

# Numerical analysis and retrofitting of an historical masonry buildings



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**Oponent:** Ing. Jan Čížek




# Outline

- Motivation
  - Aim of thesis
  - Study case
  - Analysis results
  - Conclusion
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# Motivation

- Hot topic
  - Not so well known in Czech Republic
  - Passion for architectural heritage
  - Cooperation on real project
- 



# Aim of thesis

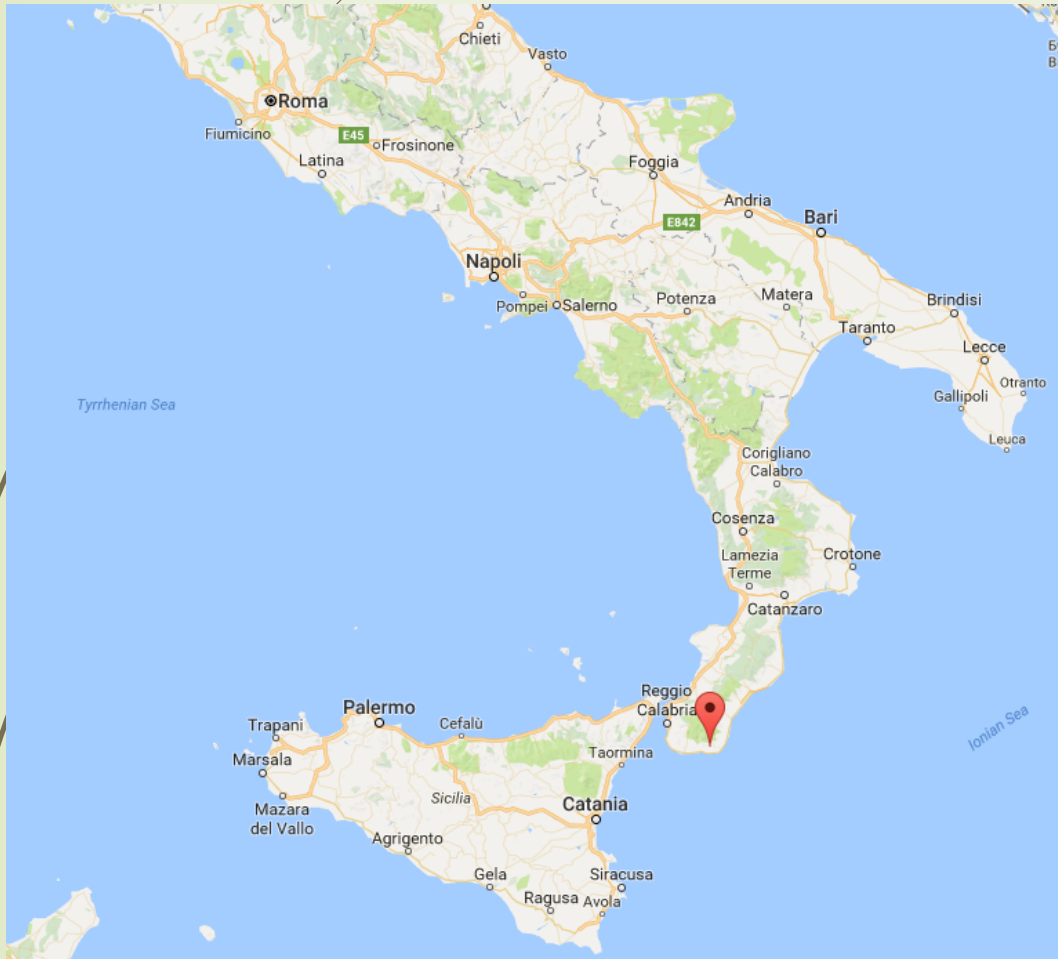
- ▶ The aim of this bachelor thesis is to perform a seismic analysis of an historical masonry building located in seismic zone based on Italian code NTC 2008 and investigate the possible retrofitting techniques in order to preserve the building in case of earthquake. Elective method will be applied on chosen structure and in case of unsatisfactory results would be the structure retrofitted.

