

SIBYL

Seismic monitoring and vulnerability framework for civil protection



**Preliminary results for the Thessaloniki applications
(Assessment of the selected buildings)**

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Introduction

- **Task C: “Rapid and low in-situ building vulnerability assessment”**
- **Seismic vulnerability assessment of selected buildings using field monitoring data**
- **Detailed modeling of the buildings**
- **Comparison with the simplified integral structural model (TU-Berlin)**
- **Thessaloniki applications → 3 buildings at the AUTh campus:**
 - ✓ **AHEPA hospital**
 - ✓ **Administration**
 - ✓ **Faculty of Philosophy**

Introduction

Aim: Assessment of seismic vulnerability using field monitoring data

Experimental procedure

Field measurements → Estimation of the actual dynamic behavior

Analytical procedure

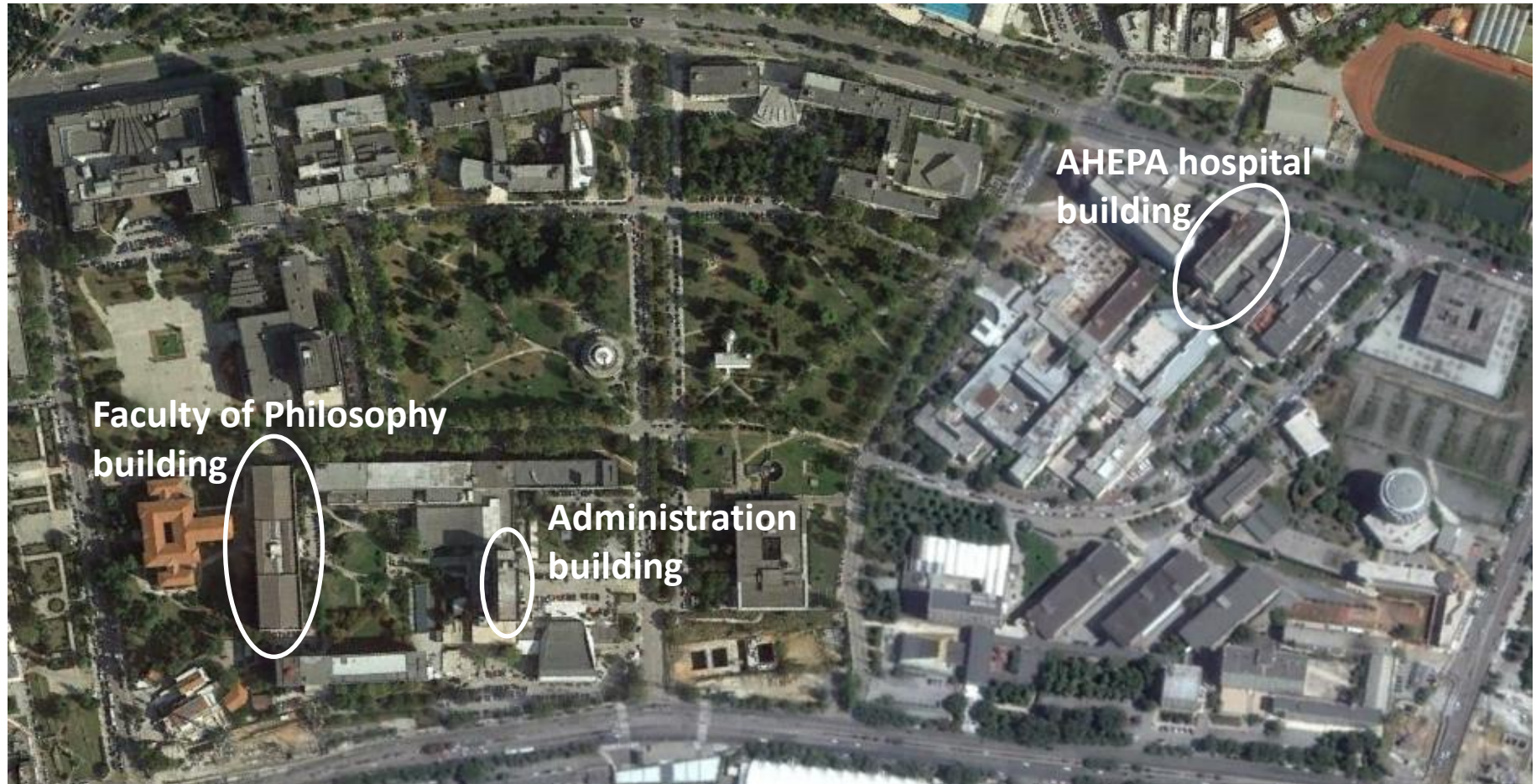
Numerical model → Estimation of the actual dynamic behavior

Update of the numerical model

Nonlinear analyses

Derivation of fragility curves

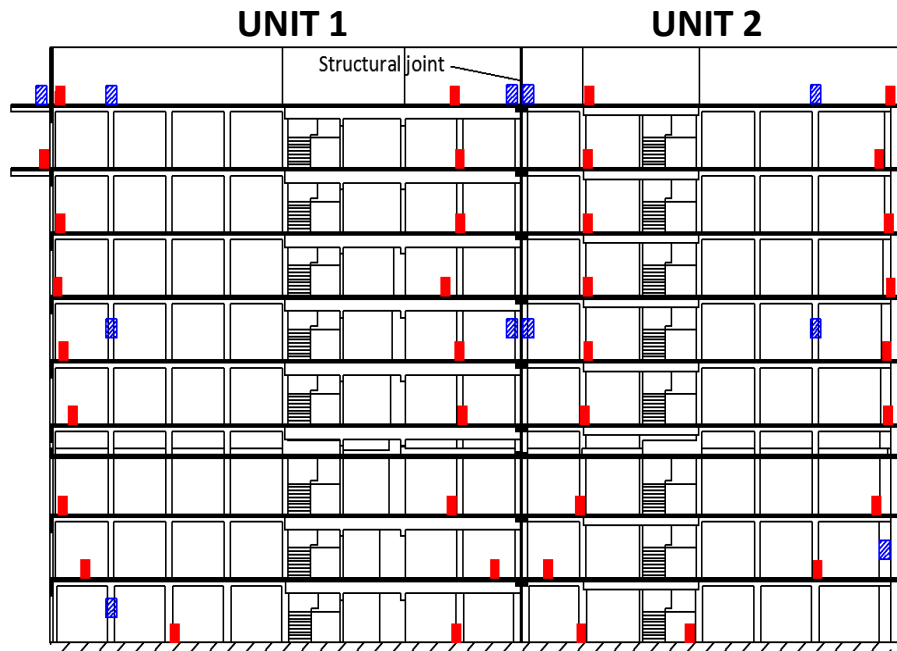
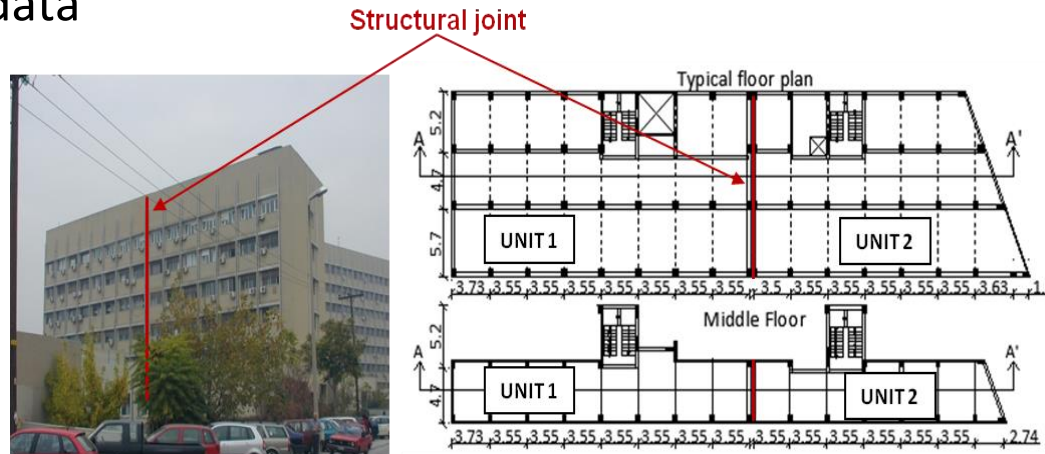
Description of the Thessaloniki applications



Description of the Thessaloniki applications

- **AHEPA hospital building**

- ✓ REAKT: Rapid post-earthquake assessment of buildings based on field monitoring data



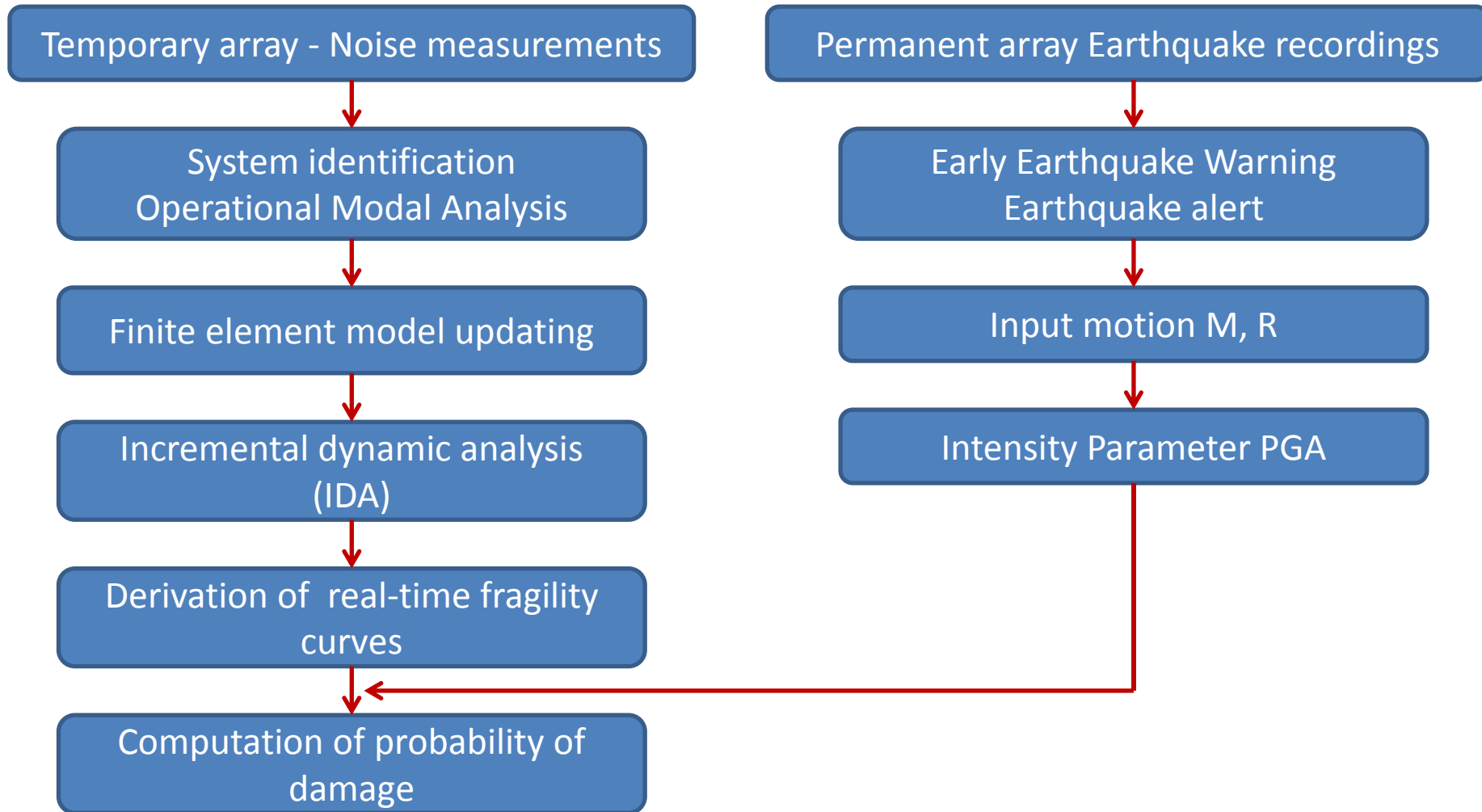
- Temporary array
- ▨ Permanent array



Ioniki 15th – 16th February 2016

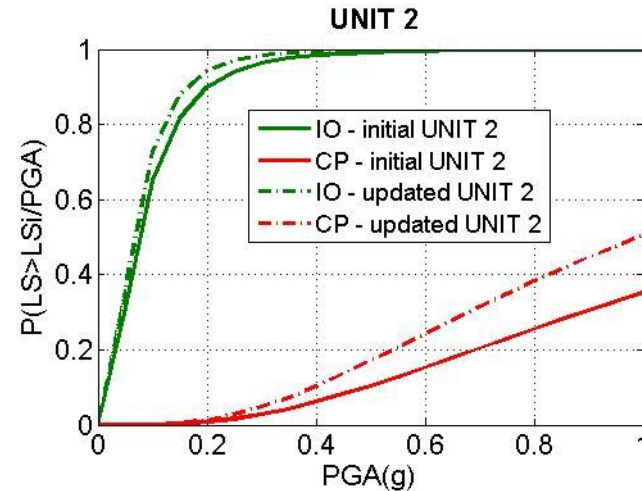
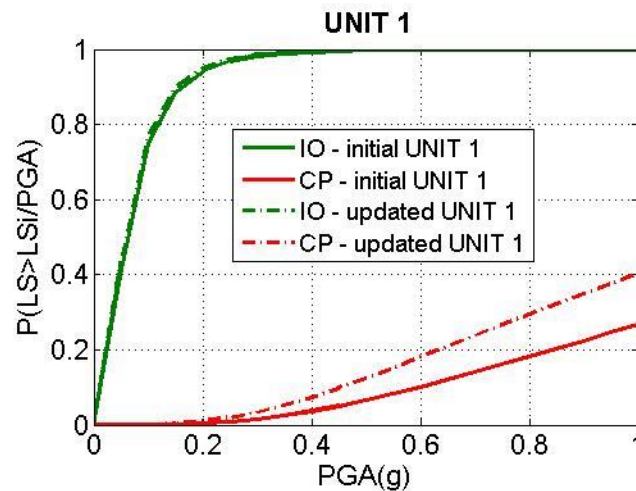
Description of the Thessaloniki applications

