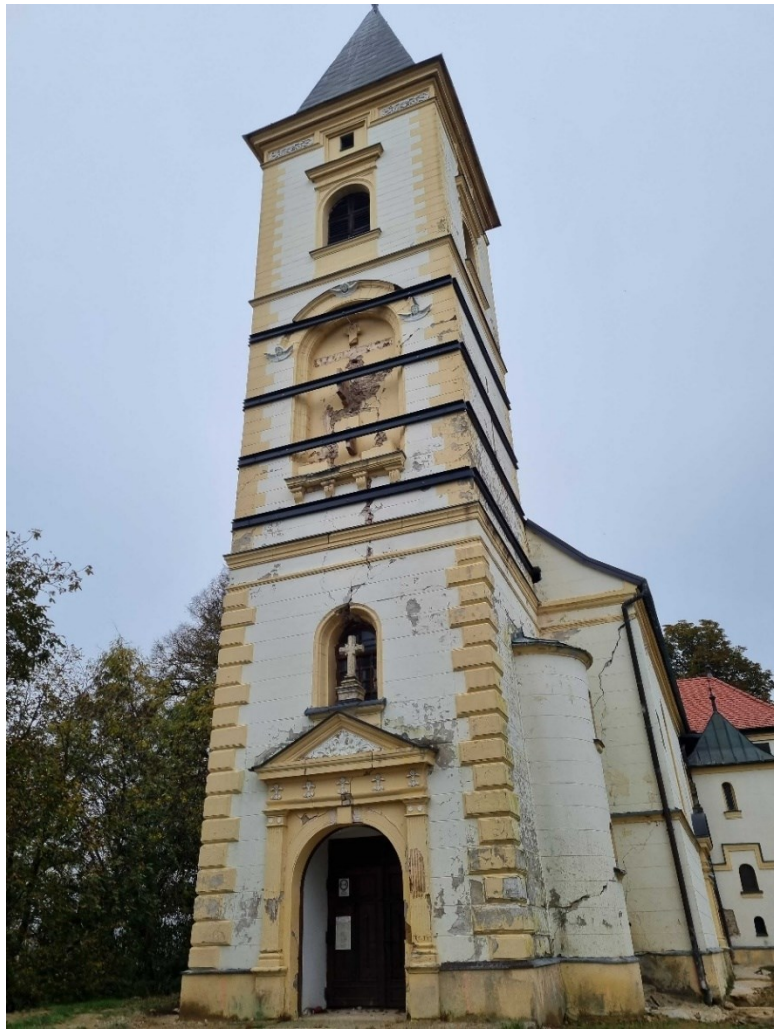

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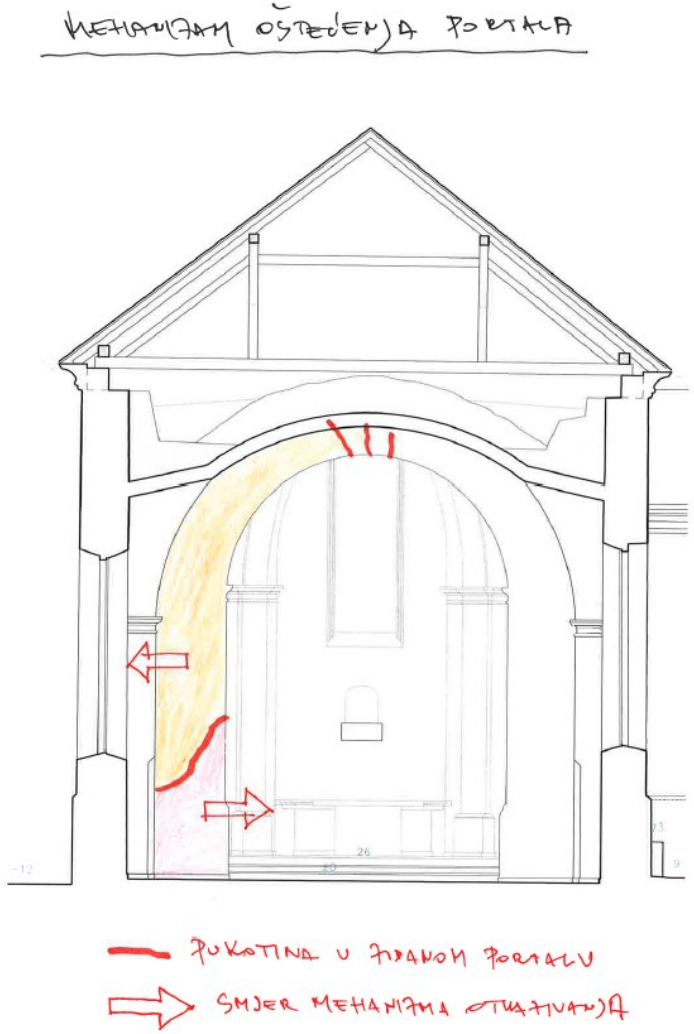
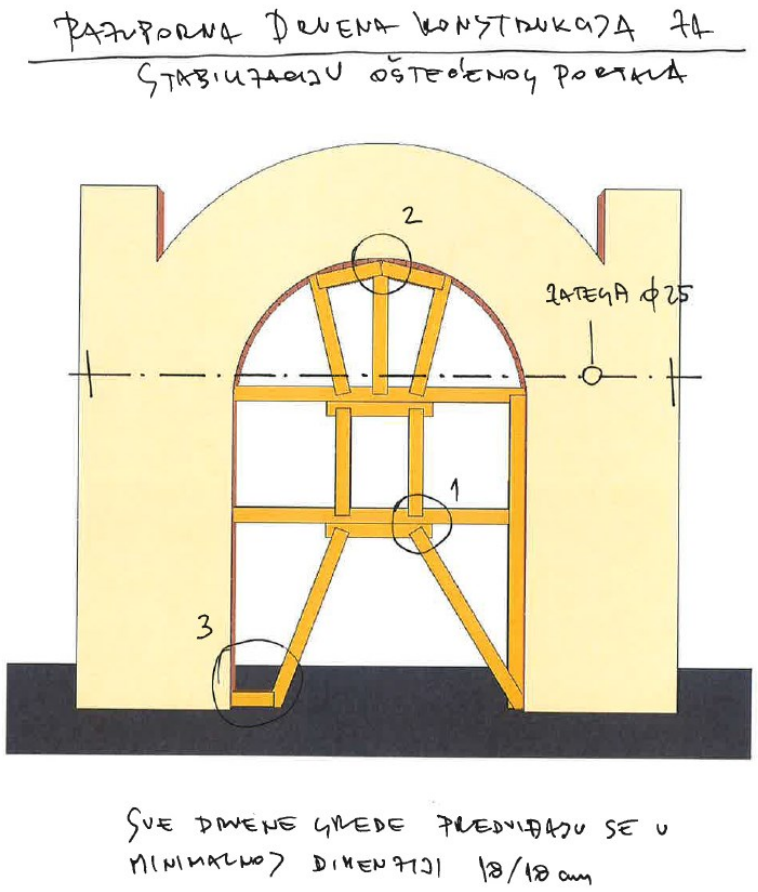
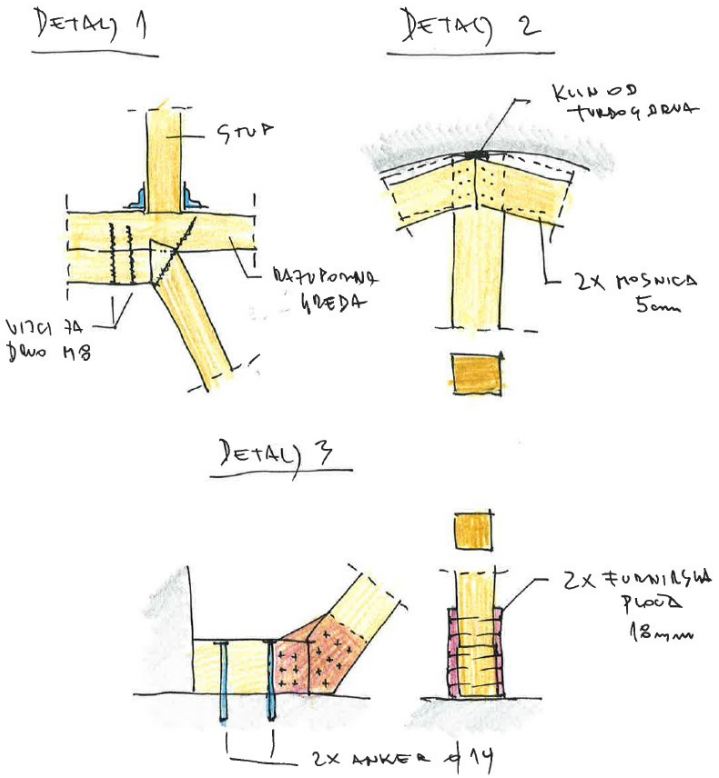






Urgent measures

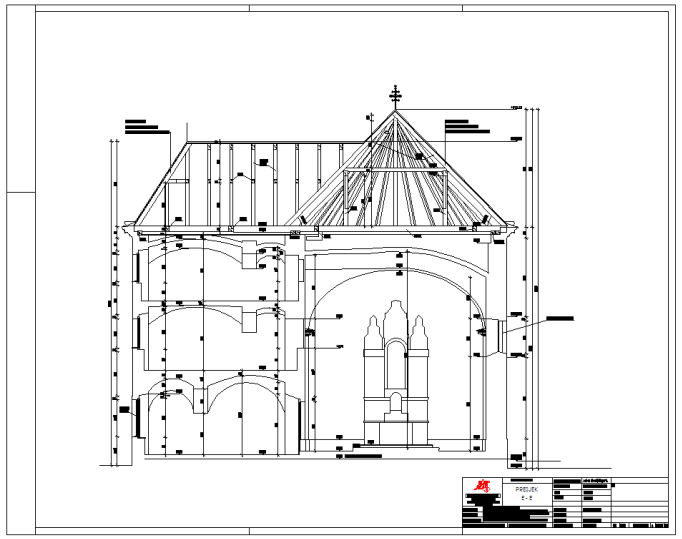
1. Anamnesis (History)

When it comes to heritage building structural interventions, a thorough

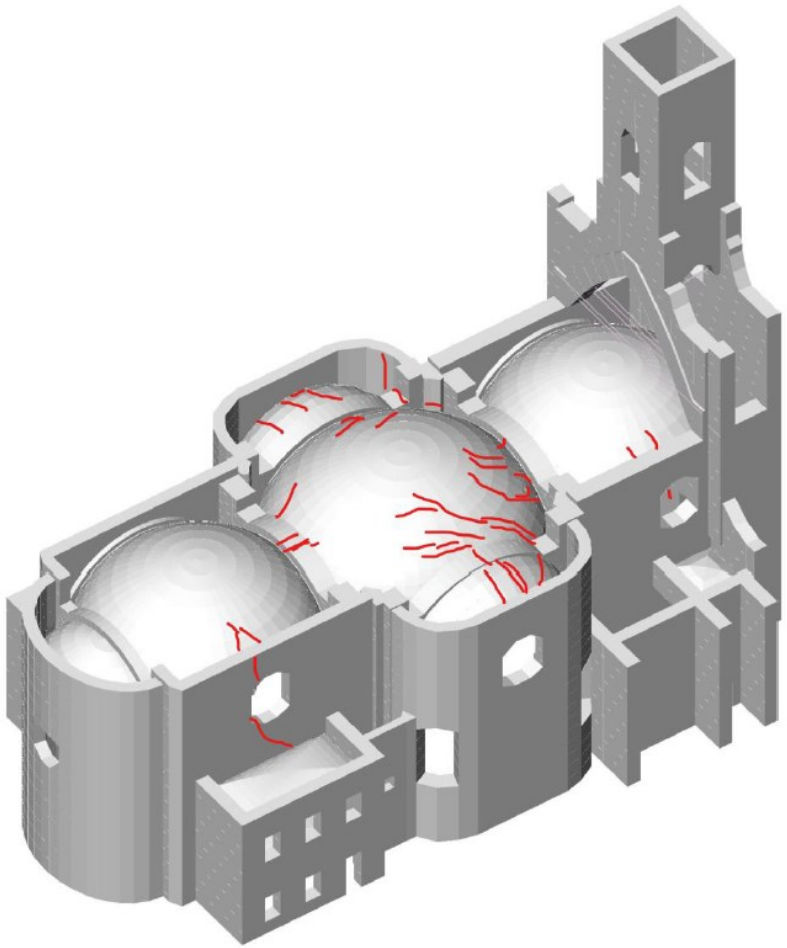
assessment is everything.

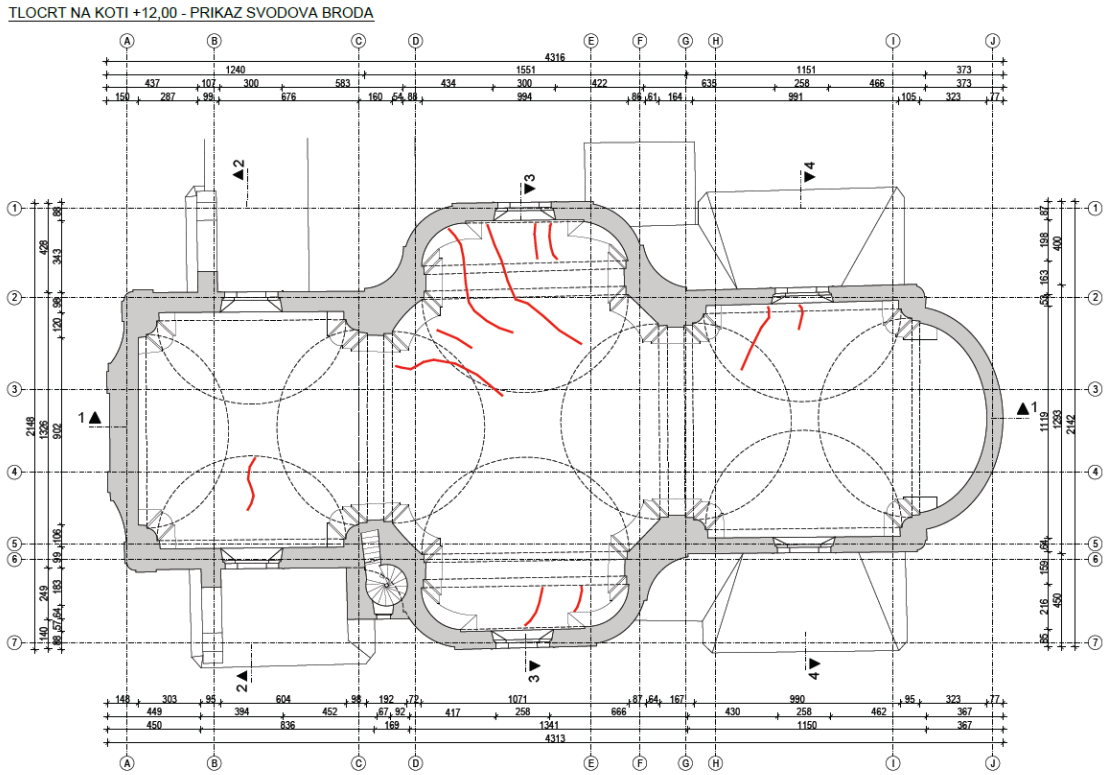
... the retrofitting measures just follow.

Architectural and BIM modeling

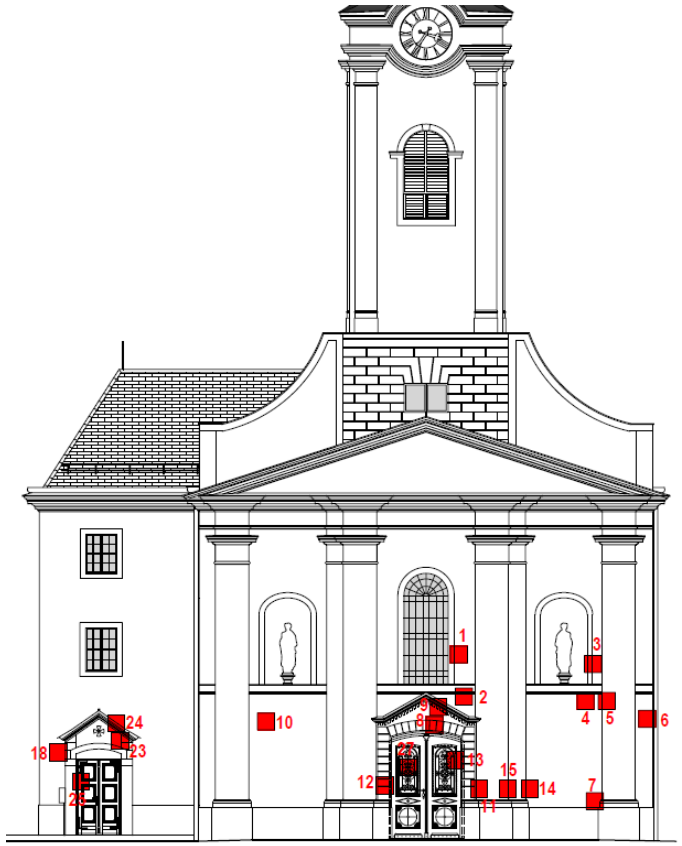


Cracks and Damage – Graphic plan

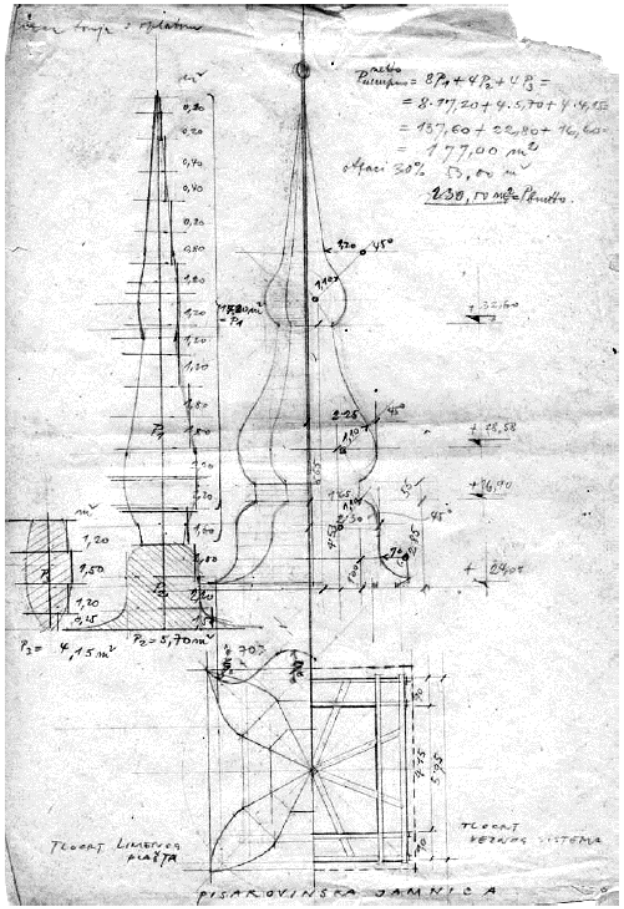




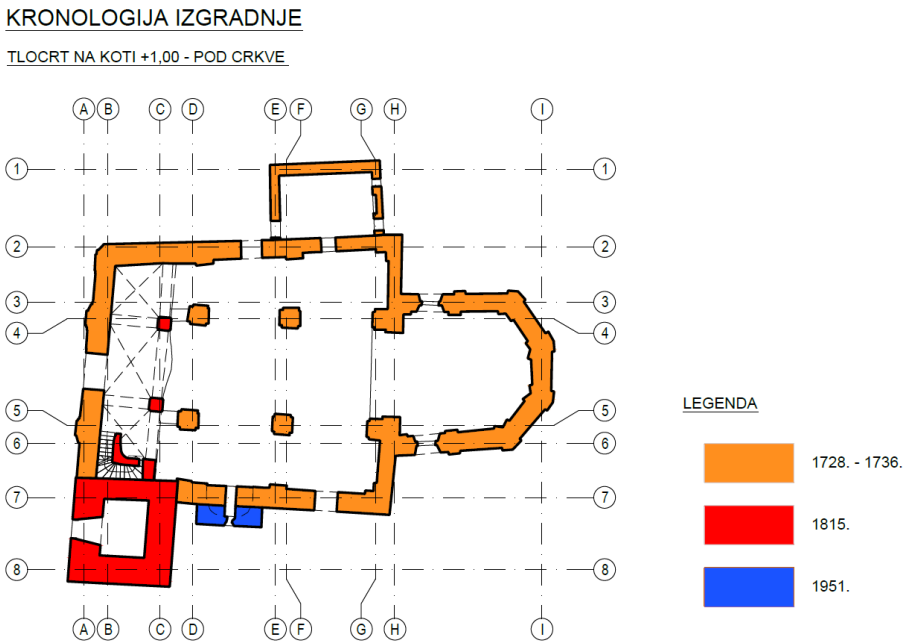
Conservation and restoration research

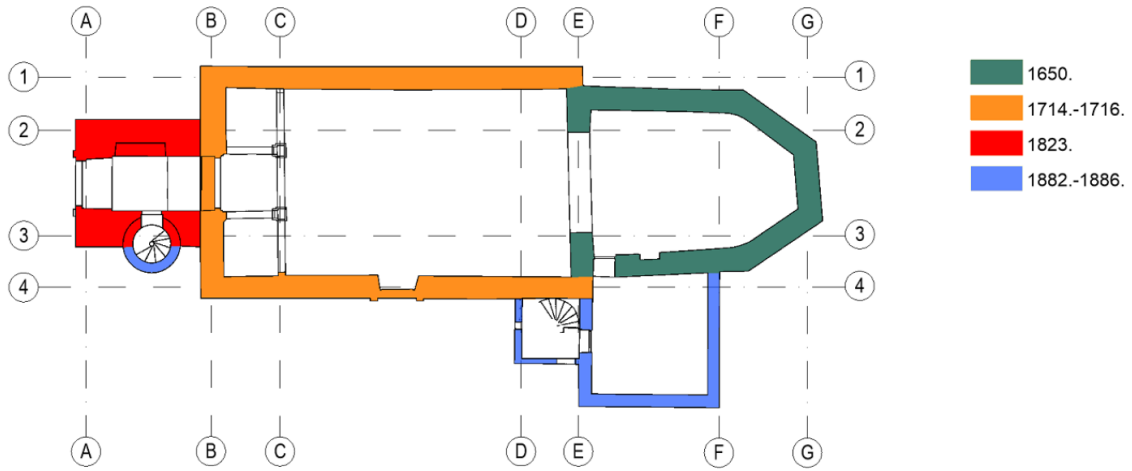


JUGOISTOČNO PROČELJE
POLOŽAJ SONDI
MJ 1:100, str. broj 12



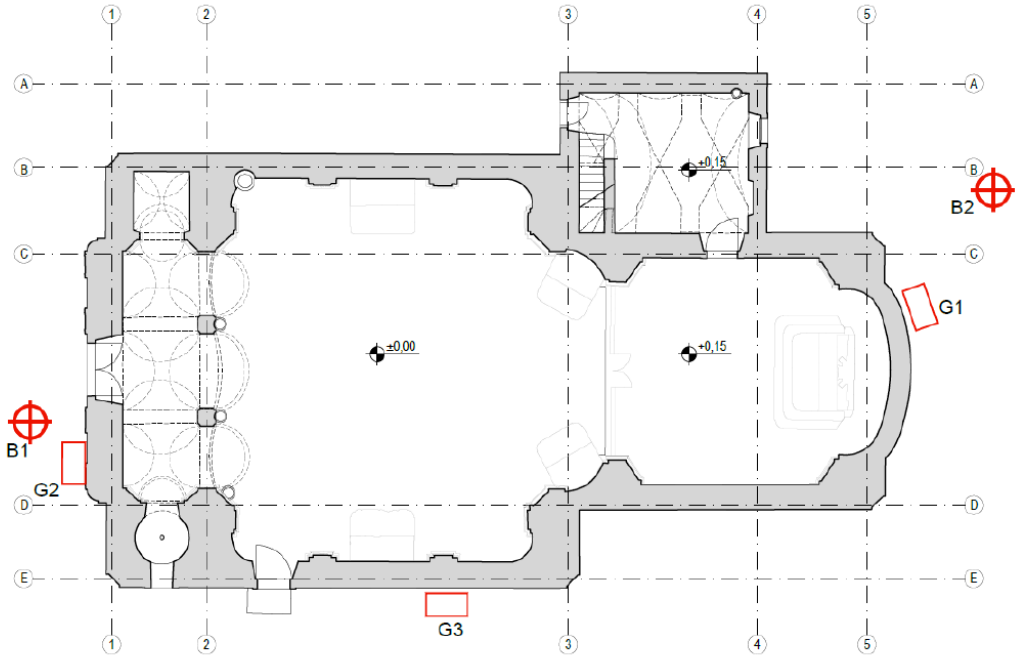
Construction Chronology



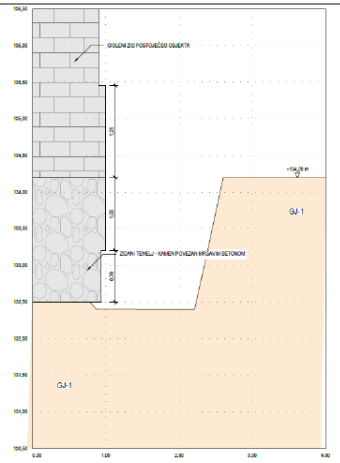


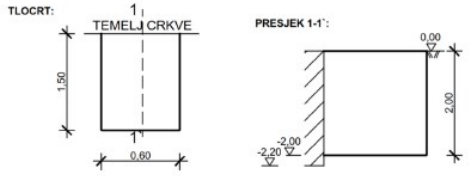
Slika 2-7 Povijesni prikaz dogradnji crkve

Geomechanical Investigation Works



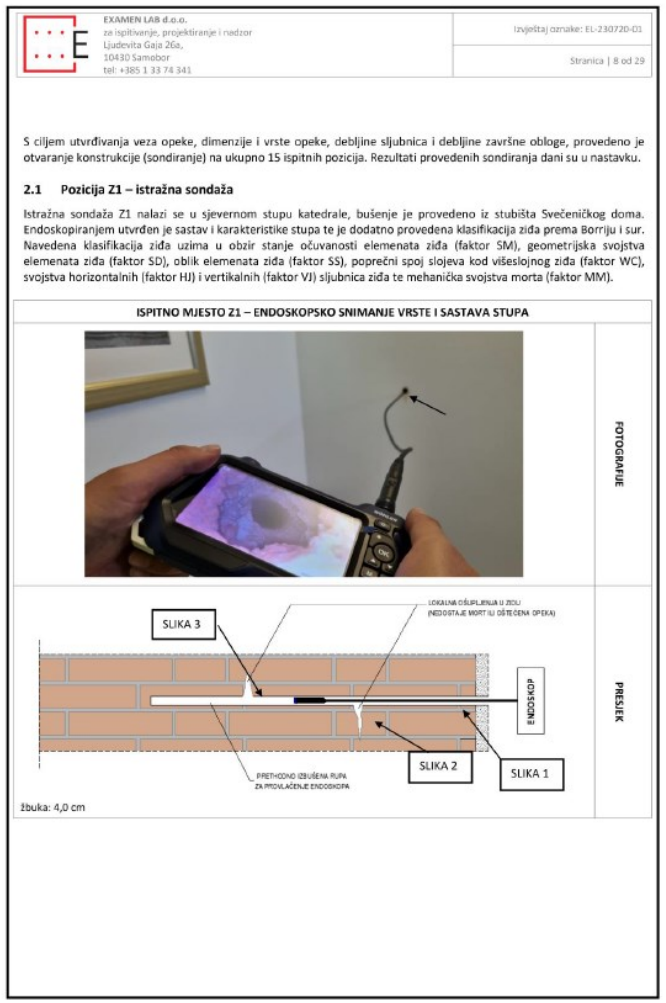
Slika 4-22 Položaj geotehničkih bušotina i istražnih jama

FOTOGRAFIJA	
POZICIJA	Temelj glavnog broda (na dijelu zvonika) na jugozapadnom pročelju.
OPIS	Temelj zvonika izveden je od kamena, bez proširenja (širina jednaka debljini zida), dubina temelja iznosi 1,7 m mjereno od razine terena.
SKICA	

FOTOGRAFIJA	
POZICIJA	Temelj zida apside na jugoistočnom pročelju.
SKICA	

Exploratory probes on the load-bearing structure

Wall Endoscopy



EXAMEN LAB d.o.o.
za ispitivanje, projektiranje i nadzor
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10430 Samobor
tel: +385 1 33 74 341

Izvještaj oznake: EL-230720-01

Stranica | 8 od 29

S ciljem utvrđivanja veza opeke, dimenzije i vrste opeke, debljine sljubnica i debljine završne obloge, provedeno je otvaranje konstrukcije (sondiranje) na ukupno 15 ispitnih pozicija. Rezultati provedenih sondiranja dani su u nastavku.

2.1 Pozicija Z1 – istražna sondaža

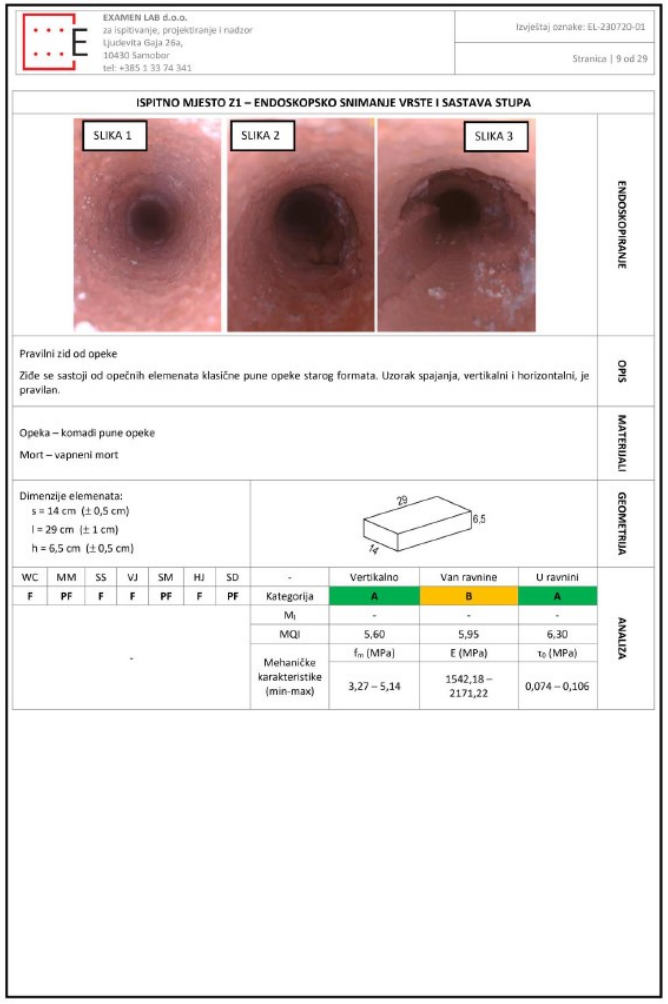
Istražna sondaža Z1 nalazi se u sjevernom stupu katedrale, bušenje je provedeno iz stubišta Svečeničkog doma. Endoskopiranjem utvrđen je sastav i karakteristike stupa te je dodatno provedena klasifikacija zida prema Borriju i sur. Navedena klasifikacija zida uzima u obzir stanje očuvanosti elemenata zida (faktor SM), geometrijska svojstva elemenata zida (faktor SD), oblik elemenata zida (faktor SS), poprečni spoj slojeva kod višeslojnog zida (faktor WC), svojstva horizontalnih (faktor HJ) i vertikalnih (faktor VJ) sljubnica zida te mehanička svojstva morta (faktor MM).

ISPITNO MJESTO Z1 – ENDOSKOPSKO SNIMANJE VRSTE I SASTAVA STUPA

FOTOGRAFIJE

PRESJEK

žbuka: 4,0 cm



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Izvještaj oznake: EL-230720-01

Stranica | 9 od 29

ISPITNO MJESTO Z1 – ENDOSKOPSKO SNIMANJE VRSTE I SASTAVA STUPA

ENDOSKOPIRANJE

OPIS

Pravilni zid od opeke

Zide se sastoji od opečnih elemenata klasične pune opeke starog formata. Uzorak spajanja, vertikalni i horizontalni, je pravilan.

MATERIJALI

Opeka – komadi pune opeke

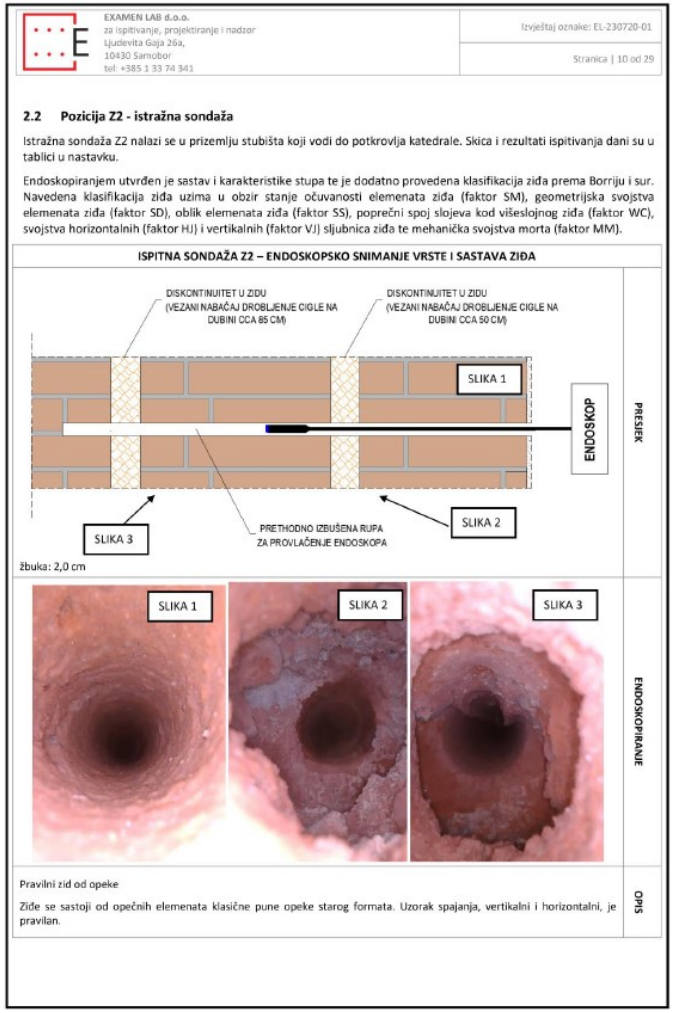
Mort – vapneni mort

GEOMETRIJA

Dimenzije elemenata:
s = 14 cm (± 0,5 cm)
l = 29 cm (± 1 cm)
h = 6,5 cm (± 0,5 cm)

ANALIZA

WC	MM	SS	VJ	SM	HJ	SD	-	Vertikalno	Van ravnine	U ravnini
F	PF	F	F	PF	F	PF	Kategorija	A	B	A
							M_I	-	-	-
							MQI	5,60	5,95	6,30
							Mehaničke karakteristike (min-max)	f_m (MPa)	E (MPa)	τ_0 (MPa)
								3,27 – 5,14	1542,18 – 2171,22	0,074 – 0,106



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10430 Samobor
tel: +385 1 33 74 341

Izvještaj oznake: EL-230720-01

Stranica | 10 od 29

2.2 Pozicija Z2 - istražna sondaža

Istražna sondaža Z2 nalazi se u prizemlju stubišta koji vodi do potkrovlja katedrale. Skica i rezultati ispitivanja dani su u tablici u nastavku.

