Structural Assessment of Historical Masonry structure

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Supervisor: doc. Dr. Ing. Luboš Podolka

Advisor: Ing. Carmen Amaddeo Phd.

Oponent: Ing. Robert Šinkner, MBA

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Outline

- Motivation
- Aim of thesis
- Study case – Description
- Study case – Analysis 1.
- Study case – Analysis 2.
- Analysis results
- Questions

Motivation

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

Aim of thesis

The aim of this master´s thesis is to perform a seismic evaluation before and after retrofitting of an historical masonry building located in seismic zone based on Italian code NTC 2008.

The chosen historical building is the "Palizzi" Castle located in the Reggio Calabria Province, Italy. The "Palizzi" castle is composed of a ground floor, first floor and under-roof level. The structure of the castle is mostly brick masonry with poor quality materials.

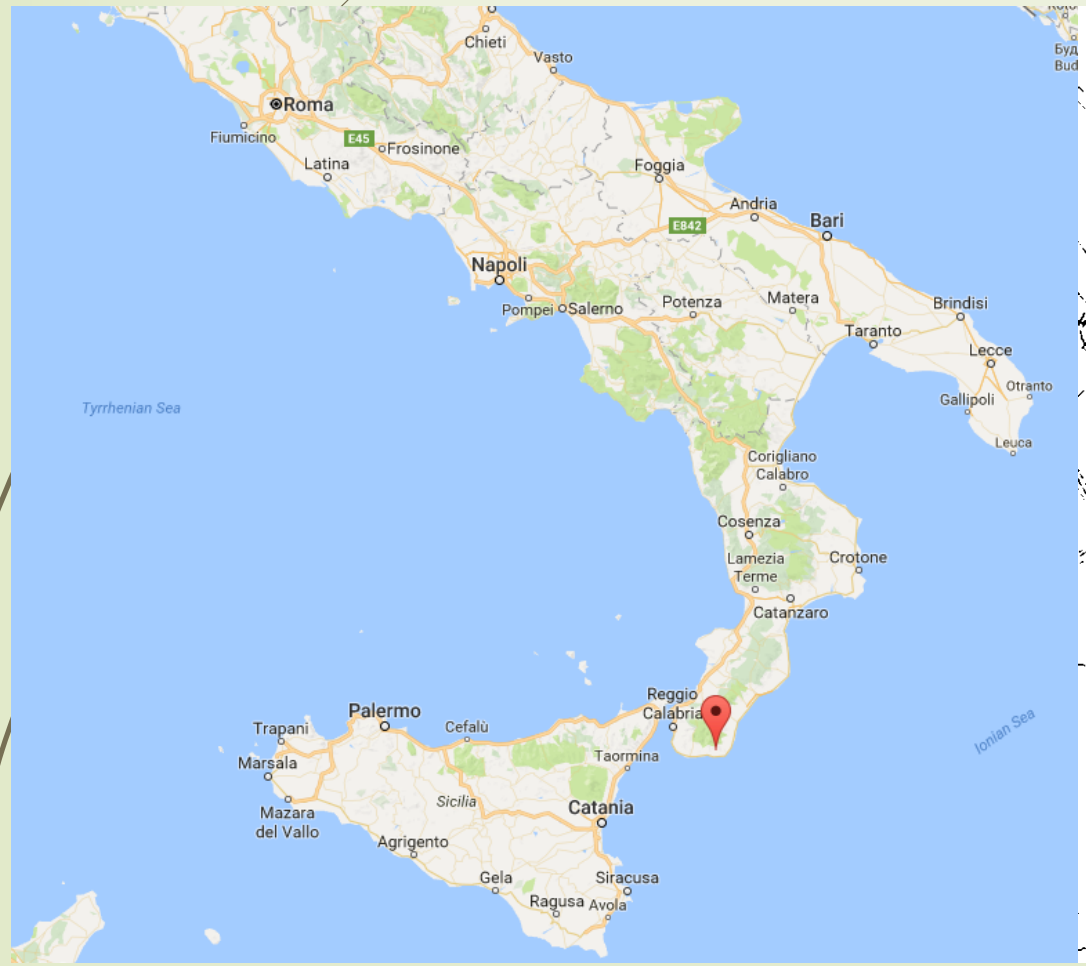
The Finite Element Model (FEM) of the structure has been built using SAP2000 software (Computers and Structures, Inc.), in particular it was performed a response spectrum analysis and also pushover analysis by using Etabs software (Computers and Structures, Inc.) of the structure. Results were verified and compared.

The outcome of this thesis will be comparison of linear and non-linear analysis on existing masonry structure with and without retrofitting.