- AHEPA hospital building



Description of the Thessaloniki applications

- **AHEPA hospital building**



1. Bindi D., Petrovic B., Karapetrou S., Manakou M., Boxberger T., Raptakis D., Pitilakis K.D., Parolai S. (2015). *Seismic response of an 8-story RC-building from ambient vibration analysis*, *Bulletin of Earthquake Engineering* 13:7, 2095-2120.
2. Roumelioti Z., Karapetrou S., Manakou M. , Pitilakis M. , Raptakis D., Bindi D., Boxberger T. (2015). *The contribution of EUROSEISTEST and building monitoring arrays in Earthquake Early Warning and Rapid Damage Assessment in Thessaloniki*, *Proceedings of the 6th International Conference on Earthquake Geotechnical Engineering*, Christchurch, New Zealand, 1-4 November 2015.
3. Karapetrou S., Manakou M., Bindi D., Petrovic B., Pitilakis K. (2016). *“Time-building specific” seismic vulnerability of a high rise RC building using field monitoring data*, *Engineering Structures* 112, 114-132.

Description of the Thessaloniki applications

- Administration building

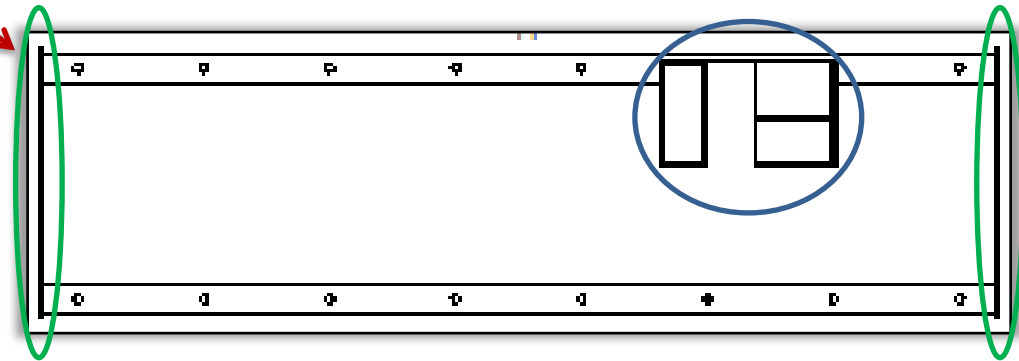


- ✓ Built in 1964 (Royal Decree of 1959)
- ✓ 9-storey with basement
- ✓ Dual force resisting mechanism:
frames + core walls
- ✓ Frontal walls between the 2nd and 8th floor
- ✓ Peripheral walls in the basement
- ✓ Foundation: mainly isolated footings without tie beams; soil type B (EC8)

	+ 29.6m
8 th floor	+ 26.4m
7 th floor	+ 23.2m
6 th floor	+ 20.0 m
5 th floor	+ 16.8 m
4 th floor	+ 13.6 m
3 rd floor	+ 10.4 m
2 nd floor	+ 7.2 m
1 st floor	+ 4.0 m

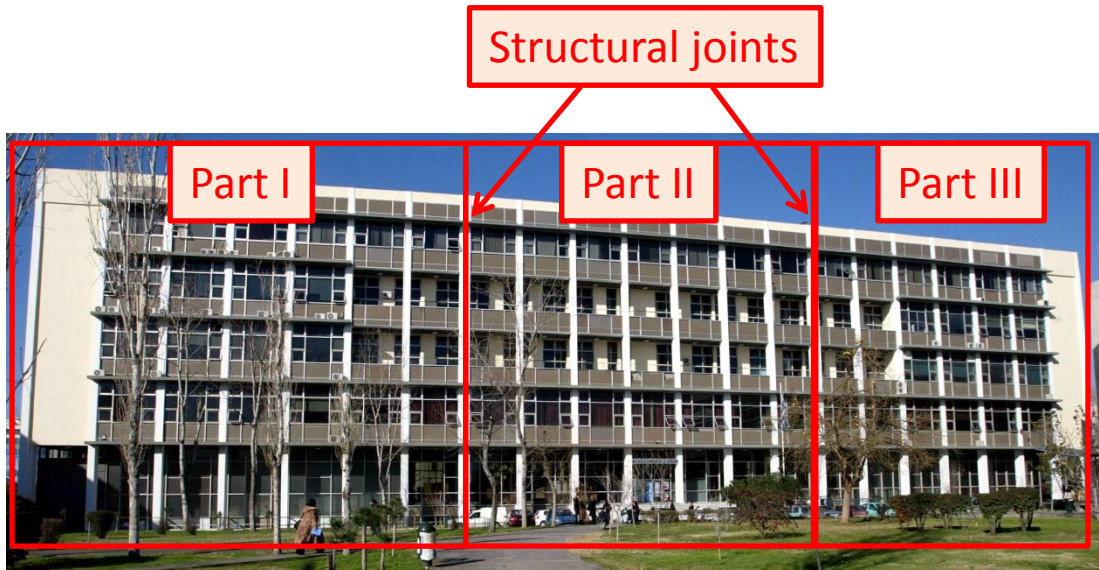
Ground floor ± 0.0 m

Basement - 4.6 m



Description of the Thessaloniki applications

- Faculty of Philosophy building



- ✓ Oblong plan with length 105m and width 25.5m

- ✓ Structural joints per 35m

- ✓ Divided in three parts with length 35m and width 25.5m



Description of the Thessaloniki applications

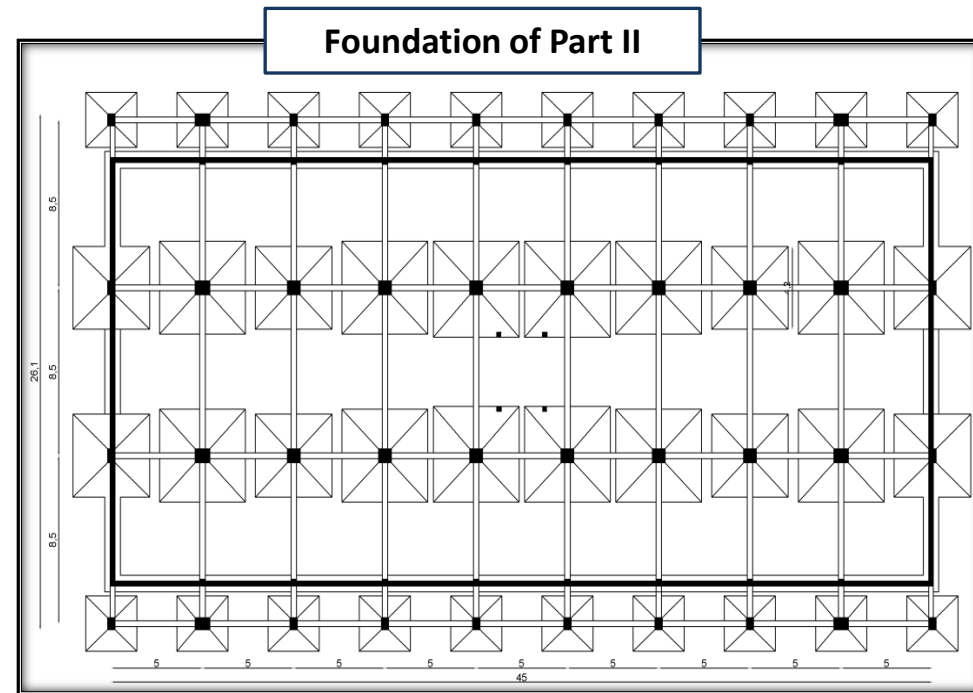
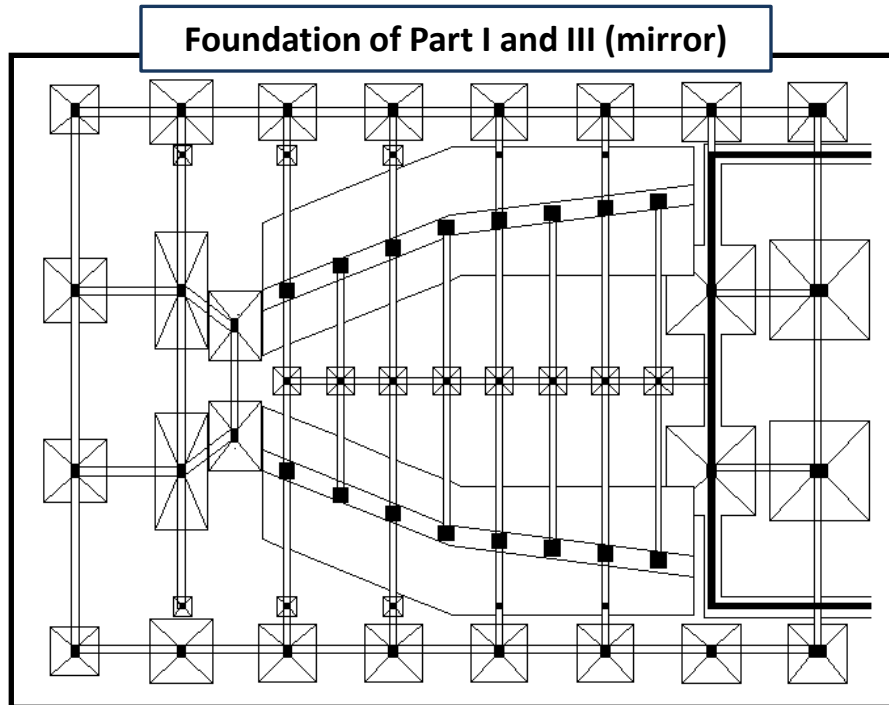
- Faculty of Philosophy building

Part I	Part II		Part III
		+ 28.65 m	
	4 th floor	+ 25.40 m	
	3 rd floor	+ 20.85 m	
	2 nd floor	+ 16.30 m	
	1 st floor	+ 11.65 m	
	Ground floor	+ 6.25 m	
+ 4.25 m			+ 4.25 m
± 0.00 m	Semi-basement	+ 1.30 m	± 0.00 m
	Basement	- 3.45 m	

- ✓ Built in 1965 (Royal Decree of 1959)
- ✓ Construction of additional floor (last floor) in 1984 – No plans available
- ✓ Moment resisting frame system
- ✓ External infill panels along the longitudinal direction in the 2nd and 3rd floors