# Study case – „Palizzi“ castle

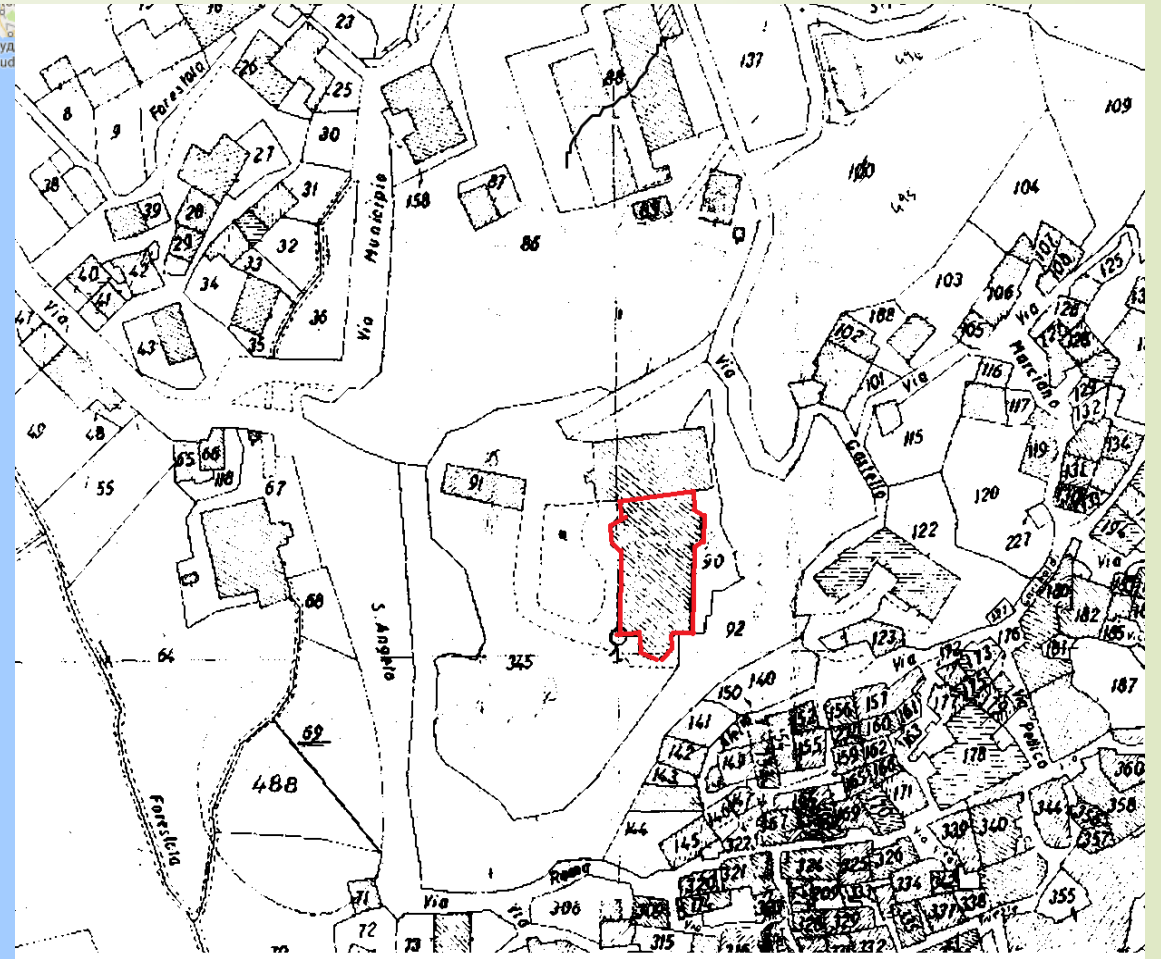


- Adress: Via Sant´Angelo, 14 Regio Calabria (RC) Palizzi, 89038, Italy
- Name of building: „Palizzi“ castle
- Permanent parcel: st. 113, 114
- Building use: Historical monument
- Owner: Municipality of Palizzi