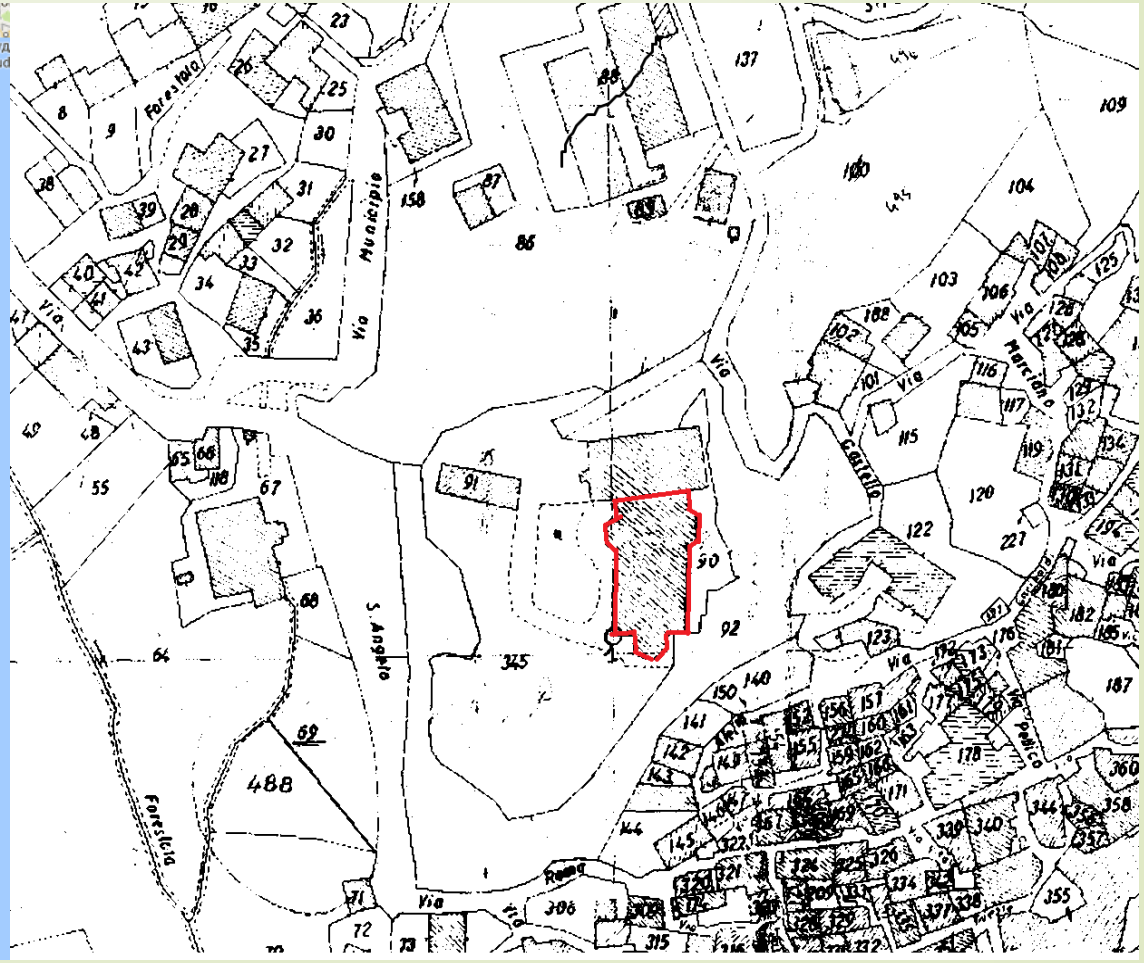
Study case – „Palizzi“ castle

- 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

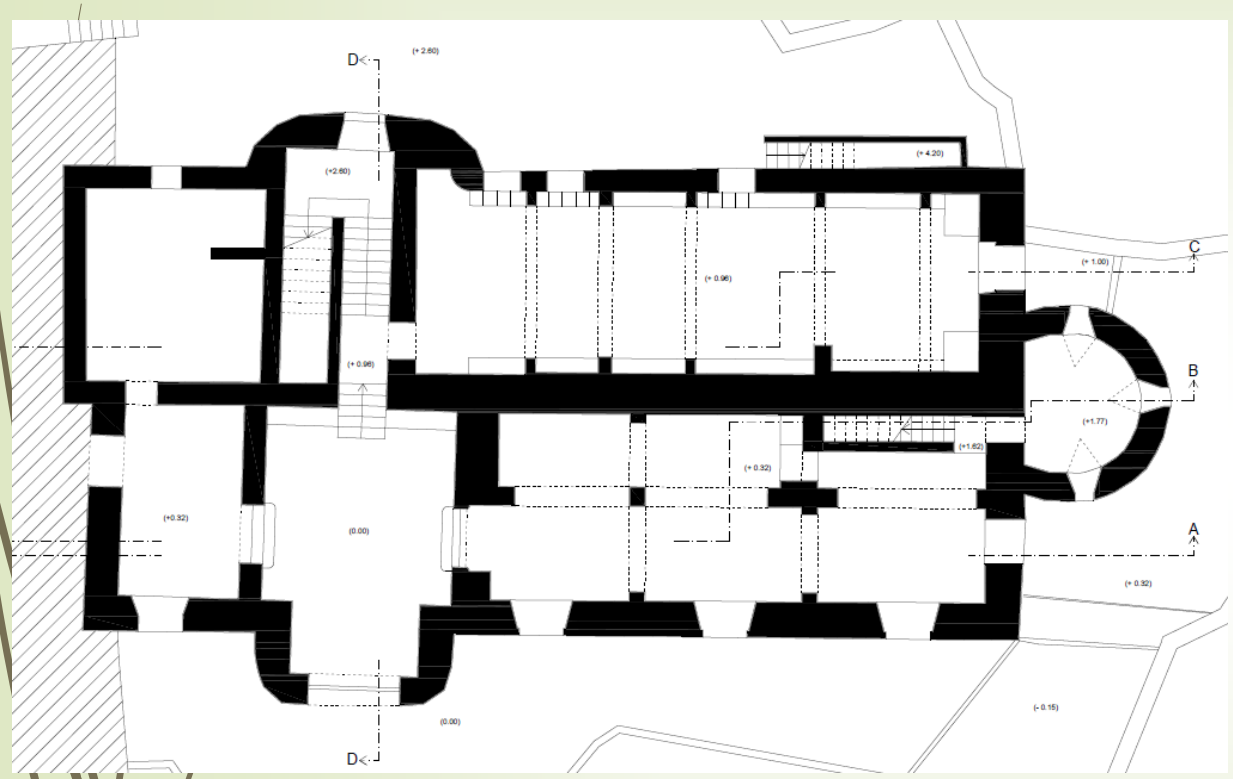
Study case – „Palizzi“ castle

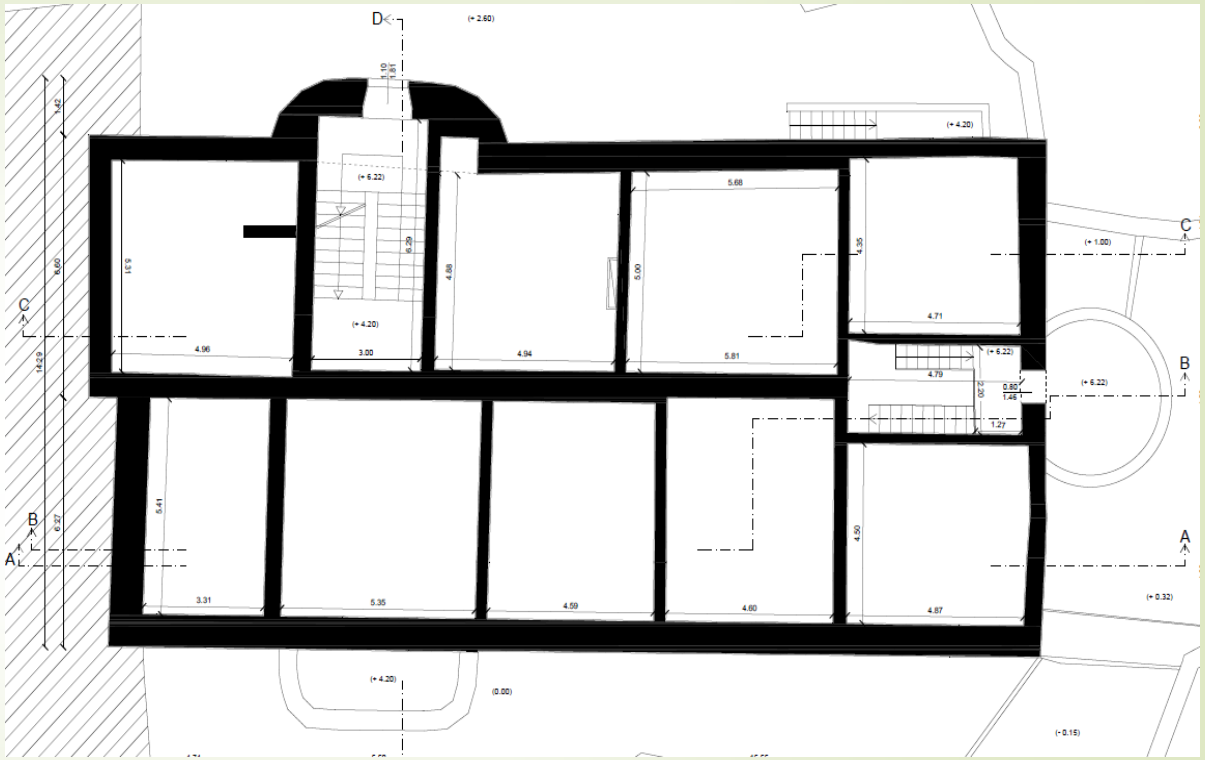


Map of Italy with location of Palizzi town (https://www.google.cz/maps/)