Description of the Thessaloniki applications

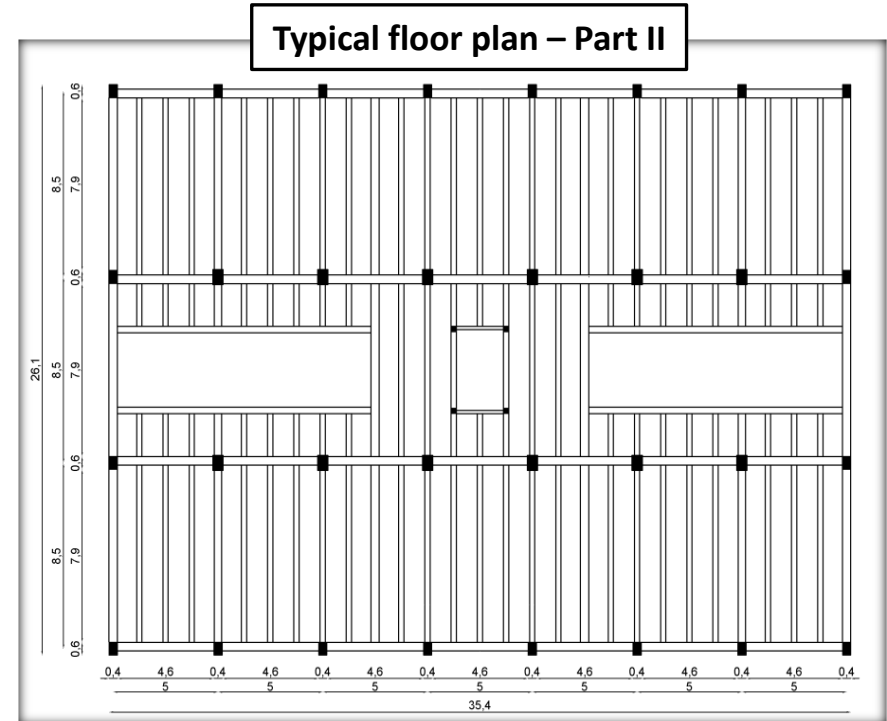
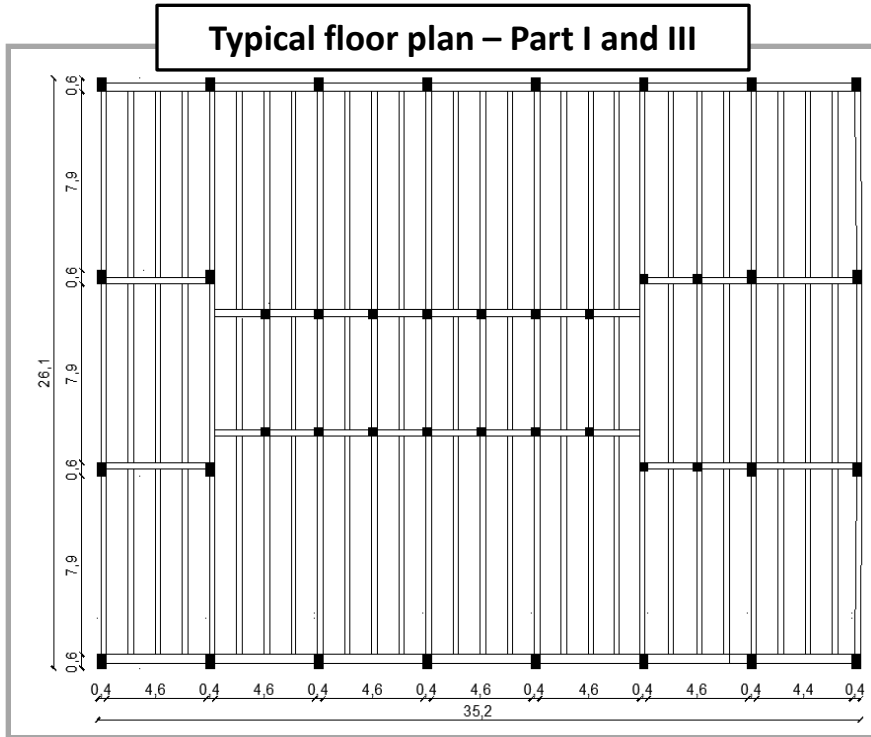
- Faculty of Philosophy building



- ✓ Peripheral walls in the basement
- ✓ Isolated footings and strip footings
- ✓ Foundation soil: stiff clay -> Soil type B (EC8)

Description of the Thessaloniki applications

- Faculty of Philosophy building

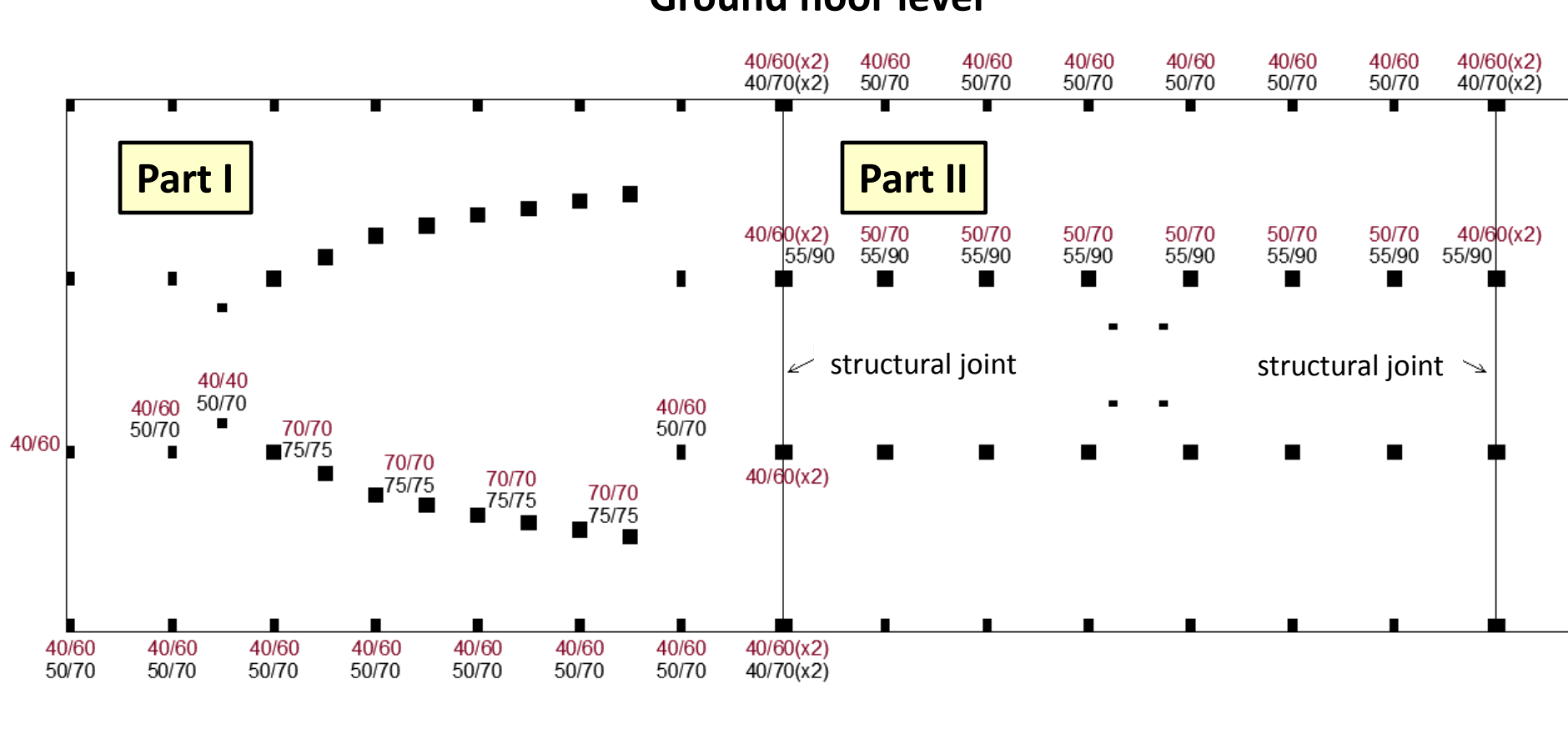


Description of the Thessaloniki applications

- Faculty of Philosophy building

- ✓ In situ measurements: dimensions of structural elements, reinforcement detection, concrete cover, floor heights

Ground floor level

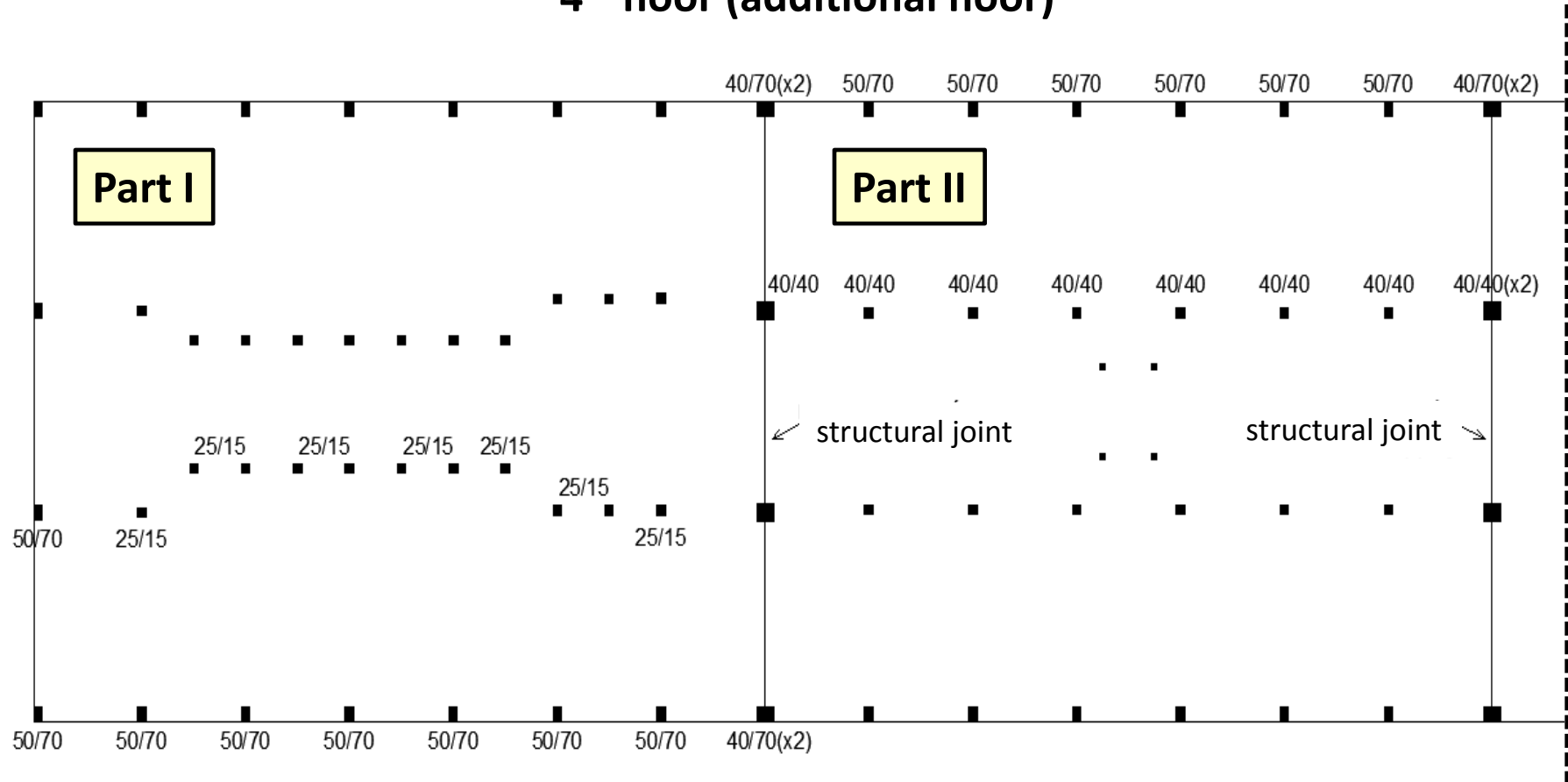


Description of the Thessaloniki applications

- **Faculty of Philosophy building**

- ✓ In situ measurements: dimensions of structural elements, reinforcement detection, concrete cover, floor heights

4th floor (additional floor)



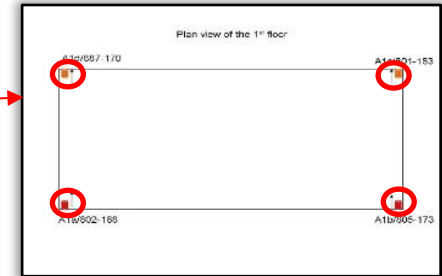
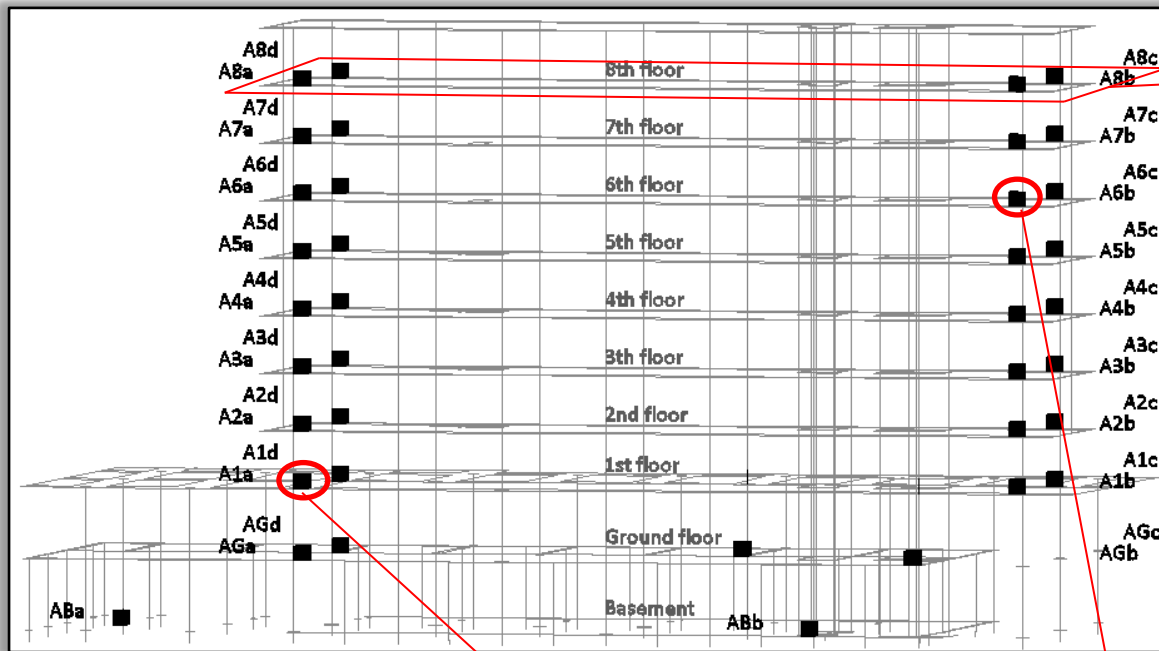
Temporary instrumentation array