Endoskopiranjem utvrđen je sastav i karakteristike stupa te je dodatno provedena klasifikacija zida prema Borriju i sur. Navedena klasifikacija zida uzima u obzir stanje očuvanosti elemenata zida (faktor SM), geometrijska svojstva elemenata zida (faktor SD), oblik elemenata zida (faktor SS), poprečni spoj slojeva kod višeslojnog zida (faktor WC), svojstva horizontalnih (faktor HJ) i vertikalnih (faktor VJ) sljubnica zida te mehanička svojstva morta (faktor MM).

ISPITNA SONDAŽA Z2 – ENDOSKOPSKO SNIMANJE VRSTE I SASTAVA ZIĐA

PRESJEK

žbuka: 2,0 cm

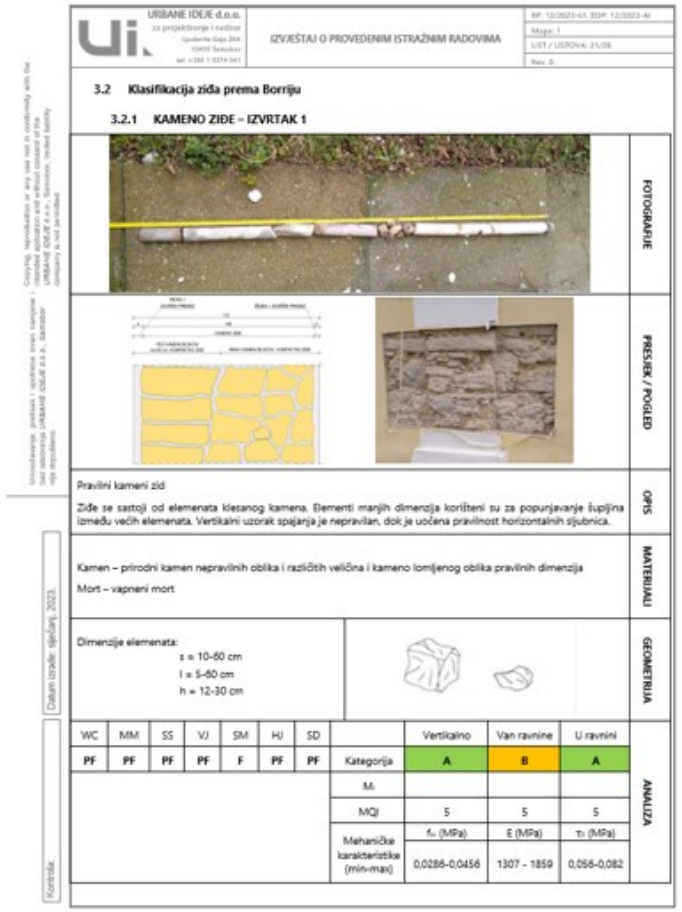
ENDOSKOPIRANJE

OPIS

Pravilni zid od opeke

Zide se sastoji od opečnih elemenata klasične pune opeke starog formata. Uzorak spajanja, vertikalni i horizontalni, je pravilan.

Wall Classification



URBANE IDEJE d.o.o.
za projektiranje i nadzor
IZVJEŠTAJ O PROVEDENIM ISTRAŽNIM RADOVIMA

3.2 Klasifikacija zida prema Borriju

3.2.1 KAMENO ZIĐE – IZVRTAK 1

FOTOGRAFIJE

PRESJEK / POGLED

OPIS

Pravilni kameni zid

Zide se sastoji od elemenata klesanog kamena. Elementi manjih dimenzija korišteni su za popunjavanje šupljina između većih elemenata. Vertikalni uzorak spajanja je nepravilan, dok je uočena pravilnost horizontalnih sljubnica.

MATERIJALI

Kamen – prirodni kamen nepravilnih oblika i različitih veličina i kameno lomljenog oblika pravilnih dimenzija

Mort – vapneni mort

GEOMETRIJA

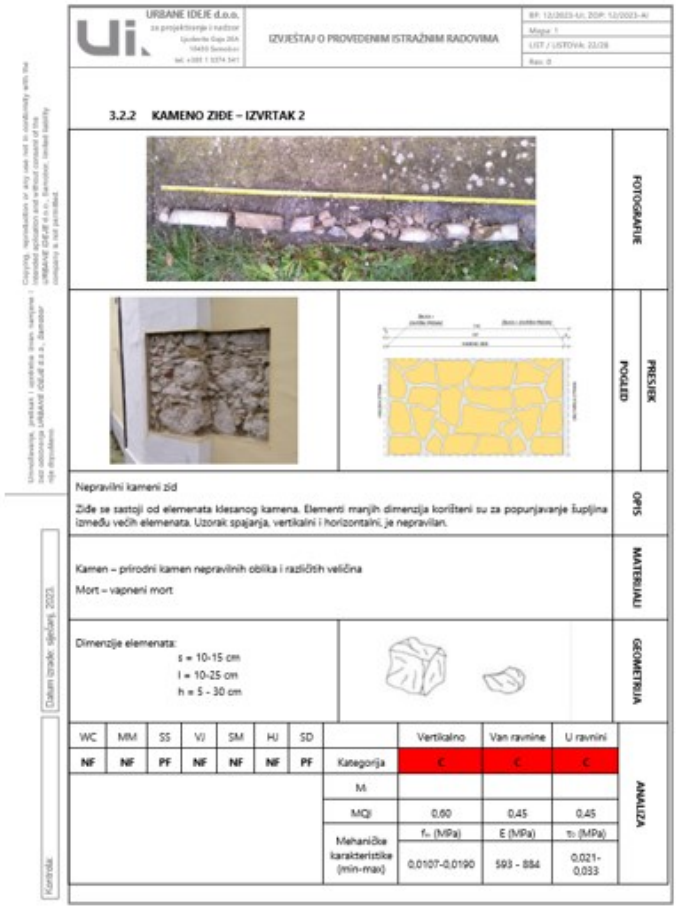
Dimenzije elemenata:
s = 10-60 cm
l = 5-60 cm
h = 12-30 cm

ANALIZA

WC	MM	SS	VJ	SM	HJ	SD		Vertikalno	Van ravnine	U ravnini
PF	PF	PF	PF	F	PF	PF	Kategorija	A	B	A
							M			
							MQI	5	5	5
							Mehaničke karakteristike (min-max)	f_m (MPa)	E (MPa)	τ_0 (MPa)
								0,0286-0,0456	1307 - 1859	0,056-0,082

Kontrola:

Datum izrade: siječanj, 2023.



URBANE IDEJE d.o.o.
za projektiranje i nadzor
IZVJEŠTAJ O PROVEDENIM ISTRAŽNIM RADOVIMA

3.2.2 KAMENO ZIĐE – IZVRTAK 2

FOTOGRAFIJE

PRESJEK / POGLED

OPIS

Nepravilni kameni zid

Zide se sastoji od elemenata klesanog kamena. Elementi manjih dimenzija korišteni su za popunjavanje šupljina između većih elemenata. Uzorak spajanja, vertikalni i horizontalni, je nepravilan.

MATERIJALI

Kamen – prirodni kamen nepravilnih oblika i različitih veličina

Mort – vapneni mort

GEOMETRIJA

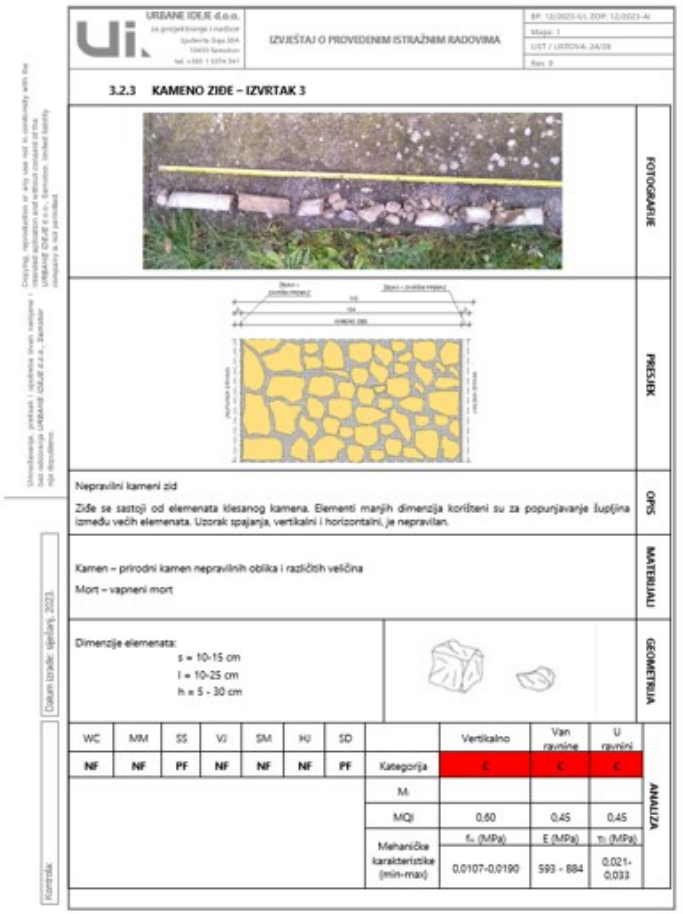
Dimenzije elemenata:
s = 10-15 cm
l = 10-25 cm
h = 5 - 30 cm

ANALIZA

WC	MM	SS	VJ	SM	HJ	SD		Vertikalno	Van ravnine	U ravnini
NF	NF	PF	NF	NF	NF	PF	Kategorija	C	C	C
							M			
							MQI	0,60	0,45	0,45
							Mehaničke karakteristike (min-max)	f_m (MPa)	E (MPa)	τ_0 (MPa)
								0,0107-0,0190	593 - 884	0,021-0,033

Kontrola:

Datum izrade: siječanj, 2023.



URBANE IDEJE d.o.o.
za projektiranje i nadzor
IZVJEŠTAJ O PROVEDENIM ISTRAŽNIM RADOVIMA

3.2.3 KAMENO ZIĐE – IZVRTAK 3

FOTOGRAFIJE

PRESJEK

OPIS

Nepravilni kameni zid

Zide se sastoji od elemenata klesanog kamena. Elementi manjih dimenzija korišteni su za popunjavanje šupljina između većih elemenata. Uzorak spajanja, vertikalni i horizontalni, je nepravilan.

MATERIJALI

Kamen – prirodni kamen nepravilnih oblika i različitih veličina

Mort – vapneni mort

GEOMETRIJA

Dimenzije elemenata:
s = 10-15 cm
l = 10-25 cm
h = 5 - 30 cm

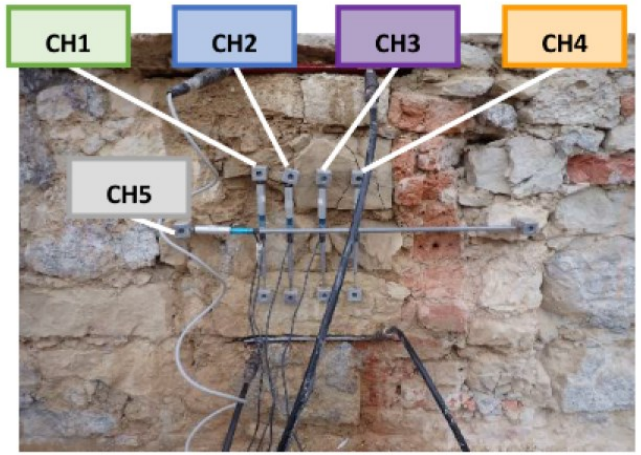
ANALIZA

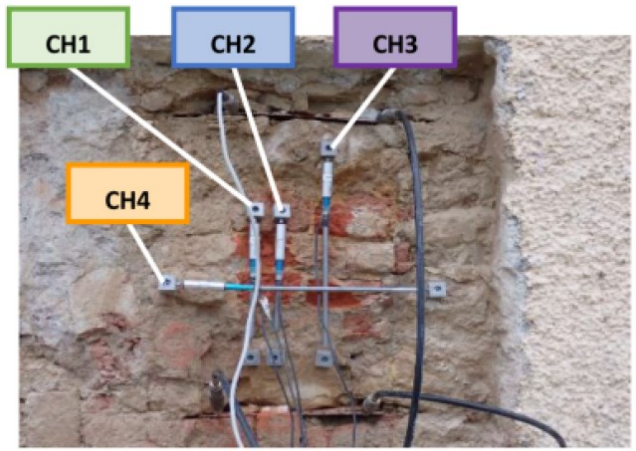
WC	MM	SS	VJ	SM	HJ	SD		Vertikalno	Van ravnine	U ravnini
NF	NF	PF	NF	NF	NF	PF	Kategorija	C	C	C
							M			
							MQI	0,60	0,45	0,45
							Mehaničke karakteristike (min-max)	f_m (MPa)	E (MPa)	τ_0 (MPa)
								0,0107-0,0190	593 - 884	0,021-0,033

Kontrola:

Datum izrade: siječanj, 2023.

Double ‘Flat-jack’





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TEST REPORT N. R2022/0172

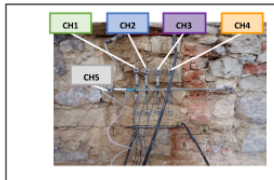
Pag. 1/4

Registry nr.:	101/2022
Job nr.:	221019_ARH
Customer:	Studio Arhing d.o.o.
Person in charge:	Dipl. Ing. Grad. Juraj Pojatina Role: commissioned structural engineer
Site:	Crkva Uznesenja Blažene Djevice Marije
Address:	Pokupsko 28, 10414, Pokupsko - Croatia

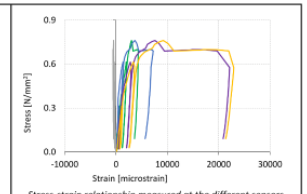
DOUBLE FLAT JACK TEST

ASTM C1197-14a

Test n.	**DFJ.01**	**Test date:**	29/11/2022	**Time:**		14.05	
Flat jack type[1]:	CON009-010	**Flat jack dim.[2]:**	350x260 mm	$K_{m,sup}$[3] =	0.887	$K_{s,sup}$[4] =	1
Masonry type[5]:	MIS	**Construction date[6]:**	NN	$K_{m,inf}$[3] =	0.898	$K_{s,inf}$[4] =	1
Maximum applied stress [N/mm²]:	0.70	**Load step cycle [N/mm²]:**		0.30			
Use of shims[7]:	No	**Ambient conditions[8]:**	4°C/70%	**Linear response limit[9]:**		-	

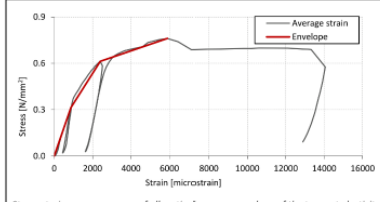


Sensors' layout



Stress-strain relationship measured at the different sensors

Tangent elasticity moduli E_{tan}



Stress-strain curves, average of all vertical sensors, envelope of the tangent elasticity modulus

E_{tan} [N/mm²]	Δ_{STRESS} [N/mm²]
358	0.00 - 0.31
197	0.31 - 0.61
42	0.61 - 0.76

Padova, Italy, 01/12/2022

Test execution
Filippo Casarin, MSc, PhD

The laboratory director
Filippo Casarin, MSc, PhD

Laboratory for tests and controls on existing structures construction materials (c-bis) art. 59, par. 2, D.P.R. n. 380/2001 and circular nr. 633/STC - 03/12/2019 – Sectors A, C and facultative test methods (for the exhaustive list of authorized test methods see www.expin.it/autorizzazioni-e-certificazioni).

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TEST REPORT N. R2022/0172

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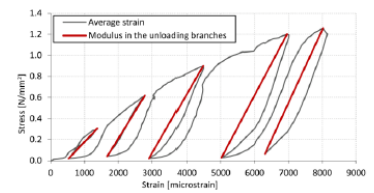
DOUBLE FLAT JACK TEST

ASTM C1197-14a

Modulus of elasticity in the unloading branches E



Stress-strain curves, average of all vertical sensors, visualization of the Young's modulus E in the unloading branches

E [N/mm²]	Δσ [N/mm²]
338	0.02 - 0.31
518	0.04 - 0.62
559	0.02 - 0.90
605	0.03 - 1.20
695	0.06 - 1.26

The Annex "Test Localization" indicates the points of execution of the tests, and is an integral part of this certificate

Notes[10]: Test performed with three vertical sensors

Observations[11]: ND

Cut executed by using a gasoline powered ring saw (EXP040)

Employed instrumentation: EXP010, EXP033÷EXP037

Key:

1) type of flat jack used: [C] semicircular; [R] rectangular

2) flat jack dimensions: [LxP] Width by Depth in mm

3) conversion factor relating internal fluid pressure to applied stress

4) ratio of measured area of the flatjack to the average measured area of the slot

5) masonry type (see italian standard NTC2018 for reference, TAB C8.5.I): [PD] irregular stone rubble masonry; [CB] roughly shaped two-layered stone masonry; [PS] coursed stone masonry with proper arrangement; [TI] irregular soft stone masonry; [TR] regular soft stone masonry; [LS] Ashlar fine masonry; [MP] solid brickwork masonry; [MS] hollow brickwork masonry; [MIS] mixed stone/brickwork masonry; [BS] regular concrete blocks masonry

6) period of construction of the building/infrastructure or [NN] unknown

7) use of shims between flat jack and masonry: [Yes/No]

8) ambient conditions [T/RH] at the time of testing

9) "elastic" response limit stress level (stress value above which the stress-strain relationship manifests a visible and properly identifiable stiffness decrease) in N/mm² or [NN] non detectable

10) description of any deviations from the standard method, of all variations, additions or exclusions to the test specification and any anomalies found or [ND] nothing to declare

11) information provided by the applicant or detected by the laboratory concerning documentation and any other form of identification and qualification of the material or [ND] nothing to declare

Padova, Italy, 01/12/2022

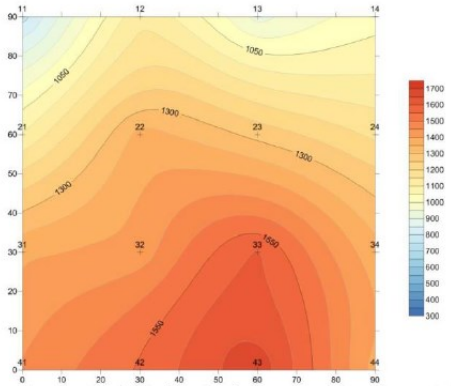
Test execution
Filippo Casarin, MSc, PhD

The laboratory director
Filippo Casarin, MSc, PhD

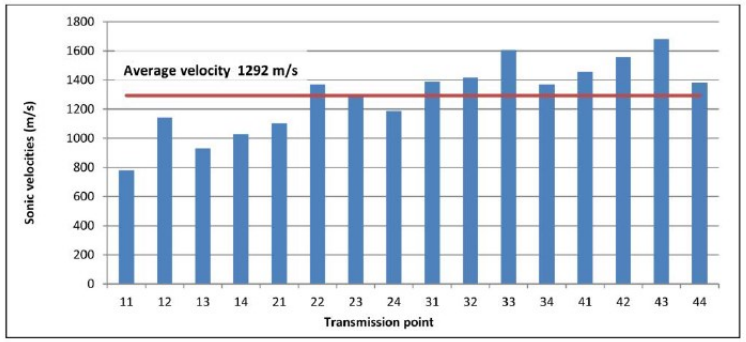
Laboratory for tests and controls on existing structures construction materials (c-bis) art. 59, par. 2, D.P.R. n. 380/2001 and circular nr. 633/STC - 03/12/2019 – Sectors A, C

Ultrasonic Wall Testing

SO.01			
Test date:	29/11/2022	Surface preparation[2]:	N
Time:	8:20	Transmission method[3]:	D
Element type[1]:	M	Grid – points mesh[4] [cm]:	4x4 30x30
The Annex "Test Localization" indicates the points of execution of the tests, and is an integral part of this certificate			
Notes[5]: ND			
Observations [6]: ND			
Employed instrumentation: EXP164, EXP165			

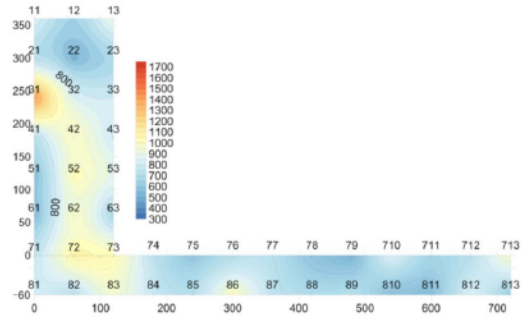


SO.01, mapping of sonic velocities (data in m/s, front view of the wall, transmission side)

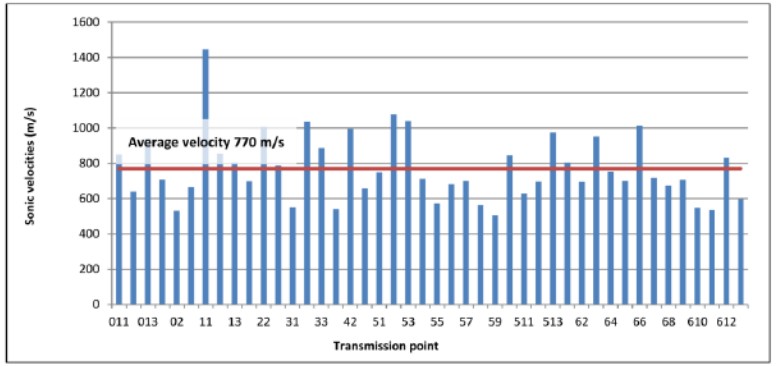


Histogram of average sonic velocities, sonic test SO.01 (data in m/s)

SO.02			
Test date:	29/11/2022	Surface preparation[2]:	N
Time:	10:20	Transmission method[3]:	D
Element type[1]:	M	Grid – points mesh[4] [cm]:	8x13 60x60
The Annex "Test Localization" indicates the points of execution of the tests, and is an integral part of this certificate			
Notes[5]: ND			
Observations [6]: ND			
Employed instrumentation: EXP164, EXP165			

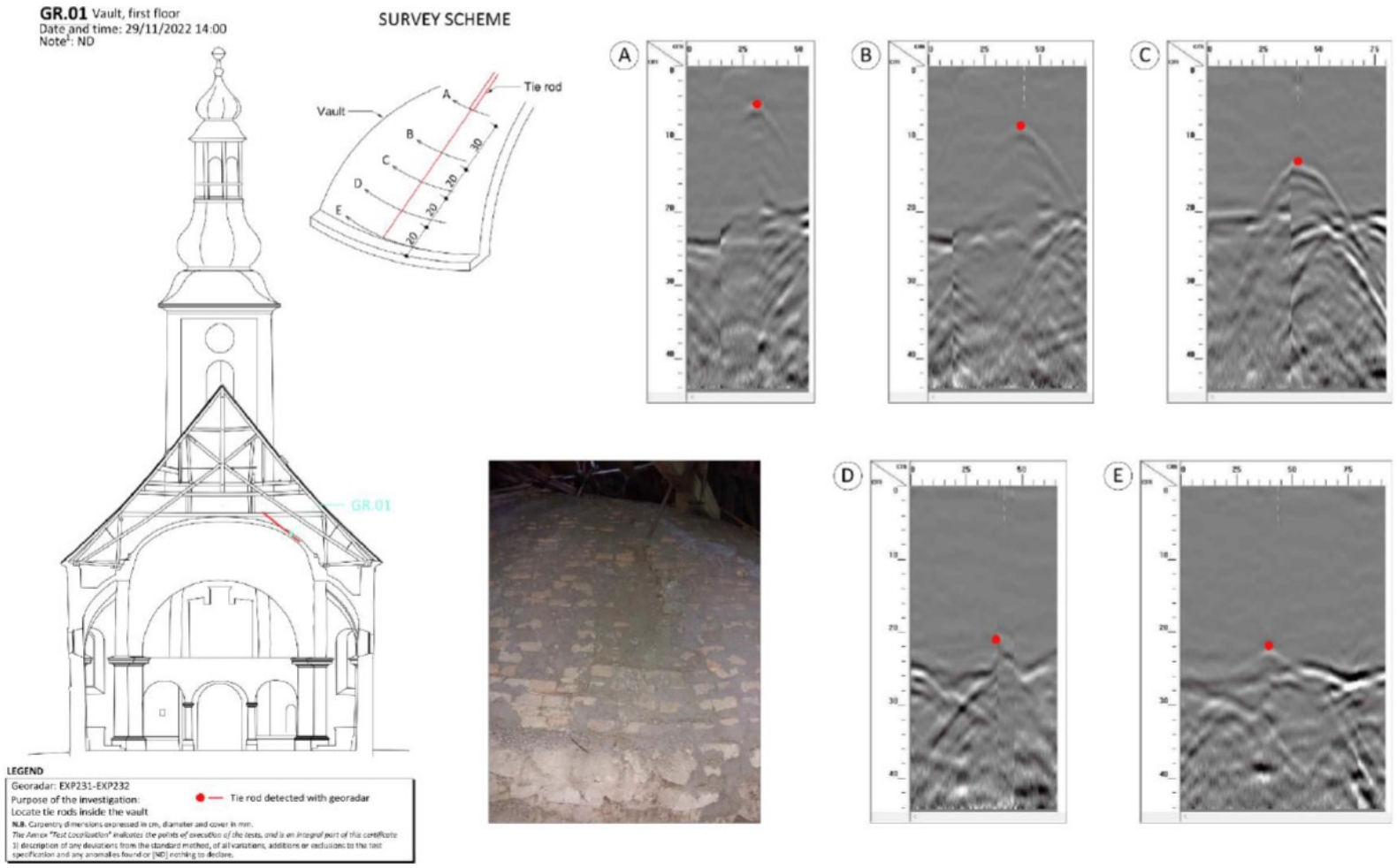


SO.02, mapping of sonic velocities (data in m/s, front view of the wall, transmission side)

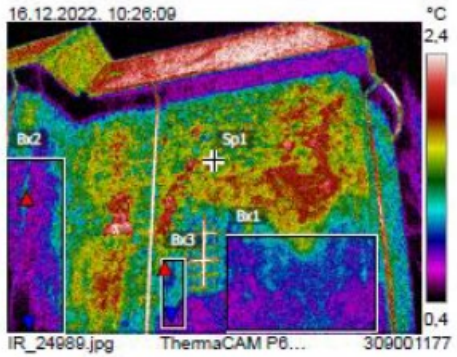


Histogram of average sonic velocities, sonic test SO.02 i (data in m/s)

Ground-penetrating radar (GPR)



Termography



Measurements

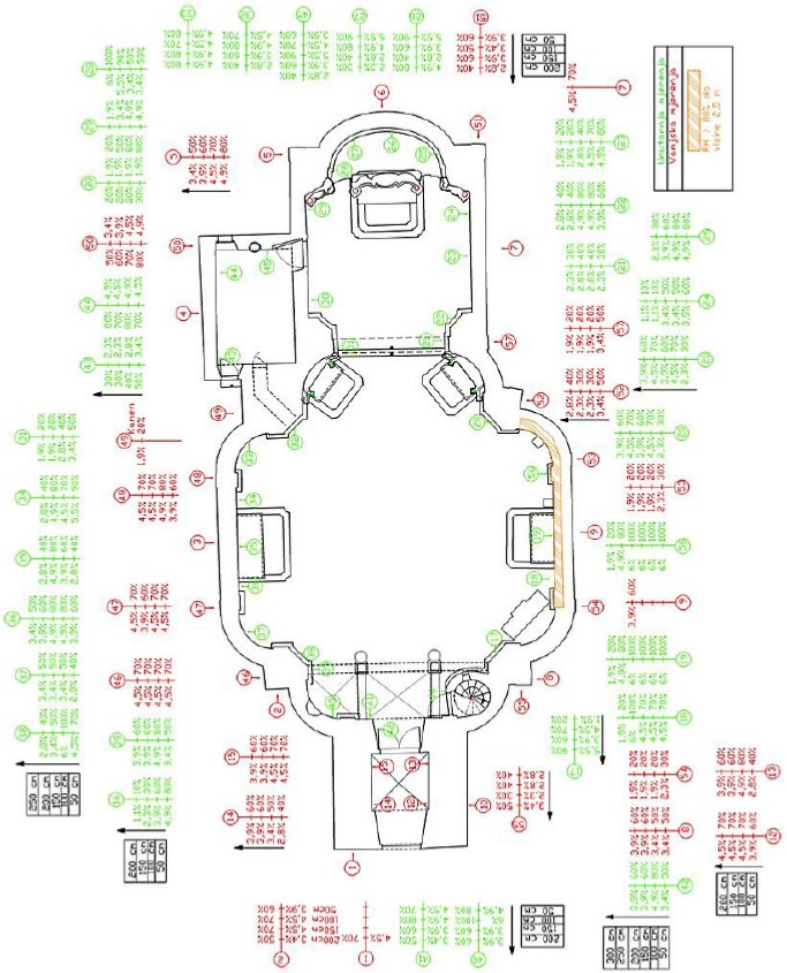
Bx1	Max	1,9 °C
	Min	- 1,5 °C
	Average	0,9 °C
Bx2	Max	1,9 °C
	Min	- 1,1 °C
	Average	0,7 °C
Bx3	Max	1,6 °C
	Min	0,2 °C
	Average	1,0 °C
Sp1		1,9 °C

Parameters

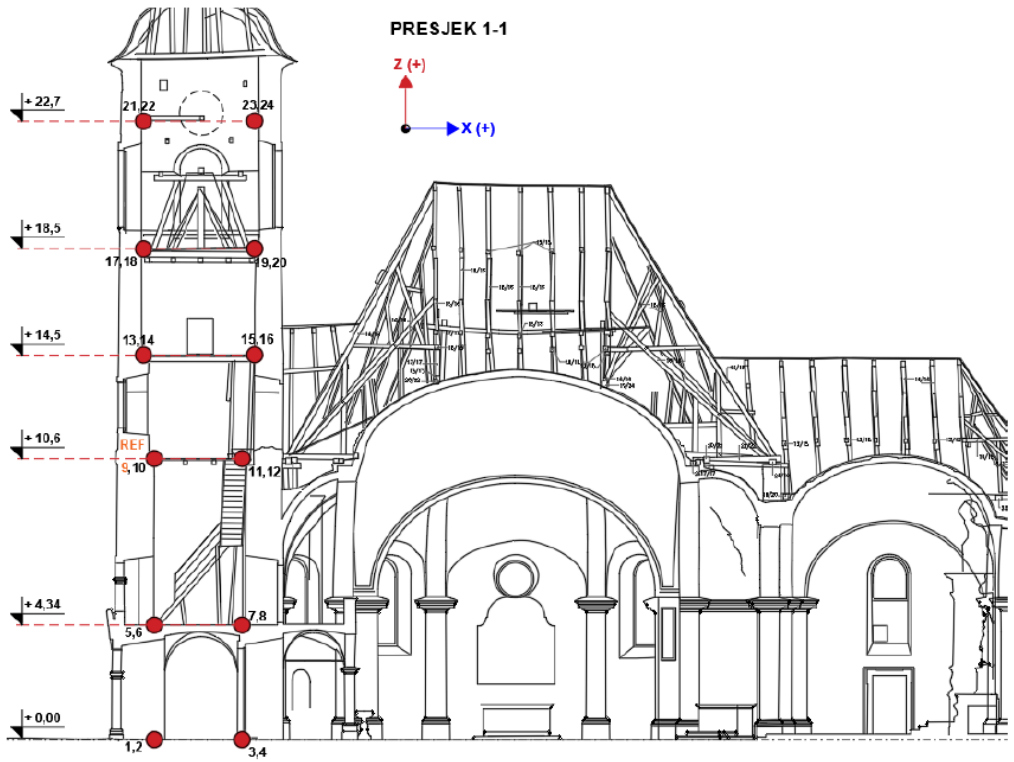
Emissivity	0.95
Refl. temp.	13 °C

Note

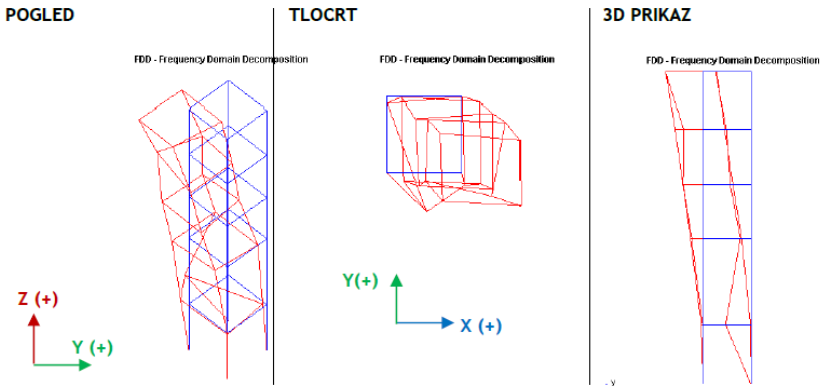
Pozicija 58
Anomalija u polju temperatura ukazuje na vlažno područje (Bx1-Bx3).
različite žbuke, boje fasade, oštećena žbuka



Dinamic ambient vibration testing

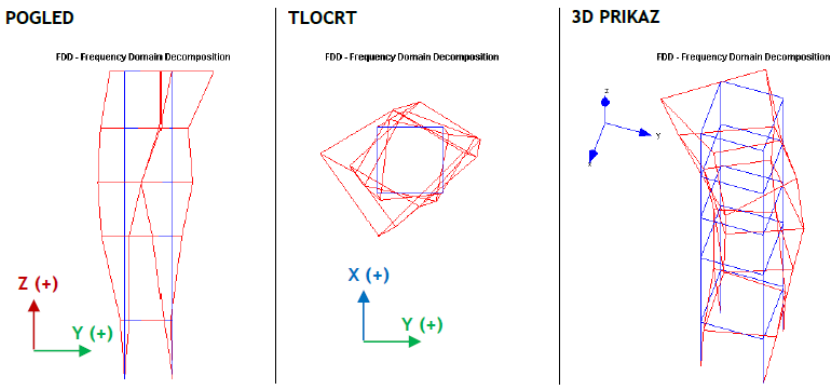


Slika 4-42 Shema mjernih mjesta za mjerenje dinamičkih parametara zvonika – PRESJEK 1-1



Slika 4-45 Eksperimentalno određeni oblik titranja s pripadajućom vlastitom frekvencijom

[Ton 1 = 1,781 Hz]



Slika 4-46 Eksperimentalno određeni oblik titranja s pripadajućom vlastitom frekvencijom

[Ton 2 = 4,094 Hz]

Chemical Analysis Of Mortar

Dr. Davide Melica
Diagnostica per il Restauro
e la Conservazione

SAMPLE MA.01 SHEET

Sample type : *fragment of brown bedding mortar*

Sampling zone : *-*

Aim of the analysis : *definition of compositional, textural and microstructural properties*

Performed analysis : *optical microscopy with polarized transmitted light*

MACROSCOPIC FEATURES OF THE SAMPLE		
1	Tipology	mortar
2	Dimensional appearance	coarse sand
3	Structural appearance	homogeneous
4	Color	
4.1.	○ whole color	brown
4.2.	○ grains	dark grey
5	Coesion (empiric evaluation)	medium (sample breaks without disgregating)
6	Decay products	not recognizable

Optical microscopy on thin section (petrographic examination)

MICROSCOPIC FEATURES OF THE BINDER		
1	Mineralogical composition	The binding matrix shows a high-order interference colour (hazel-brown) characteristic of calcium carbonate ($CaCO_3$) in the form of calcite; it is therefore attributed to the carbonation process of an aerial lime.
2	Structure	weakly lumpy
3	Texture	micritic ((crystal size <4 μm)
4	Interactions with the aggregate	absent
5	Porosity	
5.1.	○ tipology	pores and few microcracks
5.2.	○ ubication	intergranular (inside the groundmass or at the edge of the hgrains))
5.3.	○ % (by volume)	low (~15%)
5.4.	○ origin	primary (mainly formed during the shrinkage and hardening phases) and secondary (due to degradation processes)

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3

Dr. Davide Melica
Diagnostica per il Restauro
e la Conservazione

MICROSCOPIC FEATURES OF THE AGGREGATE		
1	Size	
1.1.	○ dimensional range (estimated values)	Grain size varies from coarse silt to fine gravel (0.03-3.6 mm) but it mainly falls in the fine sand (0.15-0.25 mm) and in the coarse sand (0.6-0.85 mm) classes – bimodal distribution; it spreads in the different fractions as listed below:

size classes	%
fine gravel (2-4 mm)	5
very coarse sand (1-2 mm)	10
coarse sand (0.5-1 mm)	25
medium sand (0.25-0.5 mm)	15
fine sand (0.125-0.25 mm)	25
very fine sand (0.062-0.125 mm)	10
coarse silt (0.031-0.062 mm)	10

For the reconstruction of the mortar, a sieved aggregate with a composition similar to that described below (point 6) shall be used consisting of:

size classes	%
residue on the sieve 2 mm mesh	5
residue on the sieve 1 mm mesh	10
residue on the sieve 0.5 mm mesh	25
residue on the sieve 0.25 mm mesh	15
residue on the sieve 0.125 mm mesh	25
residue on the sieve 0.062 mm mesh	10
residue on the sieve 0.031 mm mesh	10

1.2.	○ sorting	high
2	Shape (rounding and sphericity)	rounding: sub-rounded or rounded; sphericity: from medium or low
3	Surface morphology	smooth or slowly faceted
4	Orientation	absent
5	Distribution	homogeneous

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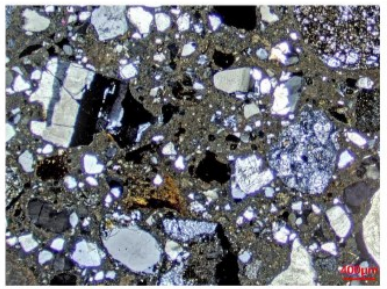
6	Composition (% by volume) (estimated values)	Aggregate has a silicatic composition; in order of decreasing abundance it spreads as listed below:

rocks or mineral types	%
• fragments of metamorphic rocks (gneisses, quartzites) consisting of quartz associated with feldspars and/or micas; each mineralogical component also appears in isolated single crystals in the binding matrix	50
• flint and flinty marls	45
• particles of clay and iron hydroxides	5
• fragments of sedimentary rocks (sparitic limestone with microfossils)	tracce

7	Admixtures	absent
8	Binder/Aggregate Ratio (by volume)	= 1:2.5

CONCLUSIONS		
1	Mixture characterization	It is a mortar consisting of carbonated aerial lime and silicatic river sand. The binding matrix has a weakly lumpy structure. The sandy aggregate is composed of metamorphic lithotypes (quartzites, gneisses) and flint; it also contains a fair amount of clay and iron hydroxides indicative of poor washing. The size of the clasts has a bimodal distribution; they fall predominantly in the fine sand class (0.15-0.25 mm) and in the coarse sand class (0.6-0.85 mm); some of them exceed 3.5 mm. The binder/aggregate ratio is 1:2.5 by volume. i
2	Secondary processes and decay products	No evidence of degradation at the expense of the binder matrix or aggregate is observed.



sample MA.01: thin section microphotograph (transmitted light, X polars).