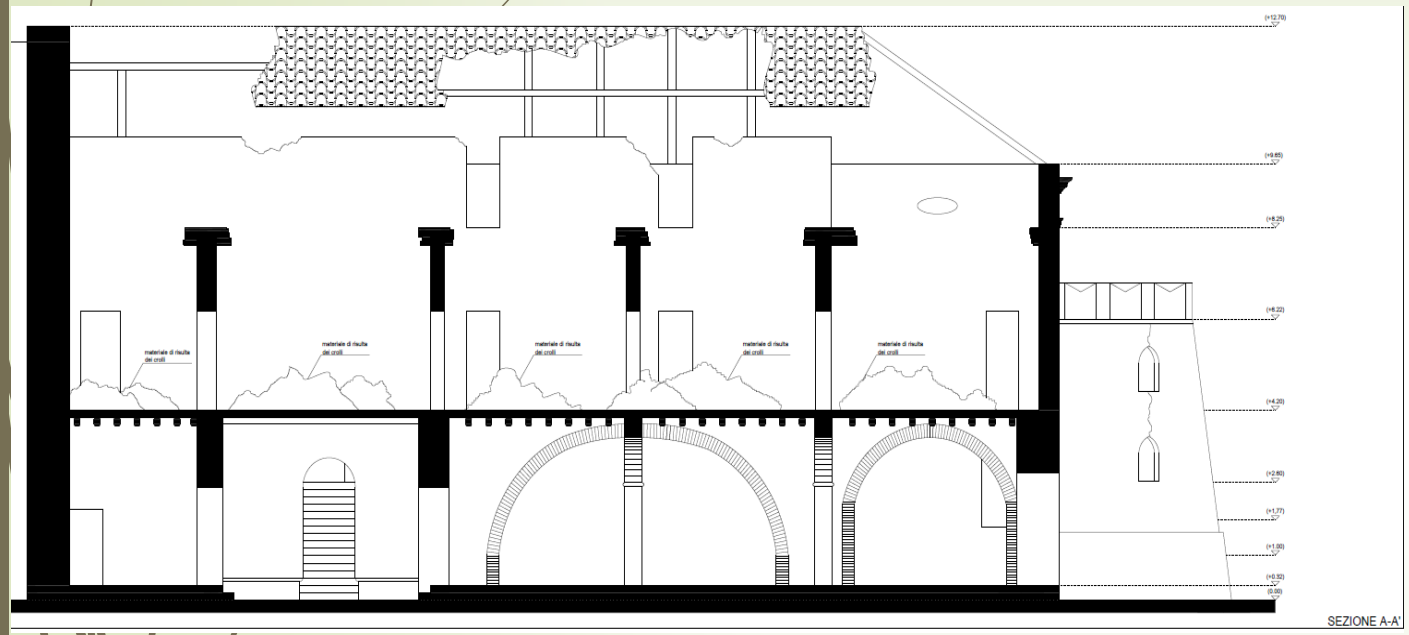


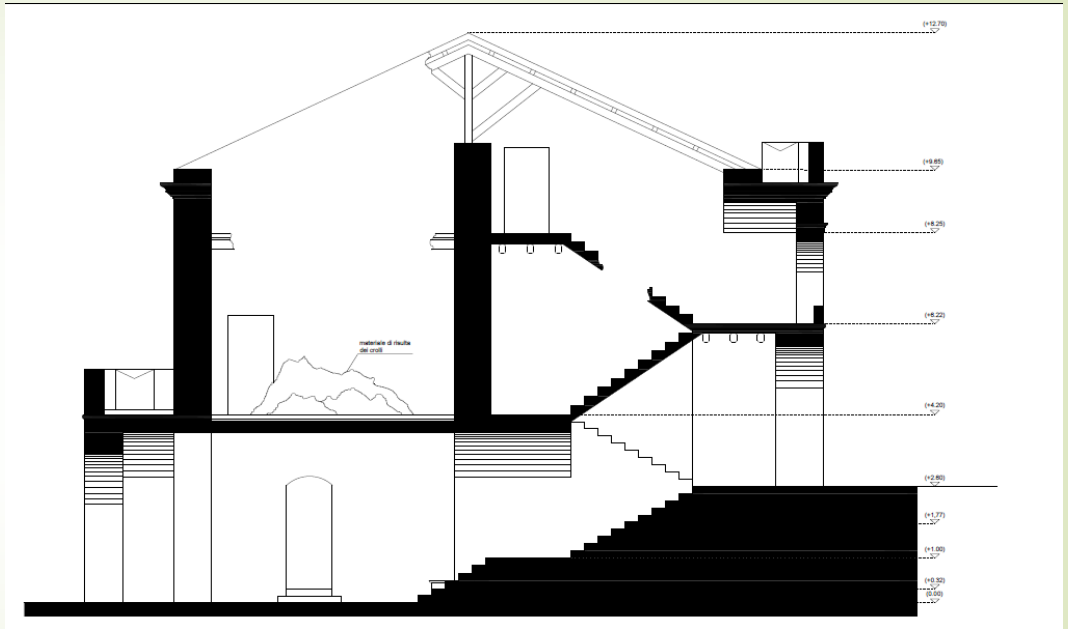
Cadastral map of Palizzi municipality showing the location of the castle





Lay-outs:

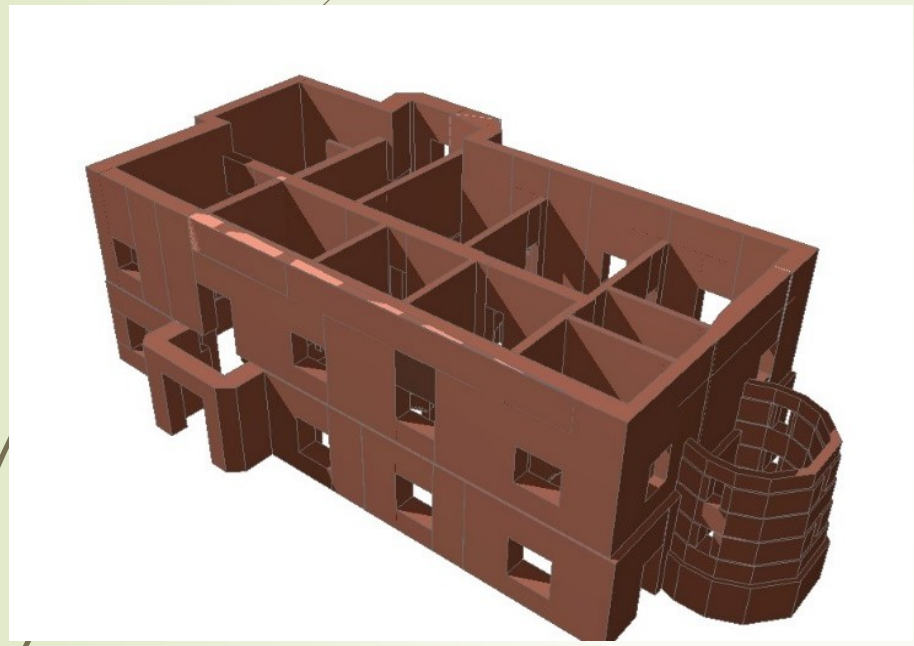




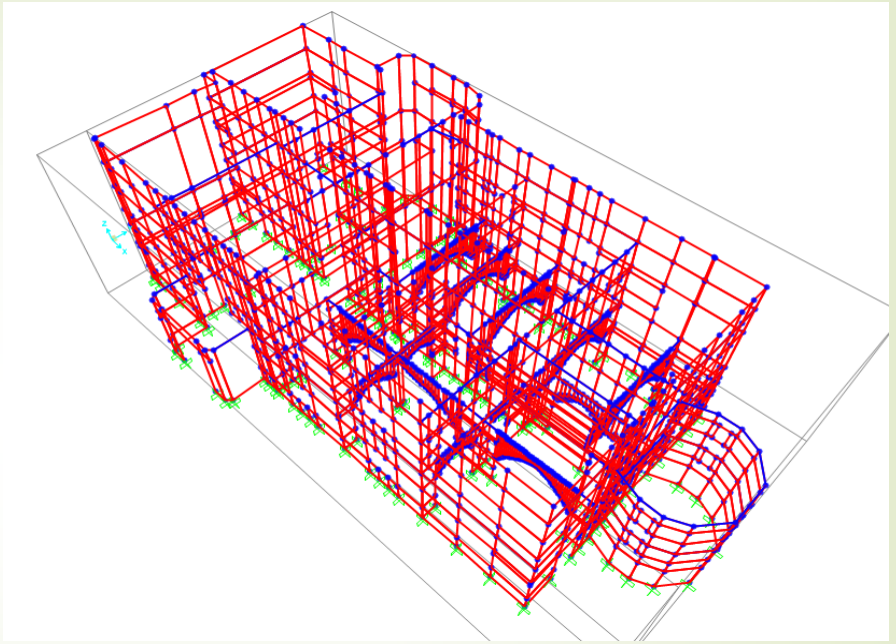
Sections:

Photo-documentation

Finite Element Model (FEM)



Archicad 21.



SAP 2000 v.19.3.