- September/October 2015: ambient noise measurements (TU Berlin, GFZ, AUTH)
- Duration of the measurements at each building: approx. 20 hours
- Sensors: 38 CUBE digitizers connected to 4.5Hz geophones
- Sampling rate: 400 Hz



Temporary instrumentation array

- Administration building



4 in each floor

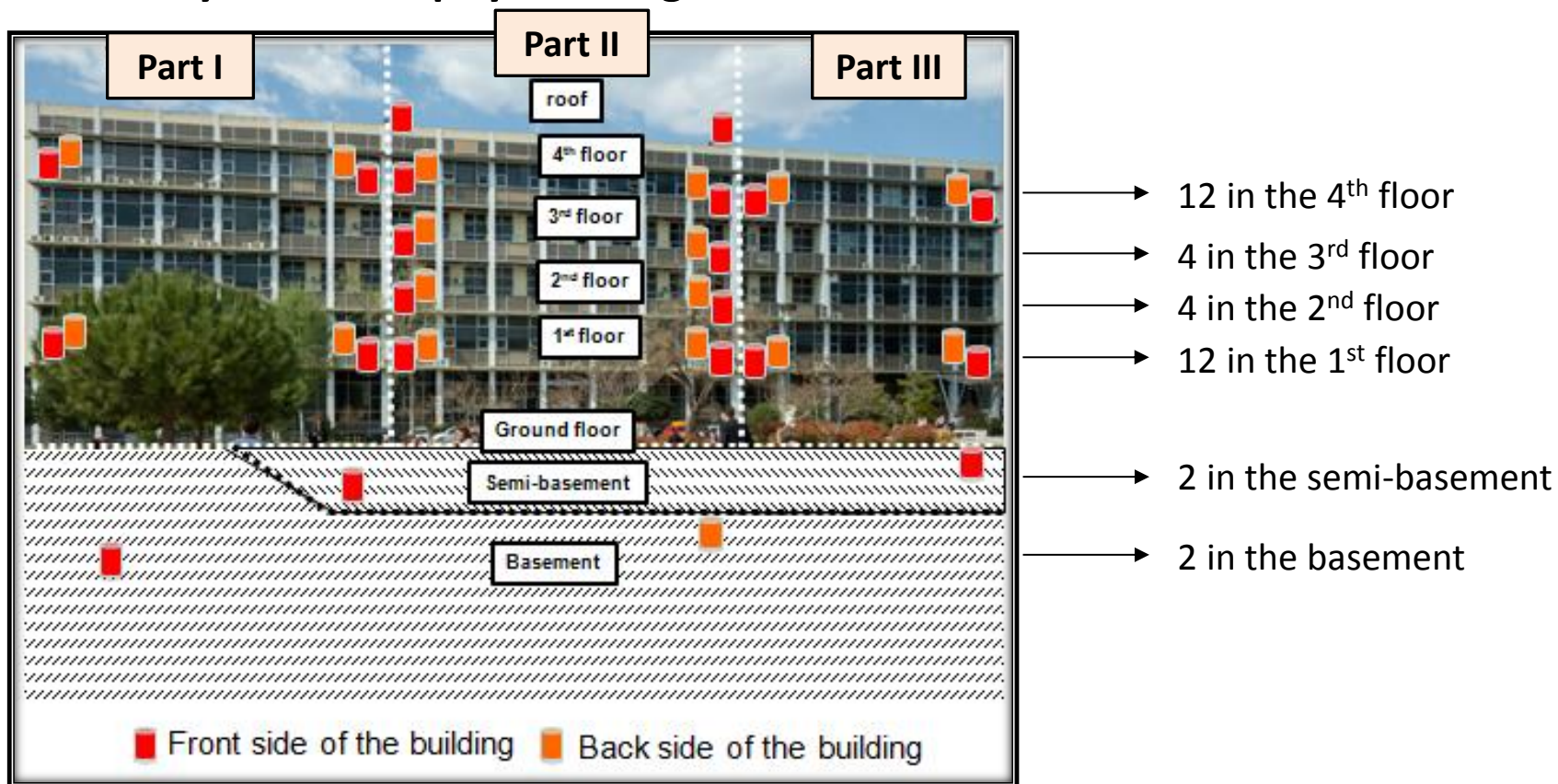
4 in the ground floor

2 in the basement



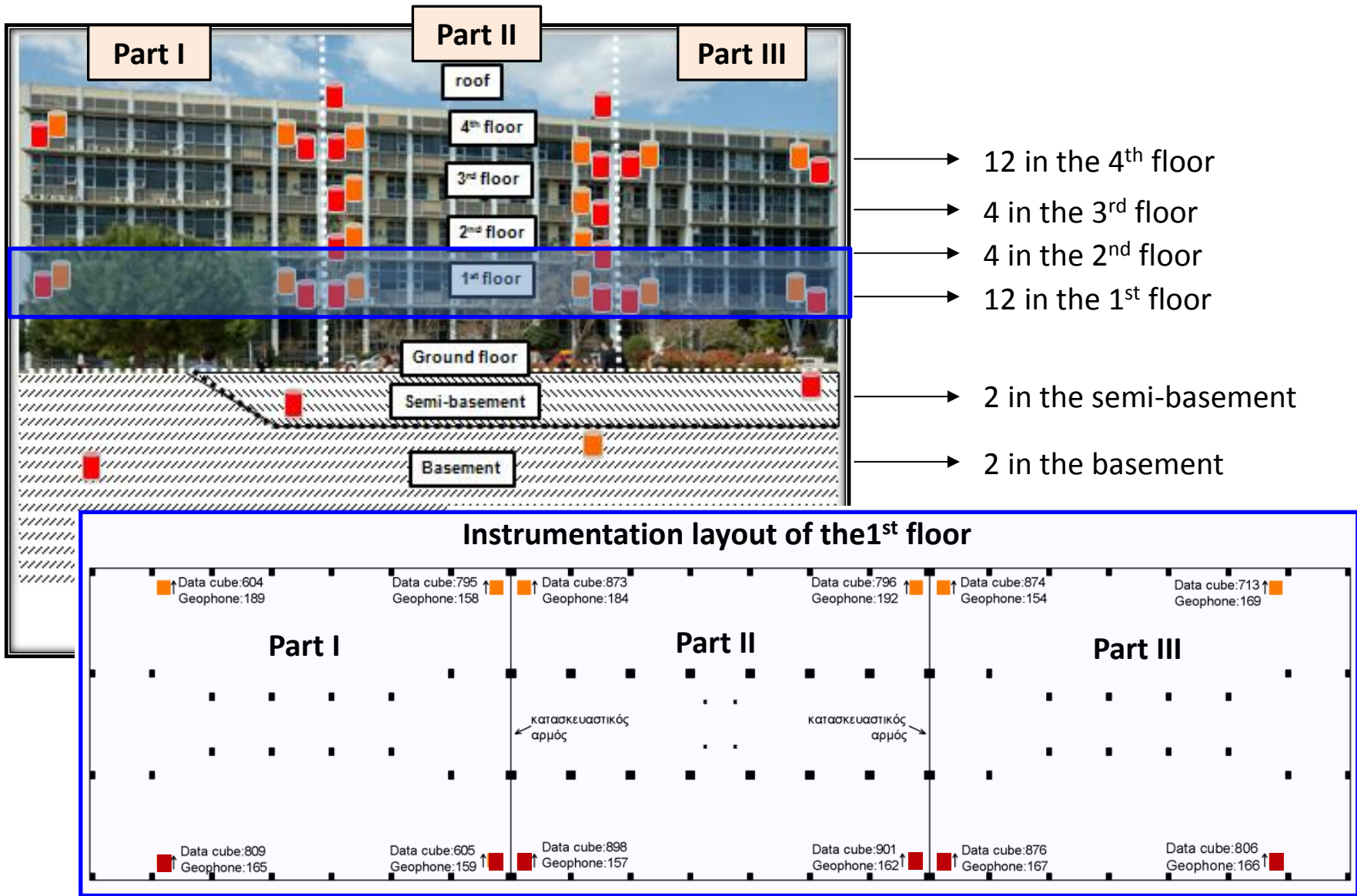
Temporary instrumentation array

- Faculty of Philosophy building



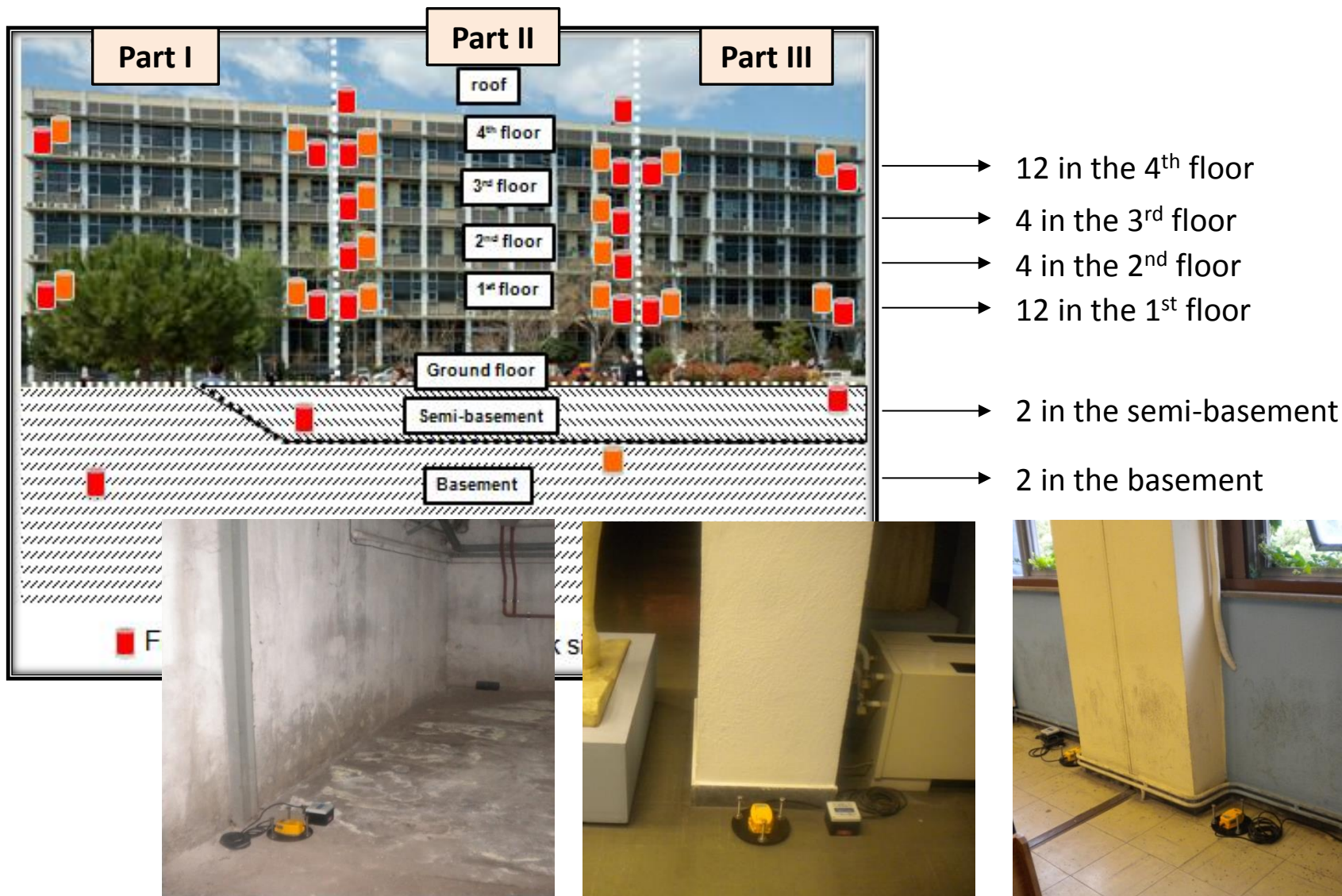
Temporary instrumentation array

- Faculty of Philosophy building

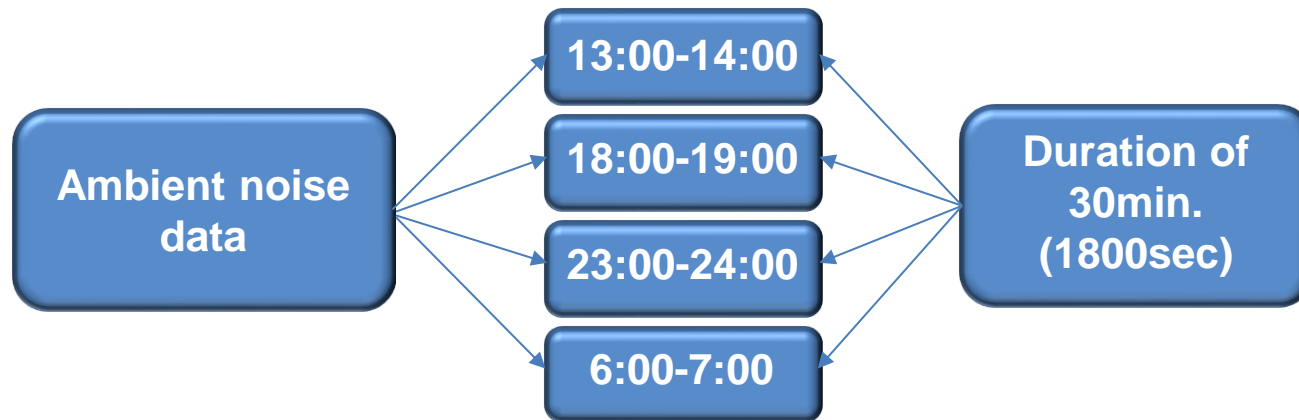


Temporary instrumentation array

- Faculty of Philosophy building



Operational Modal Analysis (OMA)



- **Data processing in SAC:**