# Study case – „Palizzi“ castle

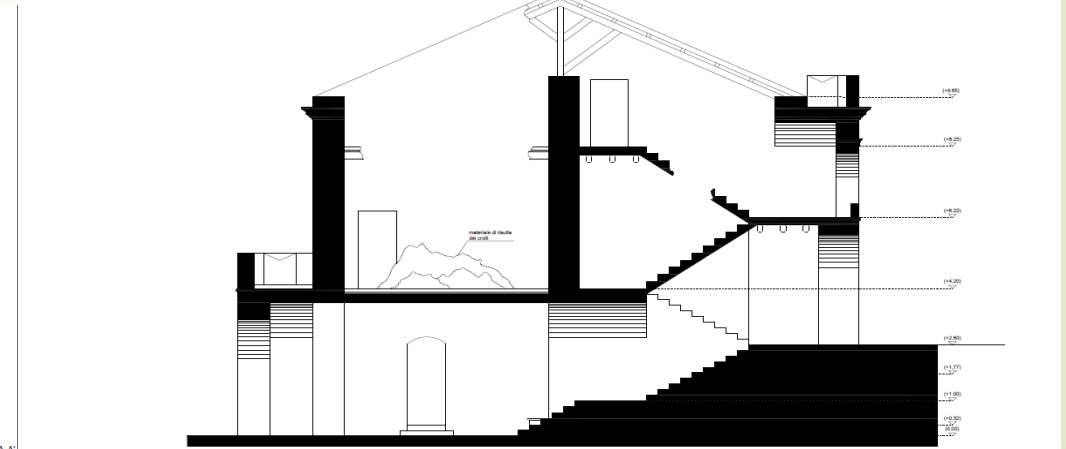
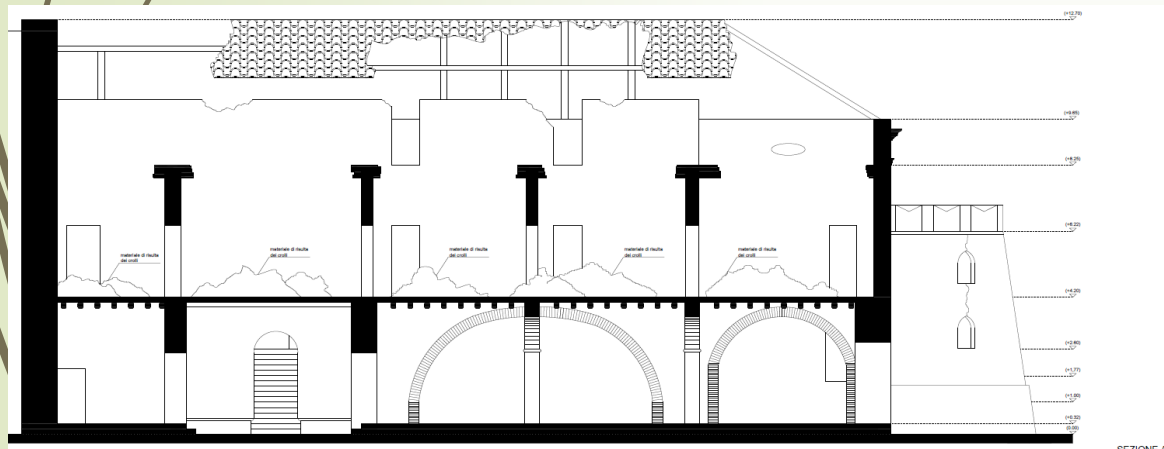
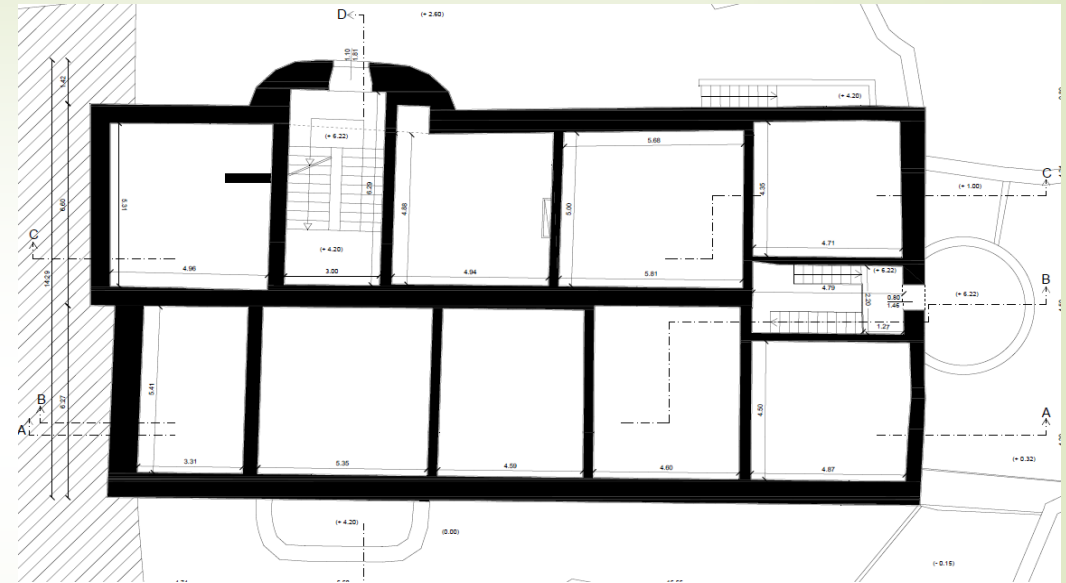
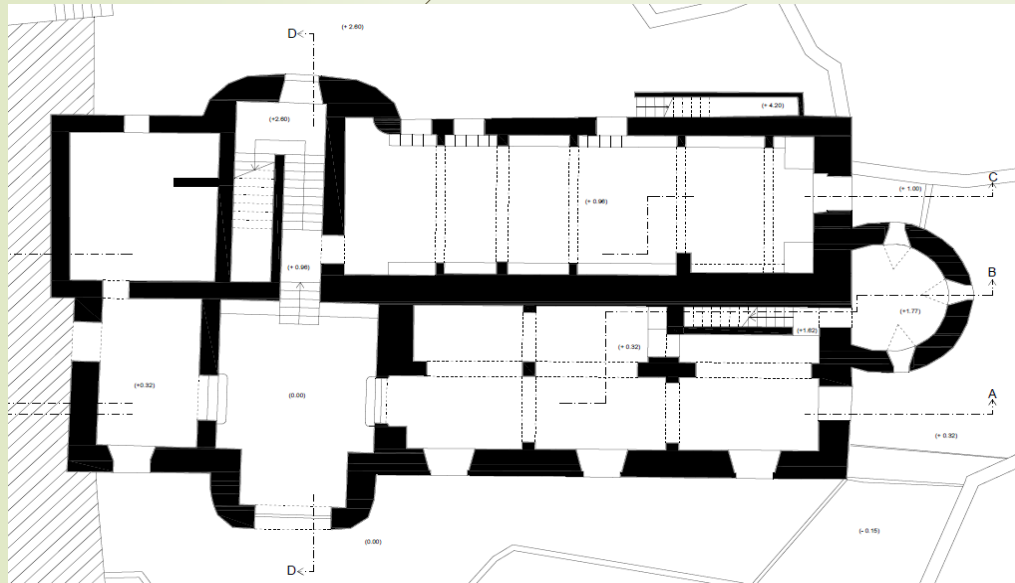


Map of Italy with location of Palizzi town (<https://www.google.cz/maps/>)