Material Properties

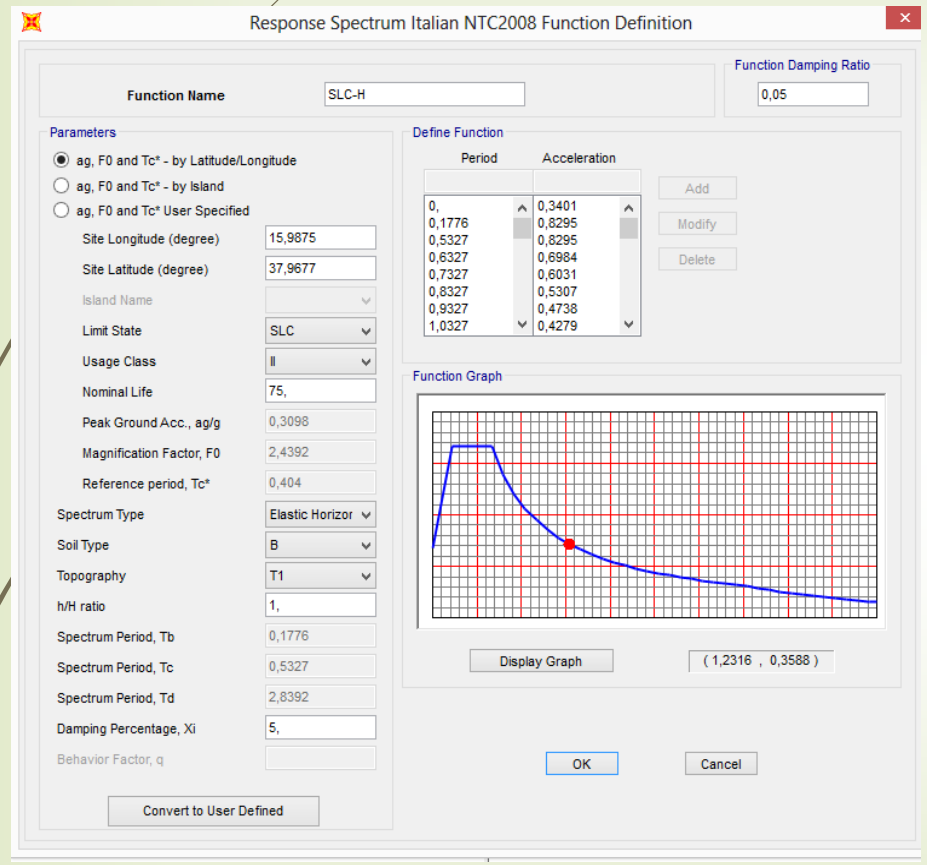
Masonry typology	f_m (N/mm²)	τ_0 (N/mm²)	E (N/mm²)	G (N/mm²)	W (kN/m³)
Brick masonry and mortar	2,52	0,60	1654	394	18
Masonry of brick and mortar (retrofitted)	4.91	1.16	3225	768	18

- Suggested properties based on historical sources and comparison
- Suggested intervention properties

- Material properties based on on-site experiments and tests.
- Suggested intervention properties

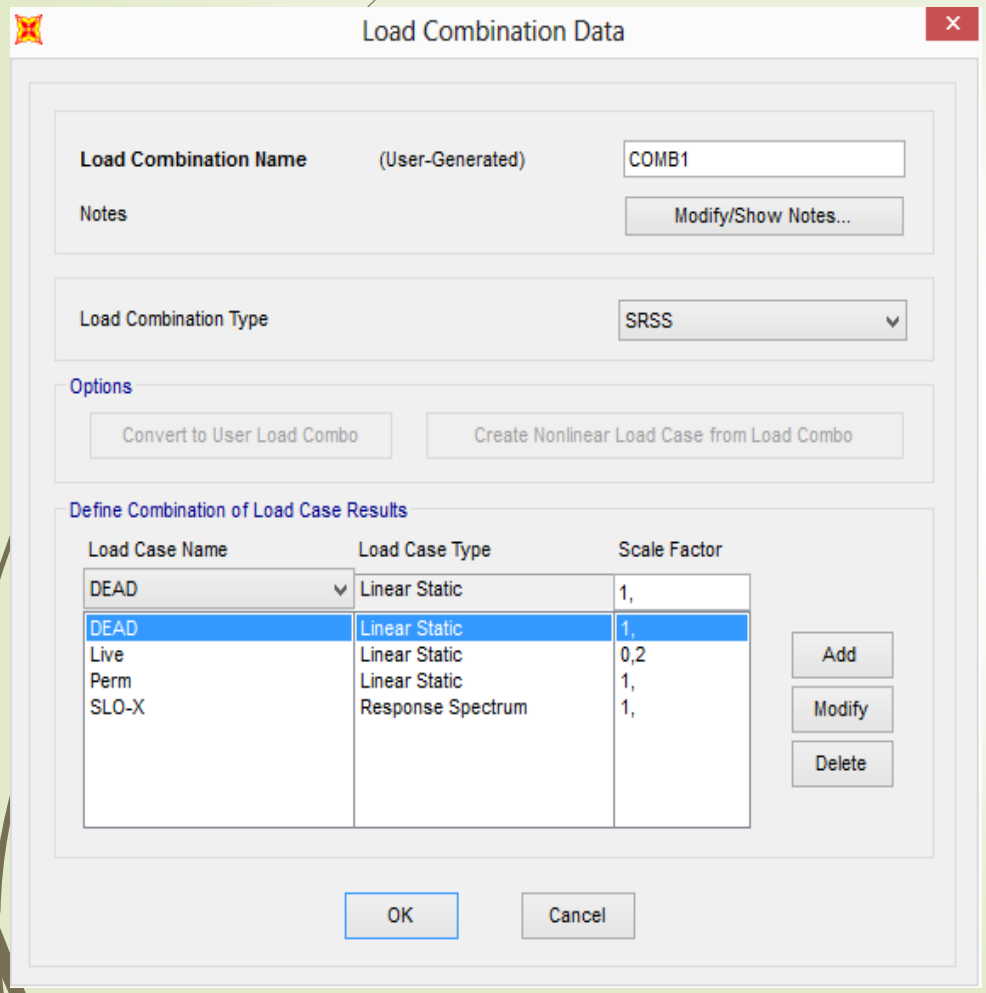
Masonry typology	f_m (N/mm²)	τ_0 (N/mm²)	E (N/mm²)	G (N/mm²)	W (kN/m³)
Mixed masonry and mortar	1,2844	0,0238	798	266	19
Masonry of brick and mortar (retrofitted)	2,10	0,137	2497,5	999	19

Analysis 1.: Response spectrum



- Latitude = 37,9677, Longitude = 15,9875
- Limit states
  - Collapse prevention Limit State (SLC)
  - Damage Limitation State (SLD)
  - Operating Limit State (SLO)
  - Life-Saving Limit State (SLV)
- Usage Class = II
- Nominal Life = 100
- Spectrum Type = Elastic Horizontal
- Soil Type = B
- Topography Category = T1
- Peak Ground Acceleration, a_g /g - $\frac{a_g}{g} = 0{,}263569$

Analysis 1.: Loads



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

Analysis 1.: Results - URM

Model without slabs – direct stress

	S22	f_m
Max stress	9,254 N/mm²	1,28 N/mm²
Average stress	0,587642 N/mm²	1,28 N/mm²
Min stress	0,007884 N/mm²	1,28 N/mm²

Model without slabs – shearing stress

	S12	τ_0
Max stress	7,516 N/mm²	0.0238 N/mm²
Average stress	0,405414 N/mm²	0.0238 N/mm²
Min stress	0,0005604 N/mm²	0.0238 N/mm²

- **S22:** Direct stress (force per unit area) acting on the positive and negative 2 faces in the 2-axis direction.
- **f_m:** Tensile strength of masonry (N/mm²)

- **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.
- **τ_0:** Shear strength of masonry (N/mm²)

Analysis 1.: Results - RM

Retrofitted model with slabs – direct stress

	S22	f_m
Max stress	11,439 N/mm²	2,1 N/mm²
Average stress	0,433839 N/mm²	2,1 N/mm²
Min stress	0,001775 N/mm²	2,1 N/mm²