baseline correction; detrending; tapering; time synchronization; decimation (sampling rate from 400Hz to 40Hz); bandpass filter (0.1-15Hz)

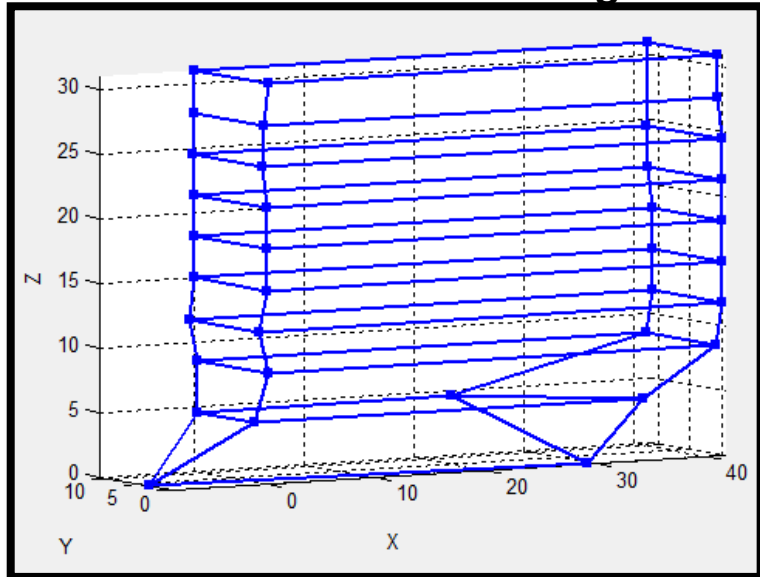
- **Operational modal analysis (OMA) in MACEC 3.2:**

- ✓ Frequency Domain Decomposition (FDD)
- ✓ Stochastic Subspace identification (SSI)

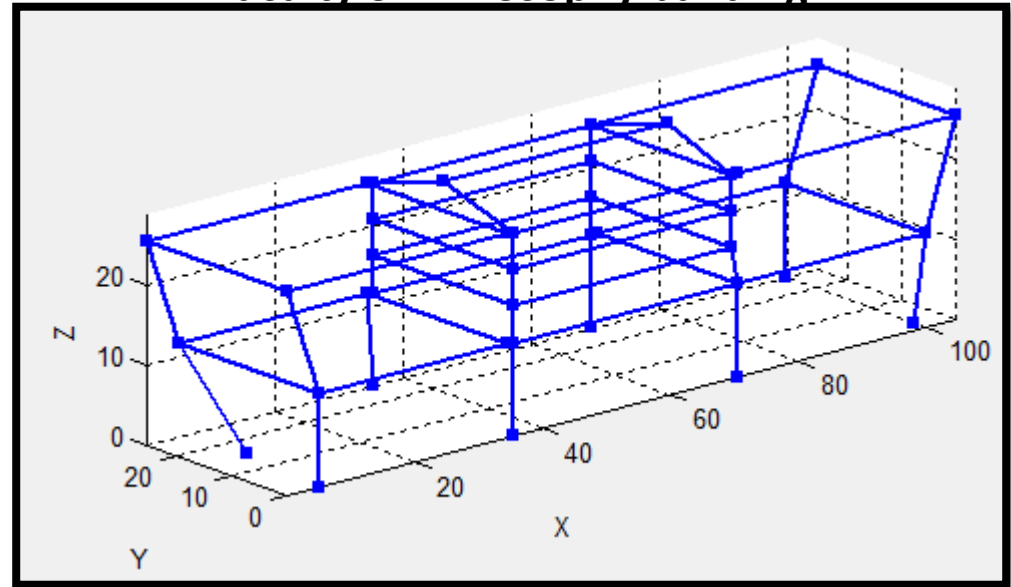
Operational Modal Analysis (OMA)

- Operational Modal Analysis (OMA) in MACEC 3.2

Administration building



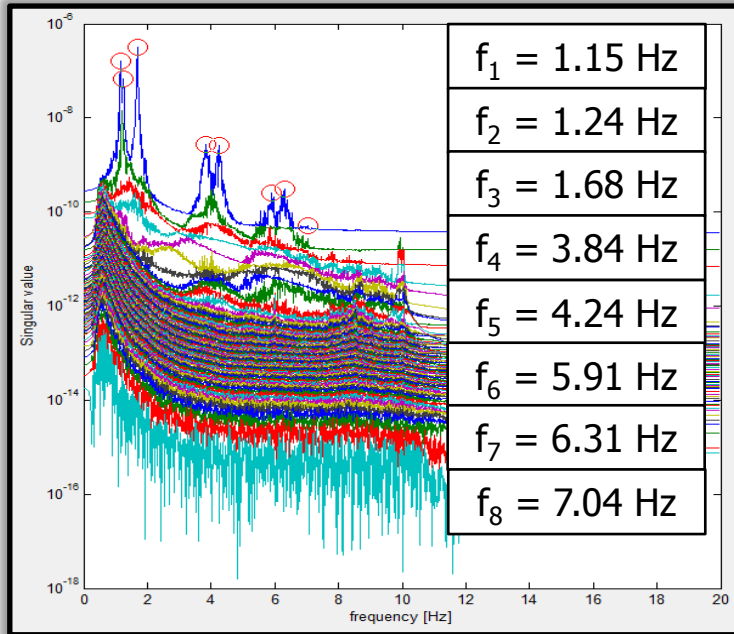
Faculty of Philosophy building



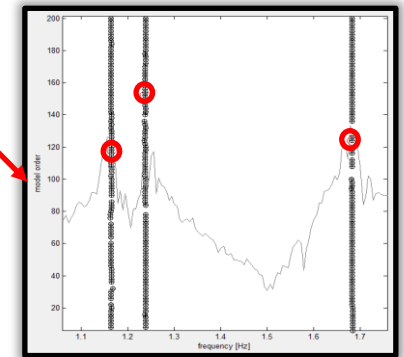
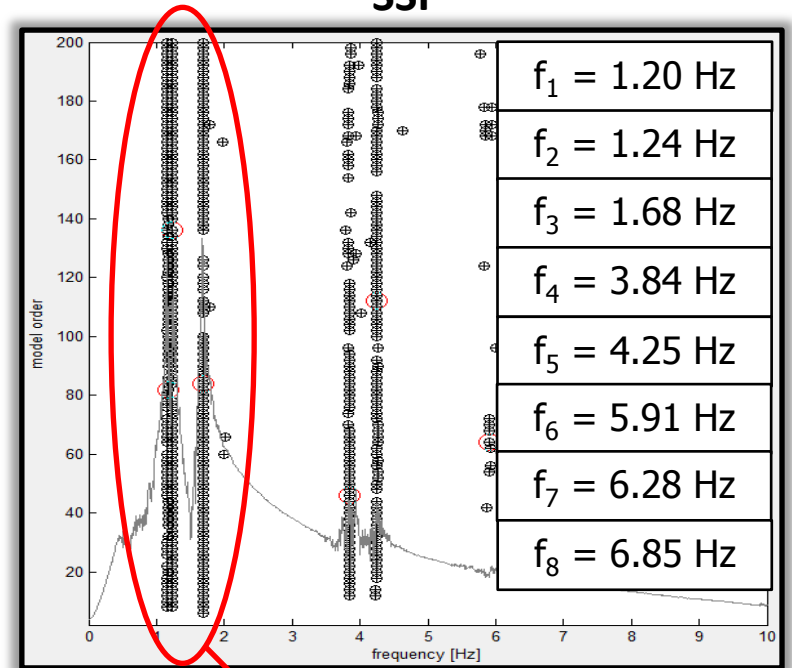
Operational Modal Analysis (OMA)

- Administration building – OMA (MACEC 3.2)

FDD

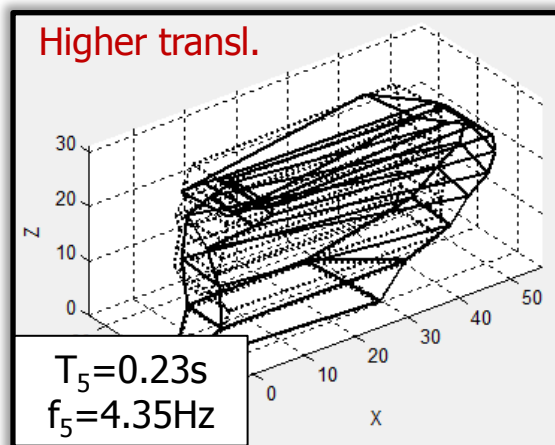
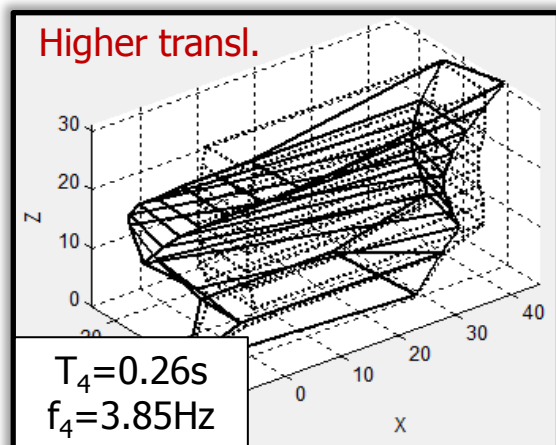
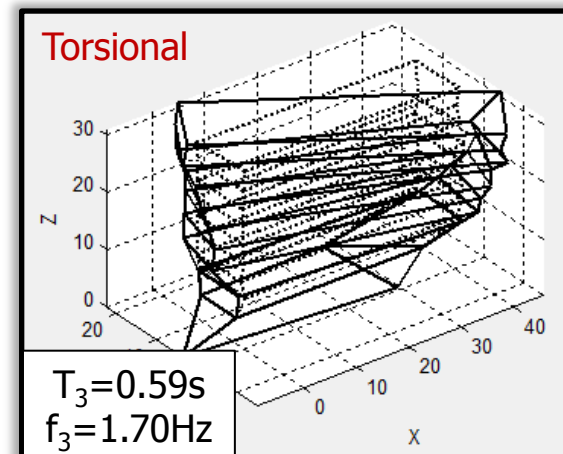
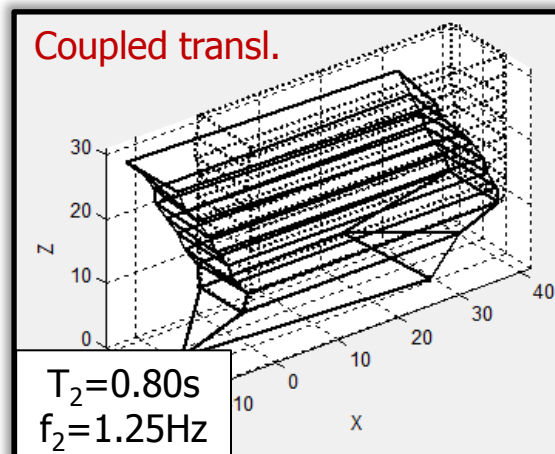
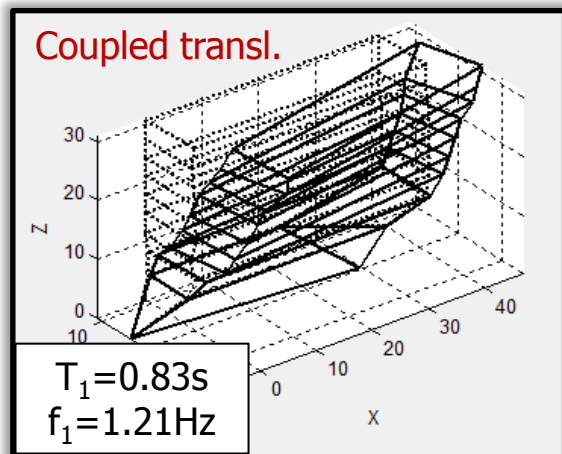