Cadastral map of Palizzi municipality showing the location of the castle

# Study case – „Palizzi“ castle

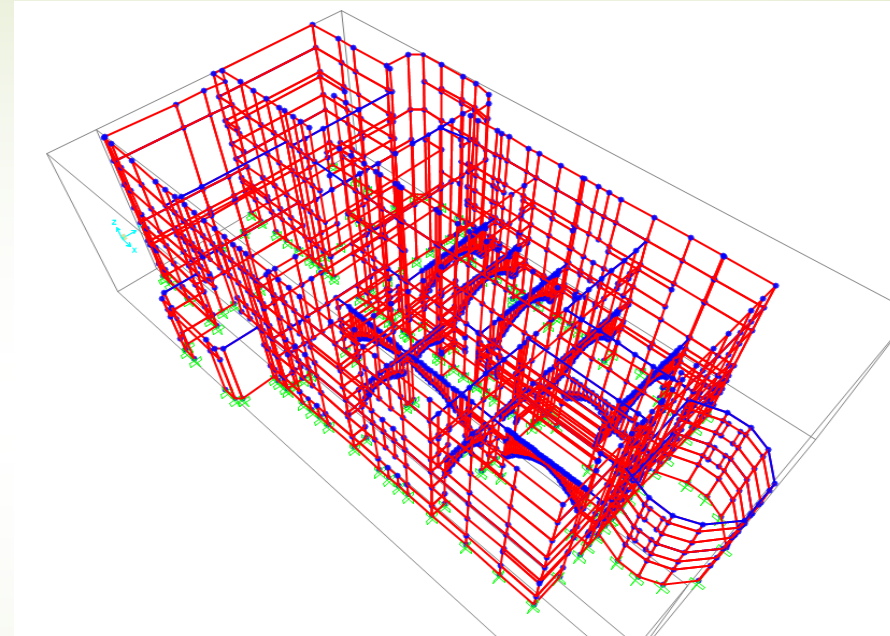
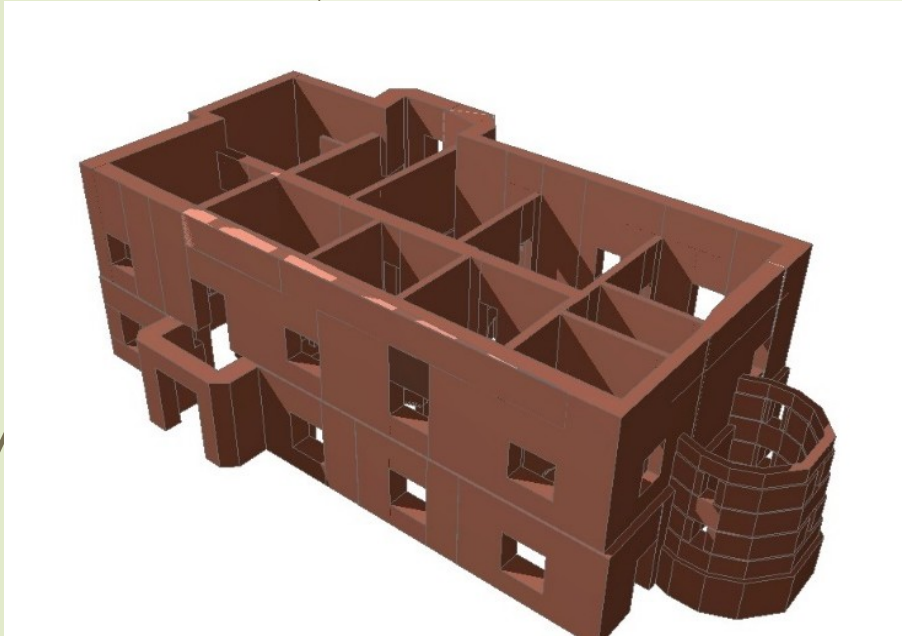