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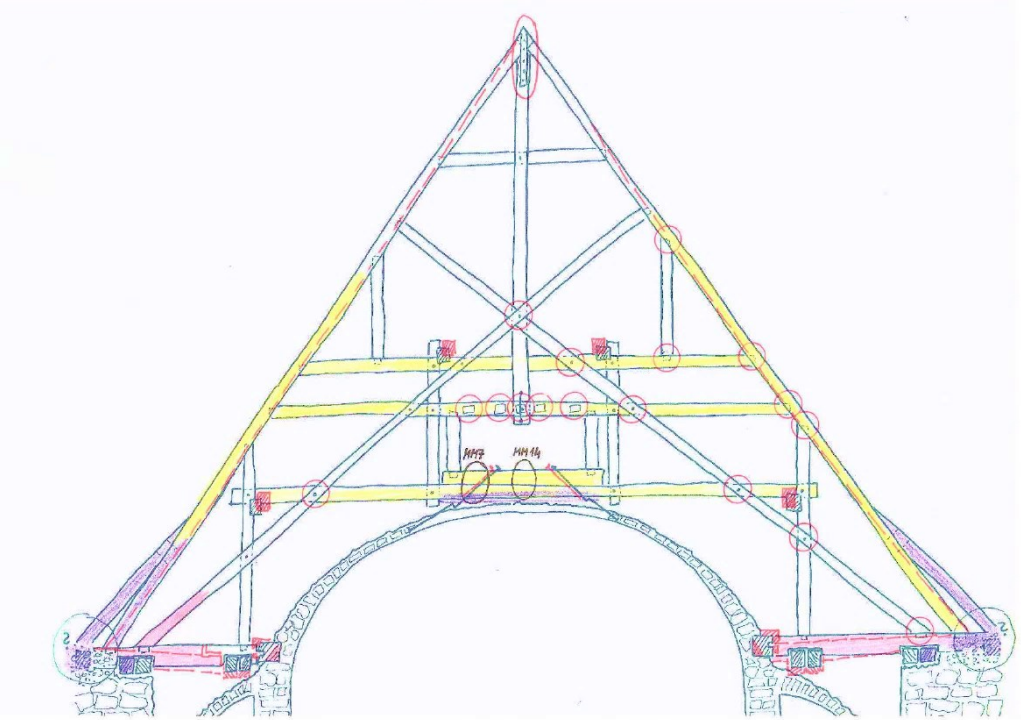
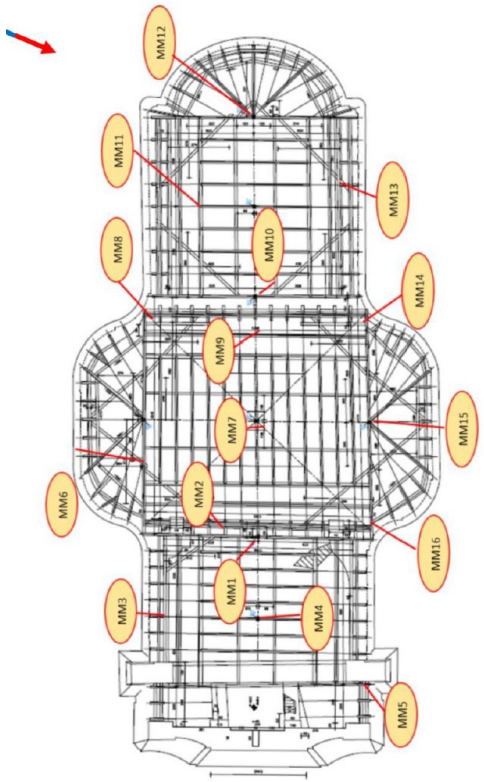
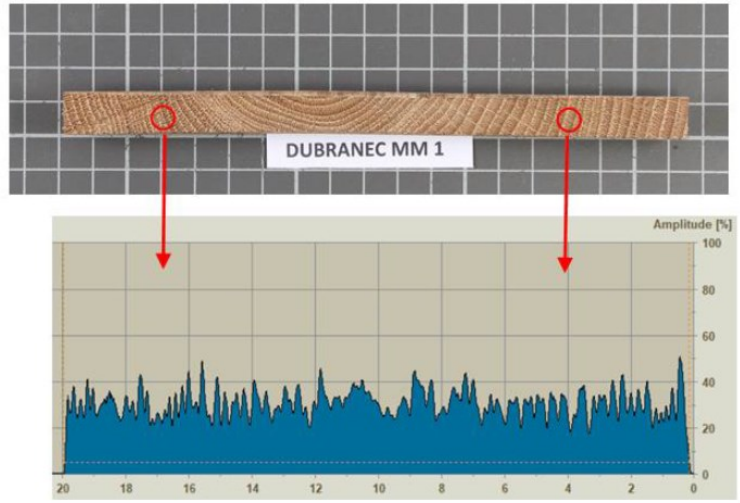
5

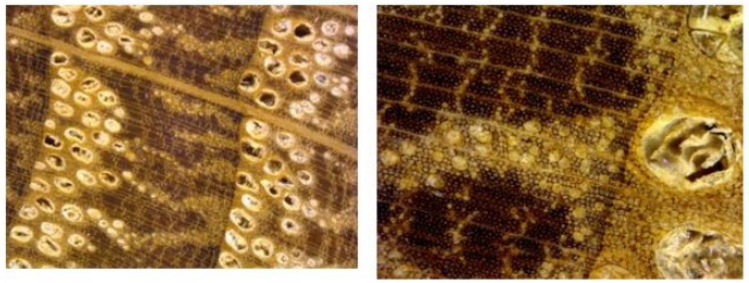
Timber Assessment





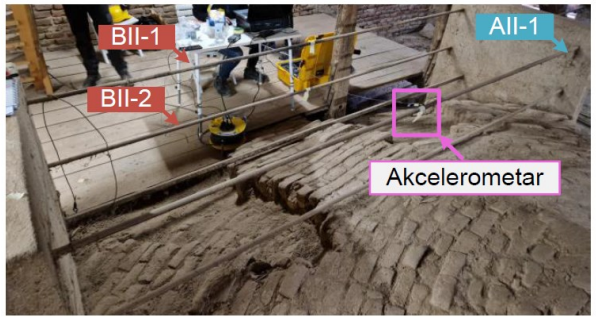


Slika 12 a) i b). Mjerno mjesto MM 1, vezna greda do tornja, izvrtak 12,5 mm. Potpuno zdrav i kompaktan presjek pokazuje ravnomjeran raspored i gustoću godova (gore, slika a) i primjeren otpor prodiranju rezistografske igle (dijagram).



Slika 13 a) i b). Mikrografije pokazuju ravnomjeran, višeredan raspored pora u ranom drvu i vrlo gusto kasno drvo s radijalnim nizovima uskih pora (10x, lijevo), te velike pore ranog drva zapunjene tilama, kao i zdrav paratrahealni parenhim kako u ranom, tako i kasnom drvu (desno, 50x)

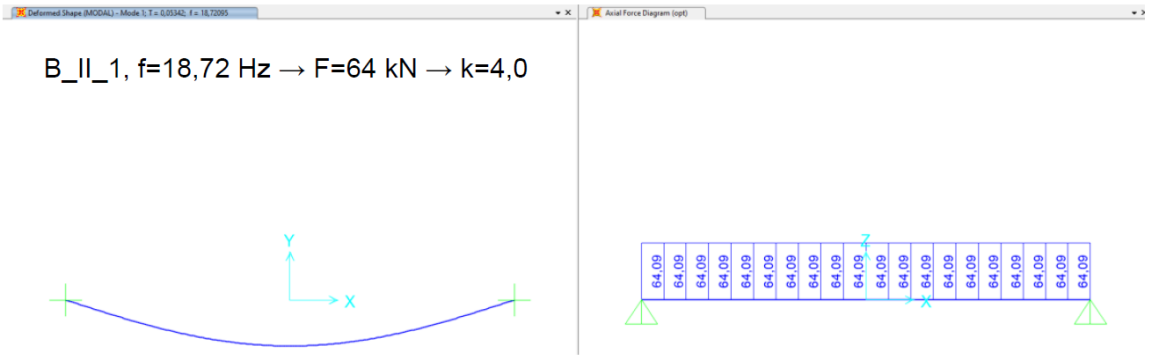
Force Measurement In Steel Ties



a)

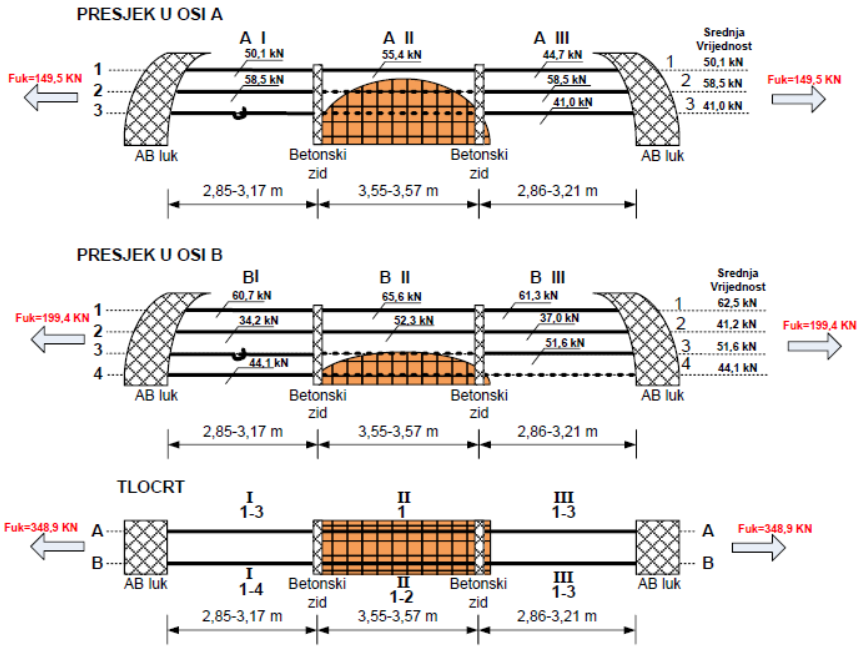
b)

Slika 4-40 (a) Mjerenje vlastite frekvencije zatega u ravnini 2 s označenim akcelerometrom i (b) Smjer mjerenja vlastite frekvencije zatege



Tablica 4-5 Usvojene vrijednosti koeficijenta k

A	I	II	III	Srednja vrijednost (kN)
1	50,1	55,4	44,7	50,1
2	58,5	-	58,5	58,5
3	-	-	41,0	41,0
			Srednja vrijednost (kN)	49,8
B	I	II	III	Srednja vrijednost (kN)
1	60.7	65.6	61.3	62.5
2	34.2	52.3	37.0	41.2
3	-	-	51.6	51.6
4	44.1	-	-	44,1
			Srednja vrijednost (kN)	49,9

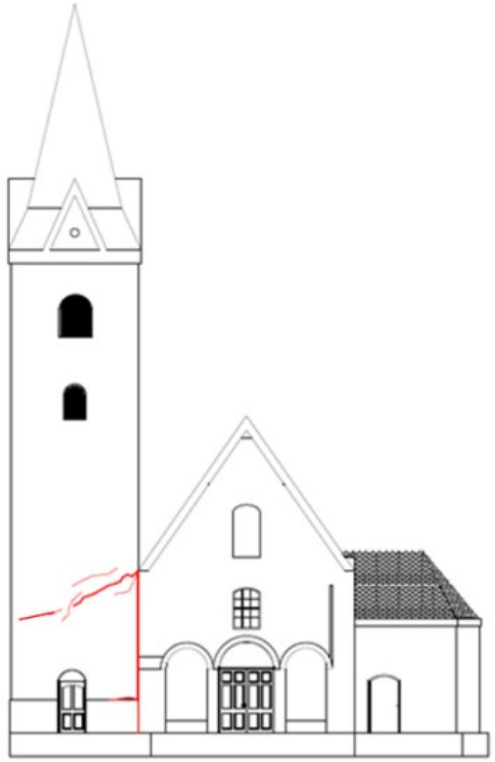


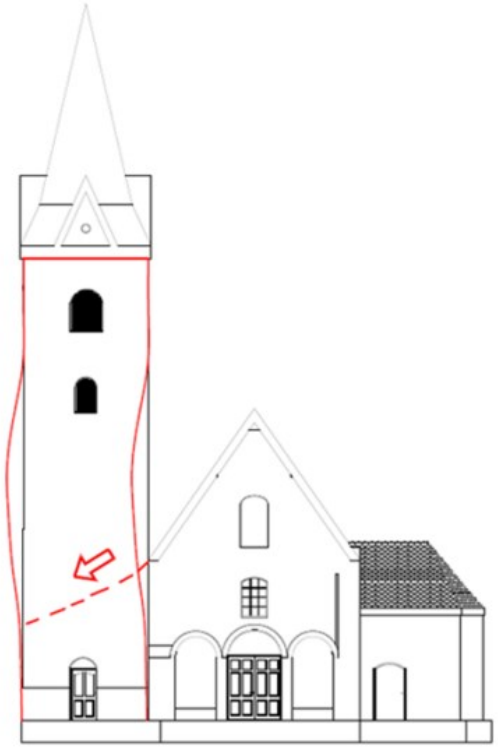
Slika 4-42 Izračunate vrijednosti sila u zategama

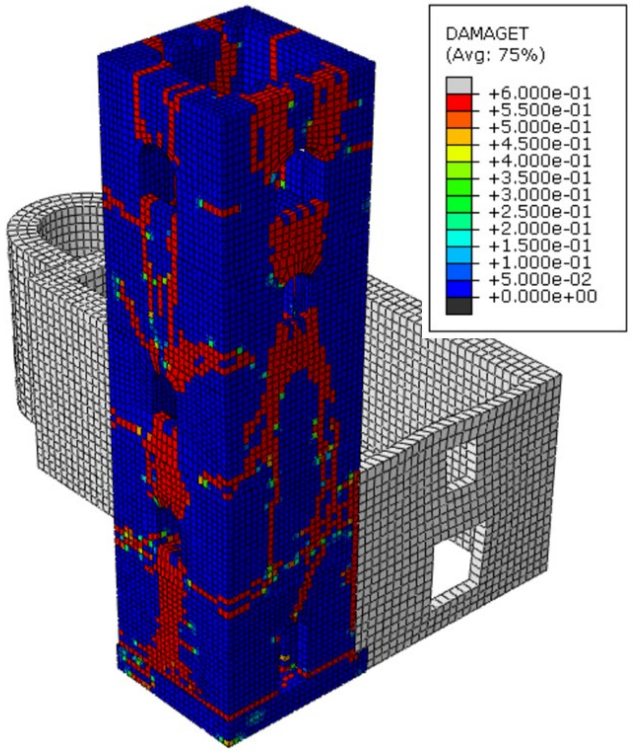
Archeology

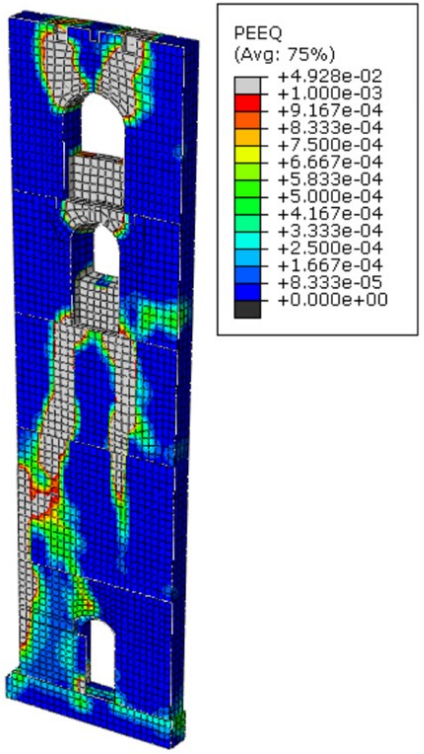
2. Diagnosis

Seismic Analysis

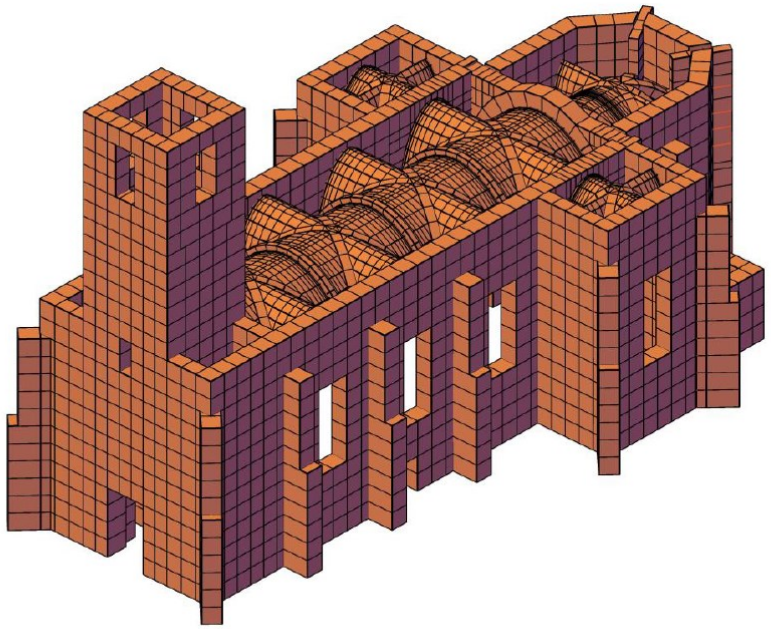




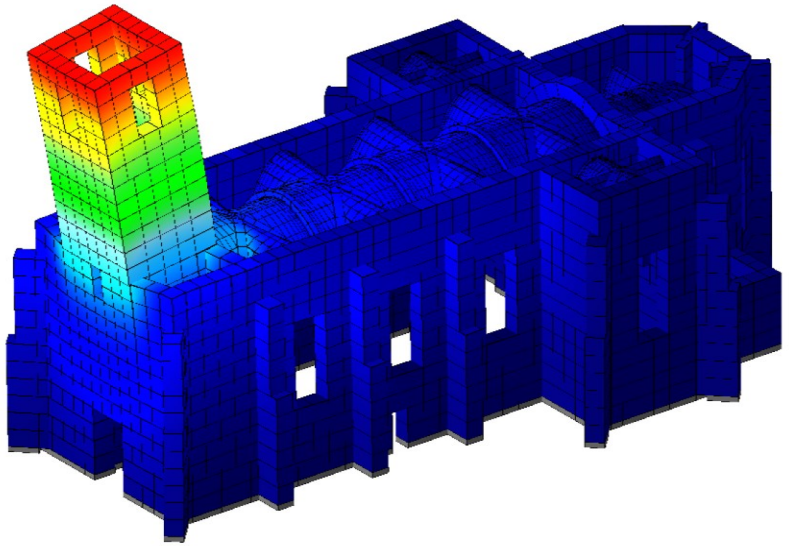




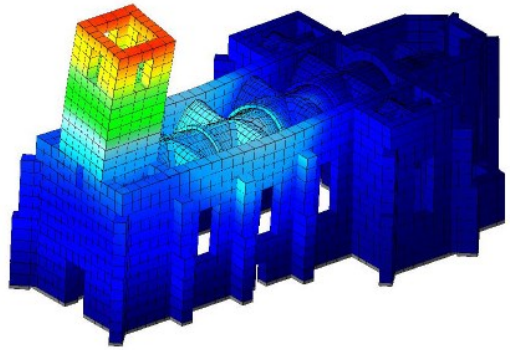
Seismic Analysis



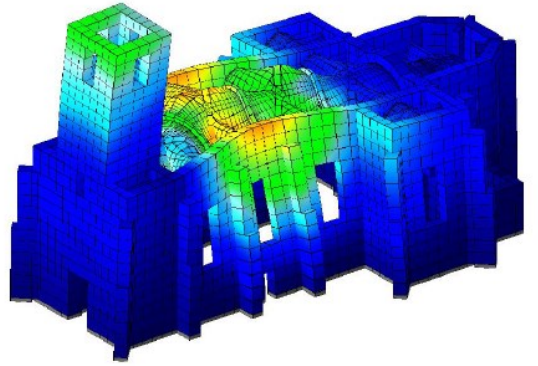
Slika 5-2 3D prikaz materijala



Slika 5-4 Prikaz prvog moda titranja T=0,47 s



Slika 5-5 Prikaz drugog moda titranja T=0,39 s

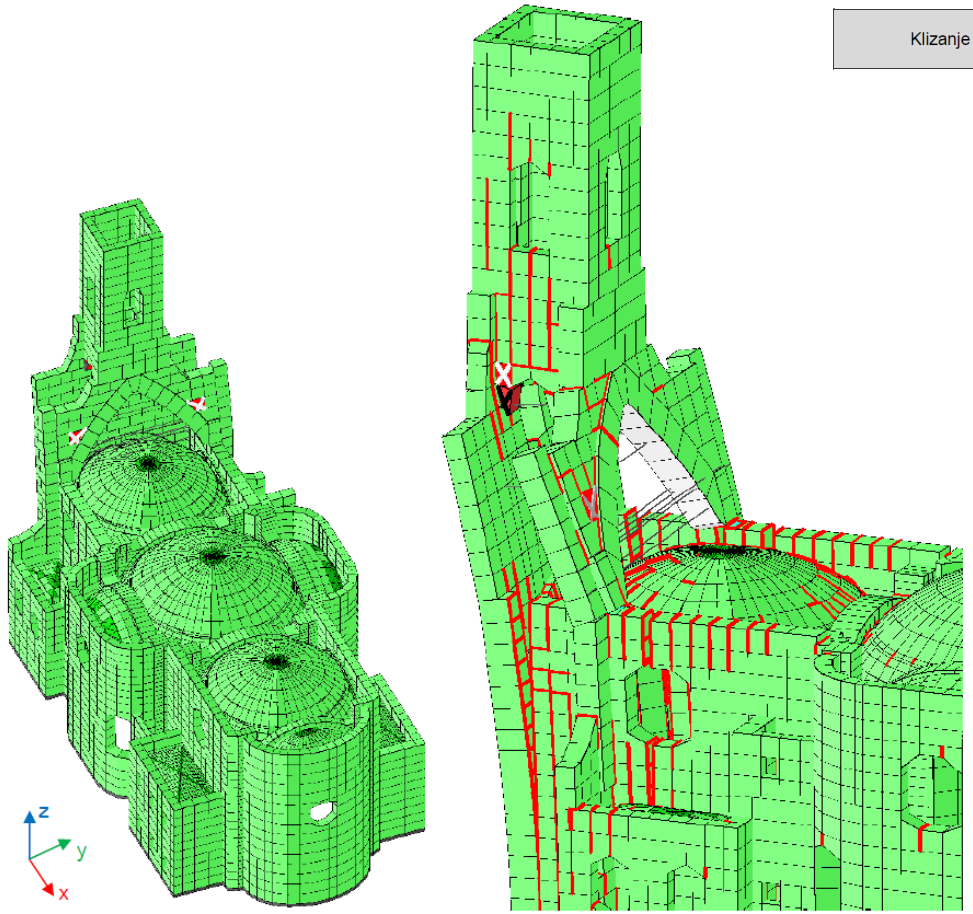


Slika 5-6 Prikaz trećeg moda titranja, T=0,34 s

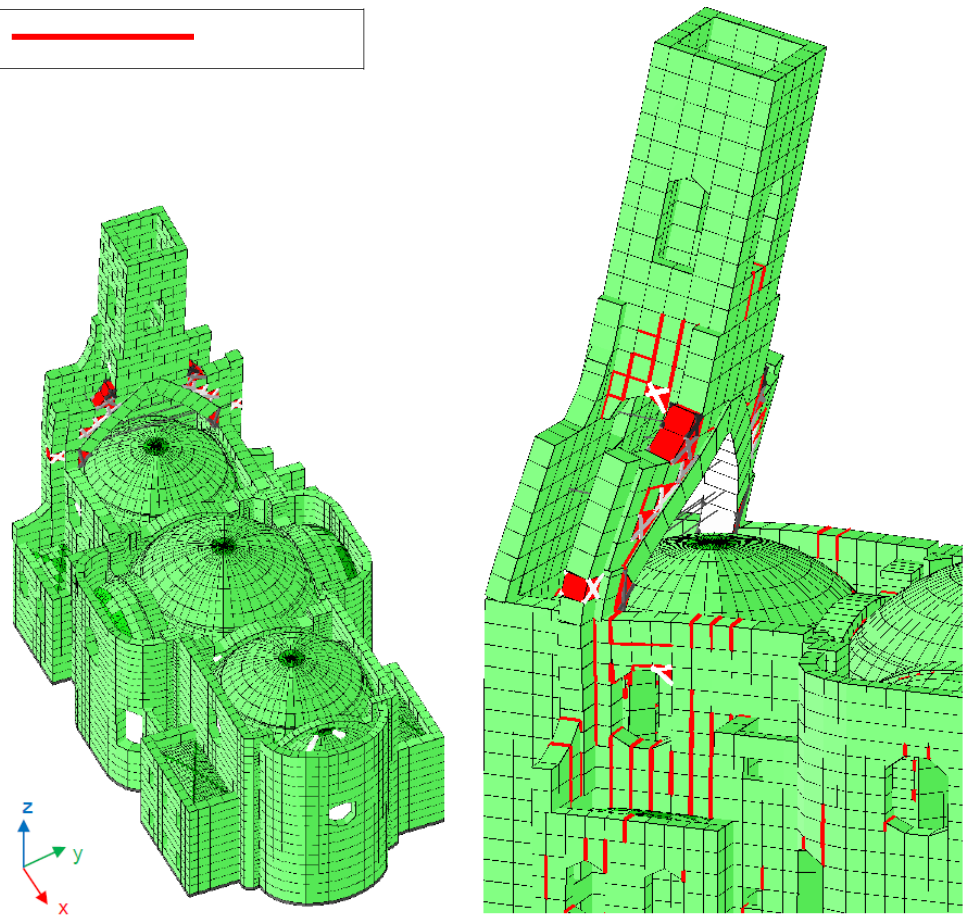
Seismic Analysis

Tip oštećenja	Razina oštećenja	
	Niska	Visoka
Dijagonalno otkazivanje		

Klizanje ploha	

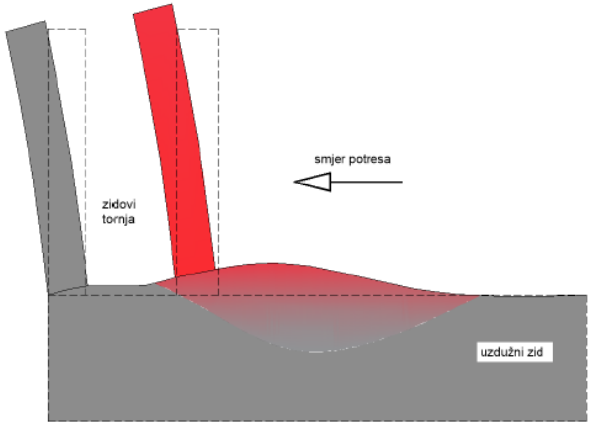


Slika 5-27 Prikaz oštećenja - Push-over u smjeru -x



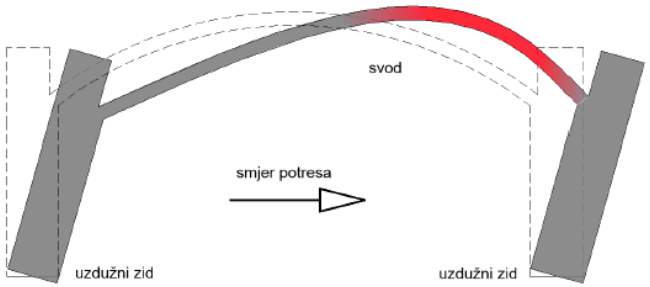
Slika 5-26 Prikaz oštećenja - Push-over u smjeru +x

Seismic Analysis

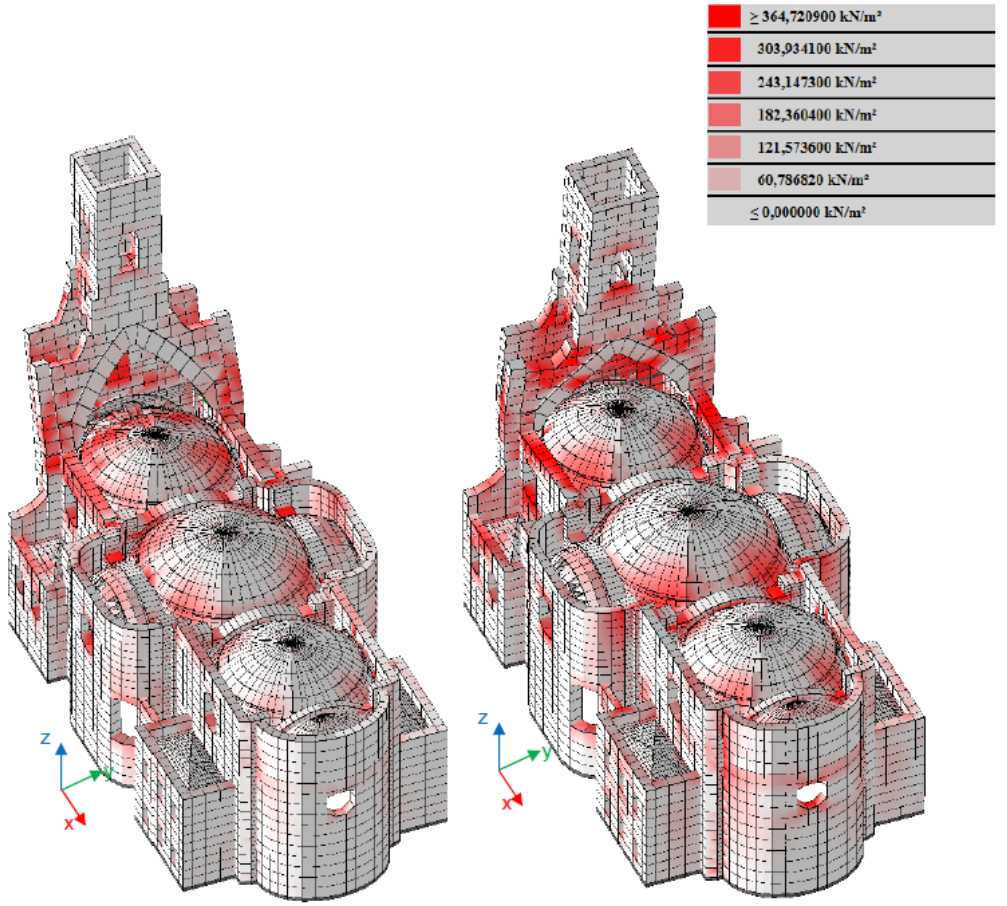


Slika 5-33 Vlačna zona zida uslijed djelovanja potresa na toranj

Pri djelovanju potresa u poprečnom smjeru (y-smjer) uzdužni zidovi crkve savijaju se van svoje ravnine uzrokujući deformaciju svodova uslijed koje se javljaju vlačna naprezanja.