SSI



Operational Modal Analysis (OMA)

- Administration building – Modes (frequencies/periods and shapes)



Operational Modal Analysis (OMA)

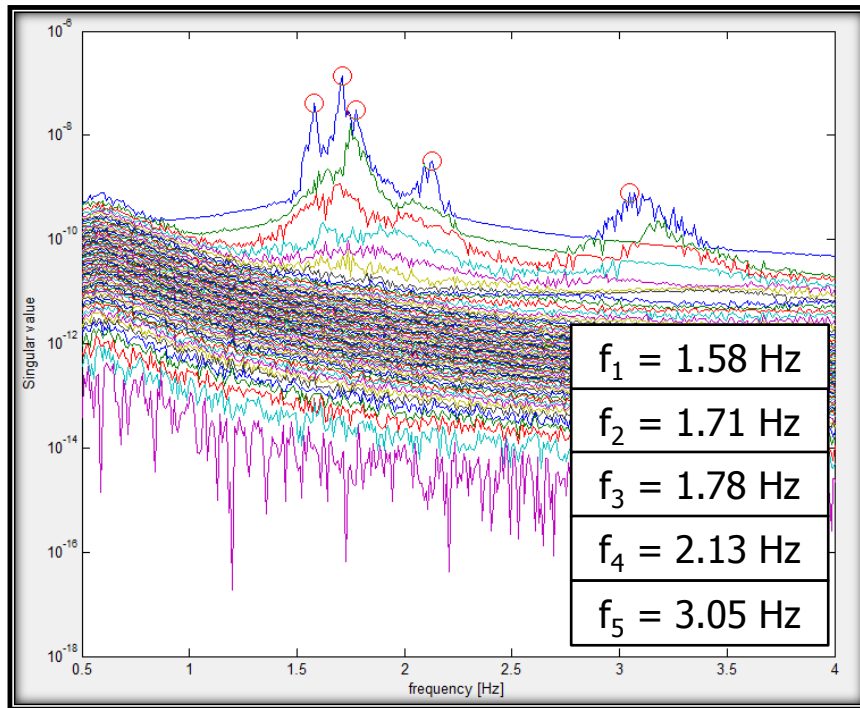
- Administration building – Modes (frequencies/periods and shapes)
 - ✓ Variation of the fundamental frequencies

Frequencies (Hz)	Recording 13:00-14:00	Recording 18:00-19:00	Recording 23:00-24:00	Recording 6:00-7:00
f_1	1.21	1.20	1.20	1.20
f_2	1.25	1.25	1.25	1.25
f_3	1.70	1.69	1.70	1.70
f_4	3.85	3.88	3.91	3.91
f_5	4.35	4.26	4.27	4.29

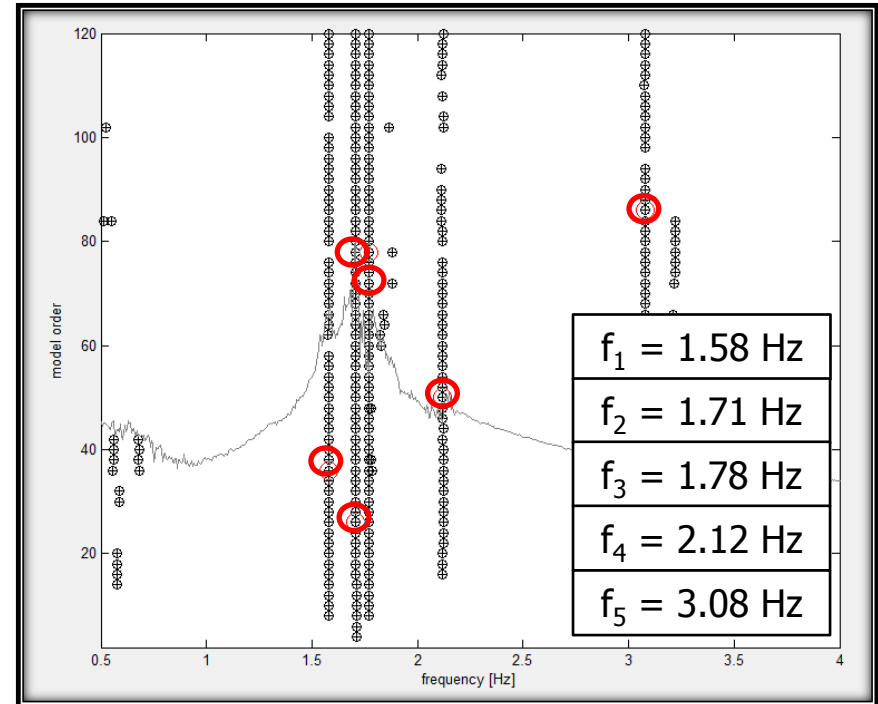
Operational Modal Analysis (OMA)

- Faculty of Philosophy building – OMA (MACEC 3.2)

FDD

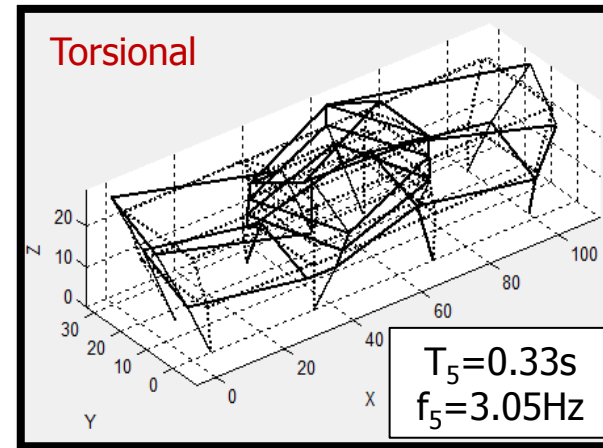
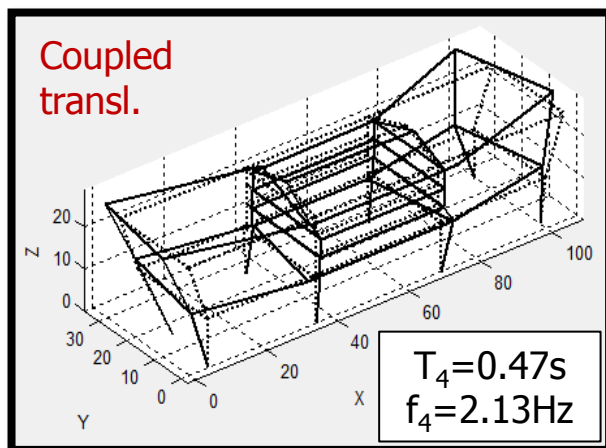
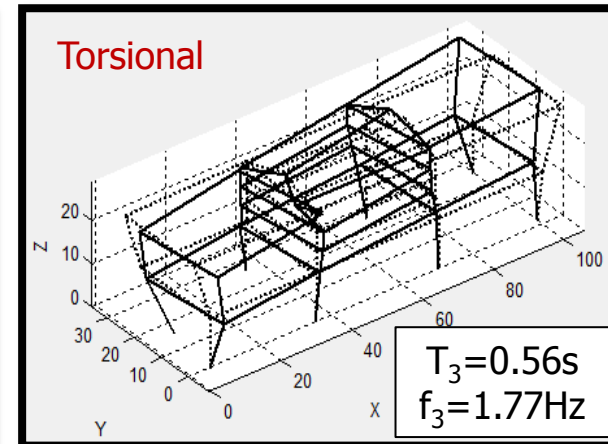
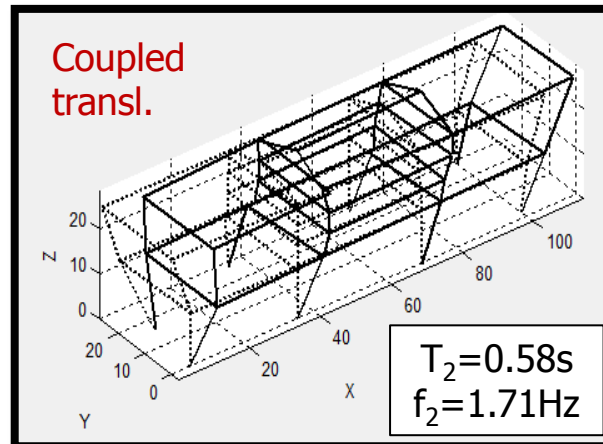
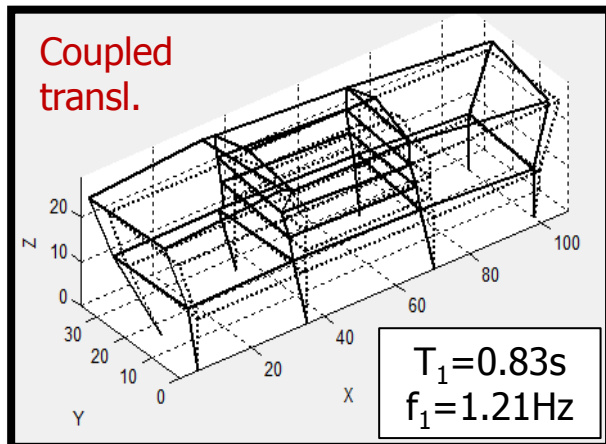


SSI



Operational Modal Analysis (OMA)

- Faculty of Philosophy building– Modes (frequencies/periods and shapes)



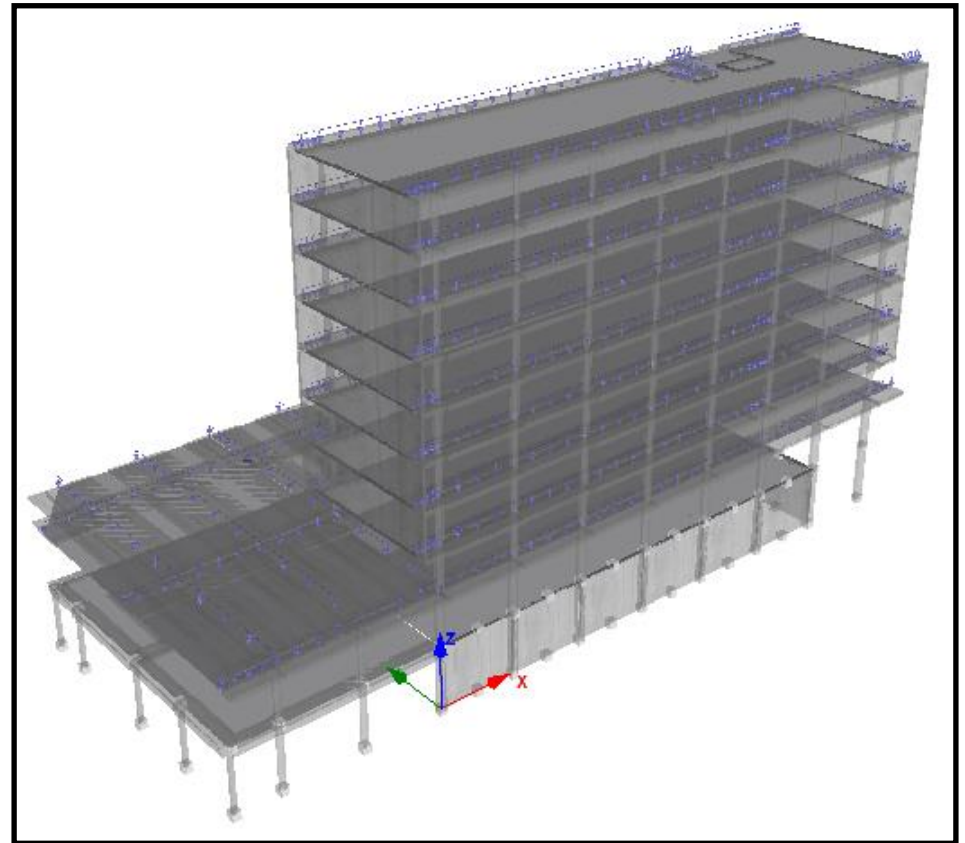
Operational Modal Analysis (OMA)