# Study case – „Palizzi“ castle



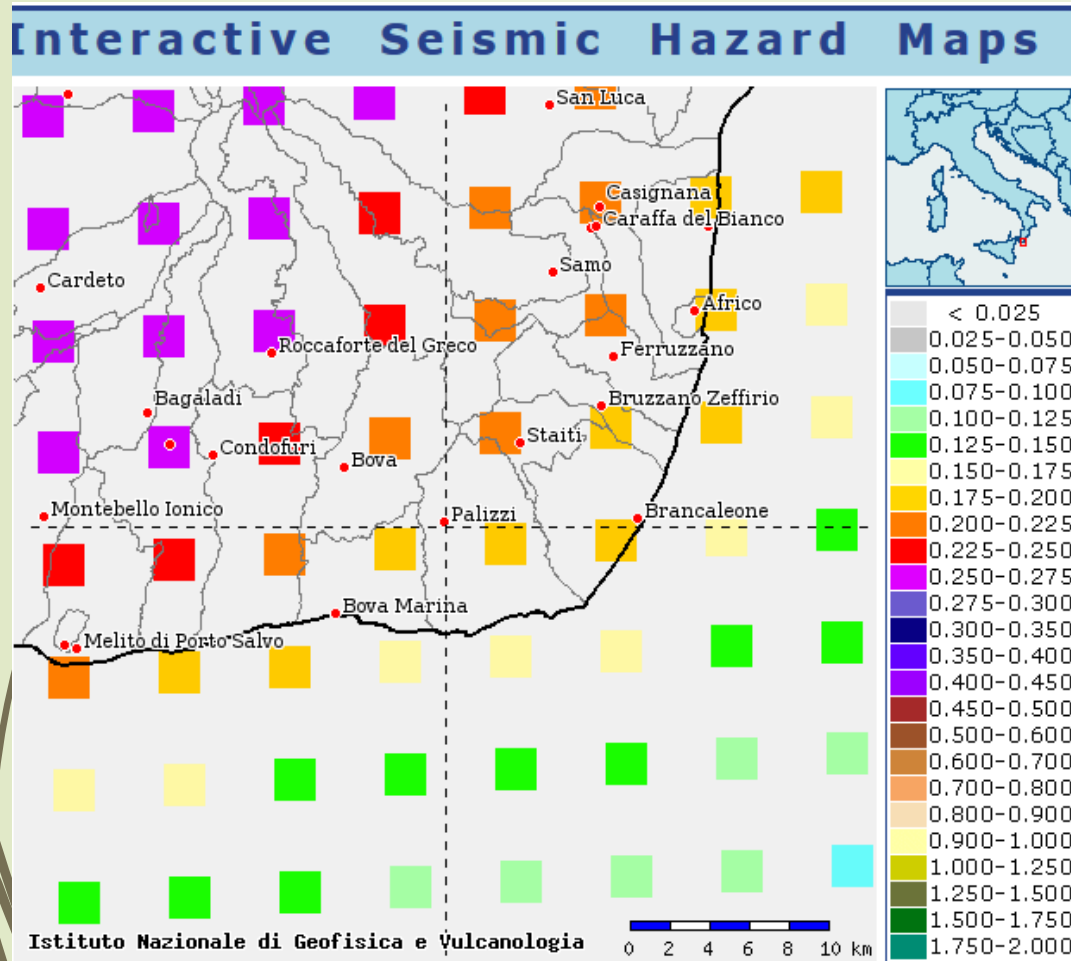


# Study case – „Palizzi“ castle



Masonry typology	(N/mm <sup>2</sup> )	(N/mm <sup>2</sup> )	E (N/mm <sup>2</sup> )	G (N/mm <sup>2</sup> )	W (kN/m <sup>3</sup> )
Brick masonry and mortar	2,52	0,60	1654	394	18
Masonry of brick and mortar (retrofitted)	4.91	1.16	3225	768	18

# Study case – „Palizzi“ castle



- Actual PGA is 0,175 – 0,200
- Region of Calabria – 1. zone – PGA is 0,301

# Study case – „Palizzi“ castle

Response Spectrum Italian NTC2008 Function Definition

Function Name: SLC-H

Function Damping Ratio: 0,05

Parameters

- ag, F0 and Tc\* - by Latitude/Longitude
- ag, F0 and Tc\* - by Island
- ag, F0 and Tc\* User Specified

Site Longitude (degree): 15,9875

Site Latitude (degree): 37,9677

Island Name: [dropdown]

Limit State: SLC

Usage Class: II

Nominal Life: 75,

Peak Ground Acc., ag/g: 0,3098

Magnification Factor, F0: 2,4392

Reference period, Tc\*: 0,404

Spectrum Type: Elastic Horizor

Soil Type: B

Topography: T1

h/H ratio: 1,

Spectrum Period, Tb: 0,1776

Spectrum Period, Tc: 0,5327

Spectrum Period, Td: 2,8392

Damping Percentage, Xi: 5,

Behavior Factor, q: [input]

Convert to User Defined

Define Function

Period	Acceleration
0,	0,3401
0,1776	0,8295
0,5327	0,8295
0,6327	0,6984
0,7327	0,6031
0,8327	0,5307
0,9327	0,4738
1,0327	0,4279

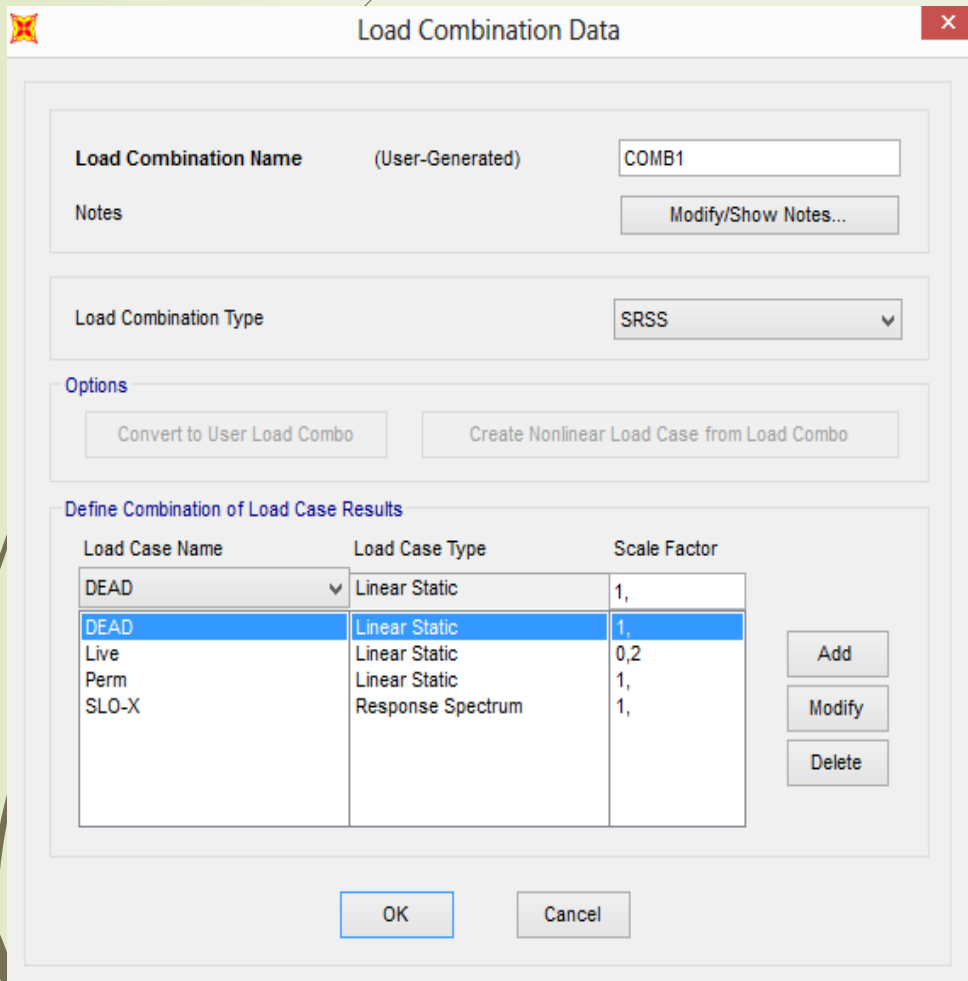
Function Graph

Display Graph ( 1,2316 , 0,3588 )