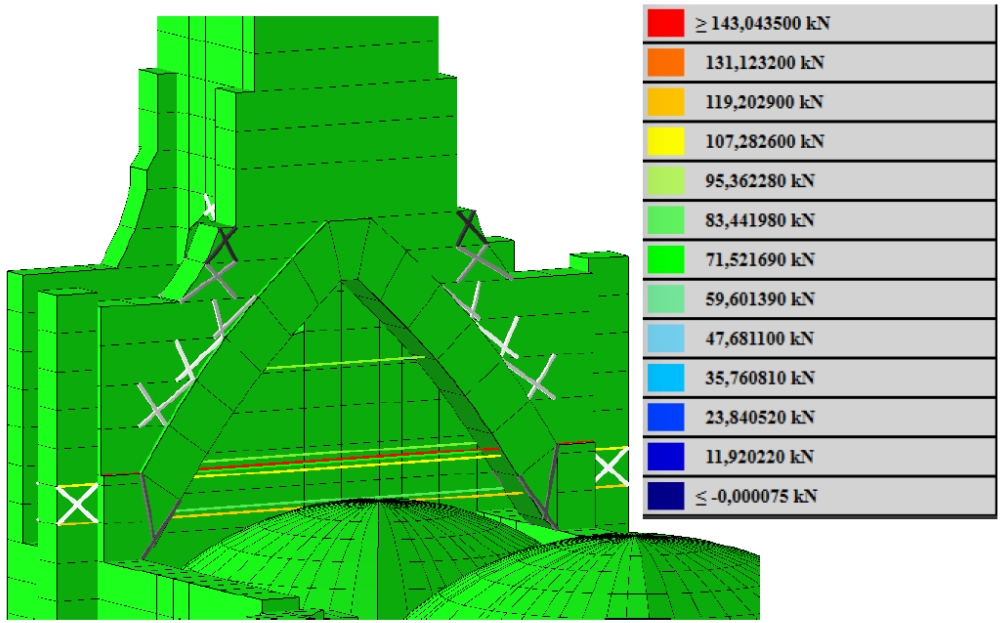


Slika 5-34 Vlačna zona svoda uslijed potresa

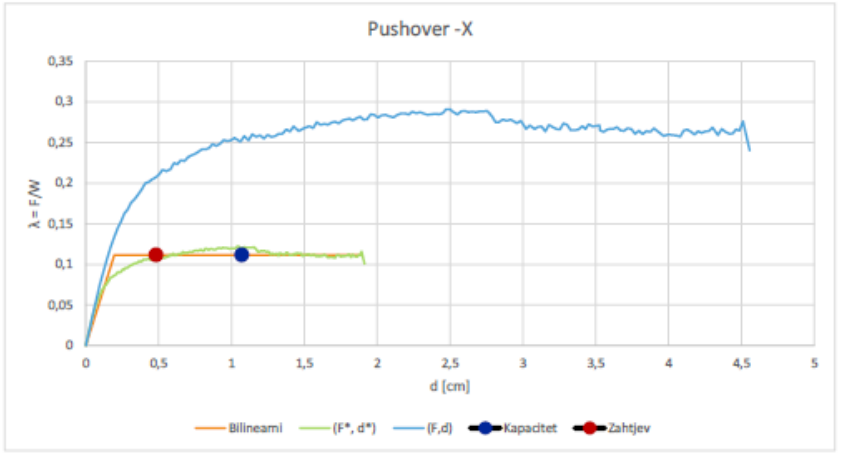


Slika 5-35 Prikaz vlačnih naprezanja - Push-over u smjeru +x i – x

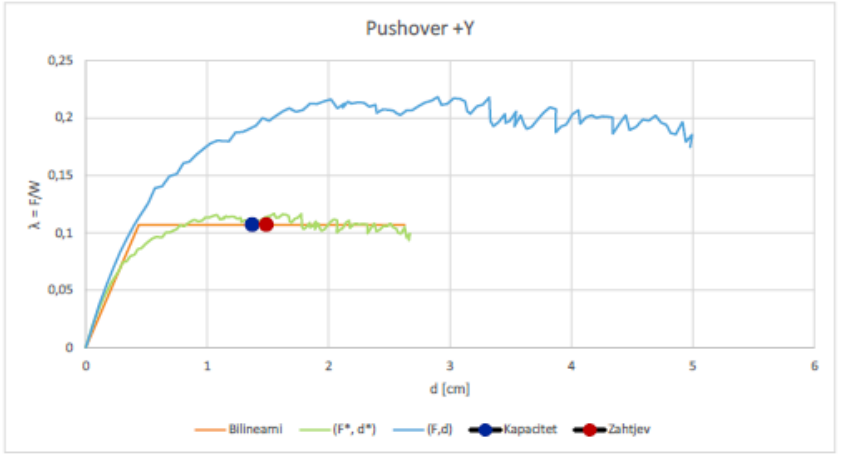
Seismic Analysis



Slika 5-68 Uzdužna sila u zategama – potresno opterećenje



Slika 5-60 Push-over -X; procjena seizmičke ranjivosti



Slika 5-61 Push-over +Y; procjena seizmičke ranjivosti

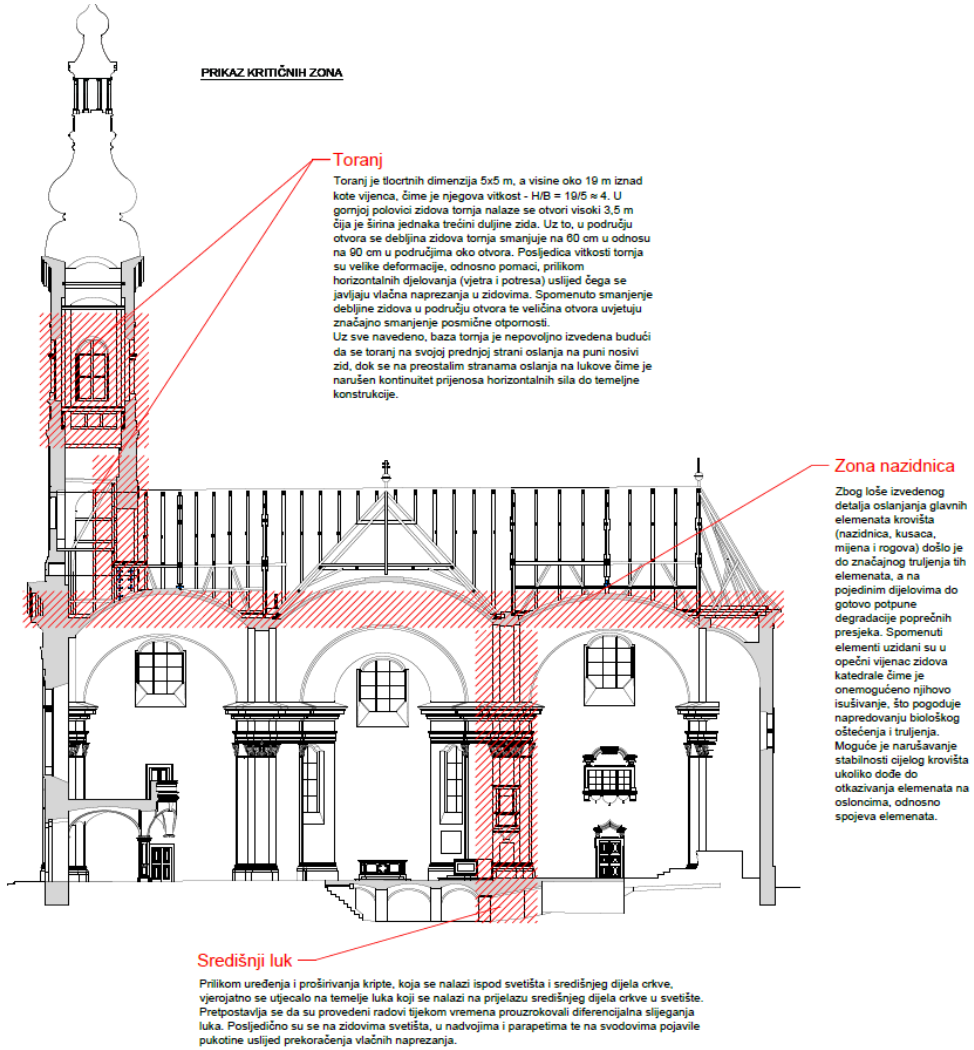
Seismic Analysis

Procjenom seizmičke ranjivosti katedrale, određene su otpornosti tornja i svodova na potrese povratnih perioda 225 godina, 475 godina i 2475 godina. U tablici ispod prikazane su pojedine otpornosti izražene u postocima koji su dobiveni usporedbom kapaciteta i zahtjeva konstrukcije.

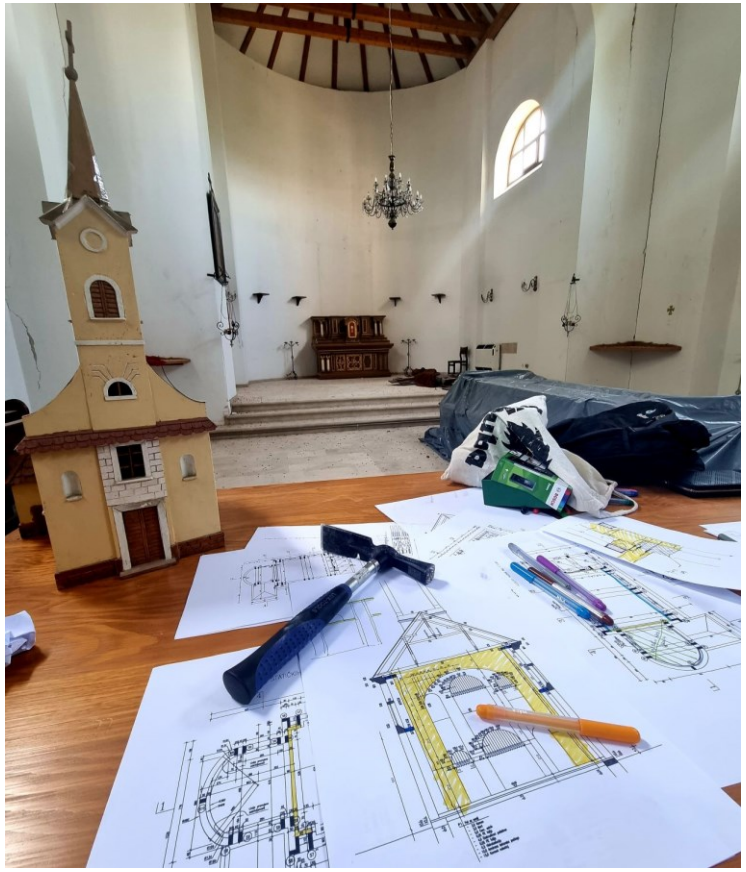
Tablica 5-10 Rekapitulacija pushover analize za sva granična stanja

	Mjerodavna analiza	Granično stanje ograničenog oštećenja – PP 225 godina	Granično stanje značajnog oštećenja – PP 475 godina	Granično stanje blizu rušenja – PP 2475 godina
Toranj	Push-over +x	64,93%	62,76%	60,90%
Svodovi	Push-over -y	40,04%	92,31%	95,65%
Katedrala	Push-over +x	40,04%	62,76%	60,90%

Potresna otpornost katedrale iznosi **40,04%** zahtijevane otpornosti prema aktualnim normama. Kritični dijelovi katedrale su toranj za smjer od zapada prema istoku te svodovi za smjer sjever-jug.

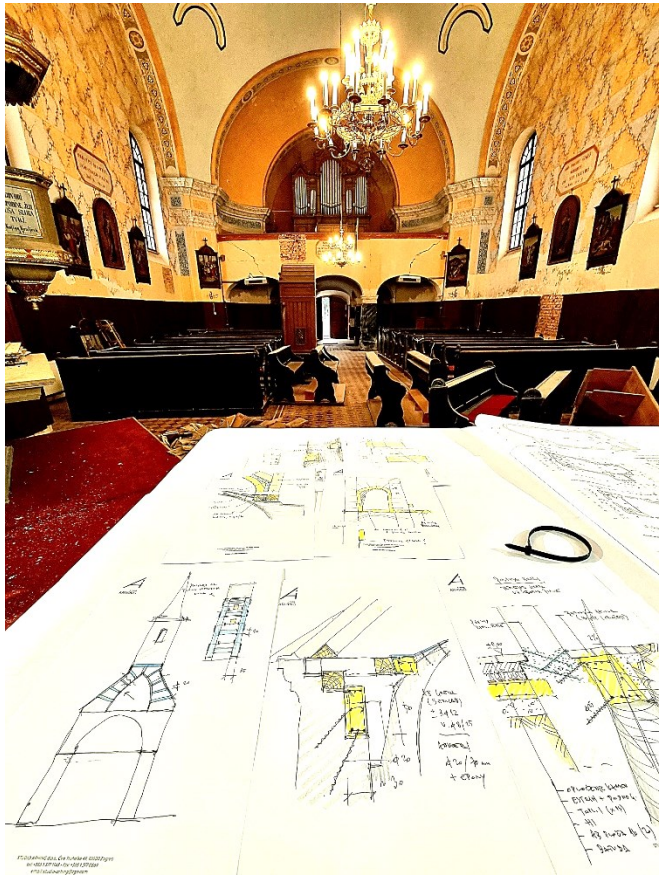


3. Therapy

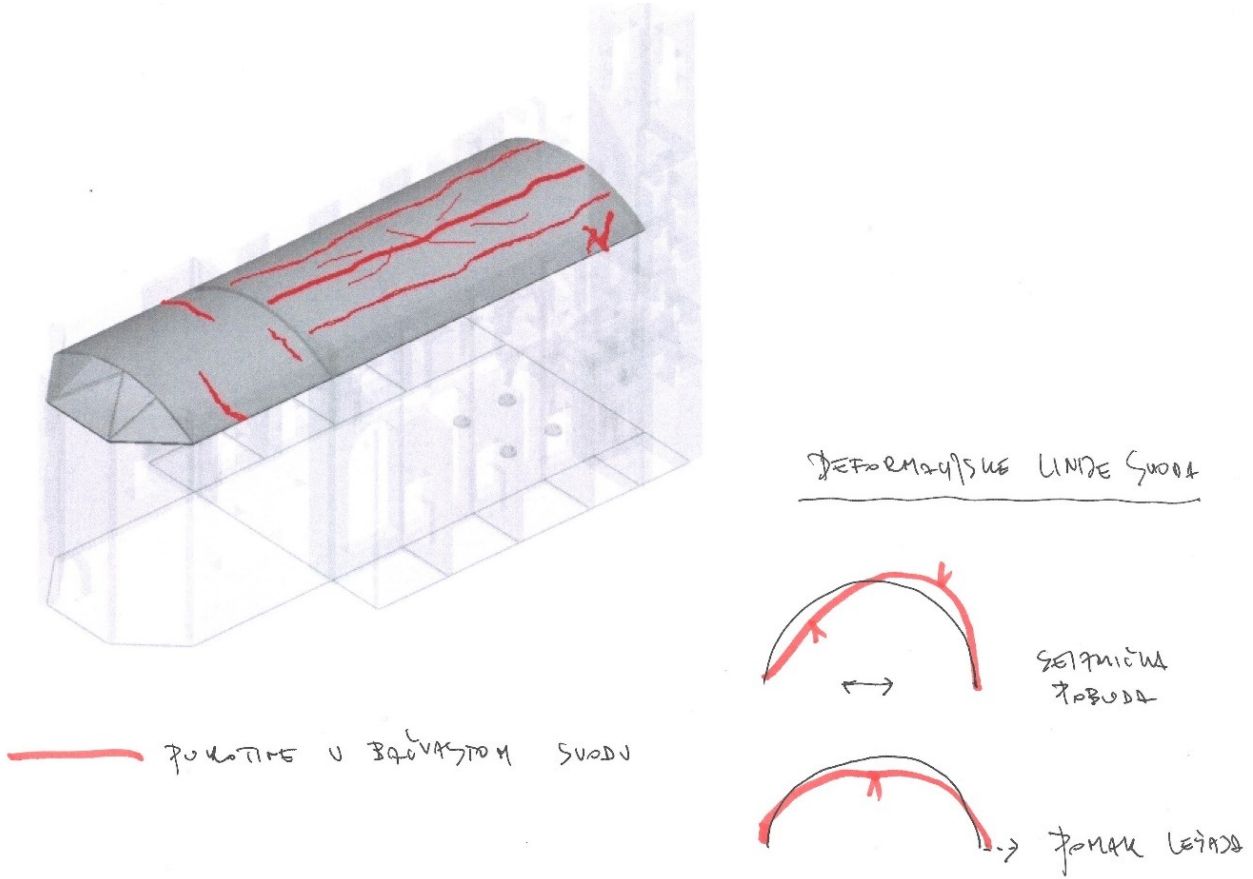


Concept First!

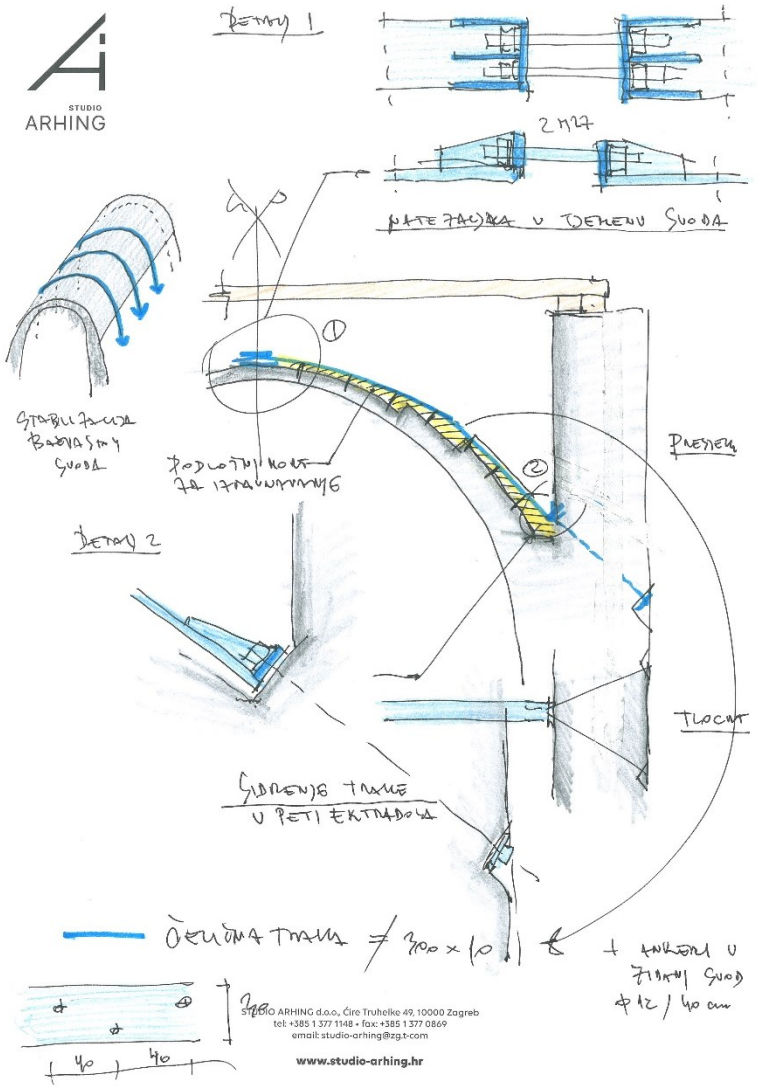
(... modeling later)

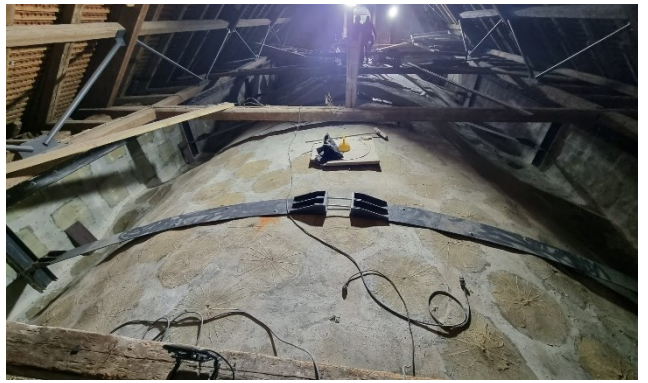


Barrel vaults

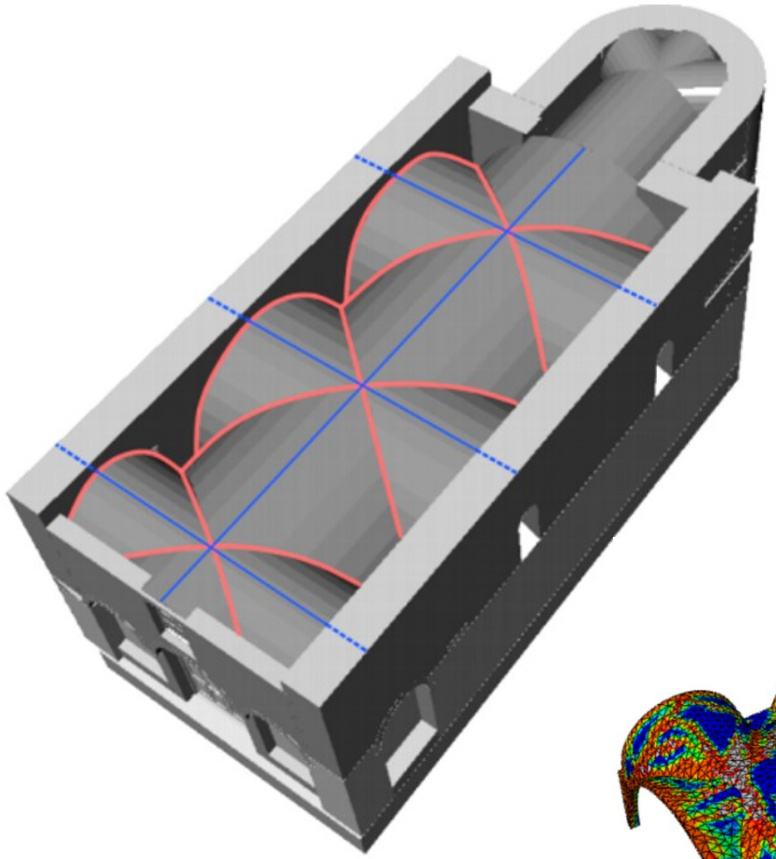


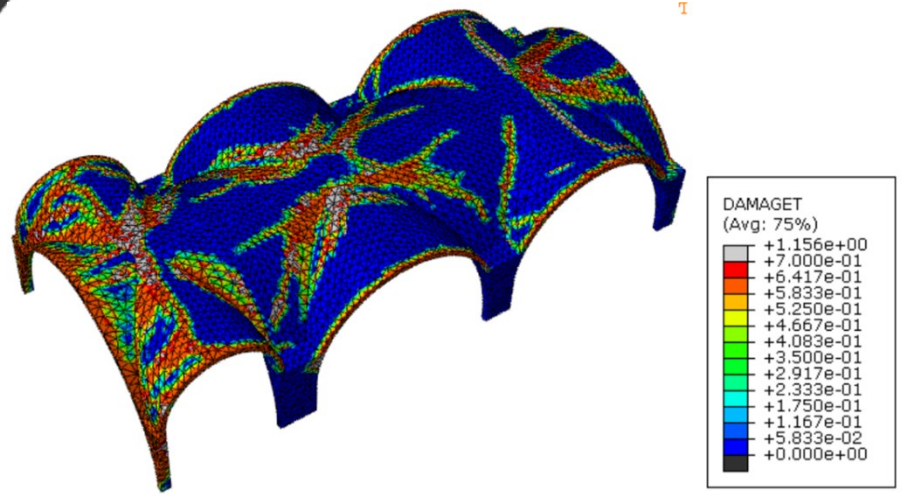
Barrel vaults



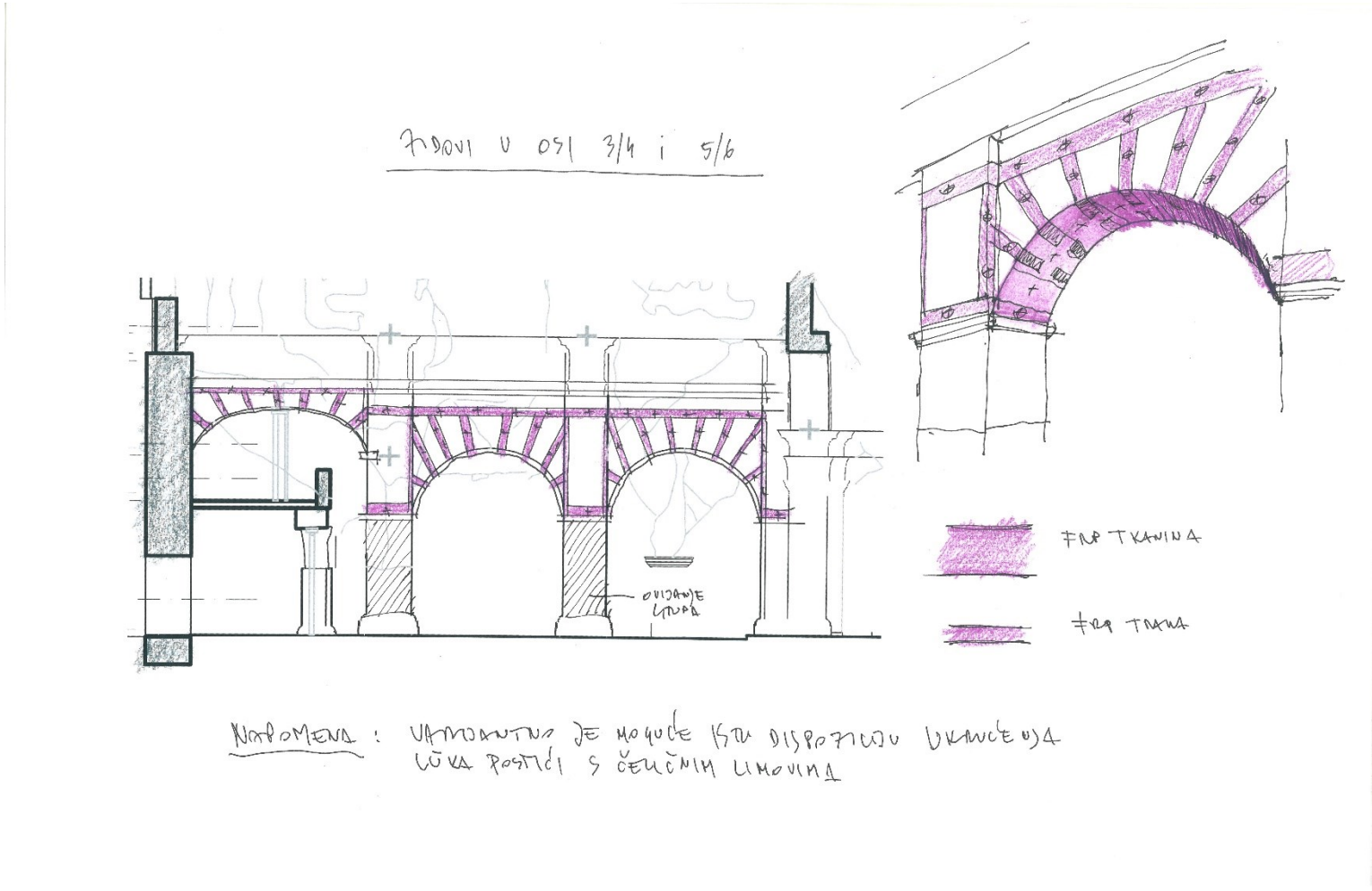


Cross vaults

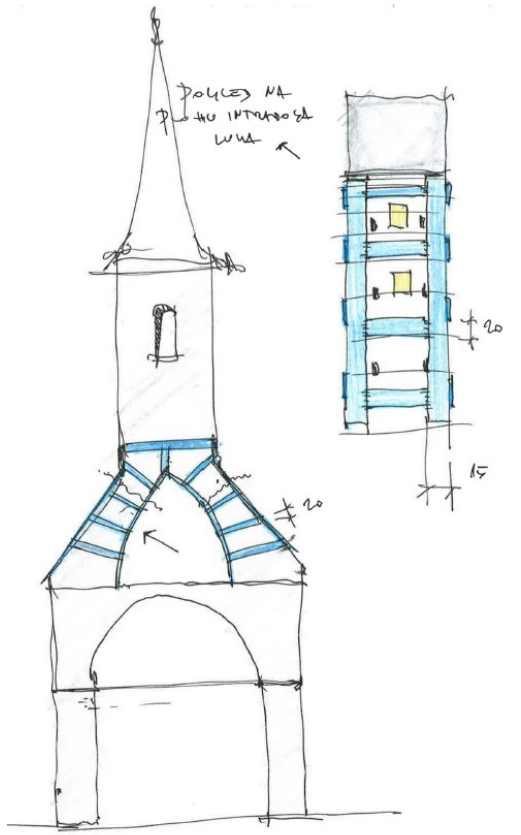


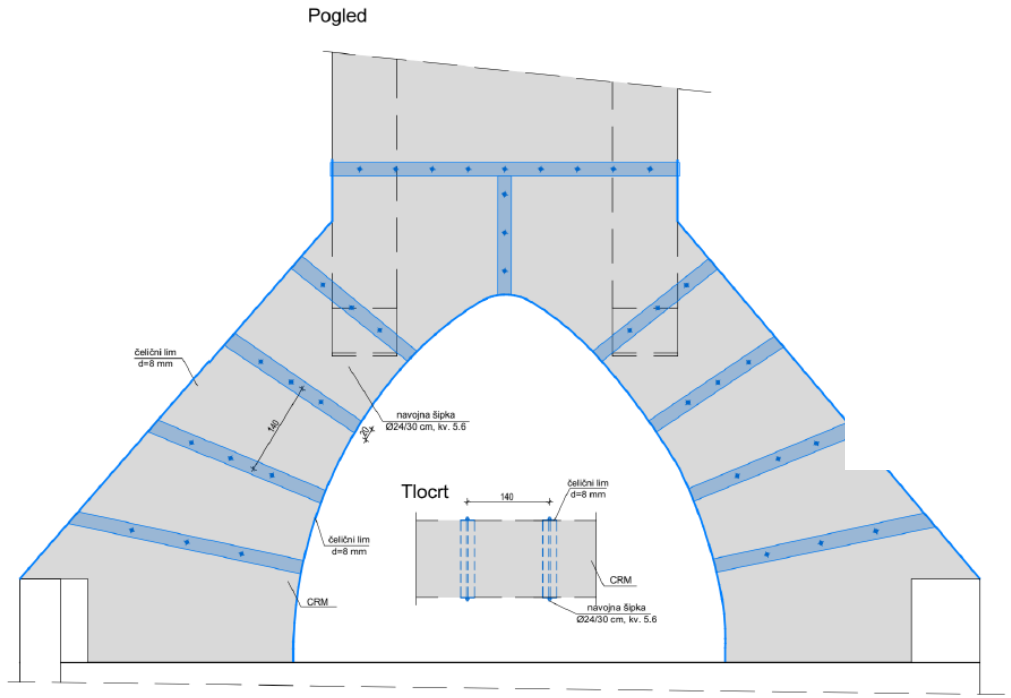


Arches

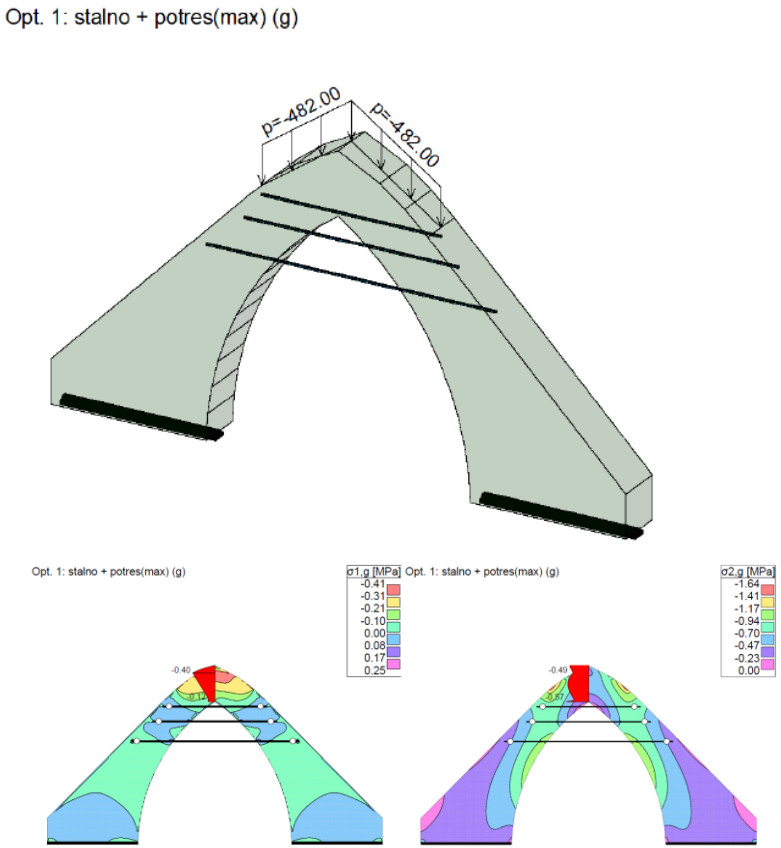

LUKOVI U OSI 3/4 i 5/6
OVIJANJE LUKOVA
FRP TKANINA
FRP TRAKA
NAPOMENA: VARIJANTNO JE MOGUĆE ISTU DISPOZICIJU UKLANJATI LUKA POSTIĆI S ČELIČNIM LIMOVIMA

Arches

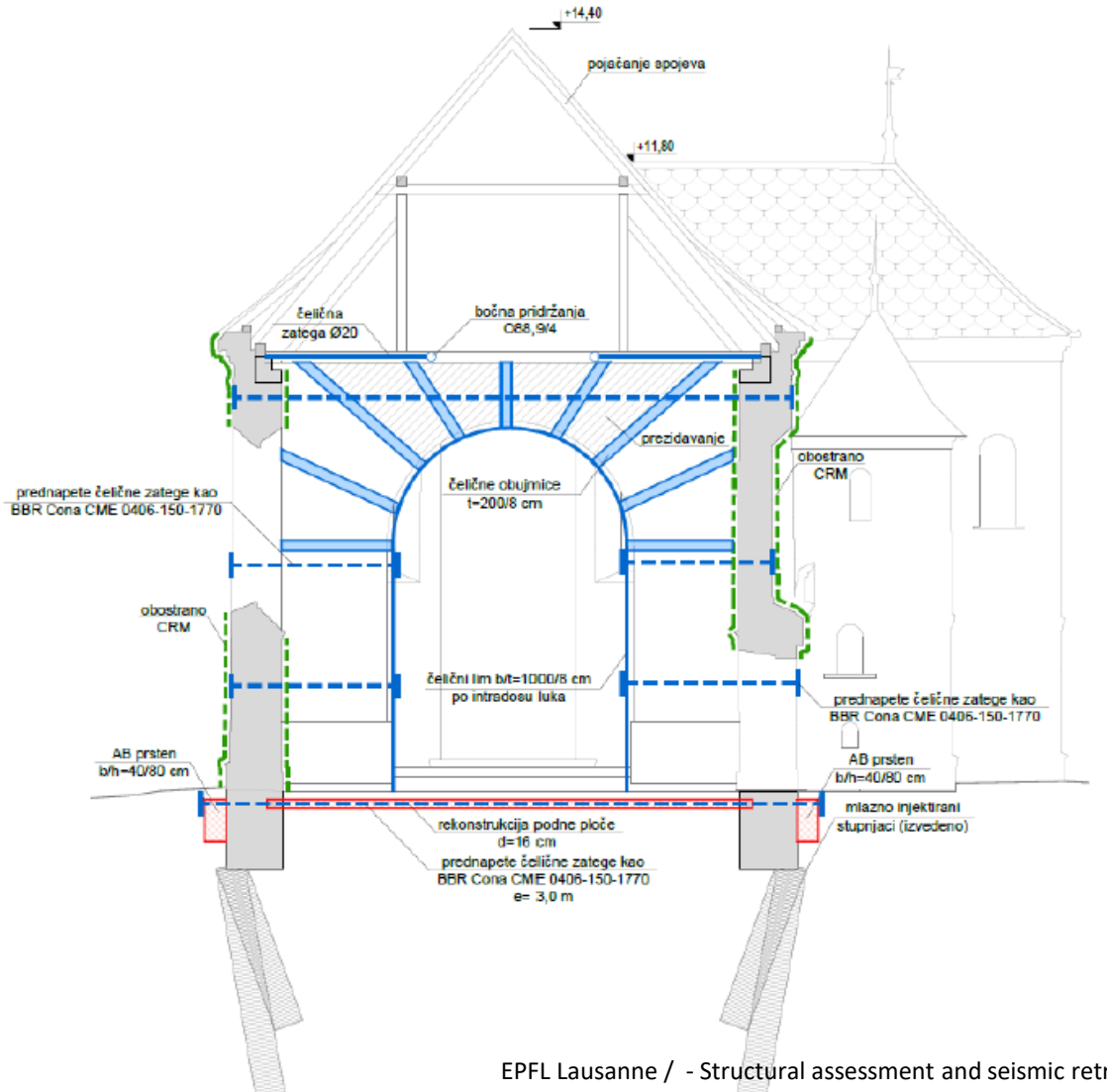


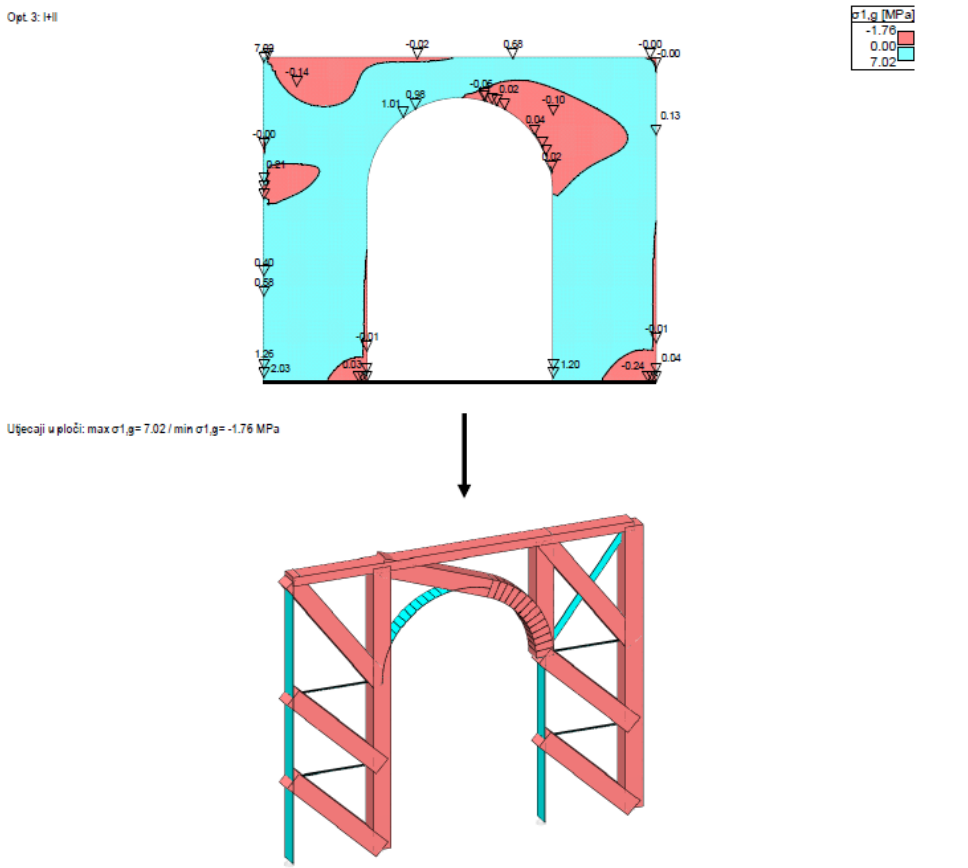


Slika 5-9 Detalj ojačanja luka



Arches

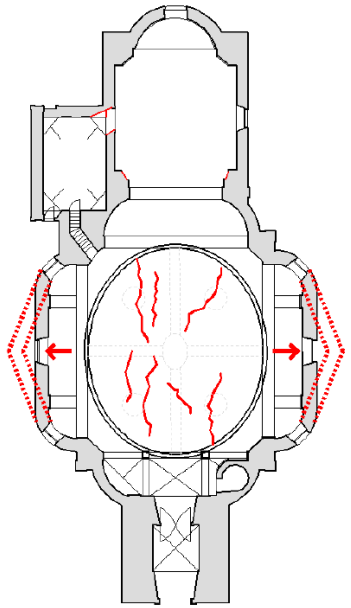


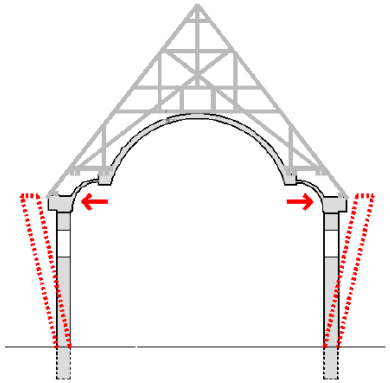


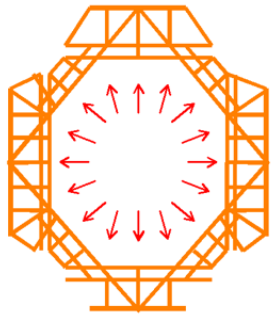
Prema gore prikazanim zonama vlačnih (plavo), odnosno tlačnih naprezanja (crveno), postavljeni su zamjenski štapni elementi prikazani u proračunskom modelu 2.