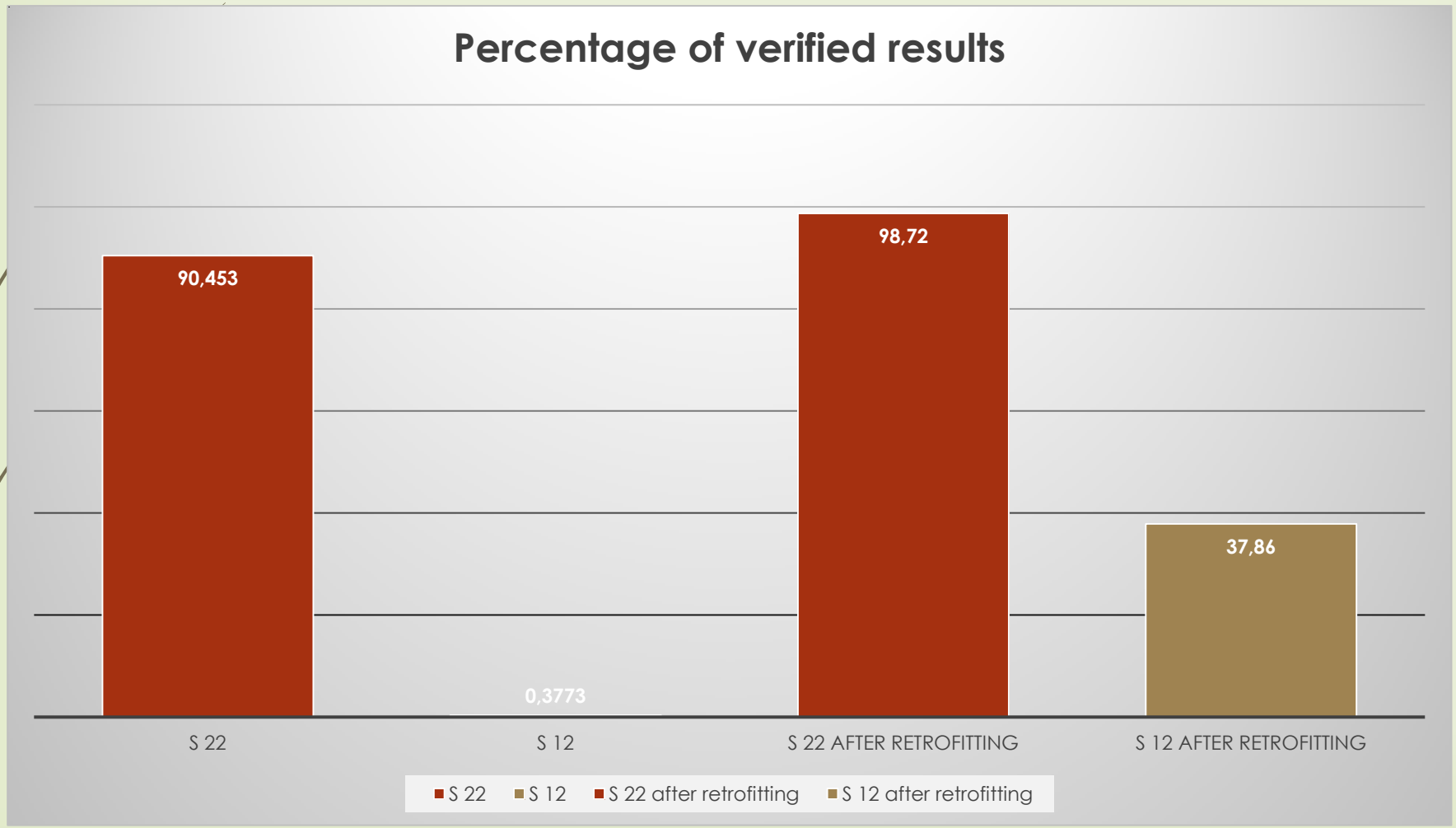
Retrofitted model with slabs – shearing stress

	S12	τ_0
Max stress	3,557 N/mm²	0.137 N/mm²
Average stress	0,258344 N/mm²	0.137 N/mm²
Min stress	0,002053 N/mm²	0.137 N/mm²

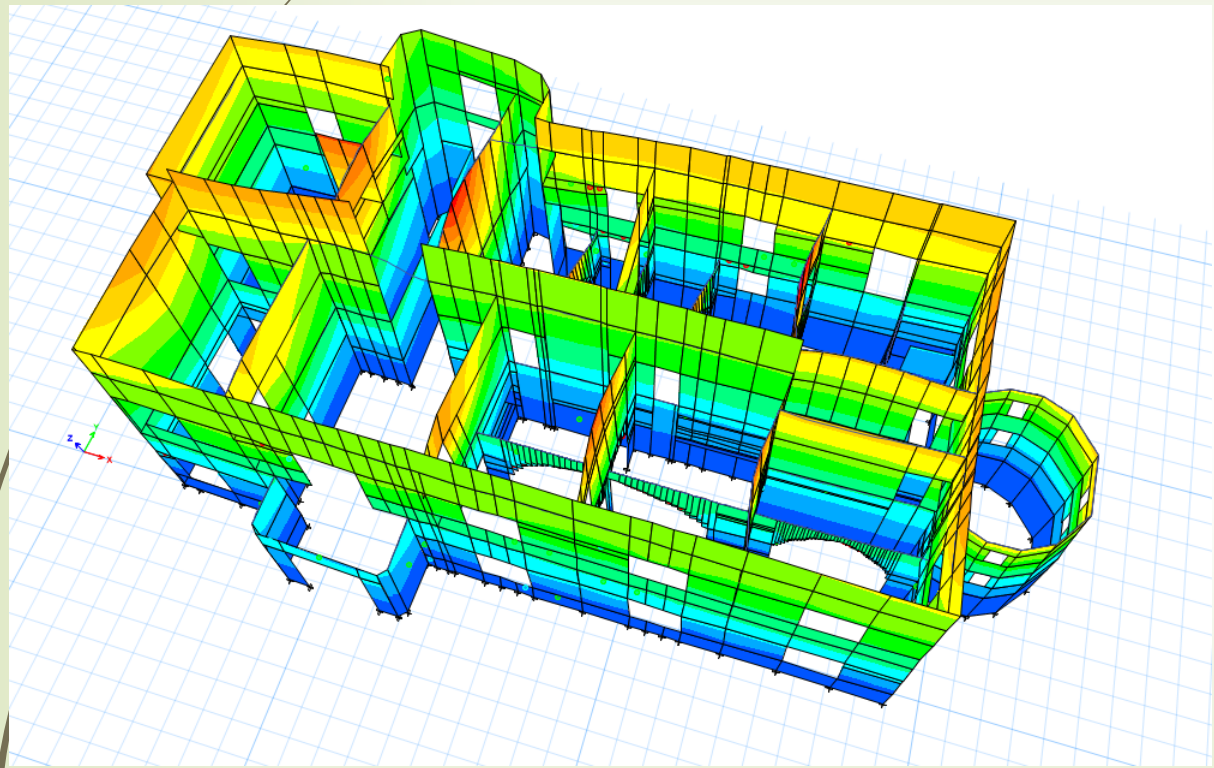
- **S22:** Direct stress (force per unit area) acting on the positive and negative 2 faces in the 2-axis direction.
- **f_m:** Tensile strength of masonry (N/mm²)

- **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.
- **τ_0:** Shear strength of masonry (N/mm²)