- Faculty of Philosophy building
 - ✓ Variation of the fundamental frequencies

Frequencies (Hz)	Recording 13:00-14:00	Recording 18:00-19:00	Recording 23:00-24:00	Recording 6:00-7:00
f_1	1.58	1.58	1.60	1.58
f_2	1.71	1.71	1.74	1.75
f_3	1.78	1.78	1.79	1.78
f_4	2.13	2.28	2.28	2.14
f_5	3.05	3.30	3.33	3.32

Numerical modeling / Finite Element Updating

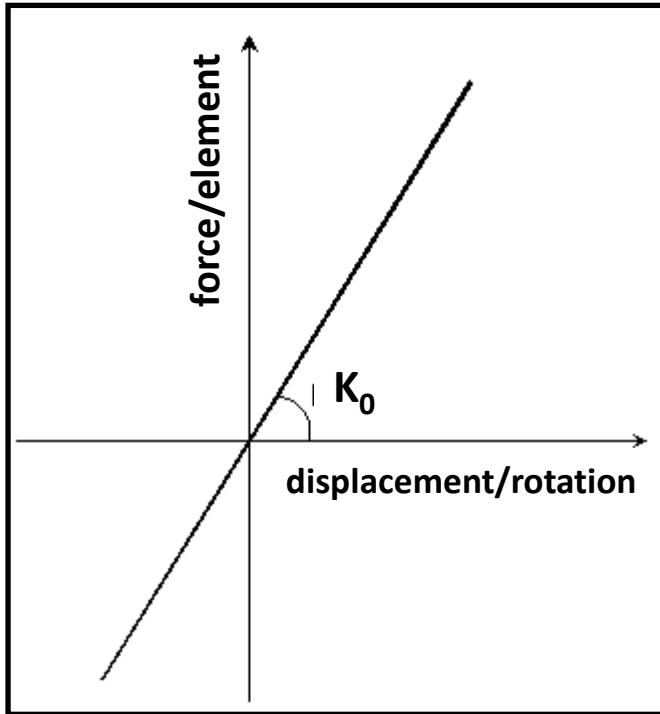
- **Administration building – SeismoStruct (SeismoSoft, v. 7)**
 - ✓ **Beam/Columns**: frame elements
 - ✓ **Peripheral concrete walls – Core walls**: equivalent beam-column model
 - ✓ Total mass: 7219 tn
 - ✓ Concrete strength: B300 -> C20/25
 - ✓ Steel strength: StIIIb -> S400
 - ✓ **Fixed base conditions**
 - ✓ Translational degrees of freedom of the building nodes are fixed at the basement level
 - ✓ Joints at the basement and the ground floor level simulated through **link elements**



Numerical modeling / Finite Element Updating

- Administration building – SeismoStruct (SeismoSoft, v. 7)

Link element in SeismoStruct



Updating procedure:

- ✓ Sensitivity modal analysis
- ✓ Extensive investigation of the **stiffness parameter** K_0 of the link elements
- ✓ Selection of the best finite element model that reflects the measured response based on the **Modal Assurance Criterion** (MAC)

$$MAC_{ij} = \frac{(\varphi_j^T \varphi_{Ei})^2}{(\varphi_j^T \varphi_j)(\varphi_{Ei}^T \varphi_{Ei})}$$

φ_j eigenvector j from numerical model

φ_{Ei} eigenvector i from field monitoring test

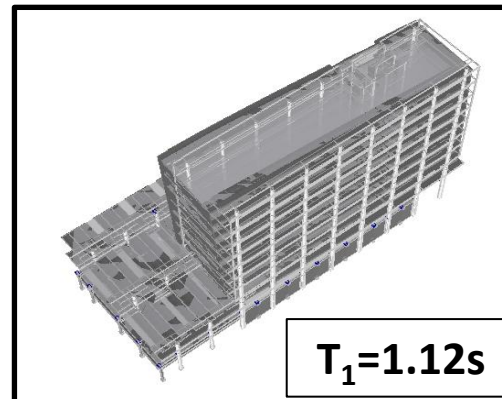
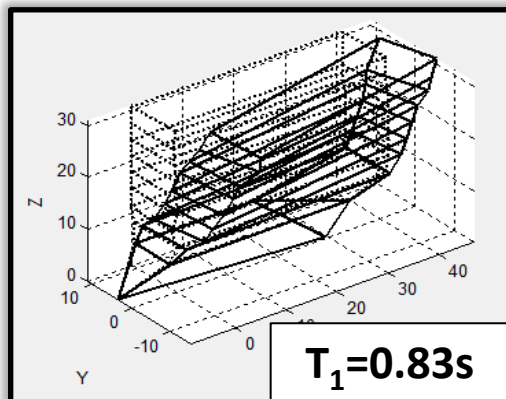
- **Best model (MAC>0.8):** $K_0 = 10^4 \text{kN/m}$ for the translational DOFs
 $K_0 = 10^6 \text{kNm/rad}$ for the rotational DOFs

Numerical modeling / Finite Element Updating

- Administration building – Comparison with measured response

1st mode

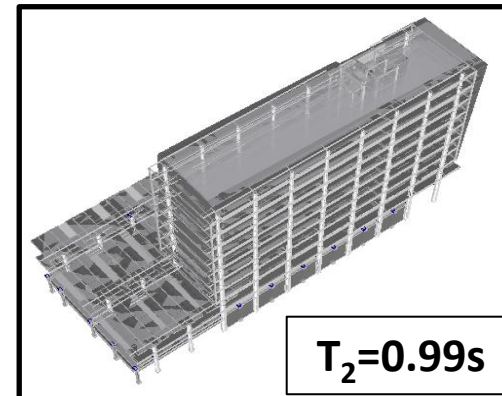
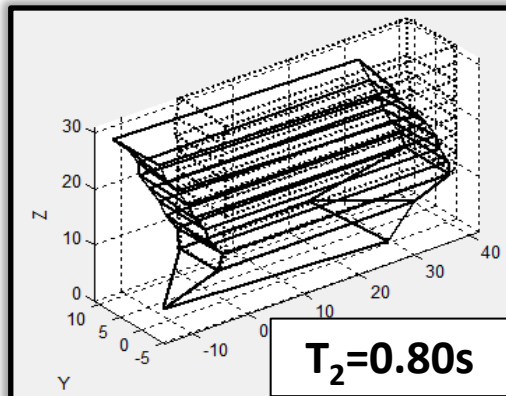
Coupled translational
along the transverse
direction



MAC=0.88

2nd mode

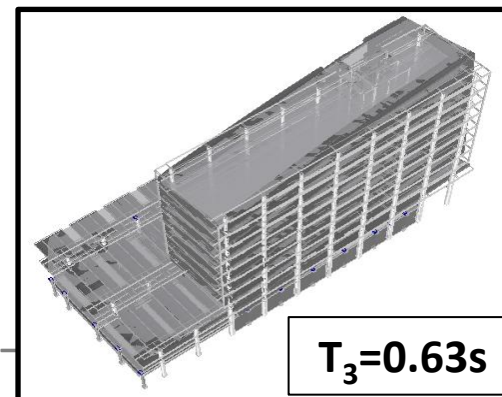
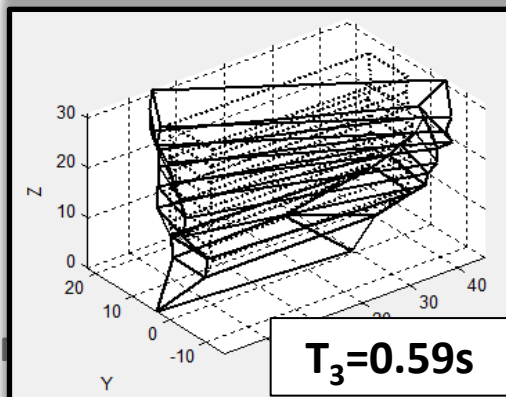
Coupled translational
along the longitudinal
direction



MAC=0.85

3rd mode

Torsional



MAC=0.84

Numerical modeling / Finite Element Updating

- Faculty of Philosophy building – SAP 2000 (Computers and Structures, Inc)

- ✓ Beam/Columns: frame elements

- ✓ Peripheral concrete walls: equivalent beam-column model

- ✓ Infill model: equivalent beam/column model

- ✓ Total mass: 9360 tn

- ✓ Concrete strength: B225 -> C16/20

- ✓ Steel strength: StIIIb -> $f_y=420\text{MPa}$

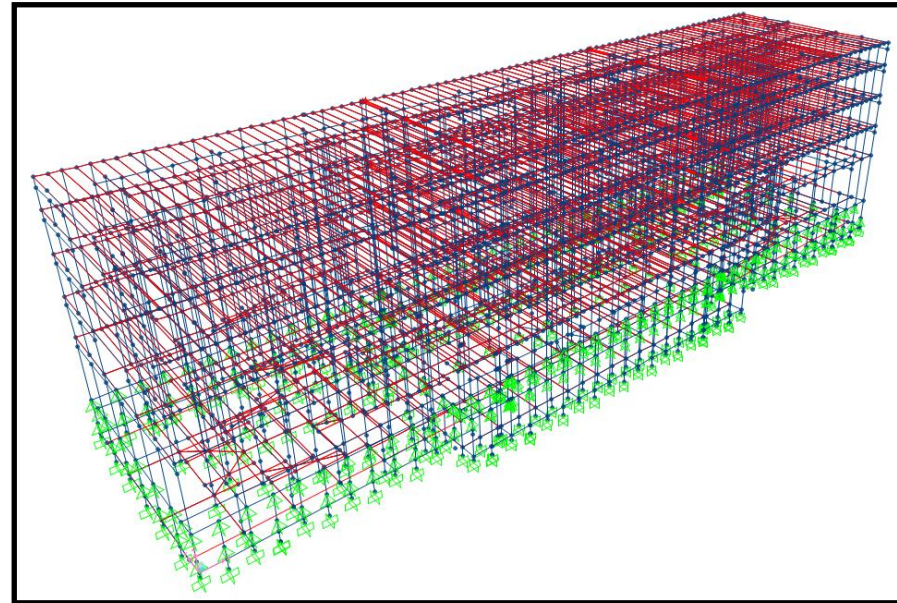
- ✓ Infill strength: $f_{m\theta}=3\text{MPa}$

- ✓ Fixed base conditions

- ✓ Translational degrees of freedom

of the building nodes are fixed at the basement level

- ✓ Joints between the building parts through link elements



Numerical modeling / Finite Element Updating

- Faculty of Philosophy building – SAP

- ✓ Extensive investigation of the link properties (**ongoing**)
- ✓ Selection of the best model based on the evaluation of **MAC (>0.8)**
- ✓ Link of gap element type with the following stiffness properties:

Translational DOFs

$$U_1 = 50000 \text{ kN/m}$$

$$U_2 = 50000 \text{ kN/m}$$

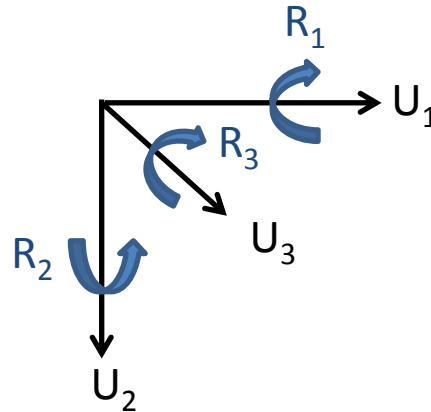
$U_3 \rightarrow$ fixed

Rotational DOFs

$$R_1 = 50000 \text{ kNm/rad}$$

$$R_2 = 50000 \text{ kNm/rad}$$

$$R_3 = 100000 \text{ kNm/rad}$$

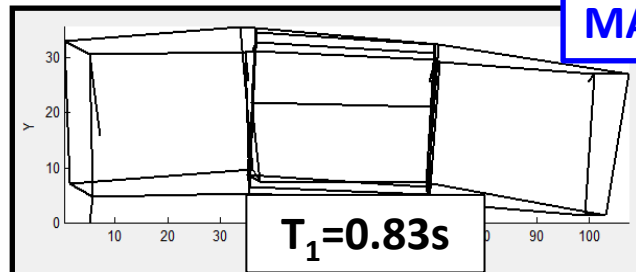


Numerical modeling / Finite Element Updating

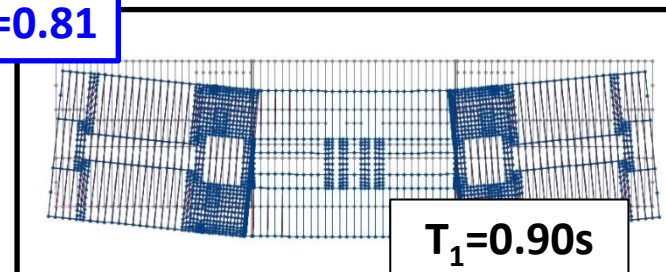
- Faculty of Philosophy building – Comparison with measured response