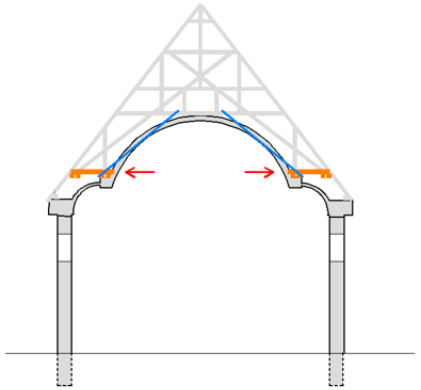
Domes

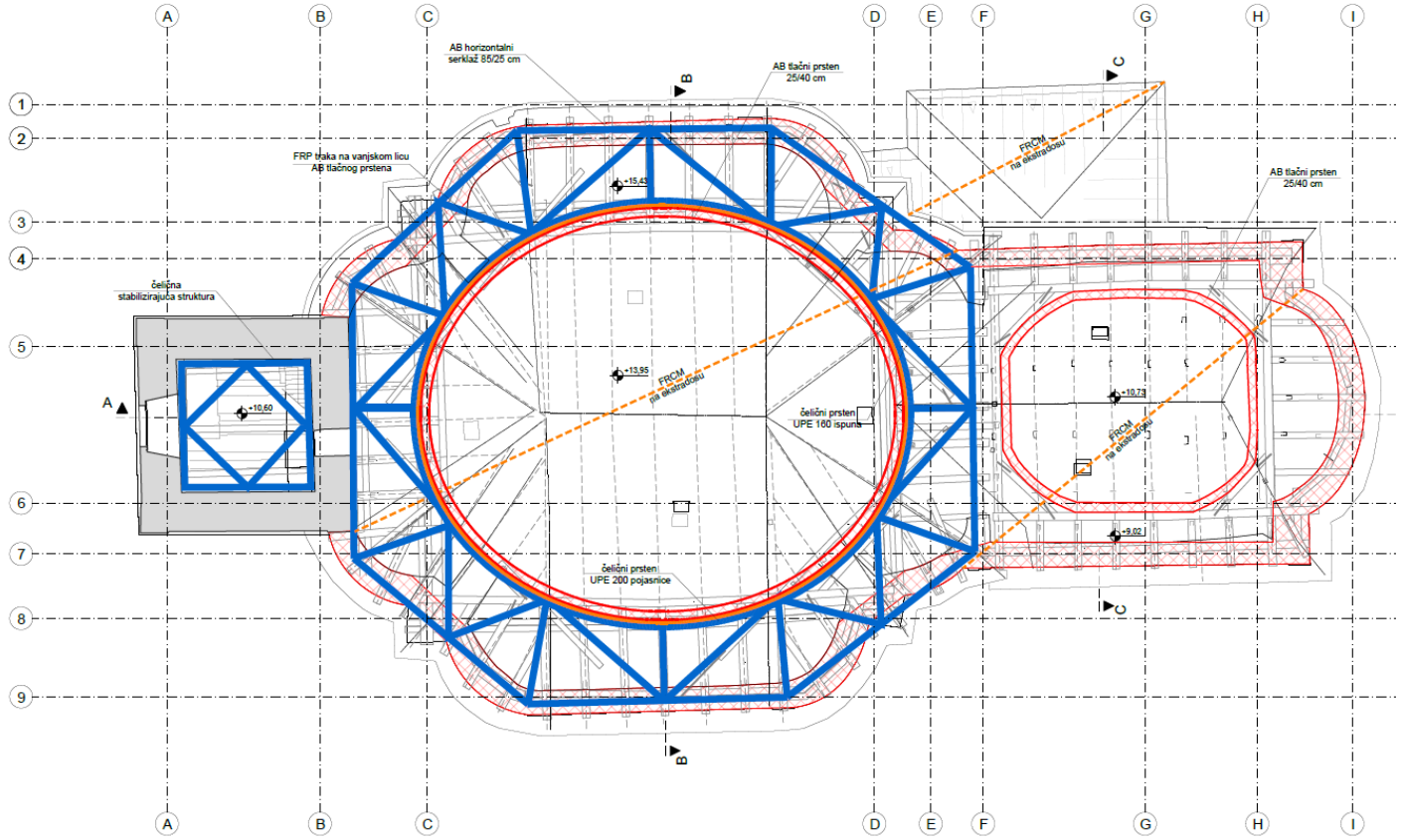
Domes



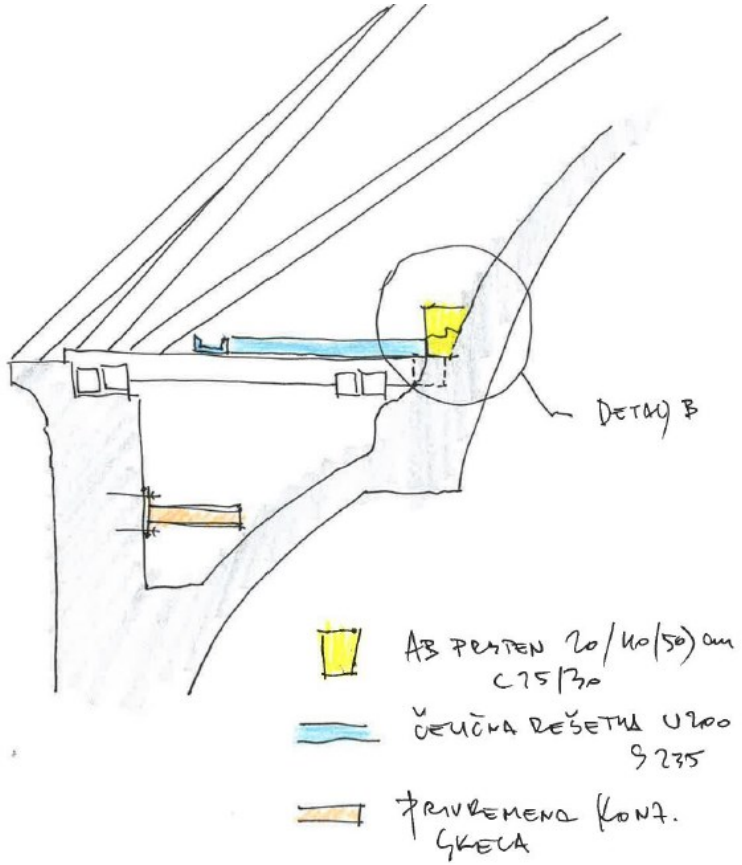


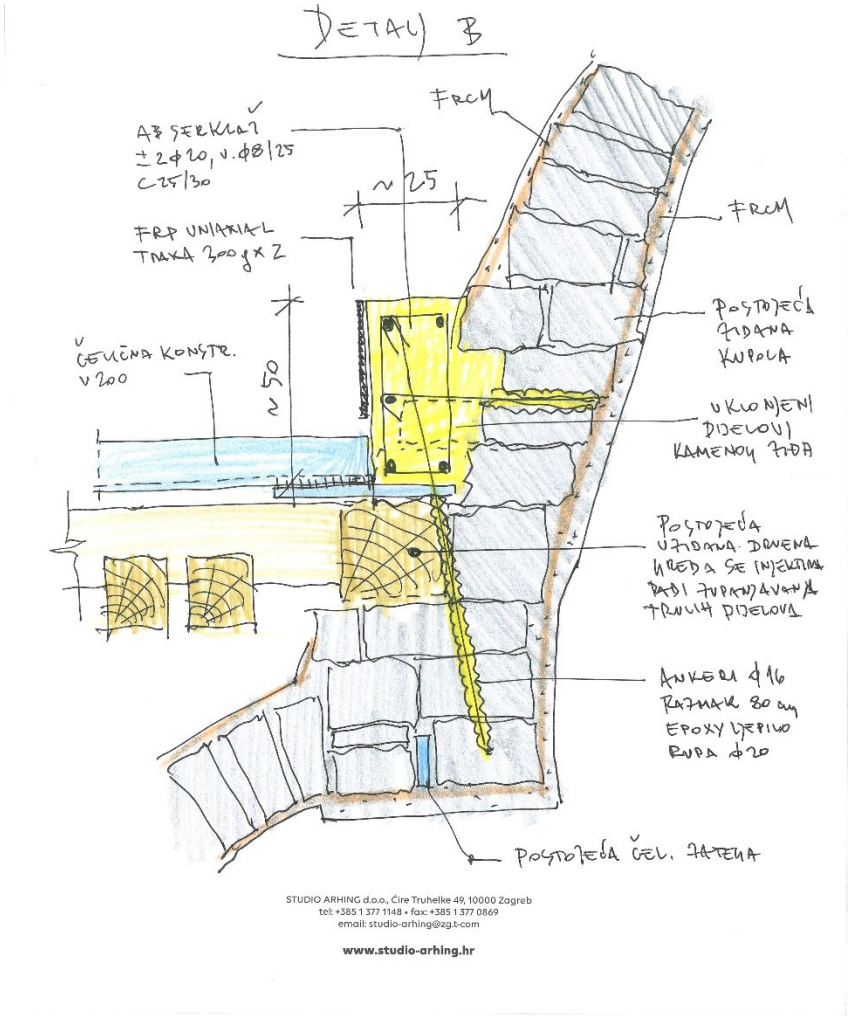





AB horizontalni serklaž 85/25 cm
AB tlačni prsten 25/40 cm
FRP traka na vanjskom licu AB tlačnog prstena
čelična stabilizirajuća struktura
čelični prsten UPE 160 ispuna
čelični prsten UPE 200 pojasnice
FRCM na ekstradosu
+15,43
+13,95
+10,60
+10,73
+9,02

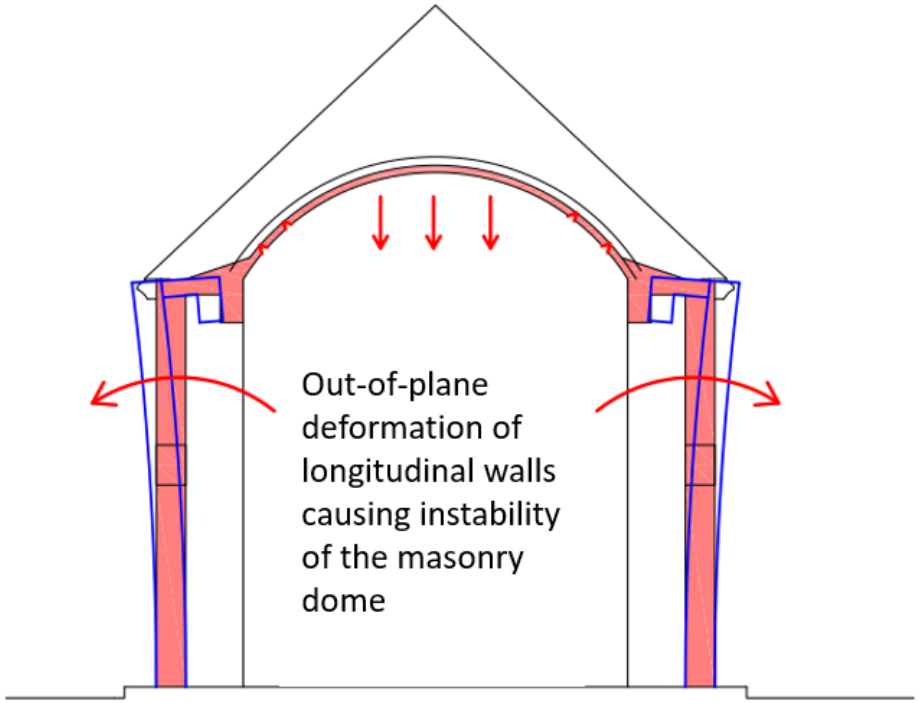
Domes

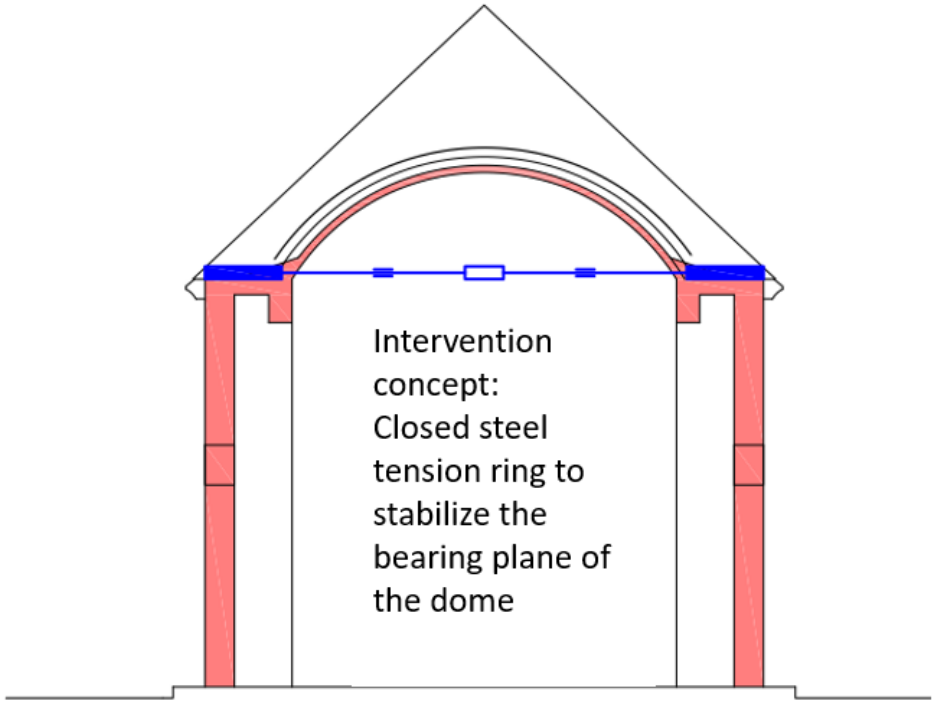

DETALJ B
AB PRSTEN 20/40/50 cm
C25/30
ČELIČNA REŠETKA U200
S235
PRIVREMENA KONT.
SKELA


DETALJ B
AB SERKLAŽ
±2420, v.Ø8/25
C25/30
FRP UNIAKIAL
TKANA 300 g/m2
FRCM
FRCM
~25
~50
POSTOJEĆA ZIDANA KUPOLA
ČELIČNA KONSTR.
U200
UKLONJENI DIJELOVI KAMENOG ZIDA
POSTOJEĆA ZIDANA. DOVEDA SE INJEKTIRA RADI ZAPUNJAVANJA PRAZNIH DIJELOVA
ANKERI Ø16
RAZMAK 80 cm
EPOXY LJEPILO
RUPA Ø20
POSTOJEĆA ČEL. ZATEGA
STUDIO ARHING d.o.o., Ćire Truhelke 49, 10000 Zagreb
tel: +385 1 377 1148 • fax: +385 1 377 0869
email: studio-arhing@zg.t-com
www.studio-arhing.hr

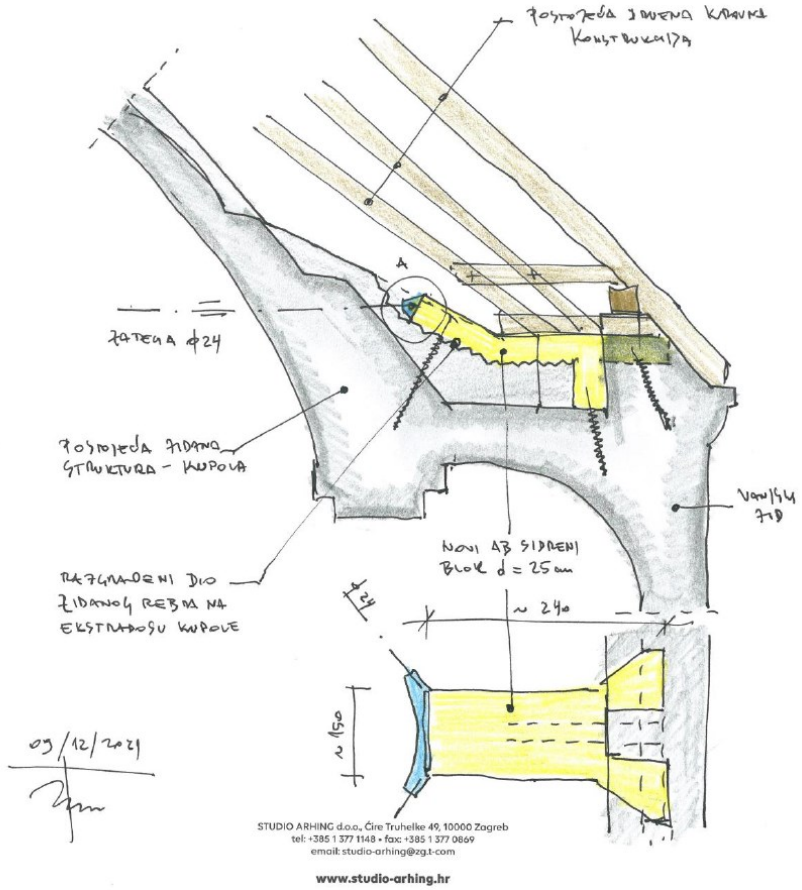
Domes

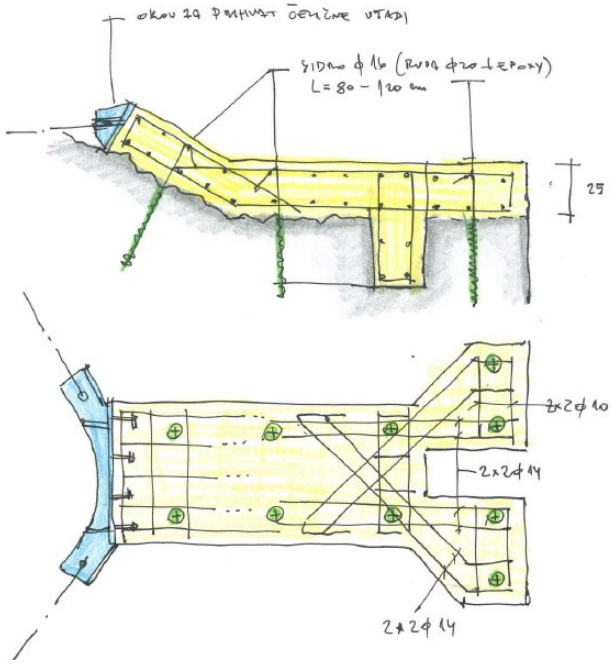
Domes

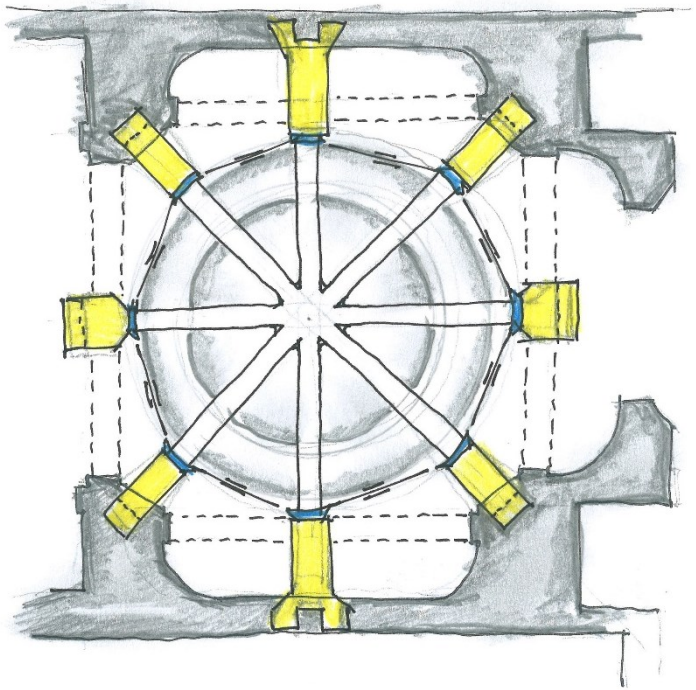

Out-of-plane deformation of longitudinal walls causing instability of the masonry dome


Intervention concept: Closed steel tension ring to stabilize the bearing plane of the dome

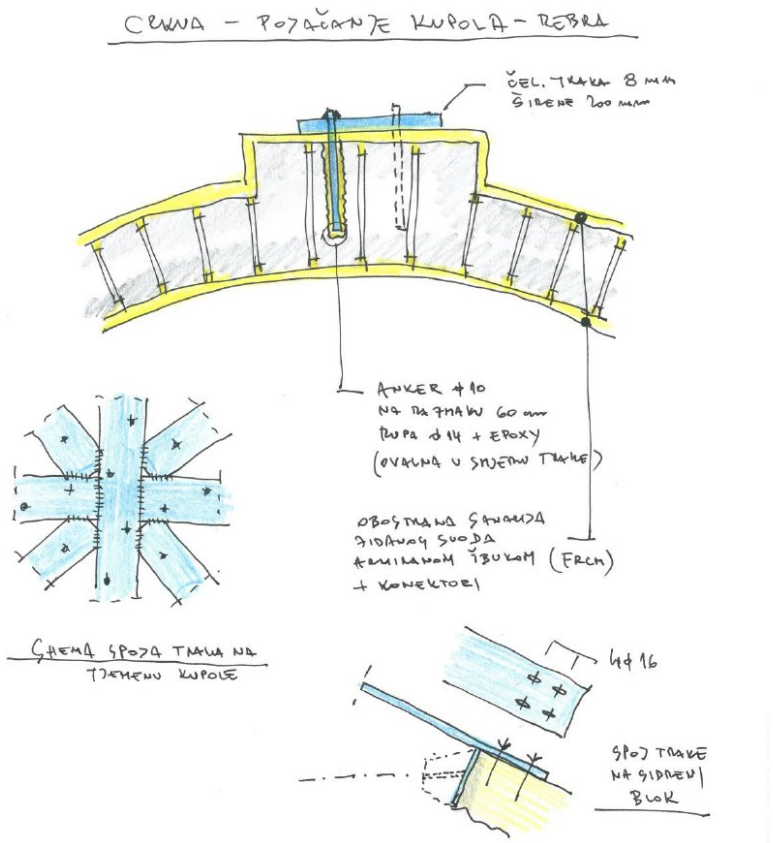
Domes


POSTOJEĆA DRVENA KRAVNA KONSTRUKCIJA
A
LATICA ϕ24
POSTOJEĆA ZIDANA STRUKTURA - KUPOLA
RAZGRADENI DIO ZIDANOG REBRA NA EKSTRADOSU KUPOLE
NOVI AB SIDRENI BLOK d = 25 cm
~ 240
~ 150
09/12/2021
STUDIO ARHING d.o.o., Ćire Truhelke 49, 10000 Zagreb
tel: +385 1 377 1148 • fax: +385 1 377 0869
email: studio-arhing@zg.t-com
www.studio-arhing.hr


SIDRO ϕ 16 (RUPA ϕ20 + EPOXY)
L = 80 – 120 cm
25
2x2ϕ10
2x2ϕ14
2x2ϕ14



Domes

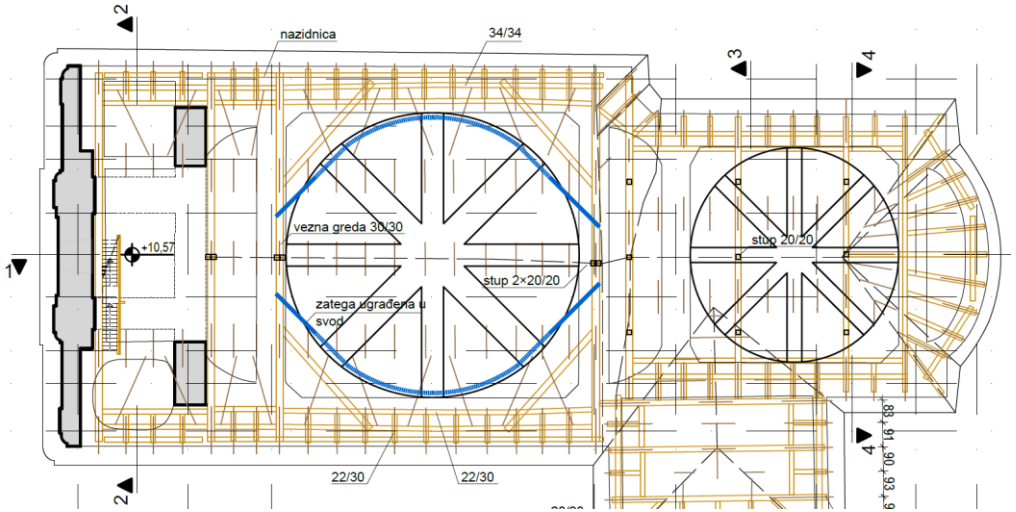


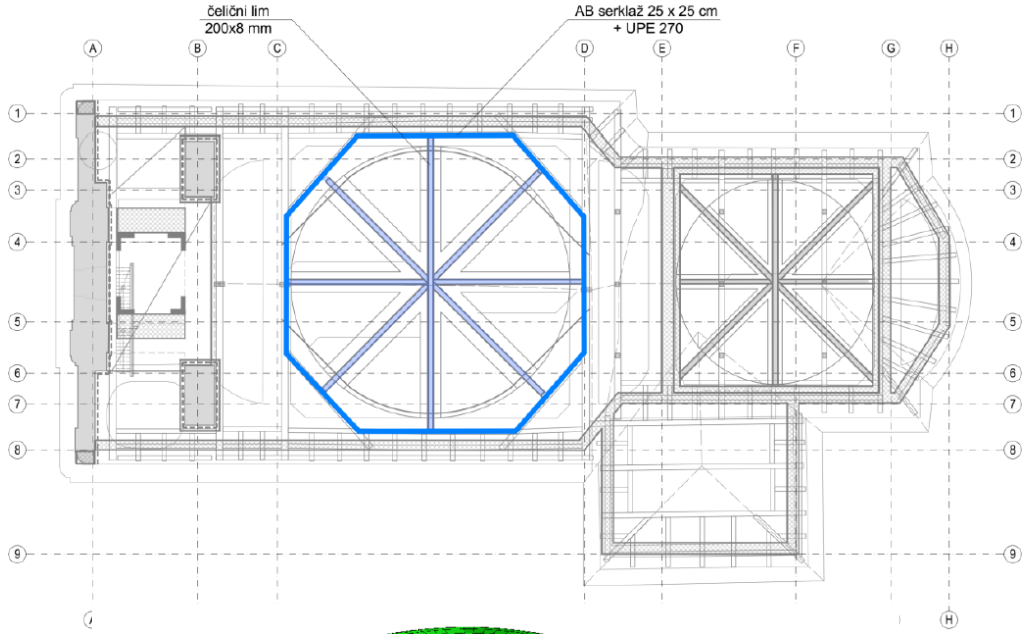
ČRNVA – POJAČANJE KUPOLA – REBRA

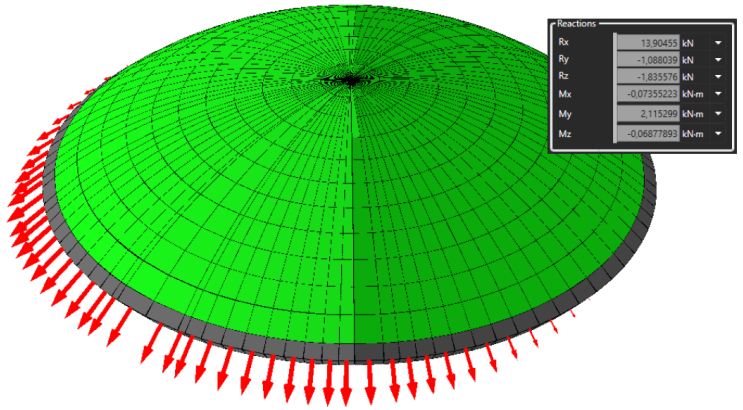
SHEMA SPOJA TRAKA NA TJEMENU KUPOLE

SPOJ TRAKE NA SIDRENI BLOK

Domes

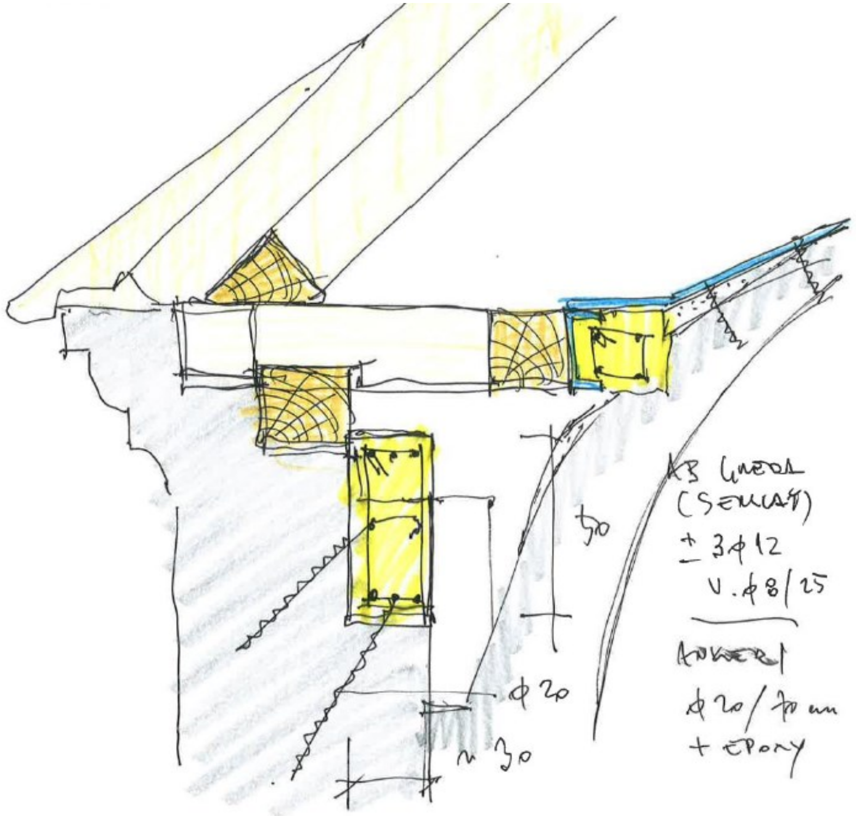




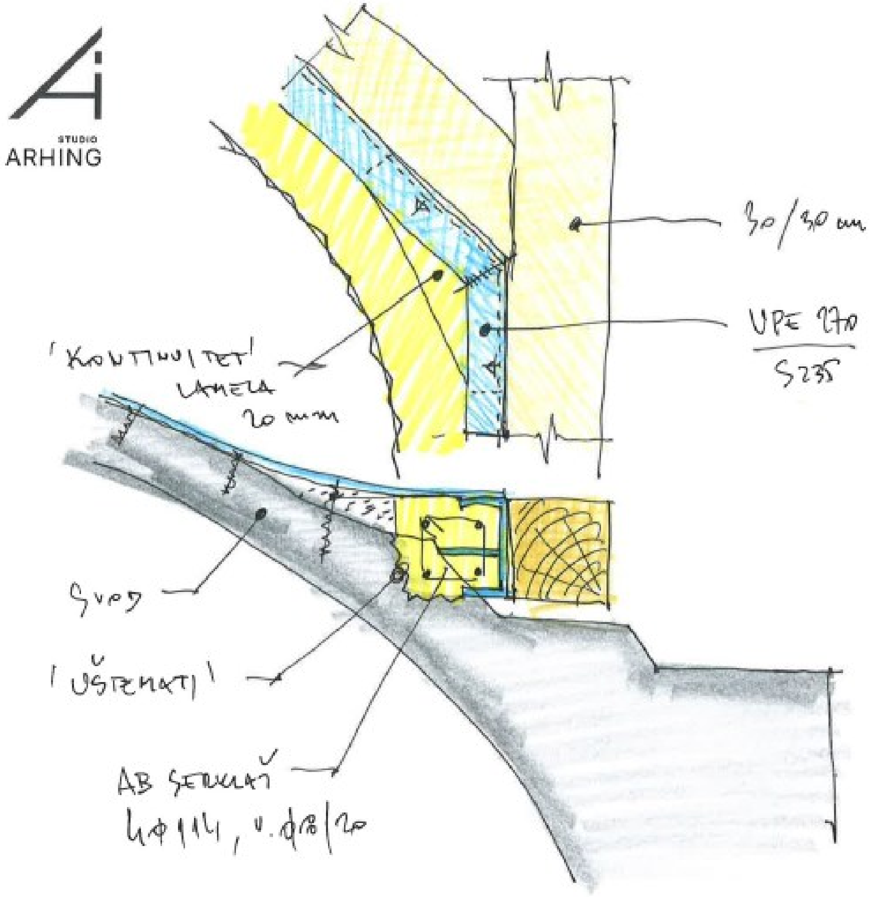


Slika 5-22 Grafički prikaz reakcija kupole i vrijedonst maksimalnih reakcija – Histra