OK Cancel

- Collapse prevention Limit State (SLC)
- Damage Limitation State (SLD)
- Operating Limit State (SLO)
- Life-Saving Limit State (SLV)

# Study case – „Palizzi“ castle



Load Combination Data

Load Combination Name (User-Generated)

Notes

Load Combination Type

Options

Define Combination of Load Case Results

Load Case Name	Load Case Type	Scale Factor
DEAD	Linear Static	1,
DEAD	Linear Static	1,
Live	Linear Static	0,2
Perm	Linear Static	1,
SLO-X	Response Spectrum	1,

- 12. load combinations
- 1. envelope
- Roof and slabs – with and without
- SRSS - Square Root of Sum of Squares

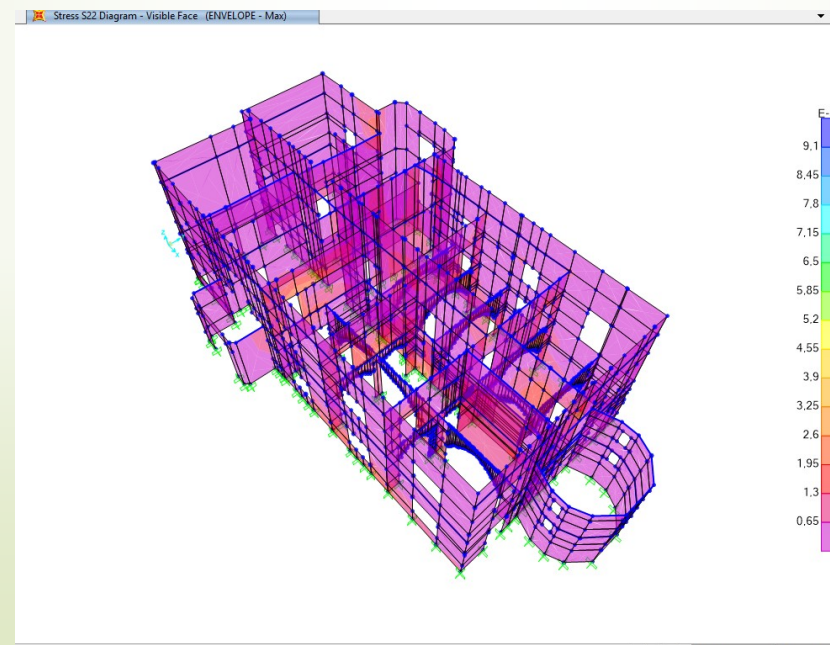
# Study case – „Palizzi“ castle

Model without slabs – direct stress

	S22	
Max stress	9,062 N/mm <sup>2</sup>	2.52 N/mm <sup>2</sup>
Average stress	0,557642 N/mm <sup>2</sup>	2.52 N/mm <sup>2</sup>
Min stress	0,007884 N/mm <sup>2</sup>	2.52 N/mm <sup>2</sup>

➤ **S22:** Direct stress (force per unit area) acting on the positive and negative 2 faces in the 2-axis direction.

➤ : Tensile strength of masonry (N/mm<sup>2</sup>)



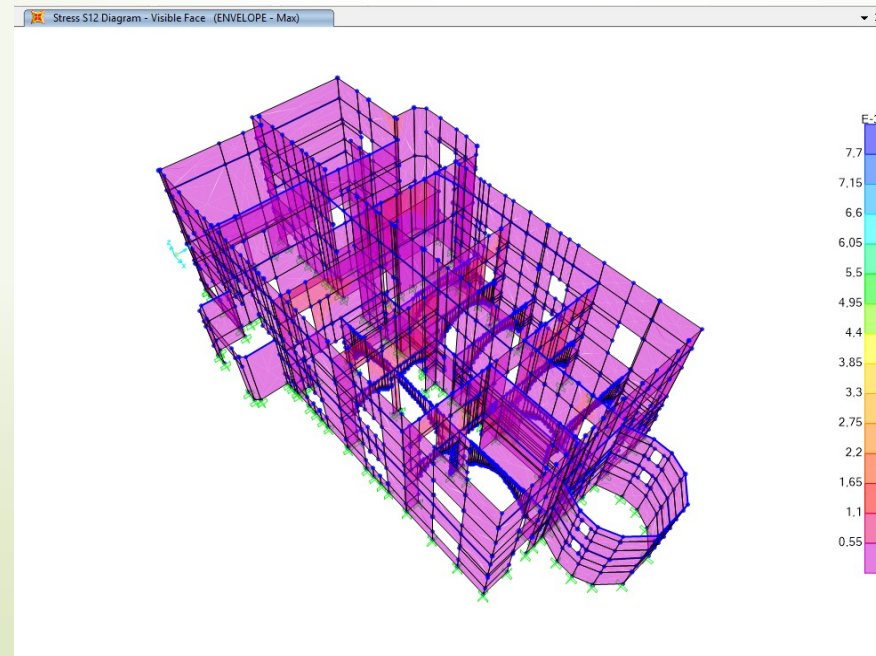
# Study case – „Palizzi“ castle

Model without slabs – shearing stress

	S12	
Max stress	7,516 N/mm <sup>2</sup>	0.60 N/mm <sup>2</sup>
Average stress	0,405414 N/mm <sup>2</sup>	0.60 N/mm <sup>2</sup>
Min stress	0,0005604 N/mm <sup>2</sup>	0.60 N/mm <sup>2</sup>

➤ **S12:** Shearing stress (force per unit area) acting on the positive and negative 1 faces in the 2-axis direction and acting on the positive and negative 2 faces in the 1-axis direction.