Analysis 1: Verification and conclusion

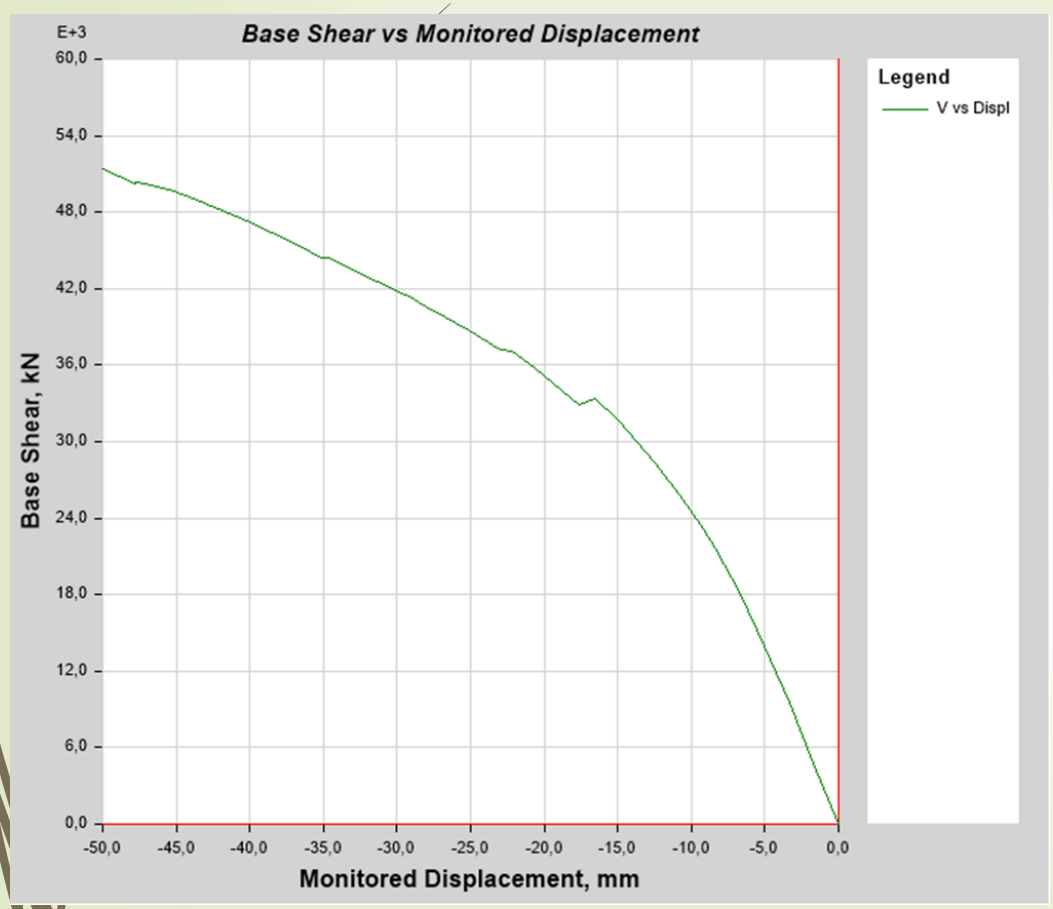


Analysis 2.: Pushover analysis

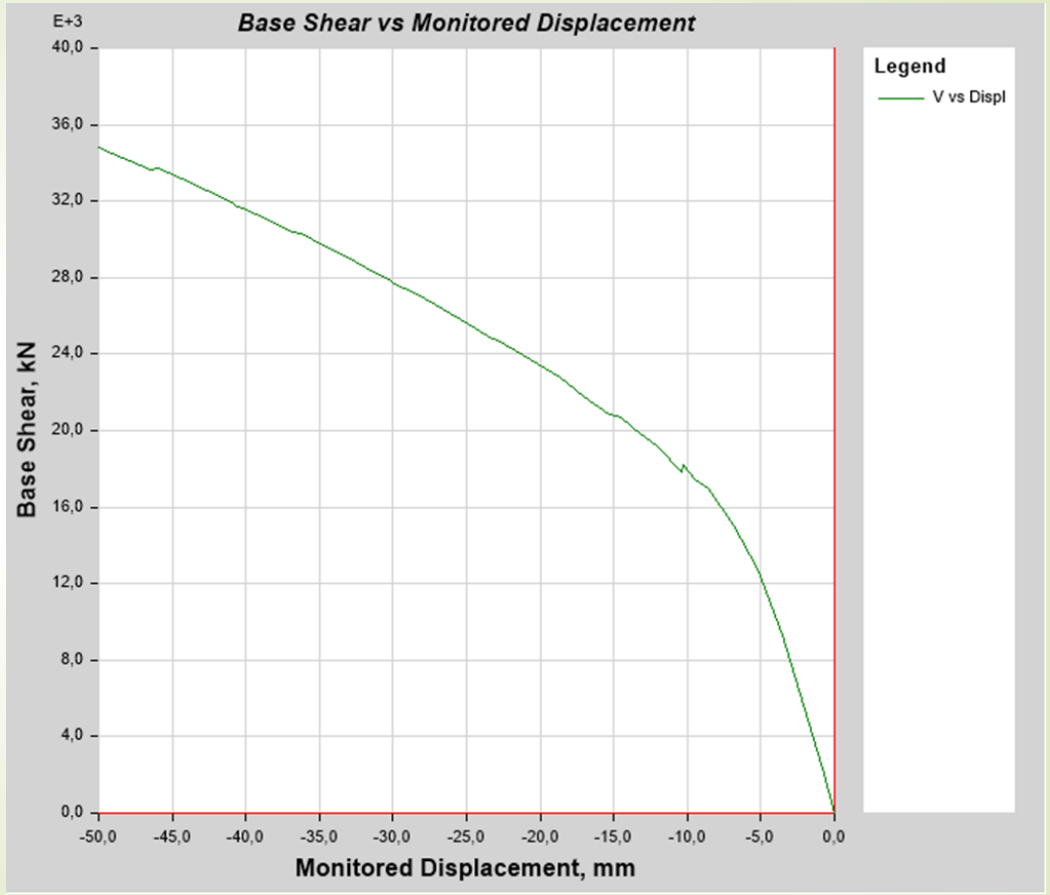


- Finite element model
- Hinges
- Lateral load
- Verification methods
  - Base shear
  - Target displacement