Domes



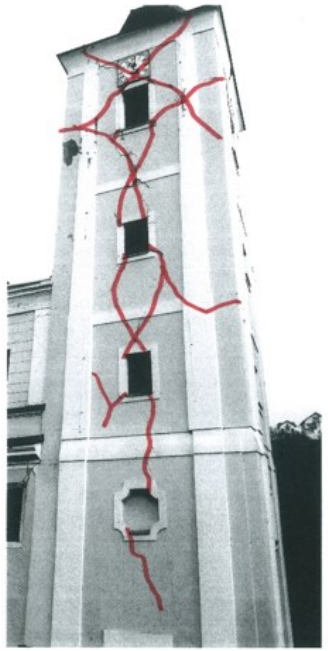
ANKERI
ϕ 20
~30



STUDIO
ARHING
30/30 cm
UPE 270
S235
LAMELA
20 mm
SVOD
AB SERKLAŽ

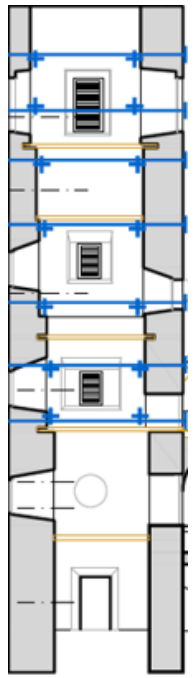
Church Towers

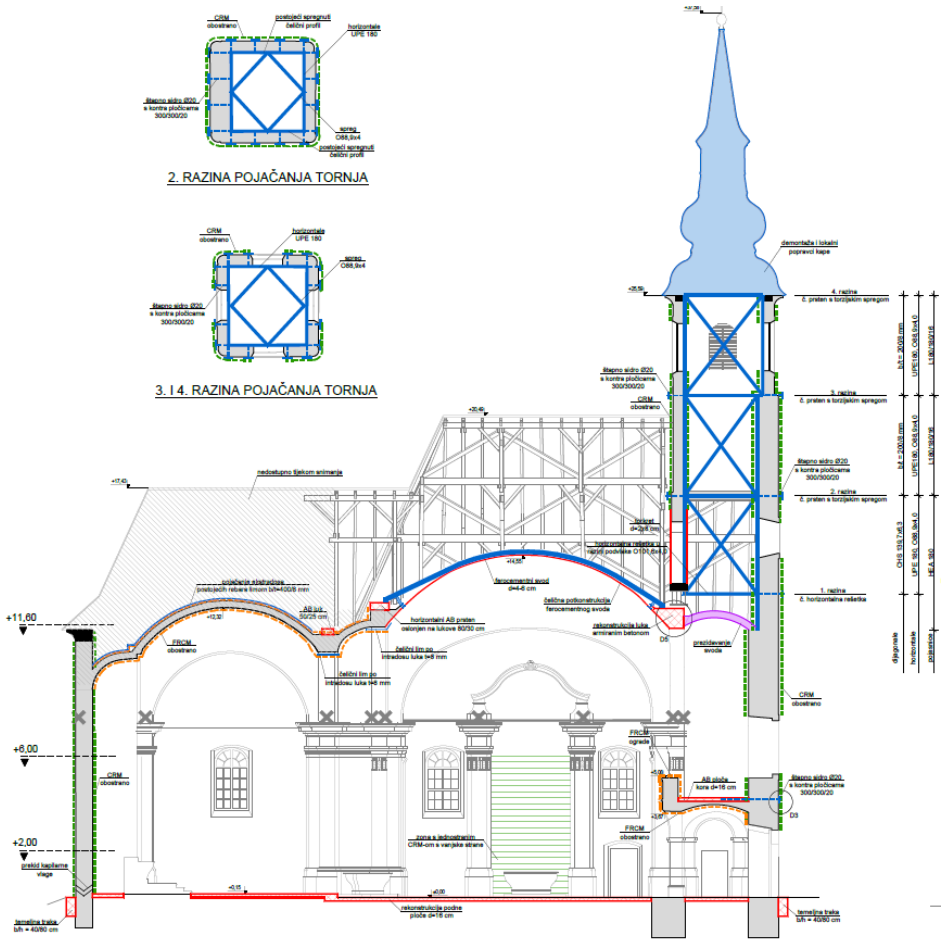
PROČELJE ZVONIKA - FOTOGRAFIJA

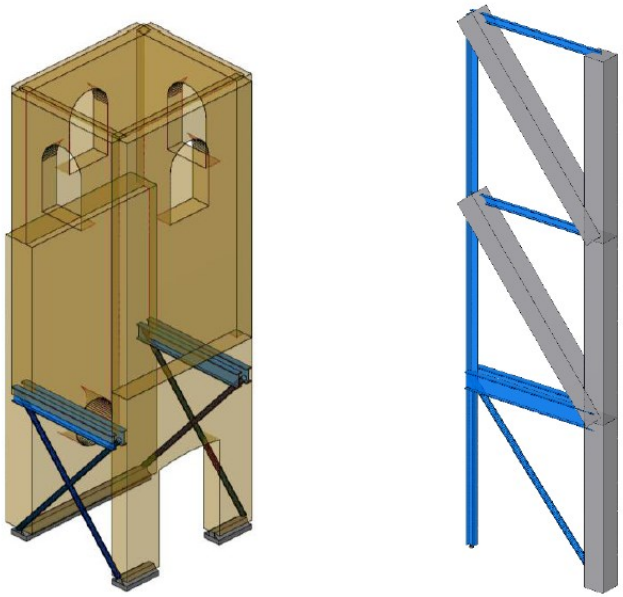


— GLAVNE LINIJE LOMA

← SMJEROVI UTVRĐENIH METALNIH TRAKA OTVRZIVANJA ZIDNIH BLOKOVA



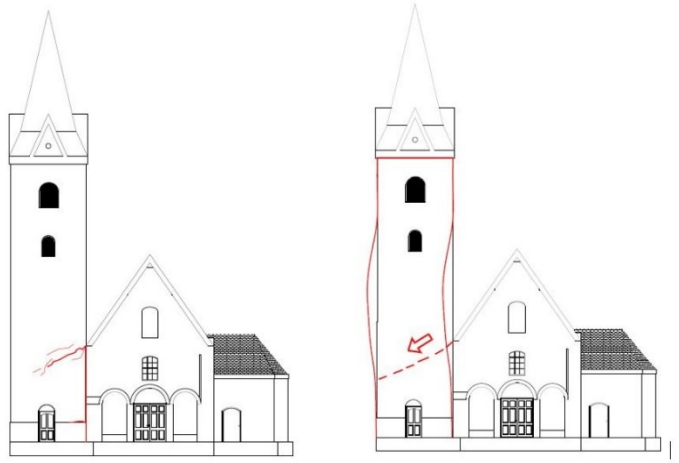


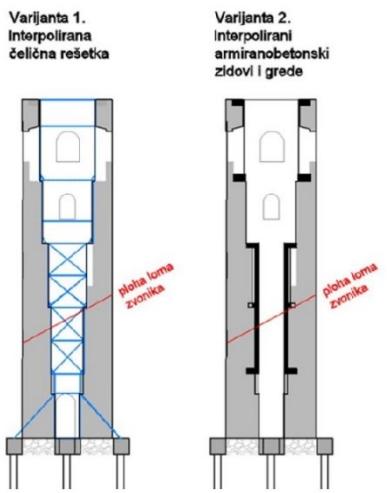


a) b)

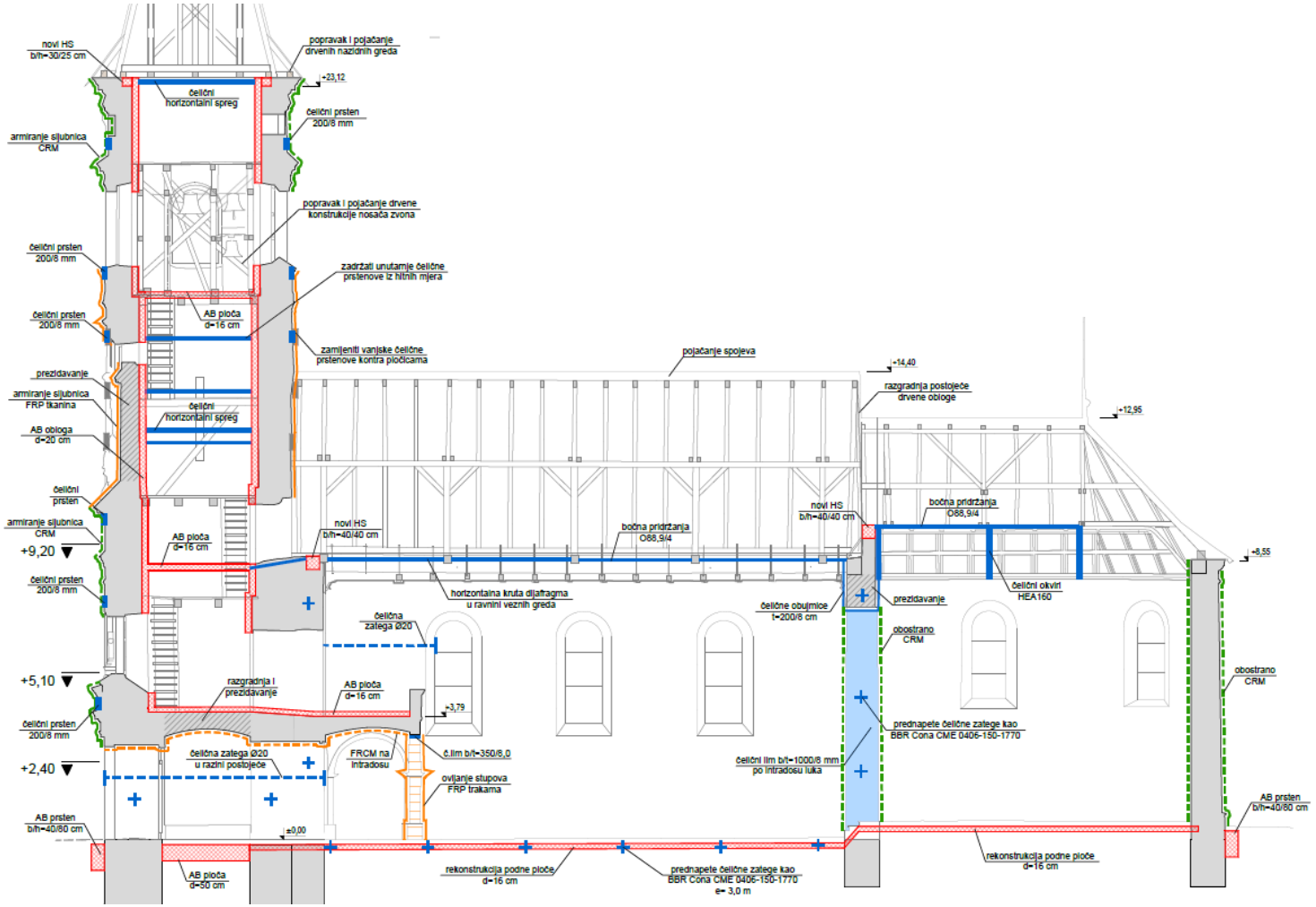
Slika 5-3 Shematski prikaz proračunskog modela 1(a) i proračunskog modela 2(b)

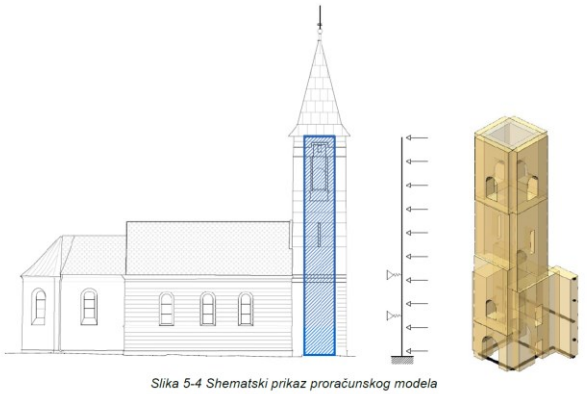
Church Towers



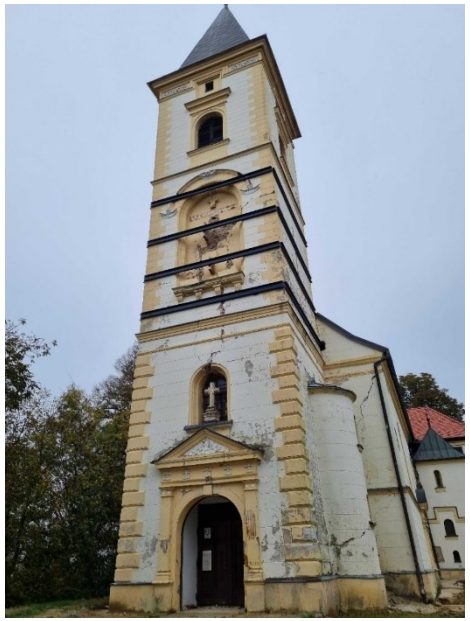


Church Towers

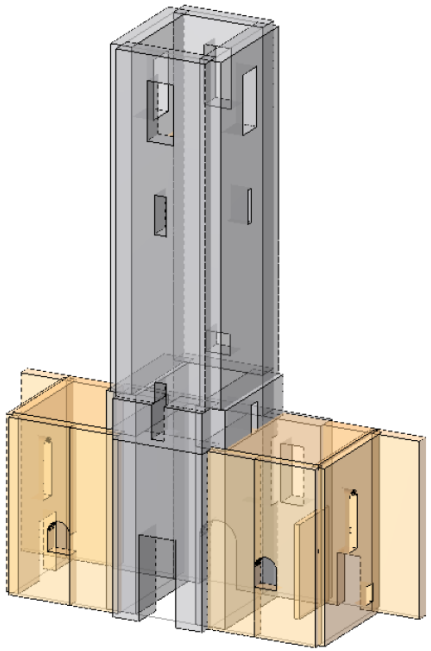


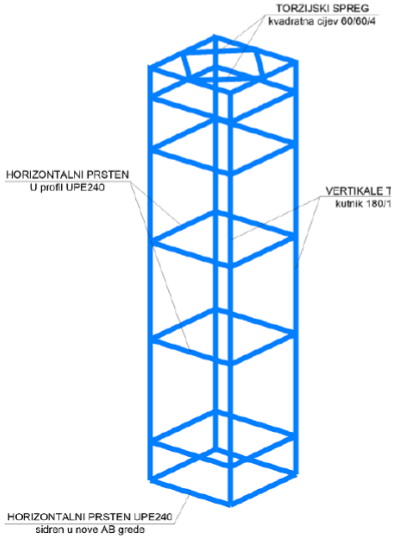


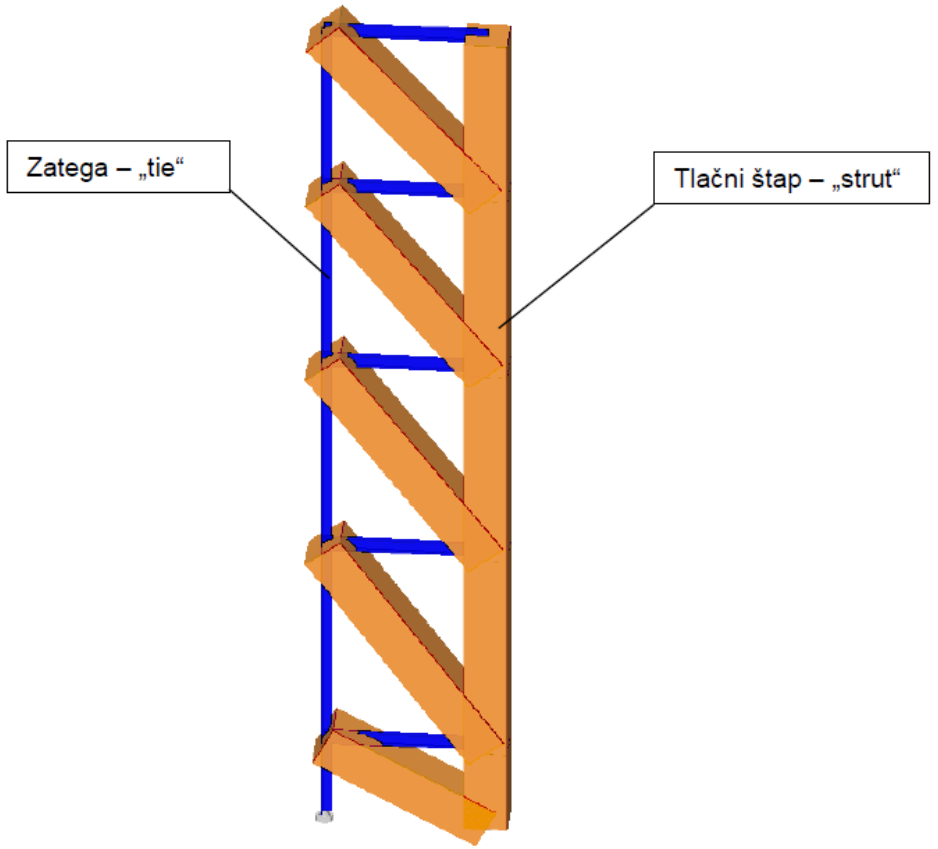
Slika 5-4 Shematski prikaz proračunskog modela