➤ : Shear strength of masonry (N/mm<sup>2</sup>)



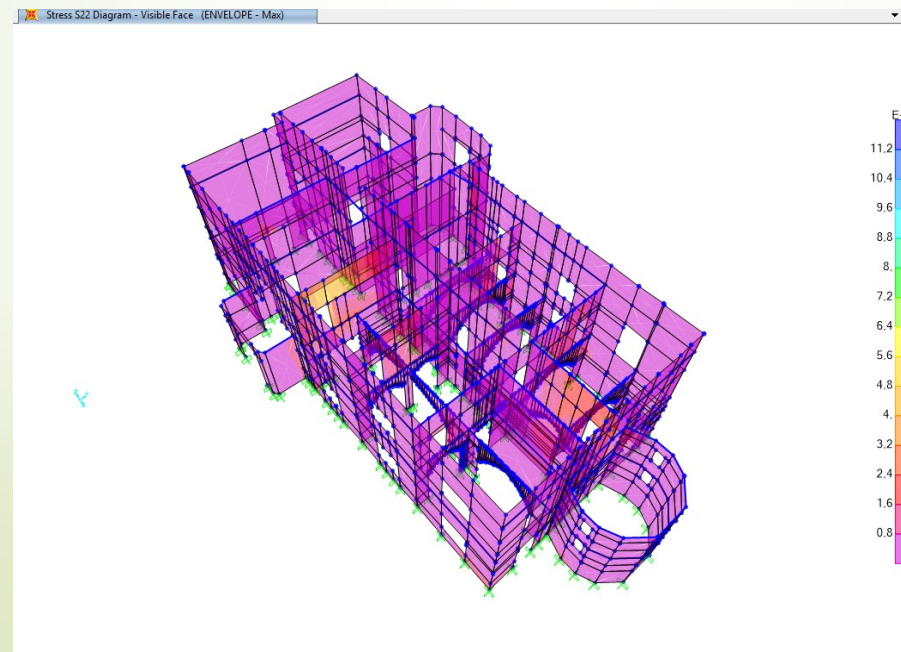
# Study case – „Palizzi“ castle

Retrofitted model with slabs – direct stress

	S22	
Max stress	11,439 N/mm <sup>2</sup>	4.91 N/mm <sup>2</sup>
Average stress	0,433839 N/mm <sup>2</sup>	4.91 N/mm <sup>2</sup>
Min stress	0,001775 N/mm <sup>2</sup>	4.91 N/mm <sup>2</sup>

➤ **S22:** Direct stress (force per unit area) acting on the positive and negative 2 faces in the 2-axis direction.

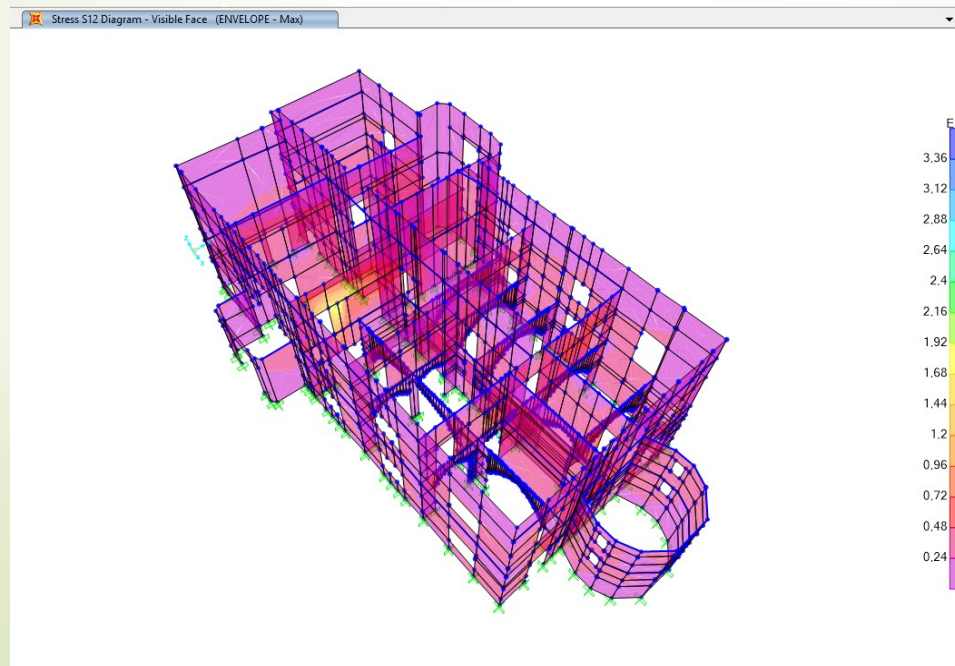
➤ : Tensile strength of masonry (N/mm<sup>2</sup>)