Analysis 2.: Base shear results - URM

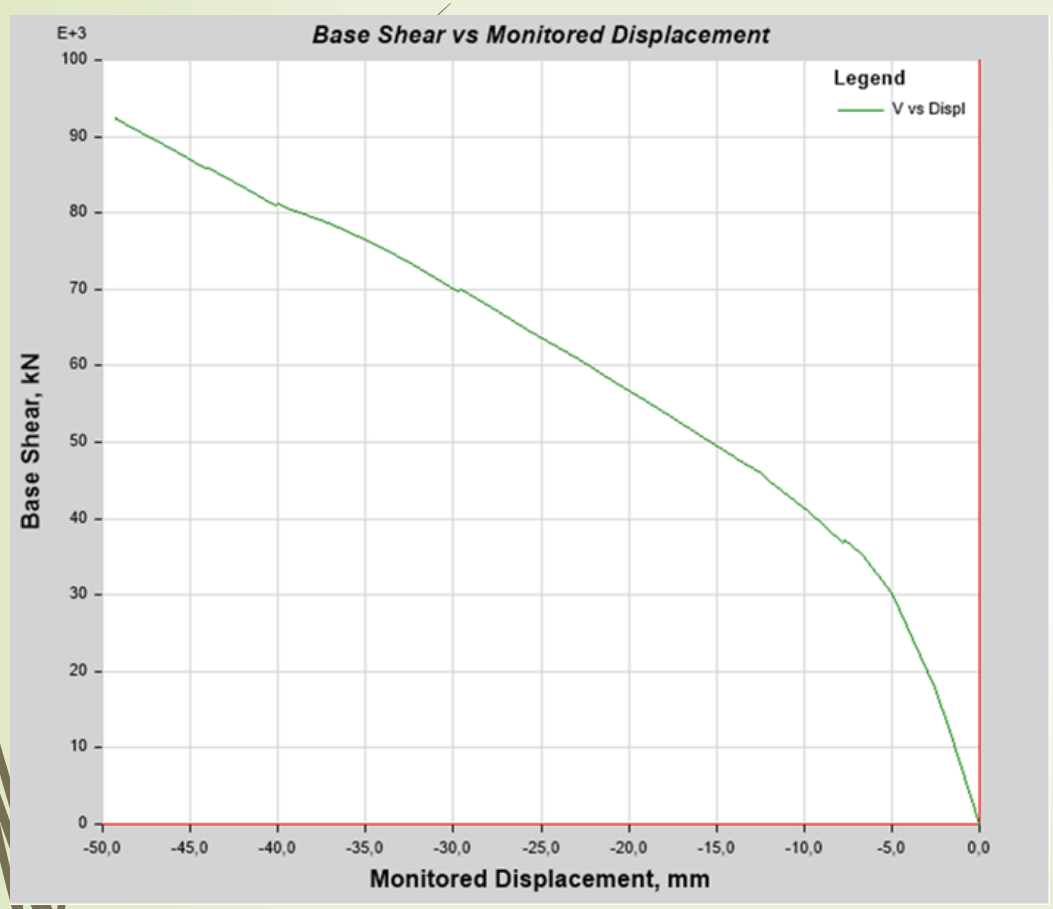


X - DIRECTION

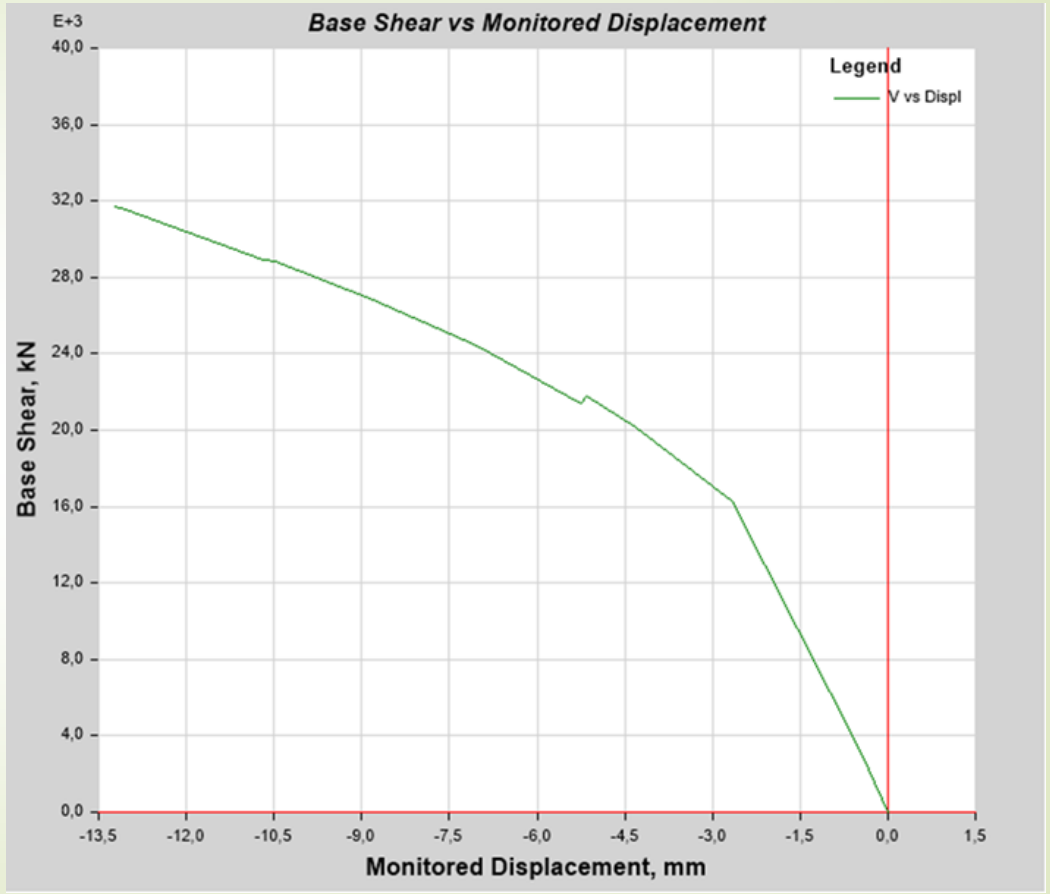


Y - DIRECTION

Analysis 2.: Base shear results - RM

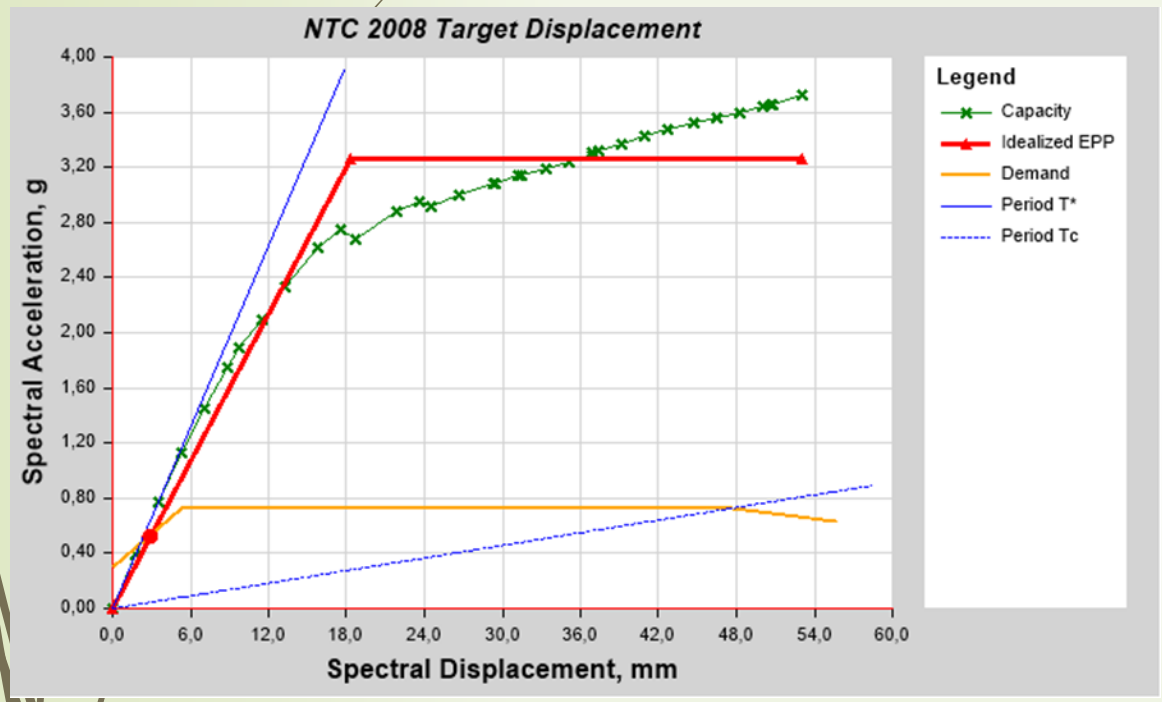


X - DIRECTION

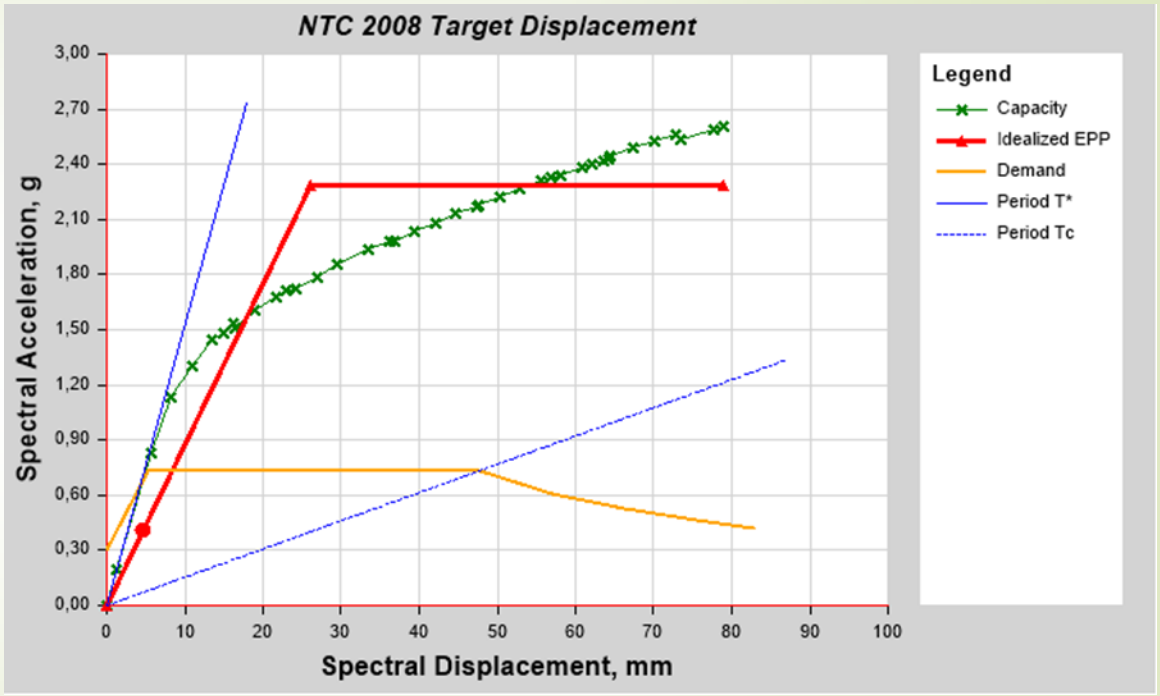


Y - DIRECTION

Analysis 2.: Target displacement - URM

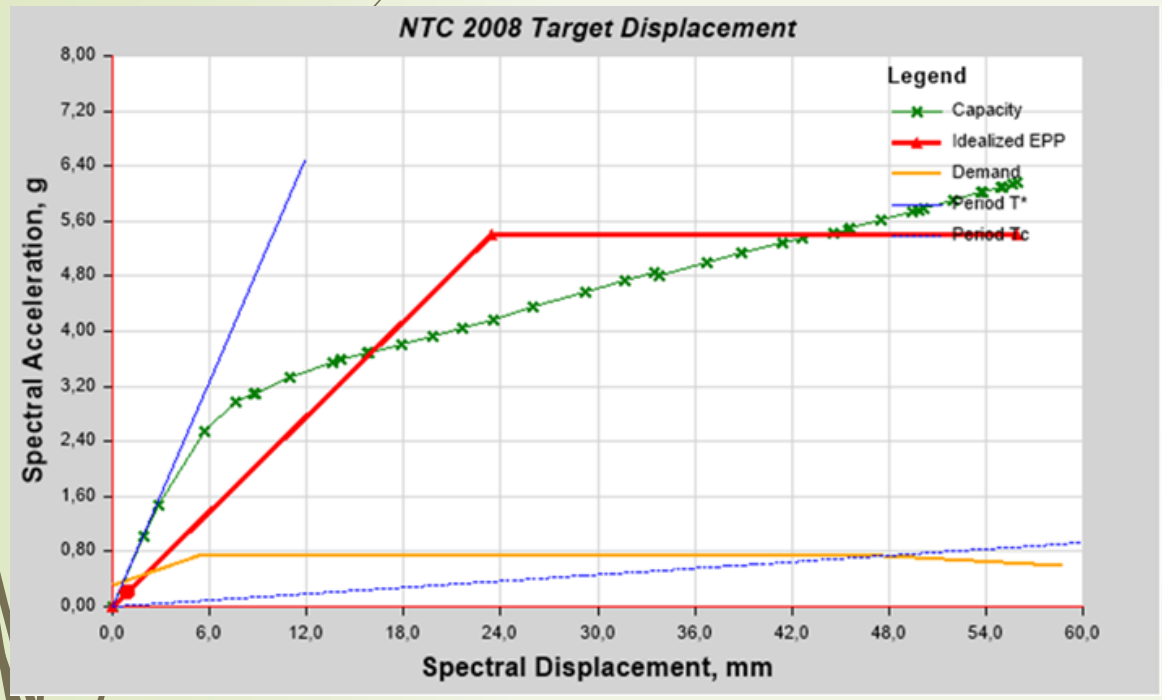


X - DIRECTION

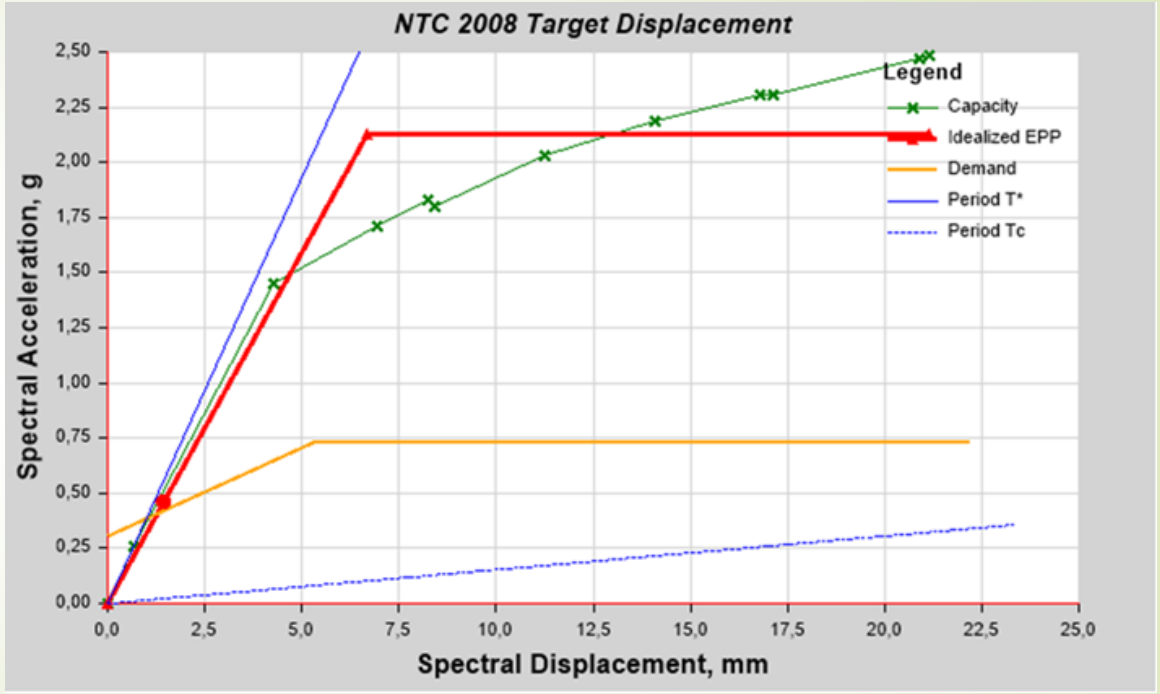


Y - DIRECTION

Analysis 2.: Target displacement - URM



X - DIRECTION



Y - DIRECTION

Analysis 2.: Verification

FE model reference	Direction	Fy*	dy* (mm)	dt* (mm)
URM	X	3,266	18,307	2,917
	Y	2,283	26,002	4,67
RM	X	5,405	23,436	4,952
	Y	4,706	32,494	6,141

dy: yield displacement*

Fy: yield force*

dt: target displacement*

Thank you for your attention!

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

Questions:

Supervisor: doc. Dr. Ing. Luboš Podolka

- Jak by bylo možno počítanou historickou stavbu zabezpečit vůči účinkům zemětřesení ?
- Počítá majitel objektu s ponecháním stavby ve stávajícím stavu bez střechy a s poškozenými stropními konstrukcemi, nebo bude nějakým způsobem stavba opravena ?

Oponent: Ing. Robert Šinkner, MBA.

- Jakou metodou byl objekt zaměřen? Laserovým skenováním nebo klasickými geodetickými metodami?
- Jak jste se dostal k takové zajímavé mezinárodní spolupráci?

Retrofitting methods

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

Experiment - NHERI@UCSD