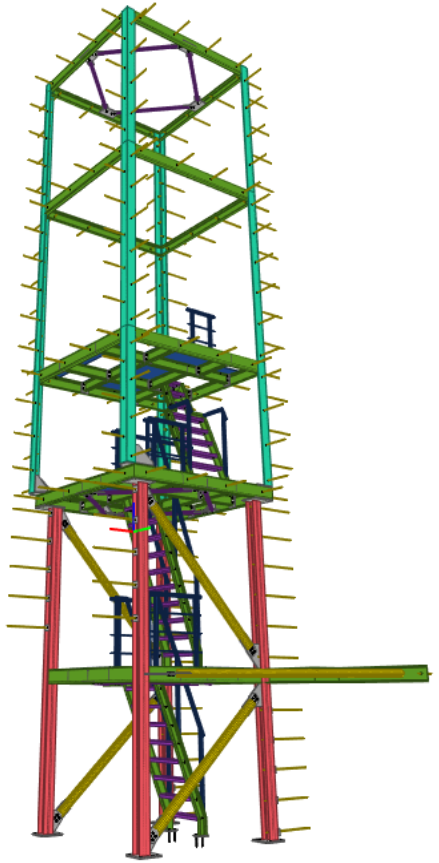


Church Towers

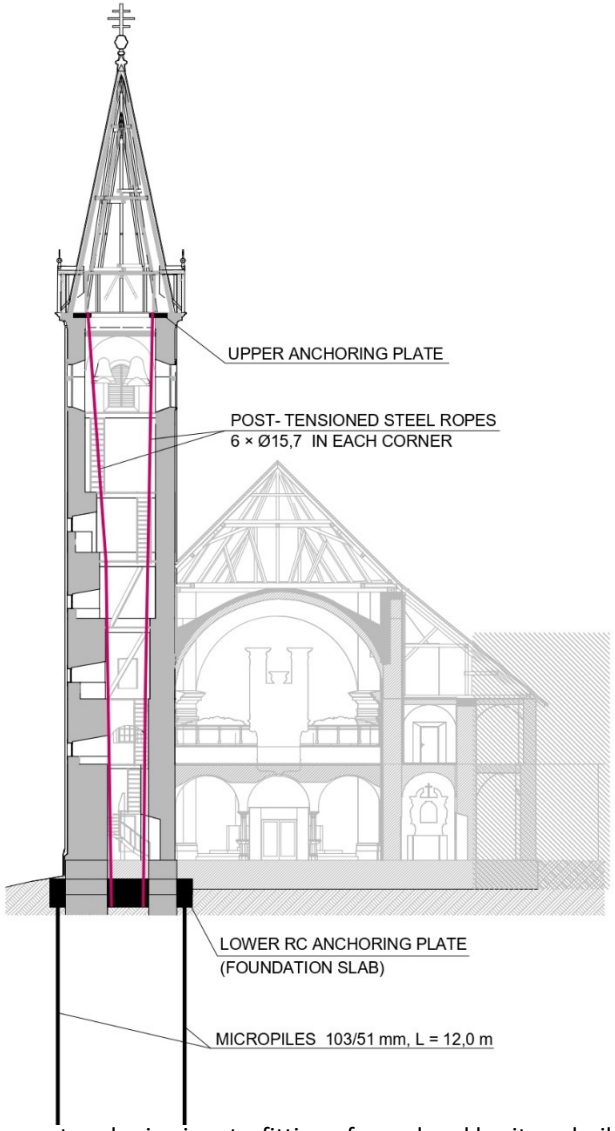


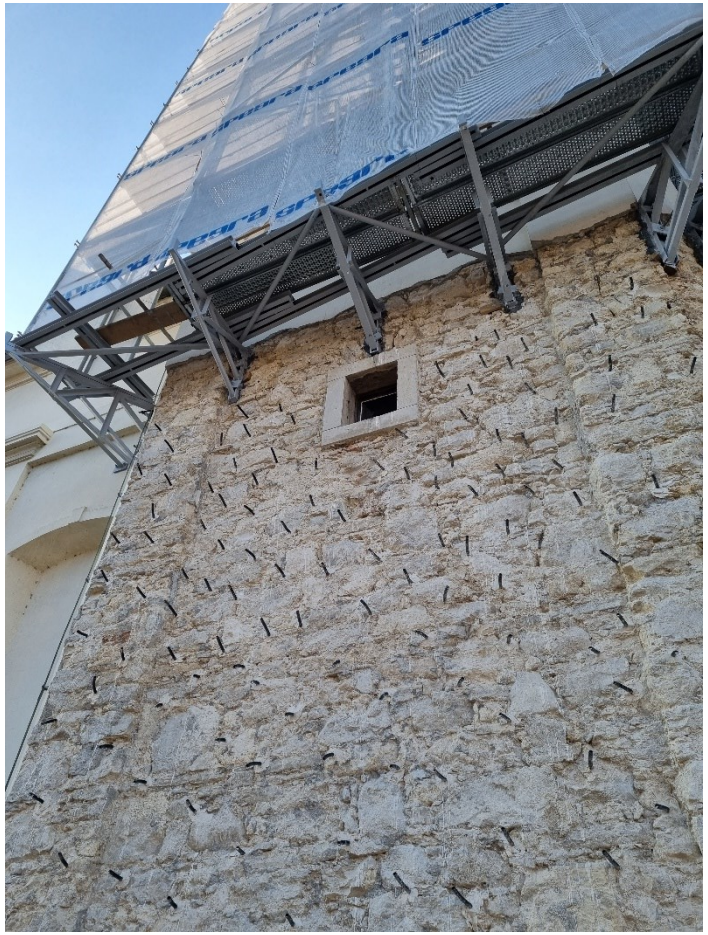




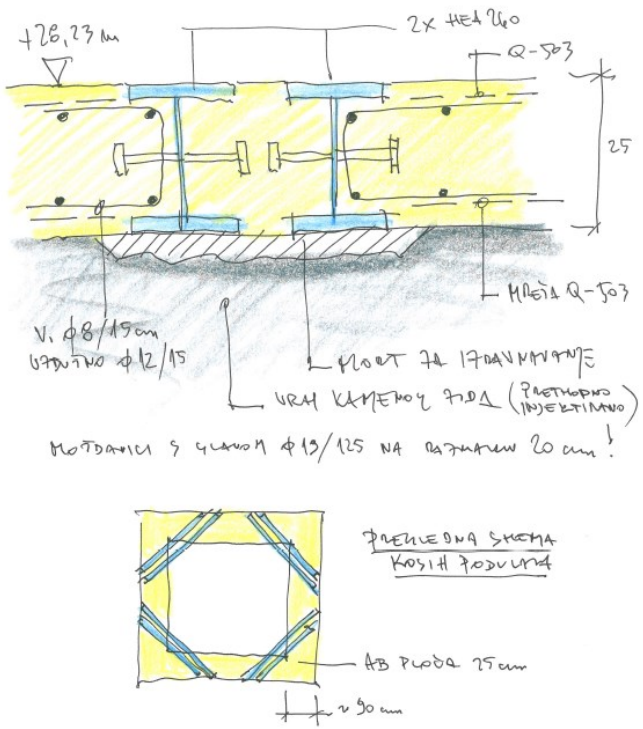


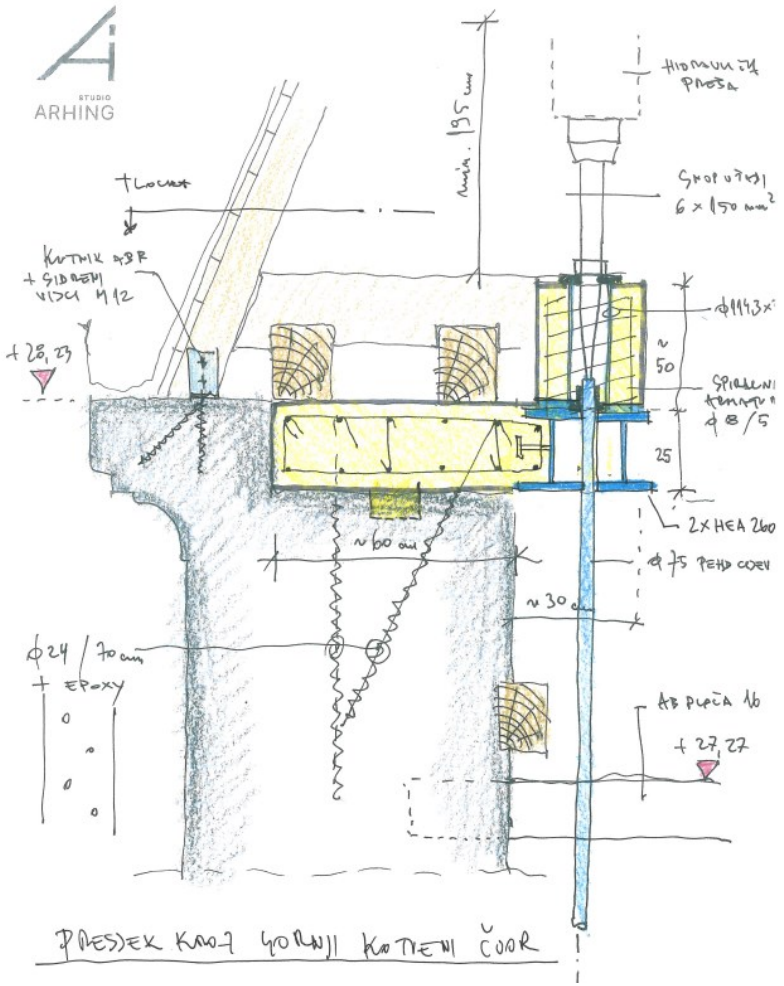
Church Towers

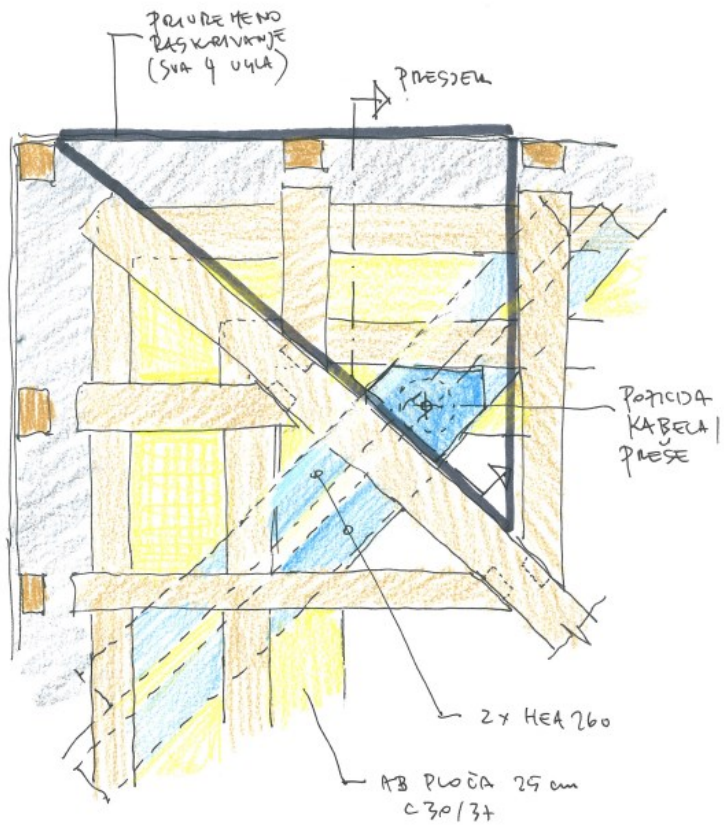




Church Towers

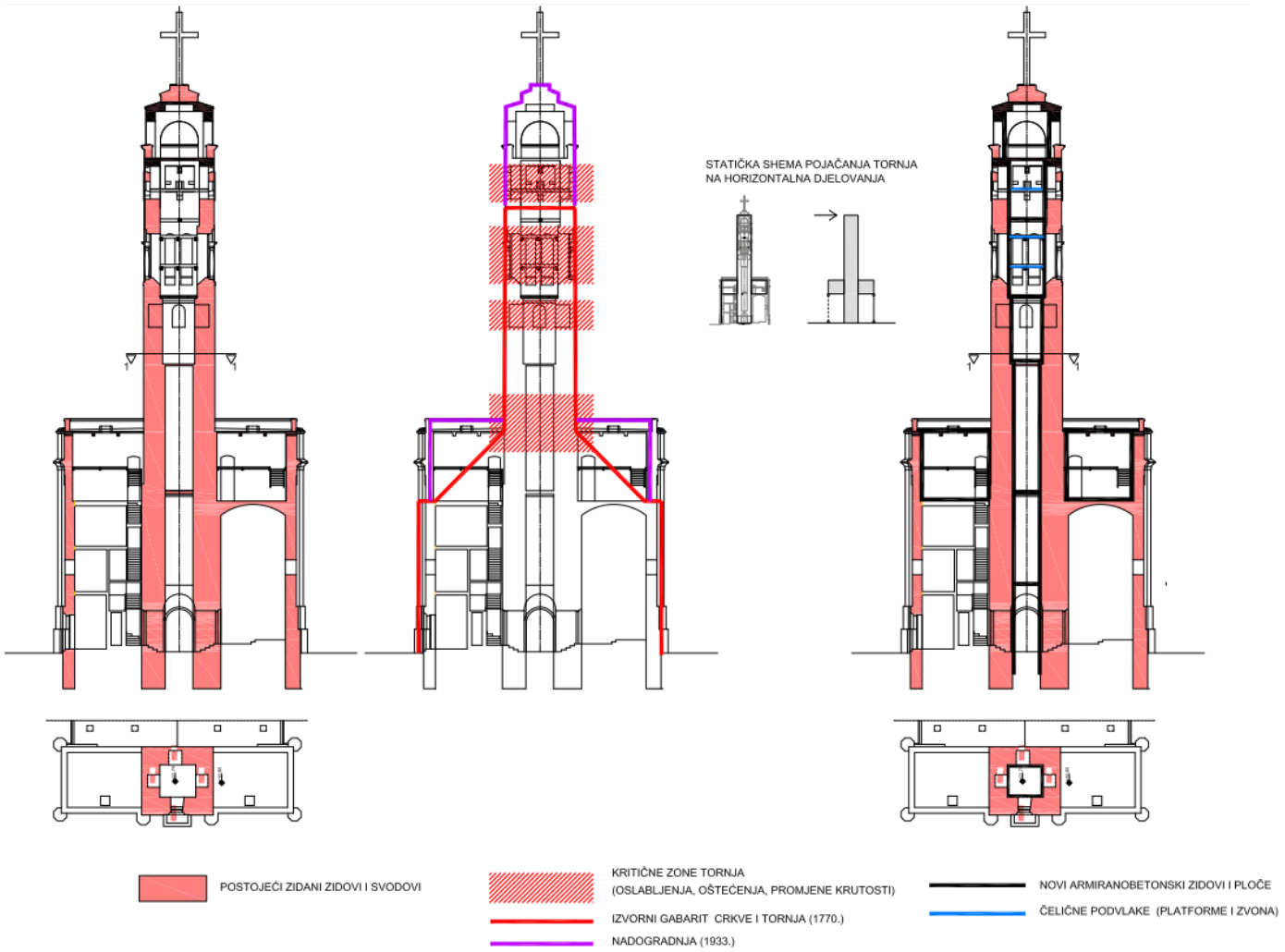


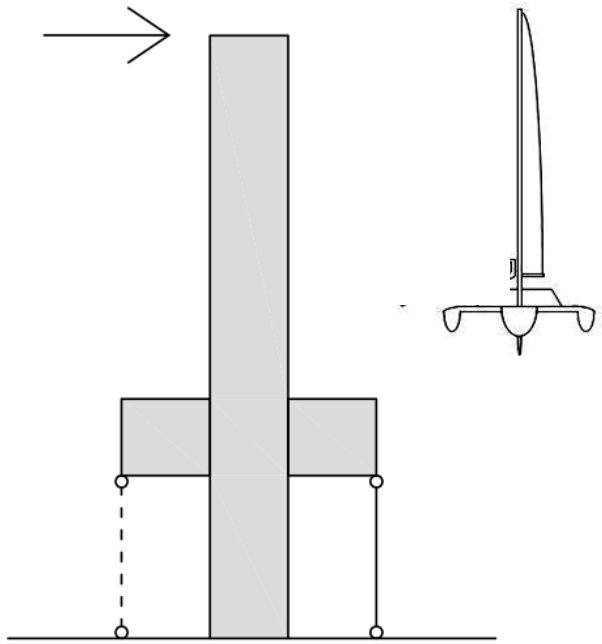




Church Towers

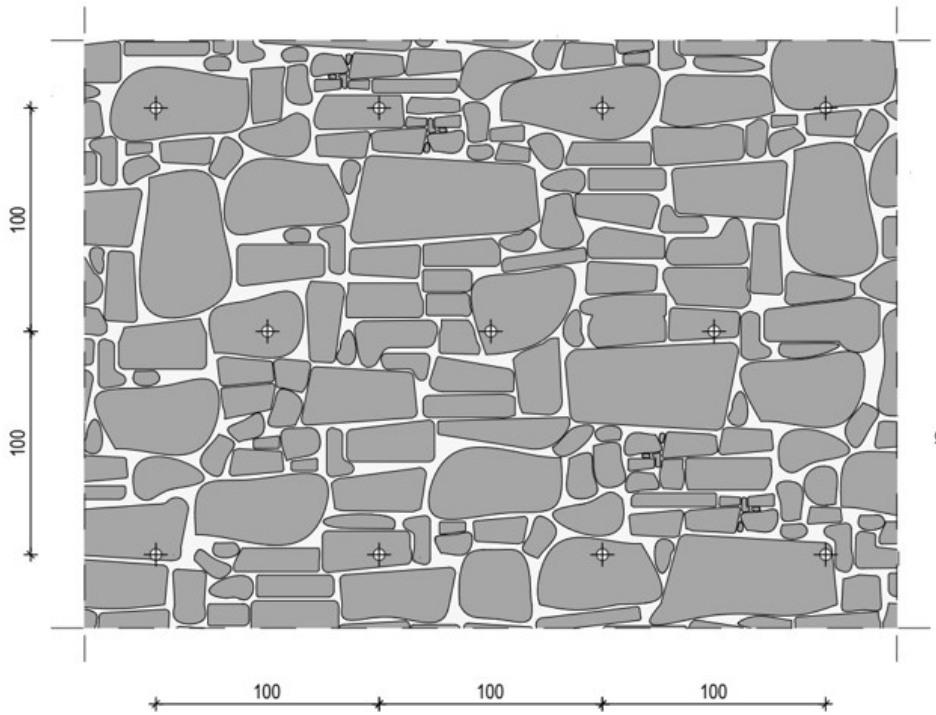
Church Towers

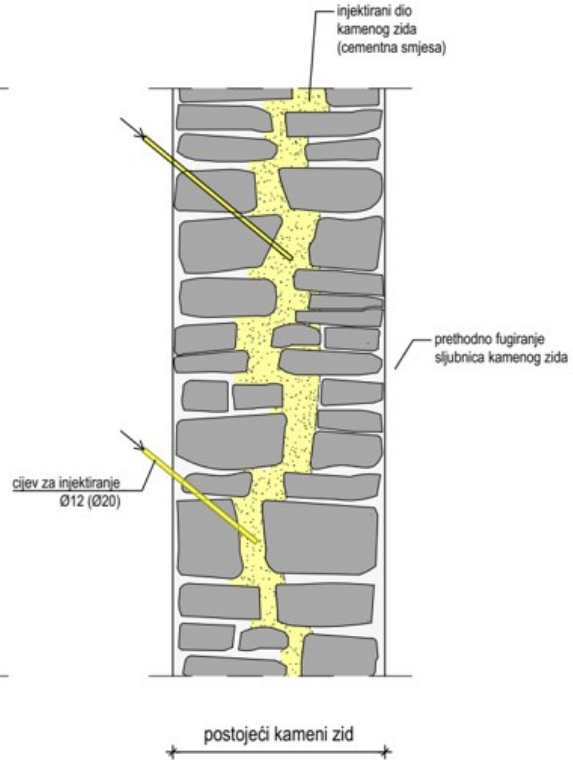


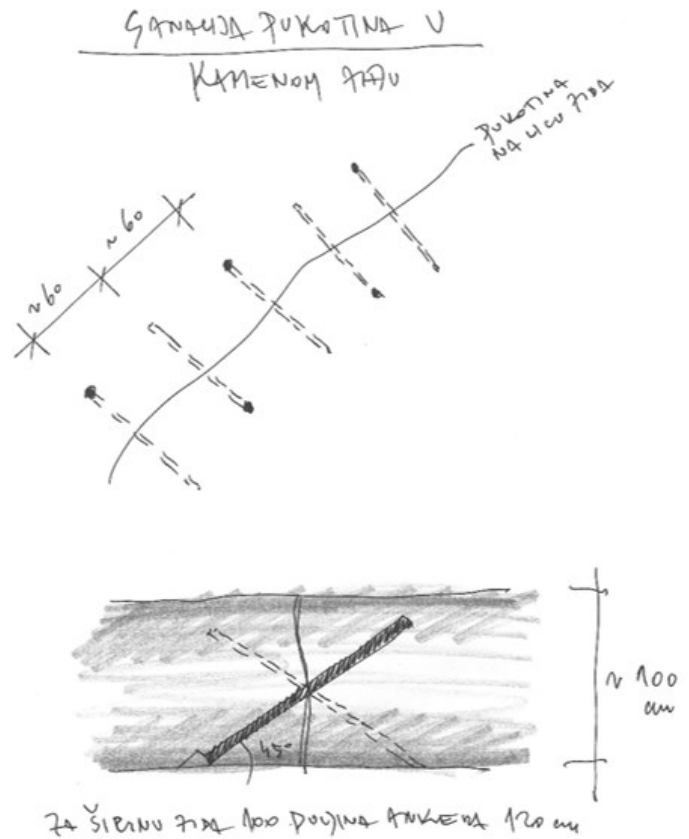


Walls

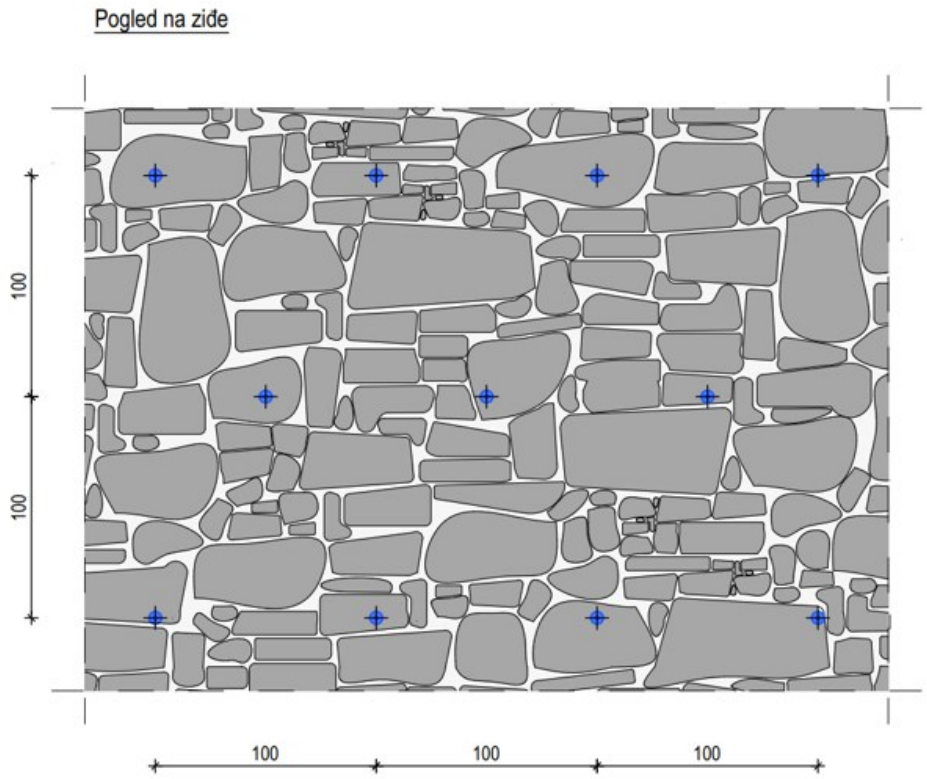
Walls

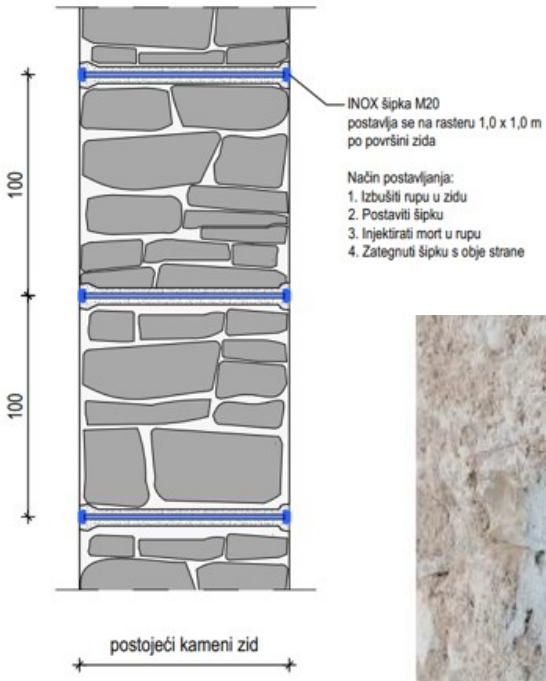

100
100
100
100
100


injektirani dio
kamenog zida
(cementna smjesa)
prethodno fugiranje
sljubnica kamenog zida
cijev za injektiranje
Ø12 (Ø20)
postojeći kameni zid

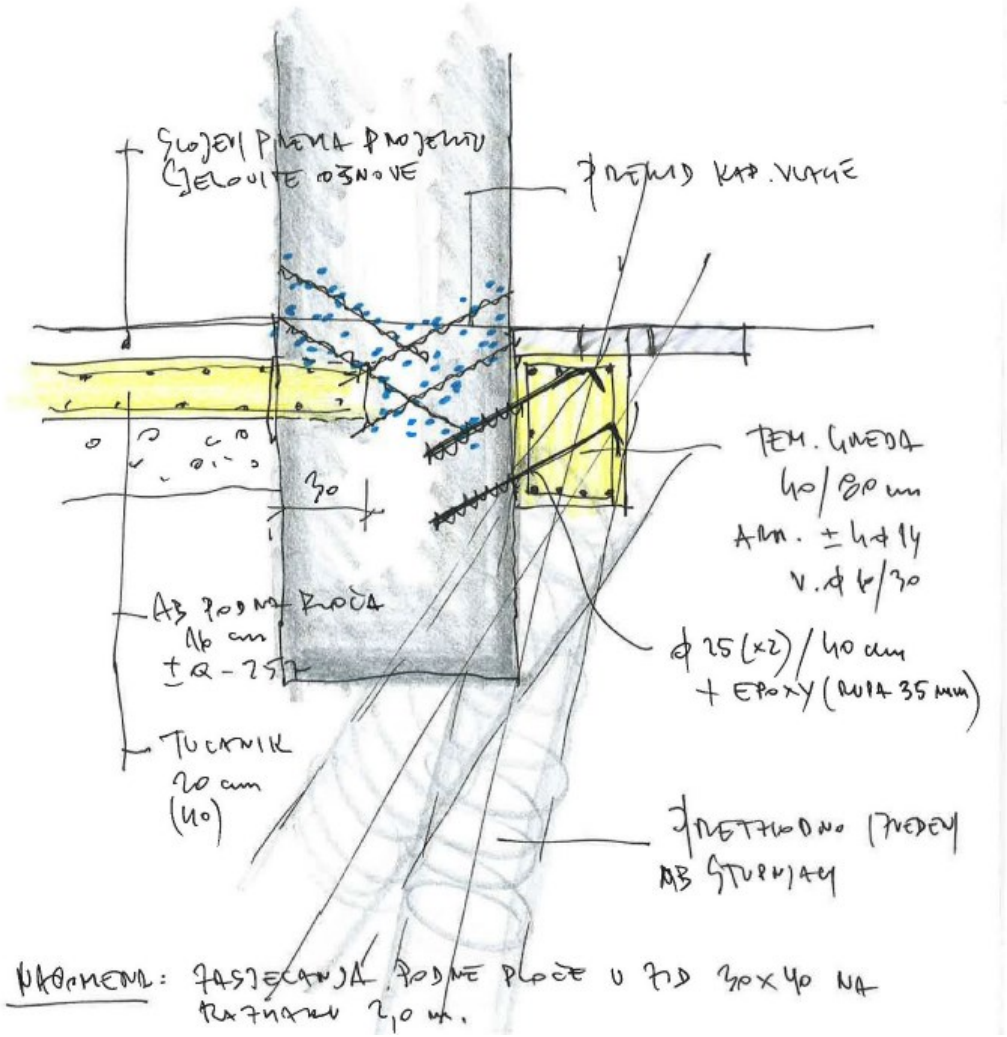

≈100 cm
45°

Walls

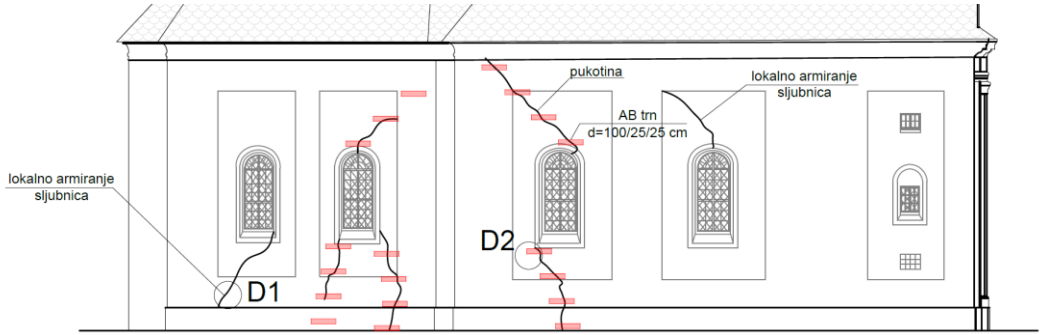

Pogled na zide
100
100
100
100
100

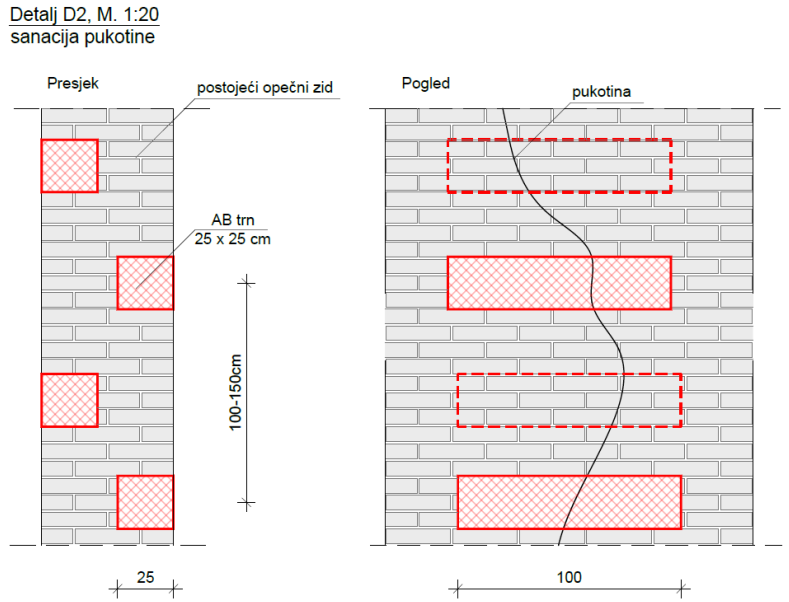

INOX šipka M20
postavlja se na rasteru 1,0 x 1,0 m
po površini zida
Način postavljanja:
1. Izbušiti rupu u zidu
2. Postaviti šipku
3. Injektirati mort u rupu
4. Zategnuti šipku s obje strane
100
100
postojeći kameni zid

Walls


TEM. GREDA
40/80 cm
ARM. ± 4+14
V.Φ 6/30
Φ 25 (x2) / 40 cm
+ EPOXY (RUPA 35 mm)
TUCANIK
20 cm
(40)
30

Walls


pukotina
lokalno armiranje
sljubnica
AB trn
d=100/25/25 cm
lokalno armiranje
sljubnica
D2
D1

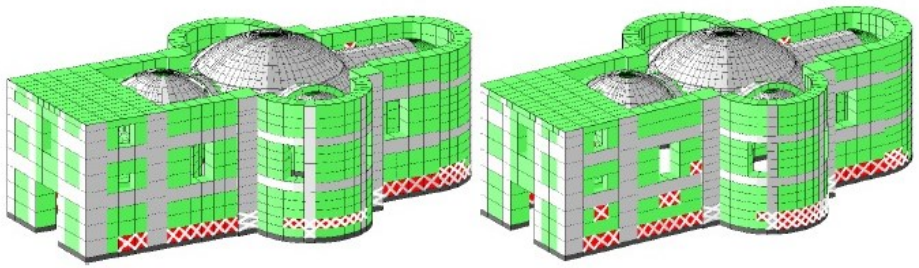

Detalj D2, M. 1:20
sanacija pukotine
Presjek
postojeći opečni zid
AB trn
25 x 25 cm
100-150cm
25
Pogled
pukotina
100

Walls

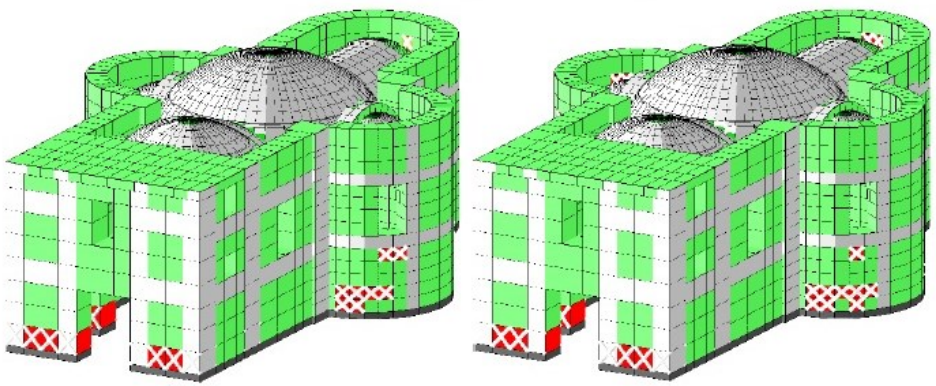
Walls

Pushover analiza:

Tip oštećenja	Razina oštećenja	
	Niska	Visoka
Dijagonalno otkazivanje	X	X



Slika 5-24 Prikaz oštećenja- Push-over u smjeru +x i – x



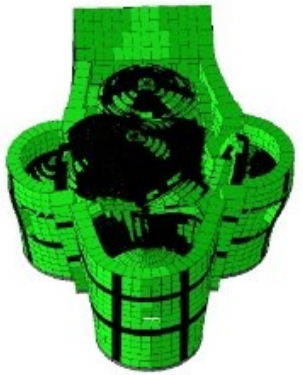
Slika 5-25 Prikaz oštećenja- Push-over u smjeru +y i – y

Modalna analiza:

Slika 5-20 Prikaz prvog moda titranja T=0,19 s

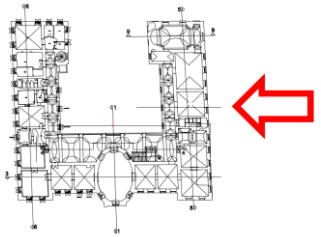
Slika 5-21 Prikaz drugog moda titranja T=0,15 s

Slika 5-22 Prikaz trećeg moda titranja T=0,14 s

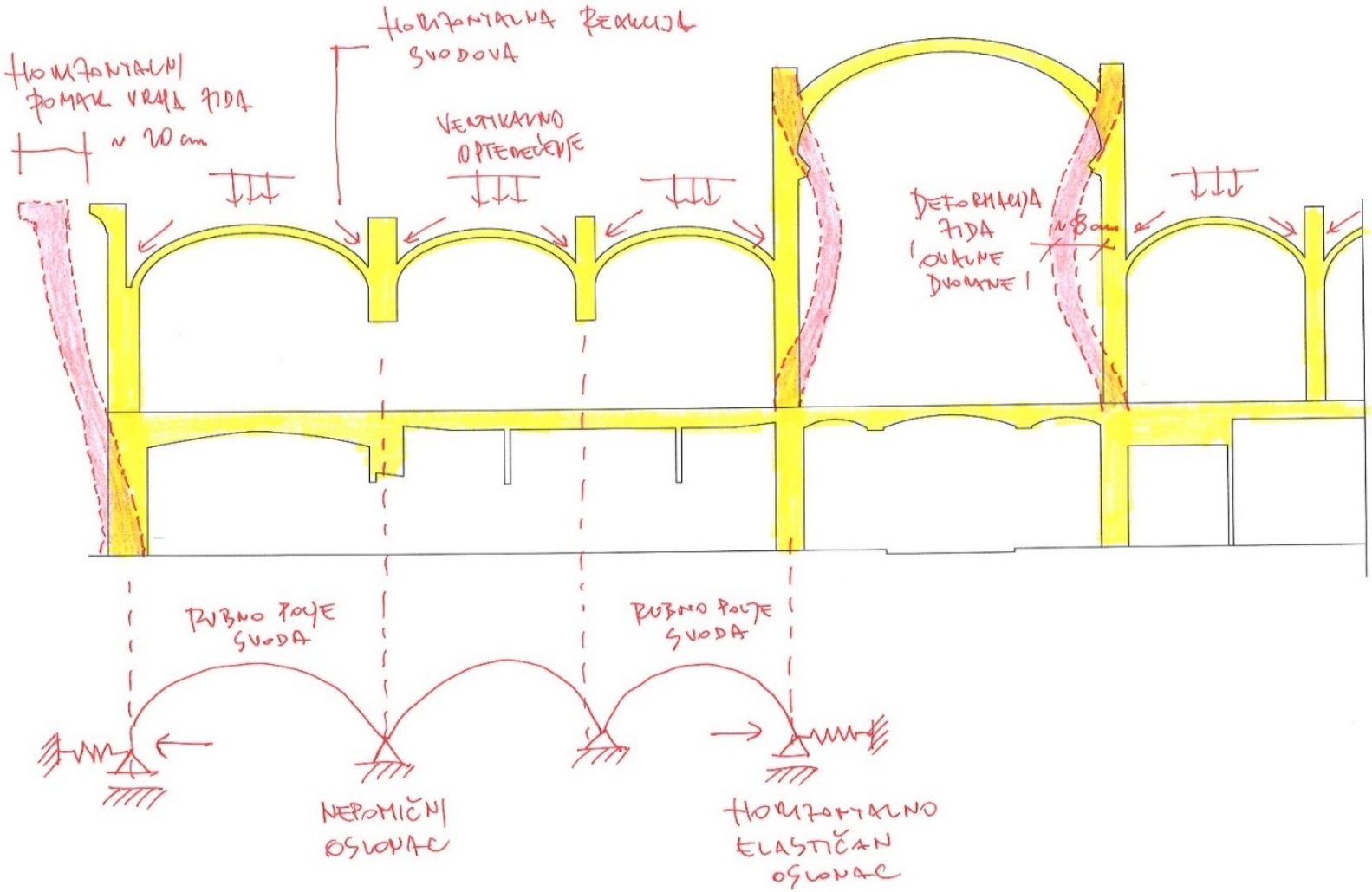


Slika 5-23 Prikaz četvrtog moda titranja T=0,13 s

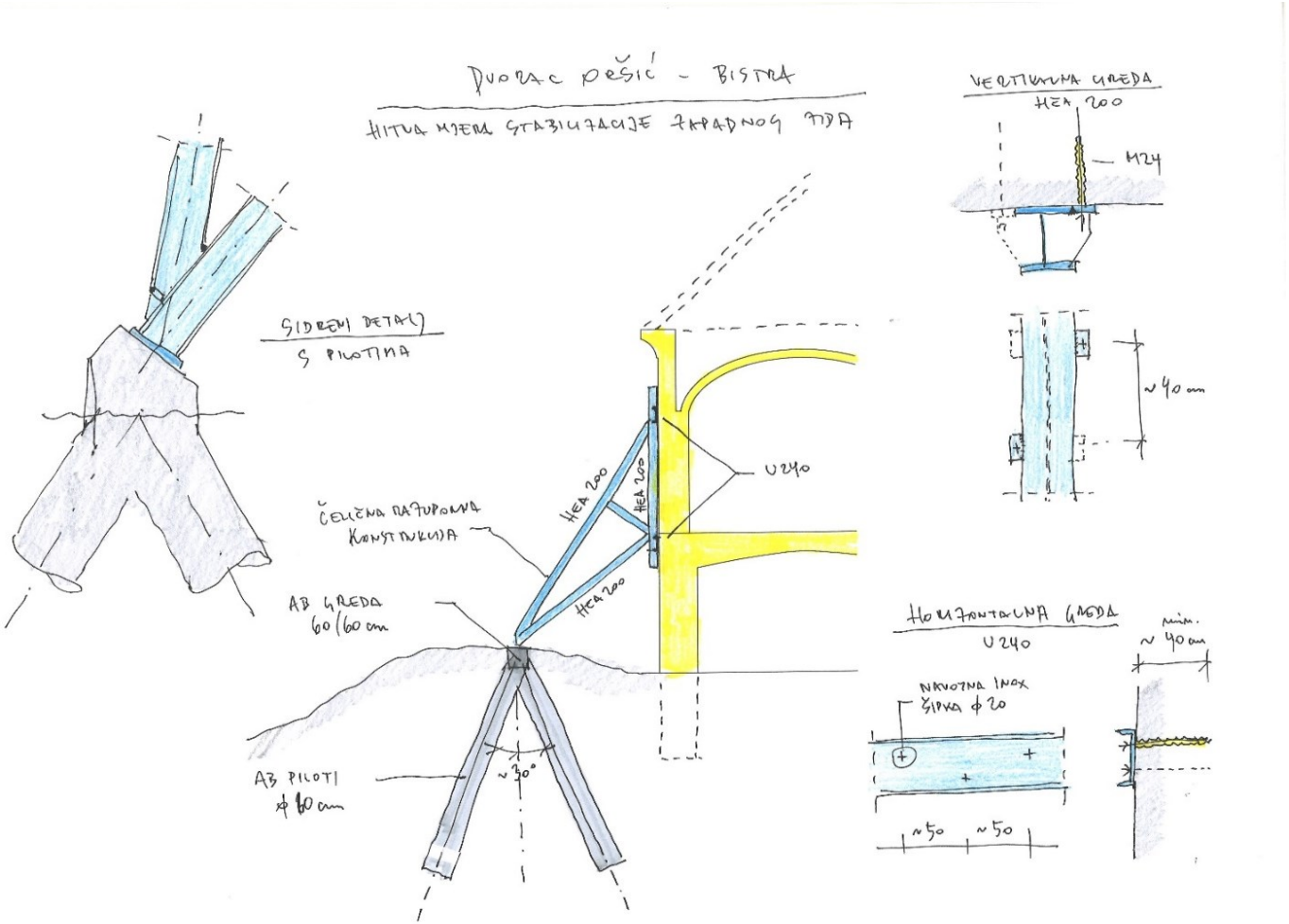
Walls

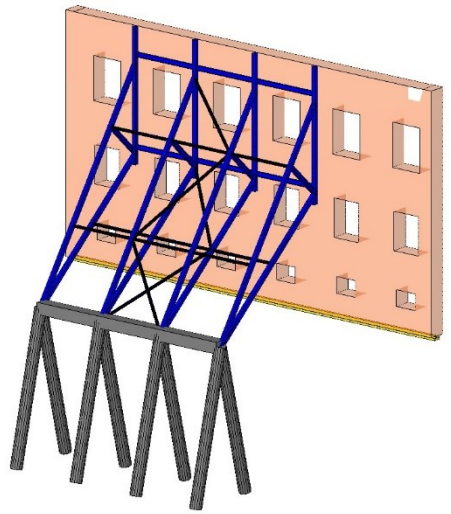


Walls

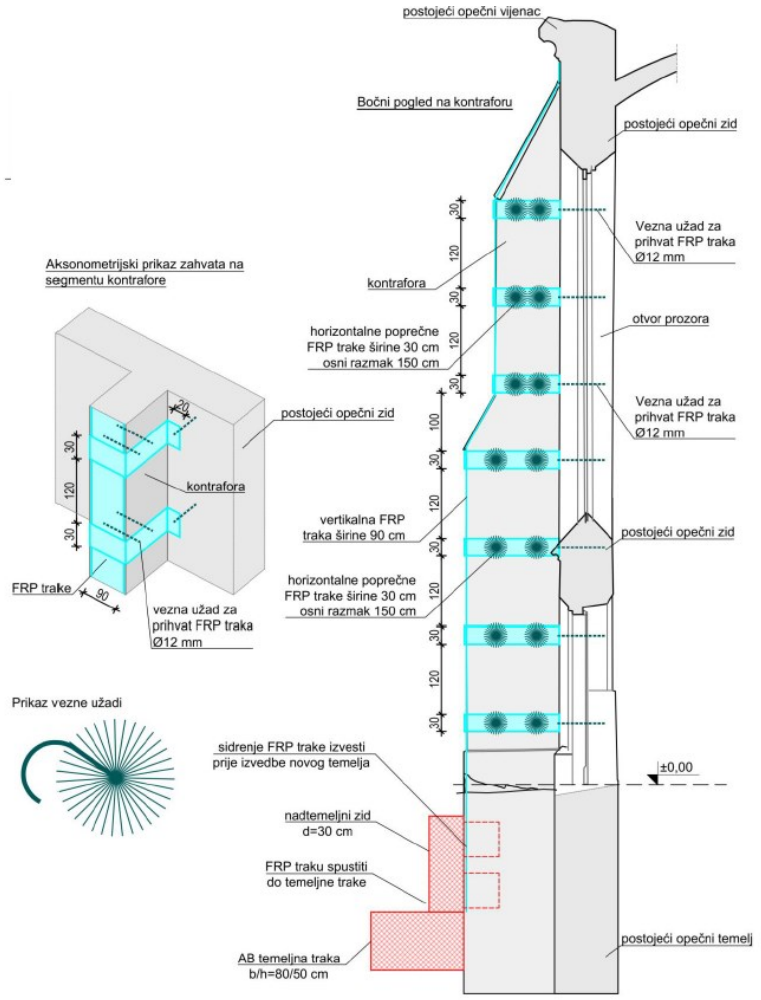

HORIZONTALNA REAKCIJA SVODOVA
HORIZONTALNI POMAK VRHA STIJA
≈ 20 cm
VERTIKALNO OPTEREĆENJE
DEFORMACIJA STIJA (DVA STANJA)
≈ 8 cm
RUBNO POLJE SVODA
RUBNO POLJE SVODA
NEPOMIČNI OSLONAC
HORIZONTALNO ELASTIČAN OSLONAC

Walls

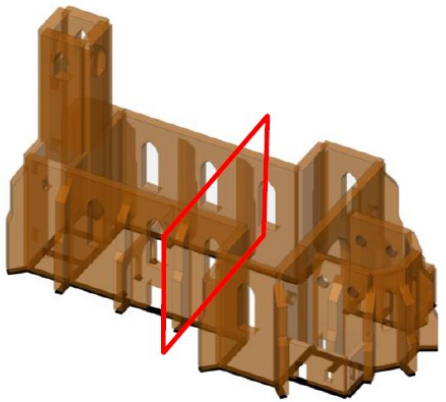

Dvorac Pešić - Bistra
HITNA MJERA STABILIZACIJE ZAPADNOG TIPA
SIDRENI DETALJ S PILOTIMA
ČELIČNA RAZUPORNA KONSTRUKCIJA
AB GREDA 60/60 cm
AB PILOTI ϕ 60 cm
HEA 200
HEA 200
HEA 200
U 240
~30°
VERTIKALNA GREDA
HEA 200
M24
~40 cm
HORIZONTALNA GREDA
U 240
NAVOJNA INOX ŠIPKA ϕ 20
min. ~40 cm
~50
~50