# Study case – „Palizzi“ castle

Retrofitted model with slabs – shearing stress

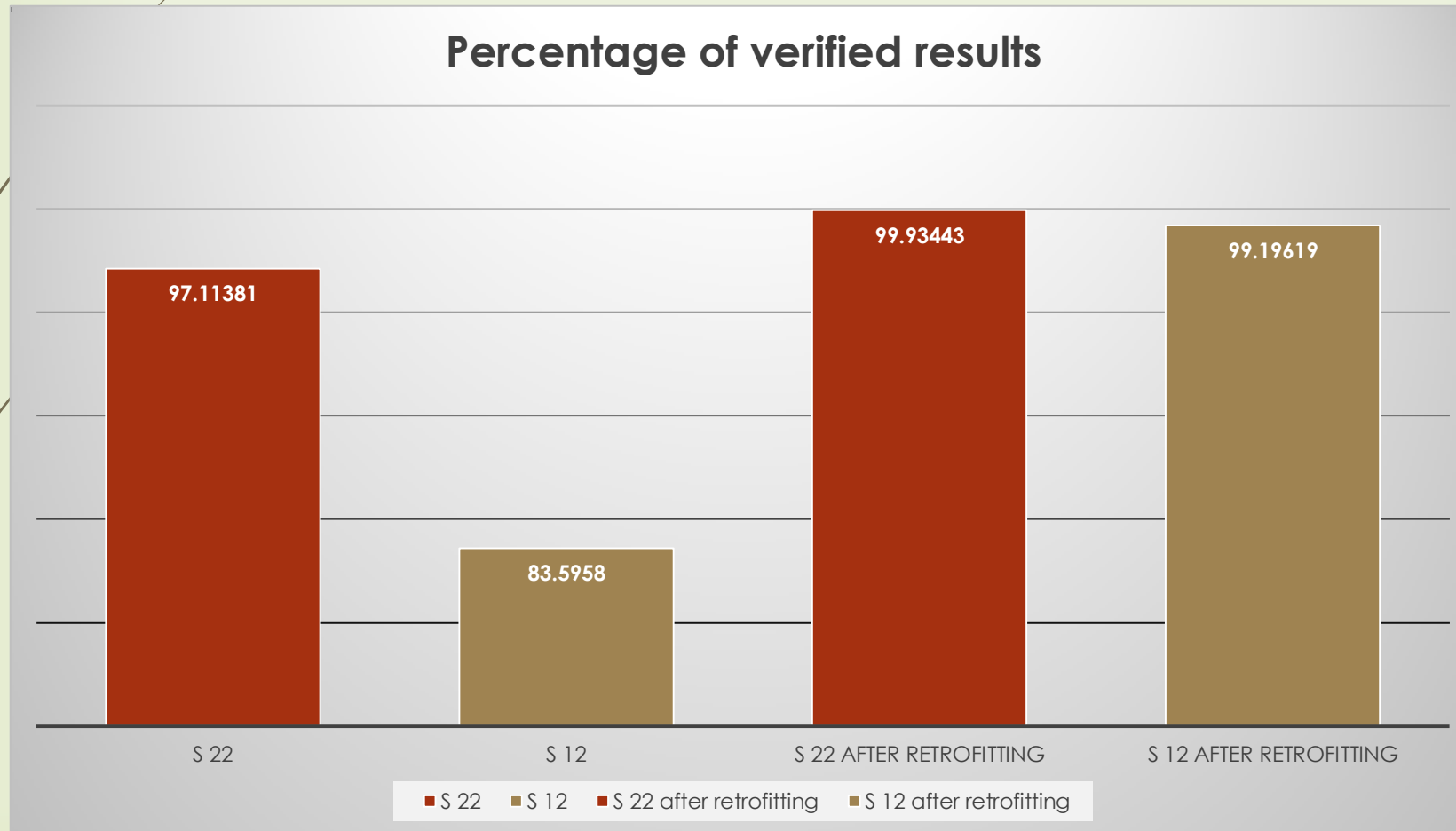
	S12	
Max stress	3,557 N/mm <sup>2</sup>	1.16 N/mm <sup>2</sup>
Average stress	0,258344 N/mm <sup>2</sup>	1.16 N/mm <sup>2</sup>
Min stress	0,002053 N/mm <sup>2</sup>	1.16 N/mm <sup>2</sup>



- **S12:** Shearing stress (force per unit area) acting on the positive and negative 1 faces in the 2-axis direction and acting on the positive and negative 2 faces in the 1-axis direction.
- $f_{v,d}$ : Shear strength of masonry (N/mm<sup>2</sup>)



# Verification and conclusion



Thank you for your attention!



**AF**  
STUDIO TECNICO  
ASSOCIATO

I want to acknowledge “Studio KR e Associati” and “Studio Associato Amaddeo-Fiumanò” for providing the blueprint and the design specification of the castle.

**KR**  
STUDIO KR e ASSOCIATI Srl

# Questions from supervisor and oponent

- Existují i jiné možnosti úpravy historické konstrukce, tak aby vzdorovala seismickému zatížení? Uveďte příklady které znáte.

Do another retrofitting methods for historical structures exist? Please give examples.

- Jaký máte názor na zpevnění zdiva injektáží? Je vhodná pro zpevnění zdiva při účincích seismického zatížení?

What is your opinion about strengthening masonry by injection method? Can the method be applied for earthquake resistance?

- V jakém zdivu obecně lze injektáž aplikovat a v jakém naopak ne? Co je rozhodující parametr?

In which type of masonry could be possible to apply injection method and in which not? What is the critical parameter?

# Retrofitting methods

## Surface treatment

- *Bamboo-Band retrofitting technique*
- *Reinforced plaster*
- *Shotcrete*
- *Fiber-Reinforced polymer (FRP)*
- *Post-tensioning*
- *Confinement*
- *Center core*
- *Injection*