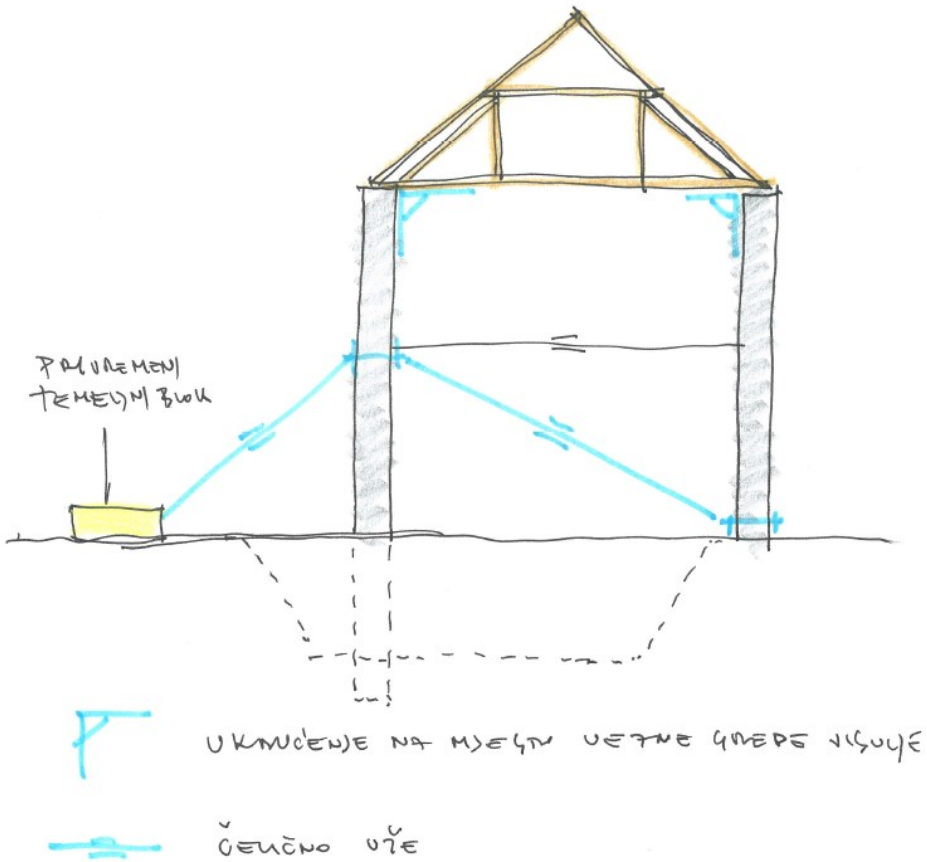
Walls



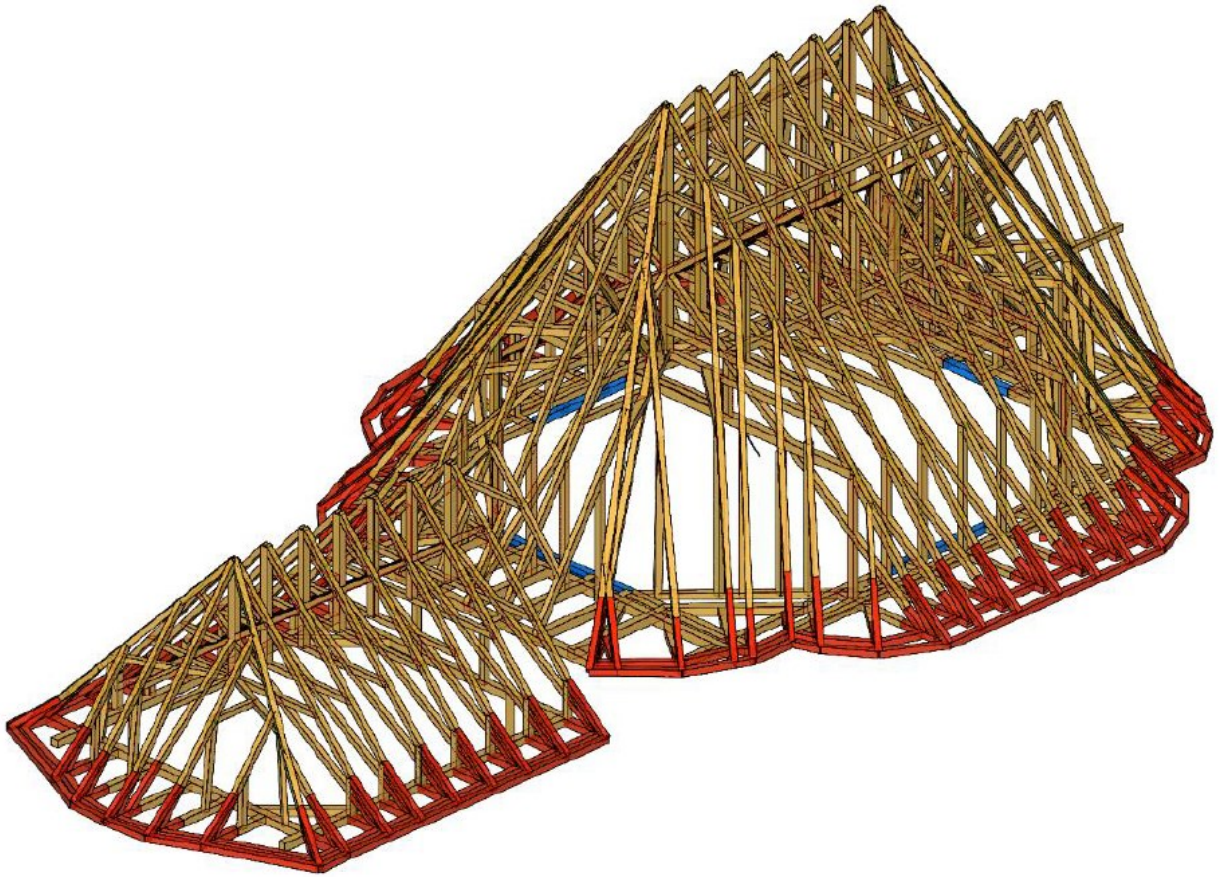
Slika 5-27 Detalj pojačanja kontrafora

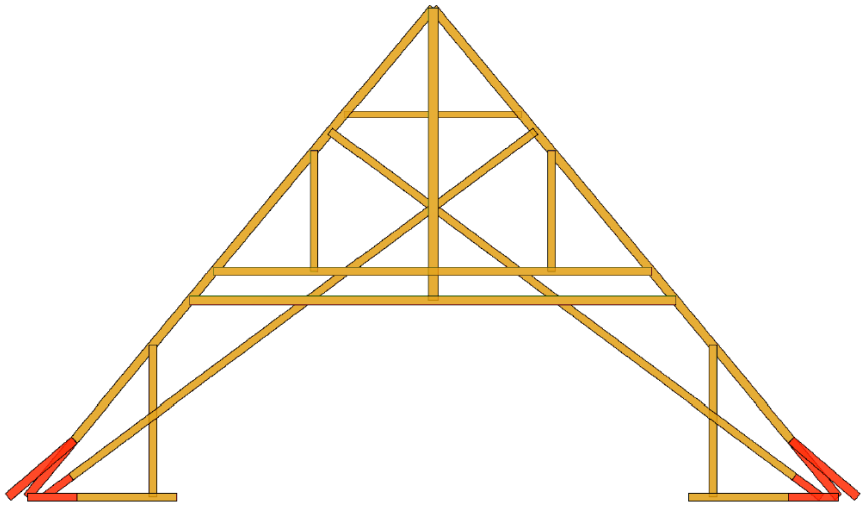


Walls


PRIMJEREN
TEMELJNI BLOK
UKLINUĆENJE NA MJESTU VEĆE GREDE VIŠUĆE
ČELIČNO UŽE

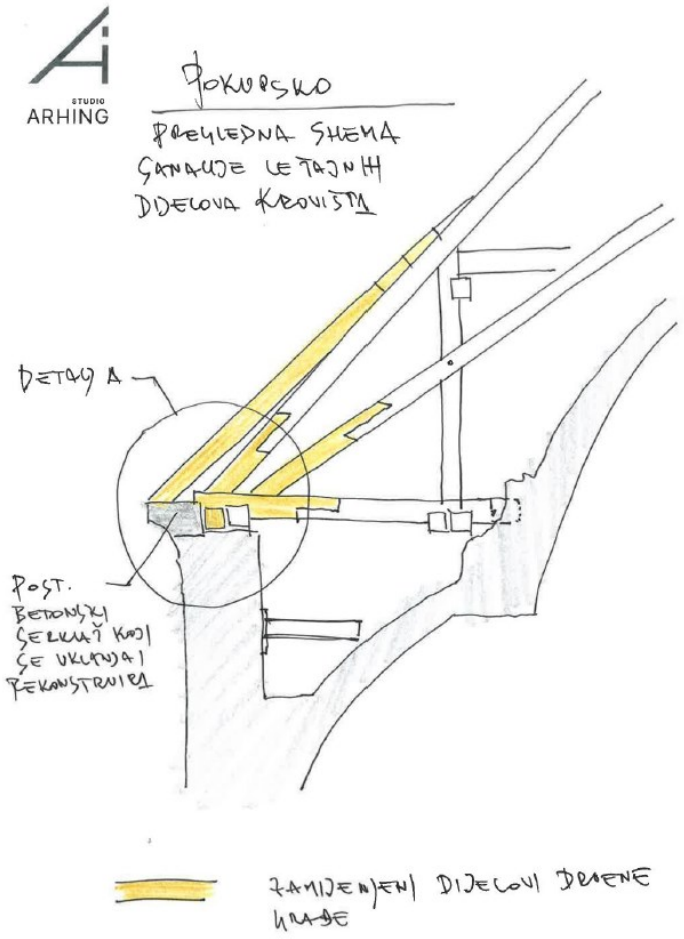
Roofs

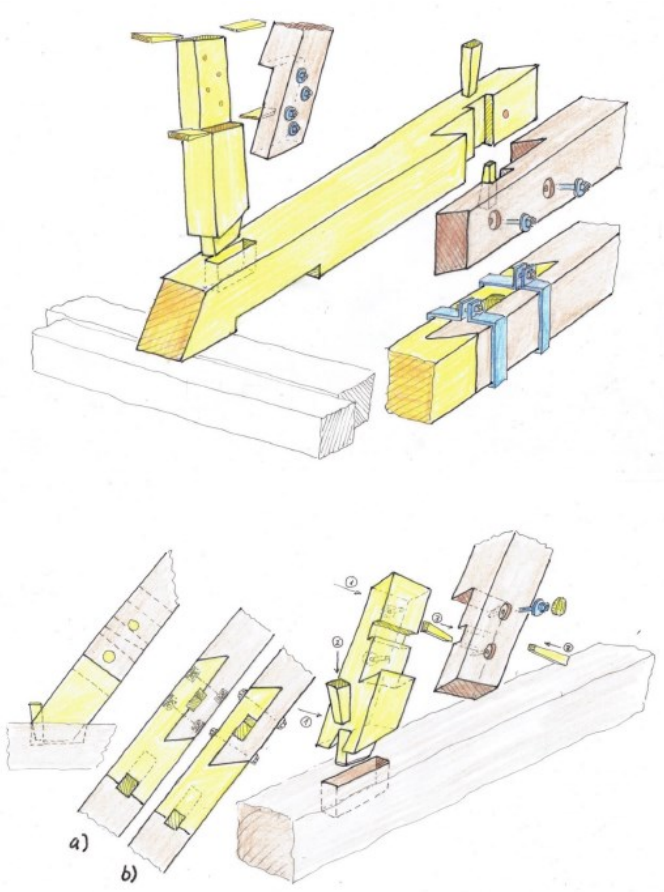


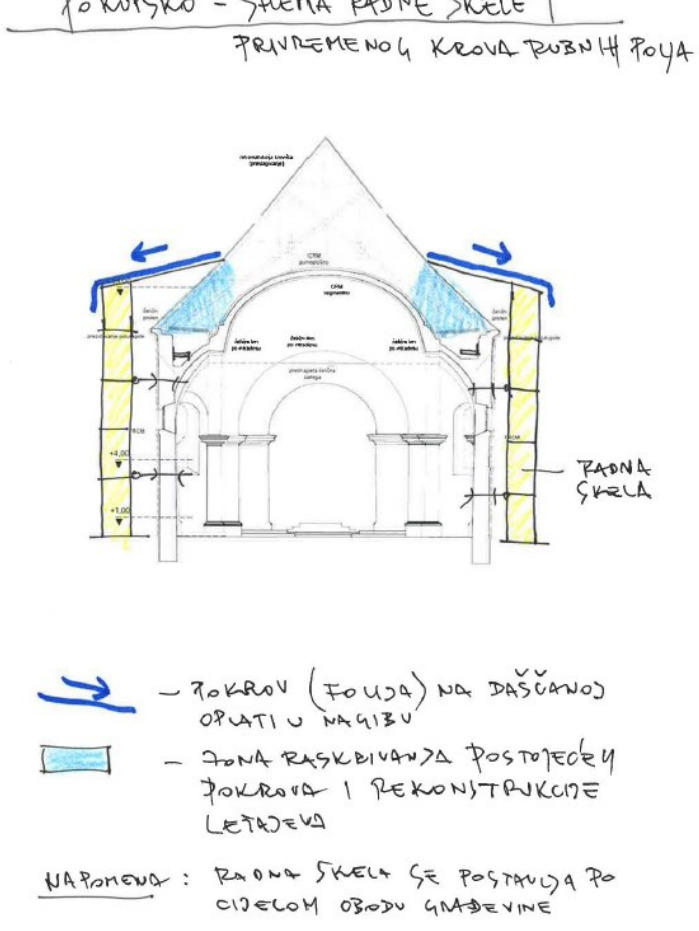


Slika 5-8 Presjek kroz glavni brod

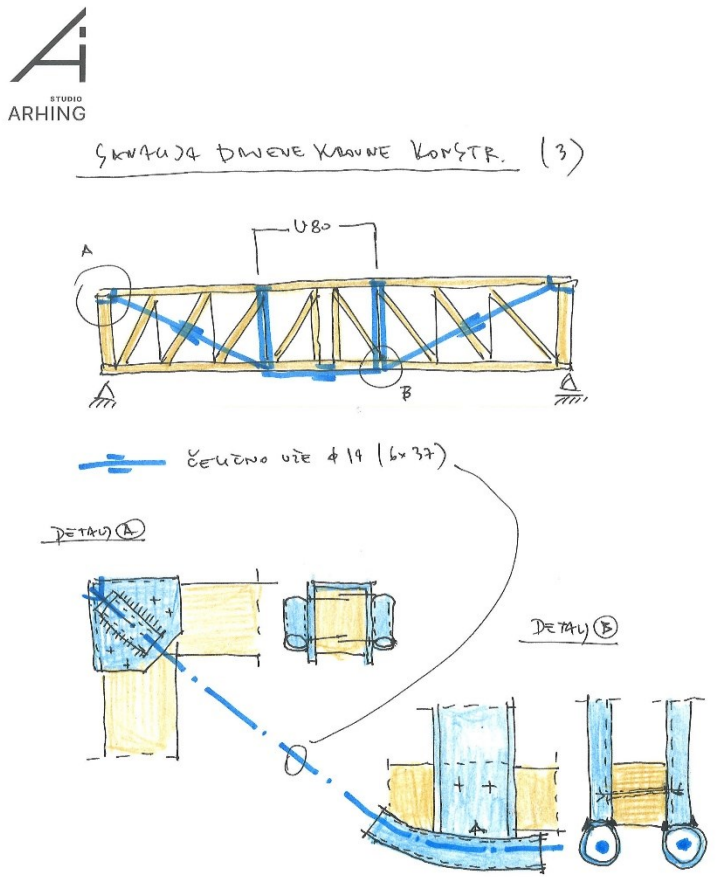
Roofs

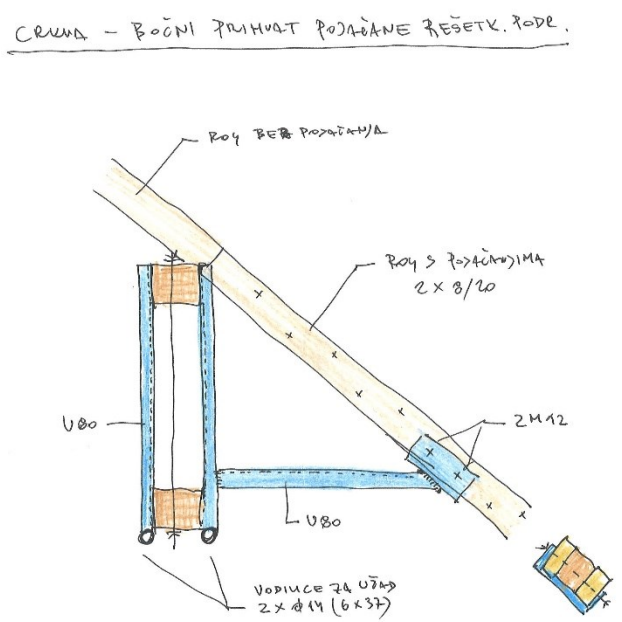

STUDIO ARHING
POKUPSKO
PREGLEDNA SHEMA
SANACIJE LETAJNIH
DIJELOVA KROVIŠTA
DETALJ A
POST. BETONSKI ŠELUŠAJ KOJI ĆE UKLANJATI I REKONSTRUIRATI
TAMNIJENI DIJELOVI DRŽENE KUĆE

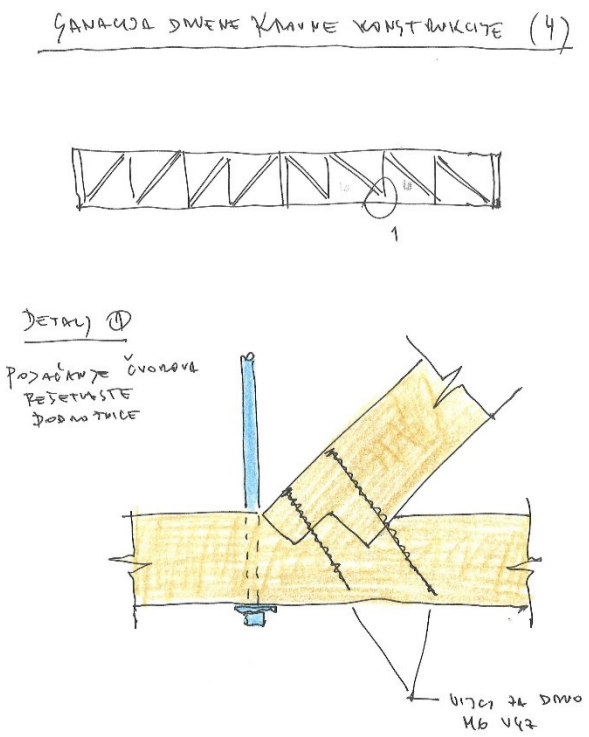

a)
b)


POKUPSKO - SHEMA RADNE SKELE I PRIVREMENOG KROVA RUBNIH POLJA
RADNA SKELA
– POKROV (FOLIJA) NA DAŠČANOJ OPLATI U NAGIBU
– ZONA RASKRIVANJA POSTOJEĆEG POKROVA I REKONSTRUKCIJE LETJEVA
NAPOMENA: RADNA SKELA ĆE POSTAVLJATI PO CIJELOM OBODU GRAĐEVINE

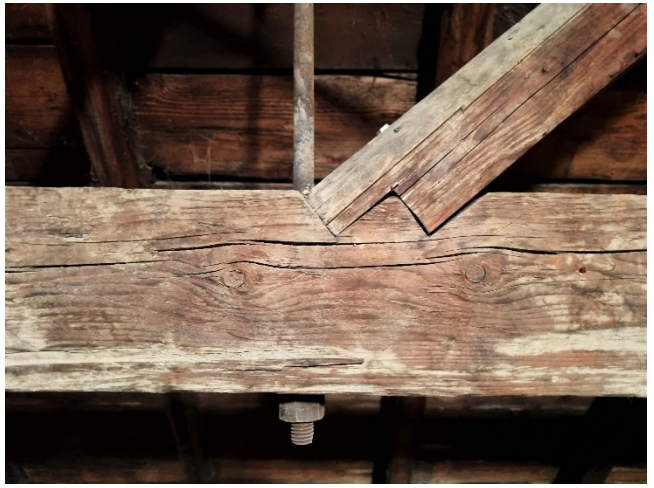
Roofs


SKICA DVENE KRAJNE KONSTR. (3)
U80
A
B
ČELIČNO UŽE ϕ 14 (6x37)
DETALJ A
DETALJ B

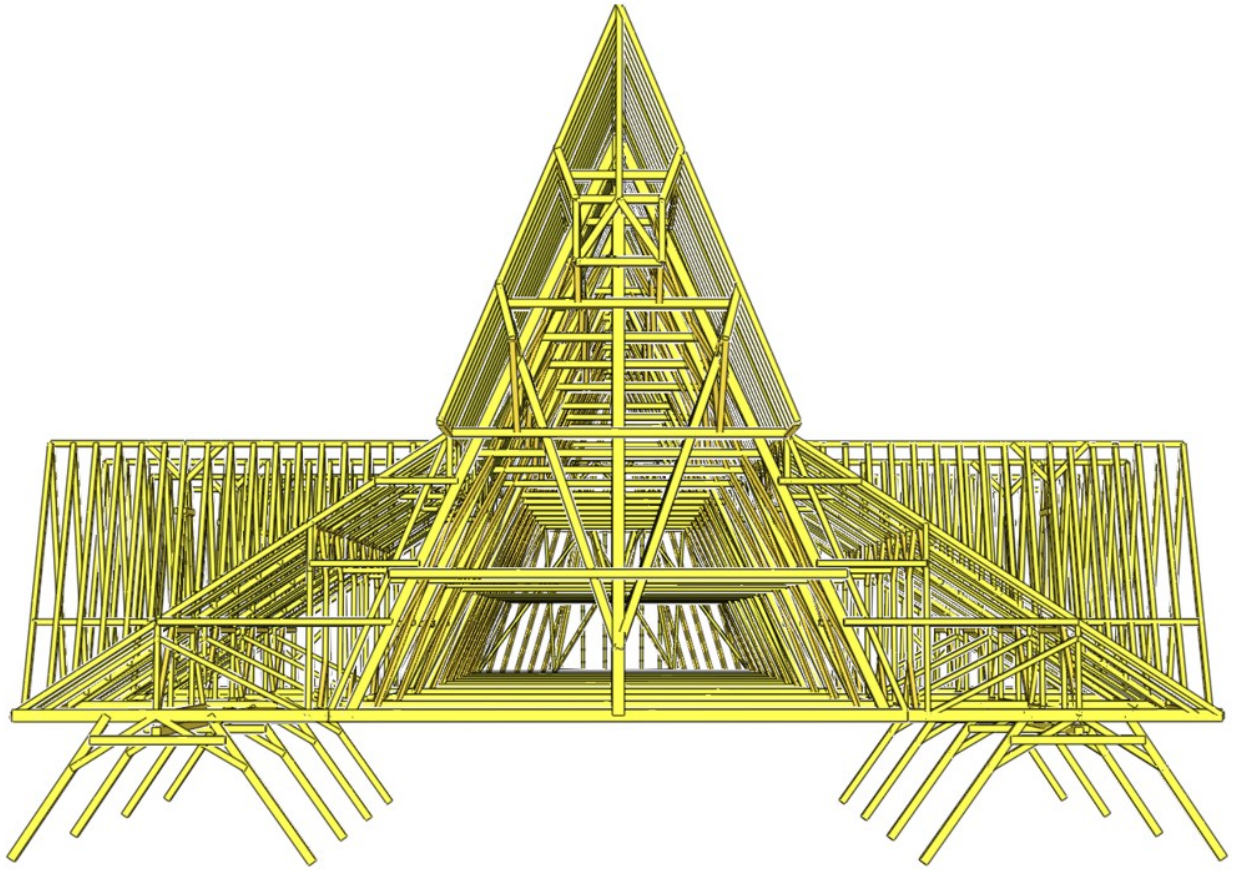

OSNOVA - BOČNI PRIHVAT POSTAJANE REŠETK. NOSIL.
NOSILEC BREZ PODPORNIKA
NOSILEC S PODPORNIKI
2 x 8/20
2M12
U80
U80
VODILICE ZA UŽAD
2 x ϕ14 (6x37)


SHEMA DVENE KRAJNE KONSTRUKCIJE (4)
1
DETALJ 1
POZAČNJE OVOJNICA
REŠETKASTE
NOSILNIKE
VIJAKI ZA DNO
M6 V4.7

Roofs

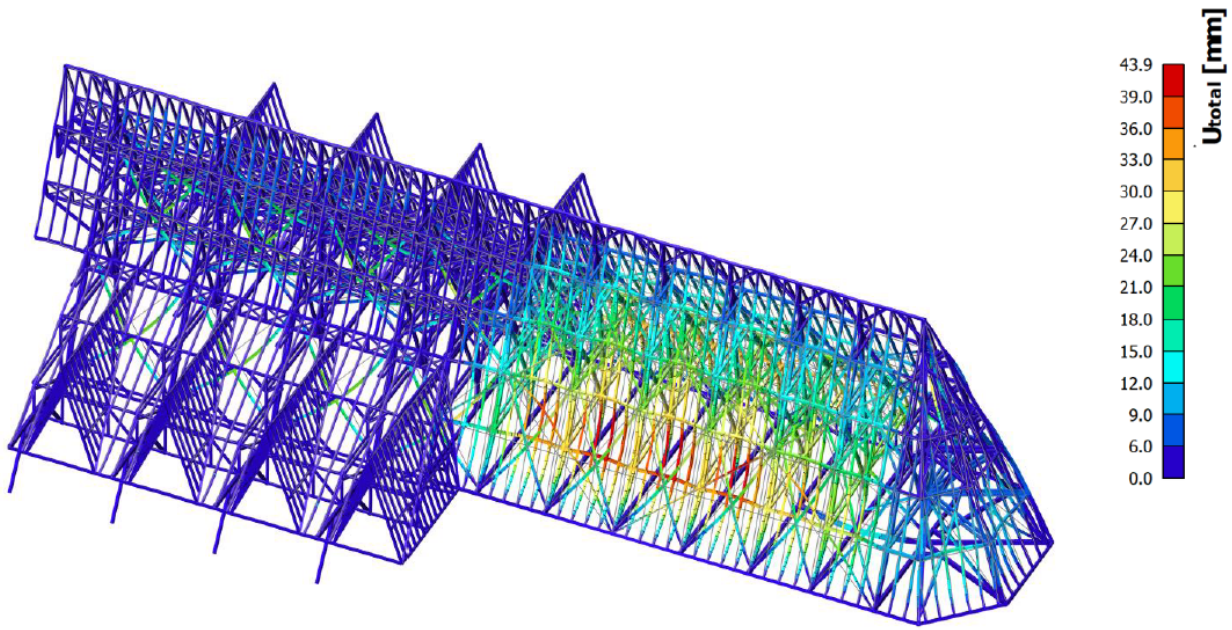


Roofs



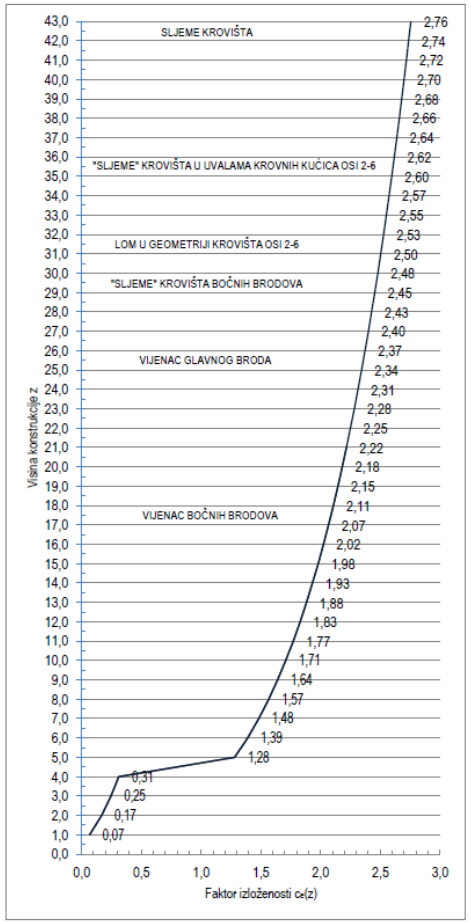
Roofs

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

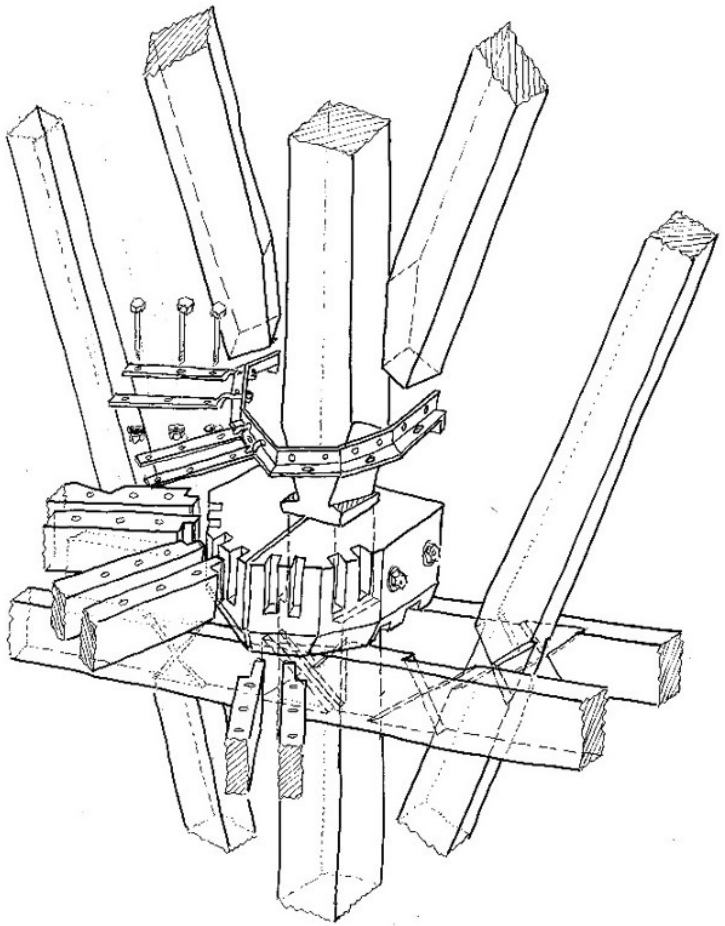


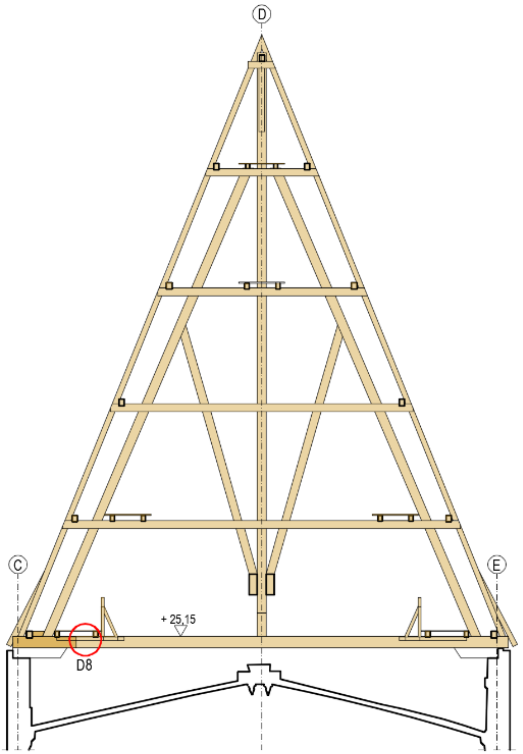
U nastavku dan tablični i grafički prikaz ovisnosti faktora izloženosti o visini konstrukcije.

z	$c_r(z)$	I_v	$c_e(z)$
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

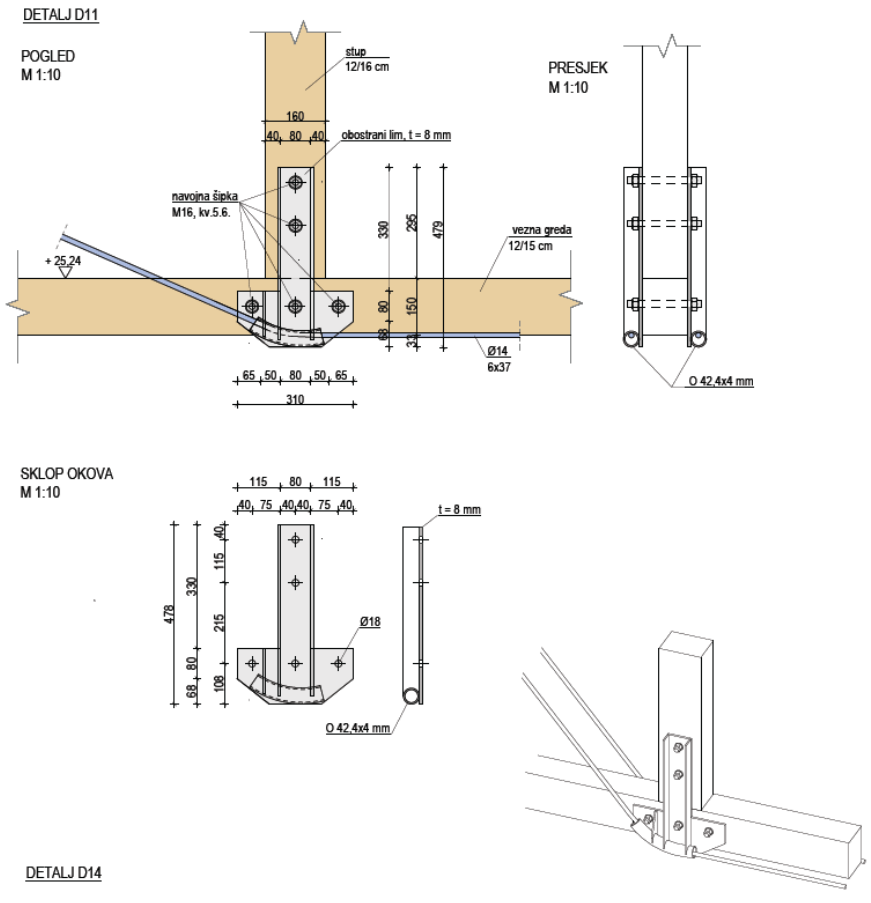


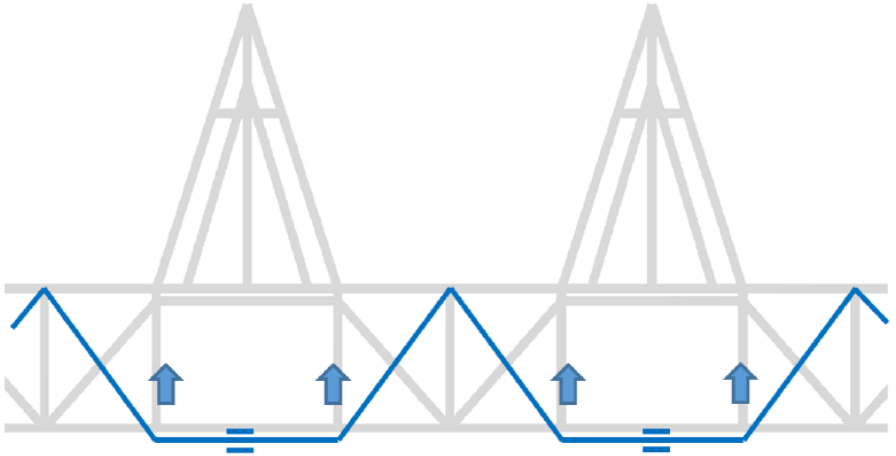
Roofs



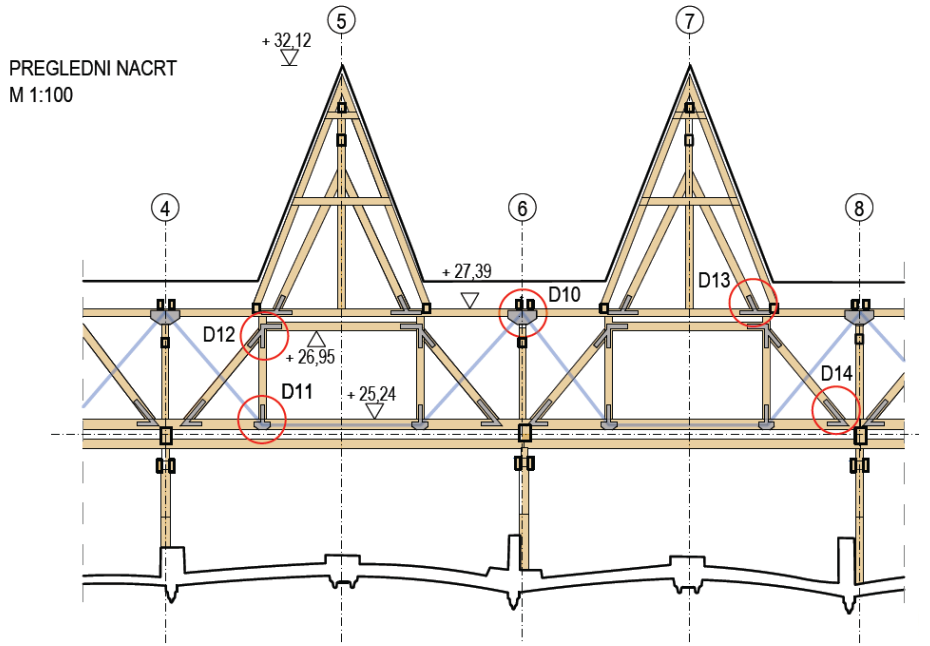


Roofs





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



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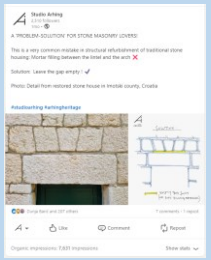
Thank you for your attention!



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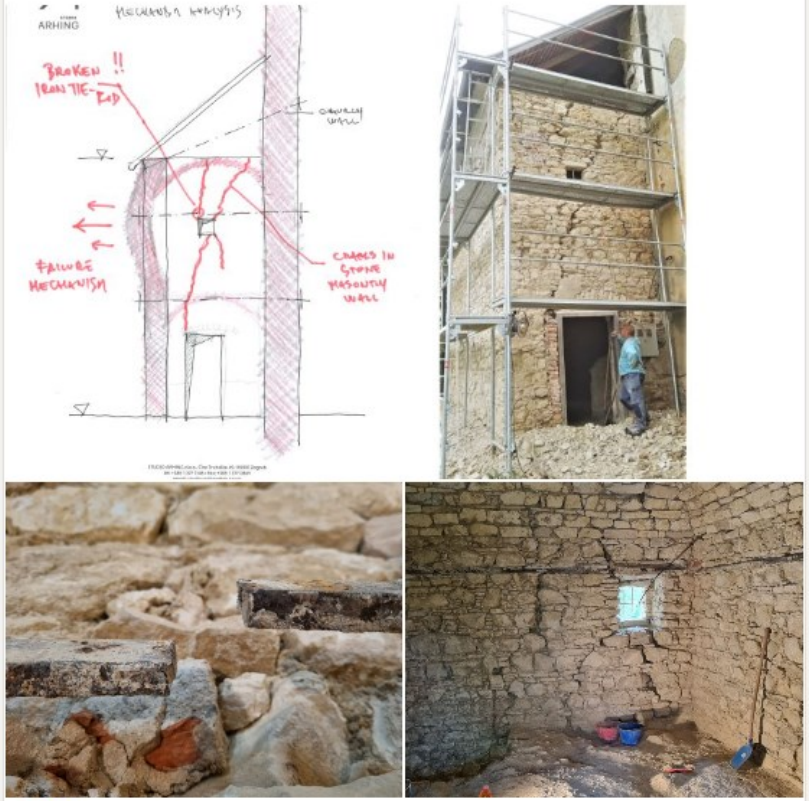

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