1st mode

Coupled translational along the transverse direction

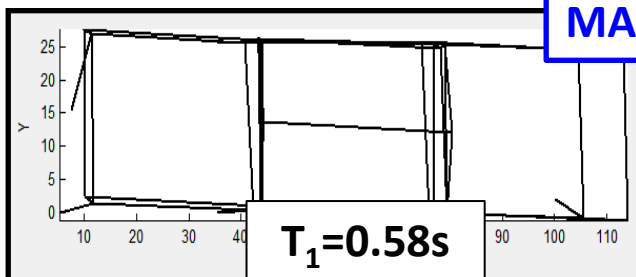


MAC=0.81

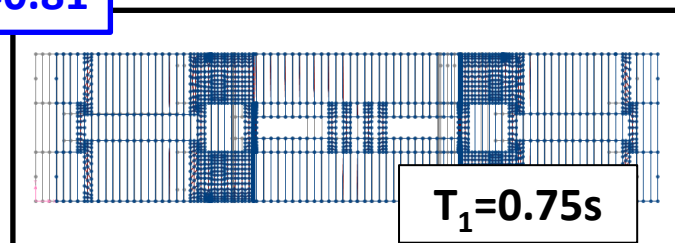


2nd mode

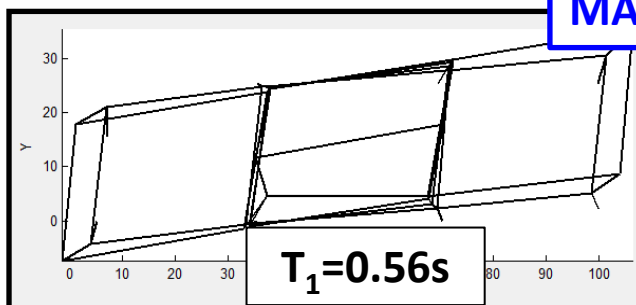
Coupled translational along the longitudinal direction



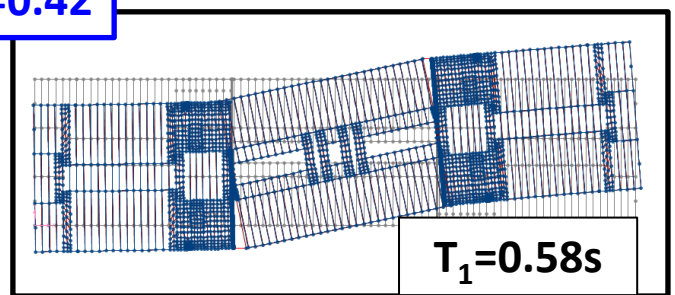
MAC=0.81



3rd mode
Torsional



MAC=0.42

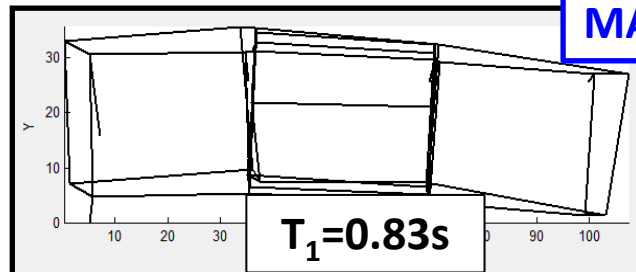


Numerical modeling / Finite Element Updating

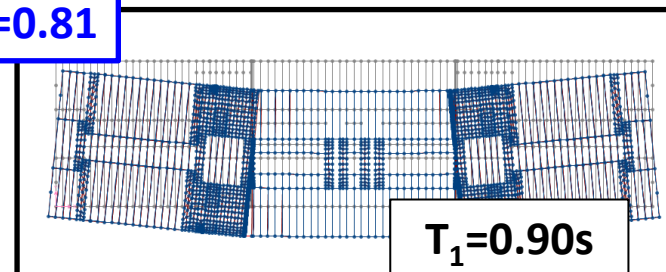
- Faculty of Philosophy building – Comparison with measured response

1st mode

Coupled translational along the transverse direction

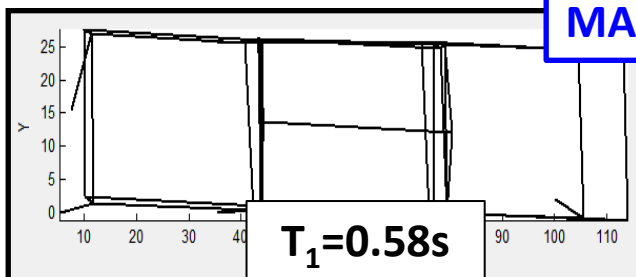


MAC=0.81

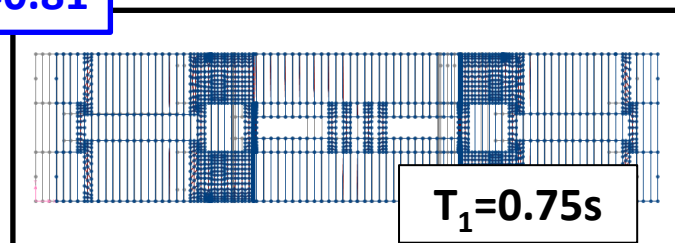


2nd mode

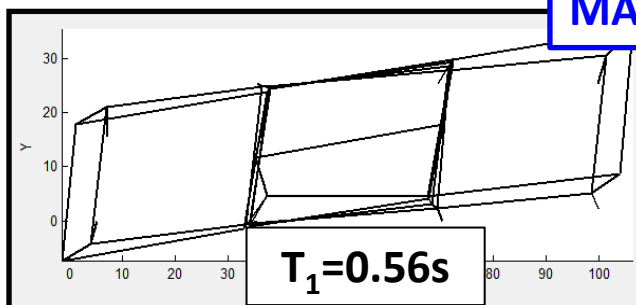
Coupled translational along the longitudinal direction



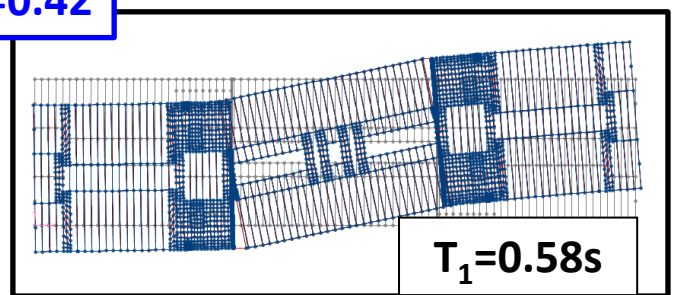
MAC=0.81



3rd mode
Torsional



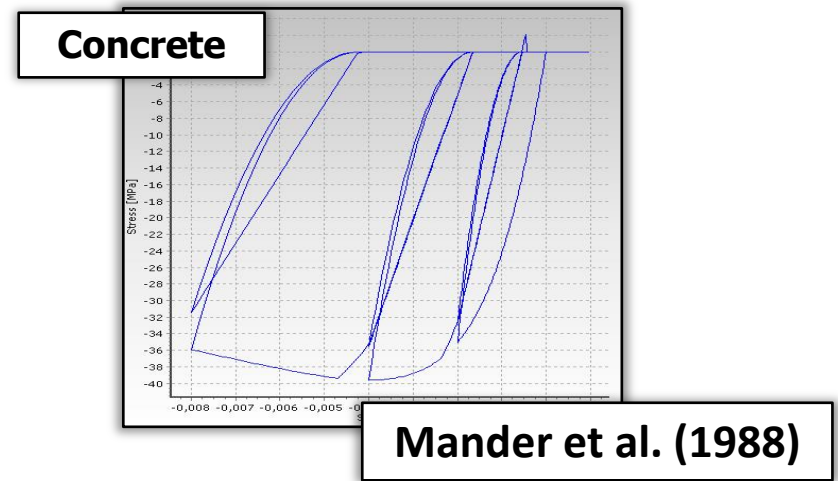
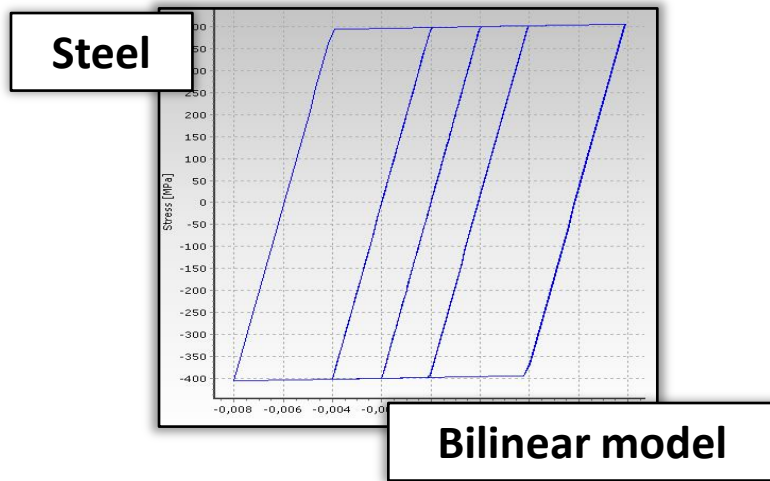
MAC=0.42



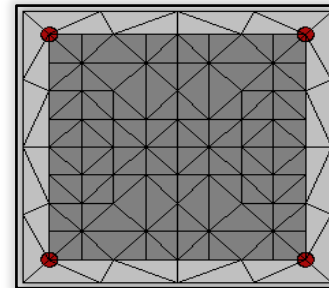
Estimation of inelastic behavior (Ongoing)

- Administration building

- ✓ Nonlinear numerical modeling – SeismoStruct (SeismoSoft, v. 7)
- ✓ Force- and displacement based formulations
- ✓ Geometric nonlinearity
- ✓ Material inelasticity

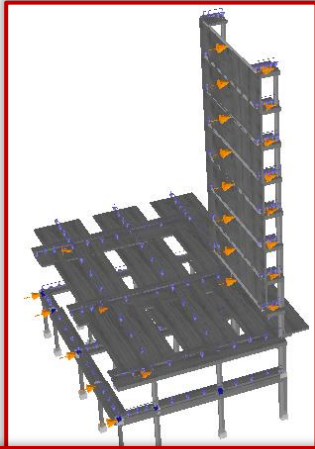


- ✓ Distributed plasticity along the structural elements
(fiber based approach)

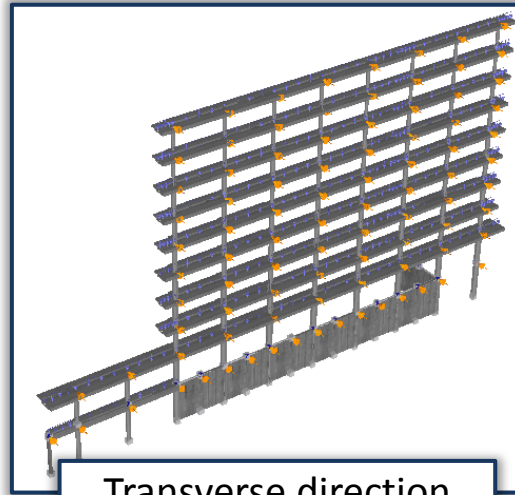


Estimation of inelastic behavior

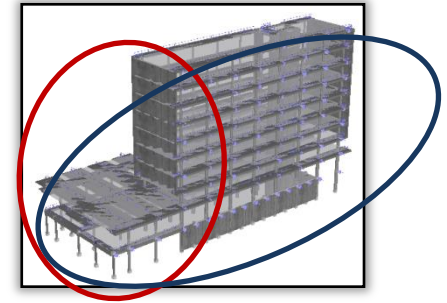
- Administration building – Pushover analysis
 - ✓ longitudinal (x) and transverse (y) direction



Longitudinal direction



Transverse direction

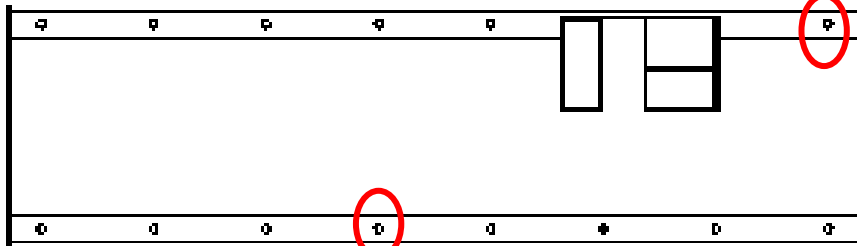


- ✓ Force distribution along the height according to EC8

$$F_i = F_b \frac{m_i z_i}{\sum m_i z_i}$$

Pushover analysis

8th Floor Level



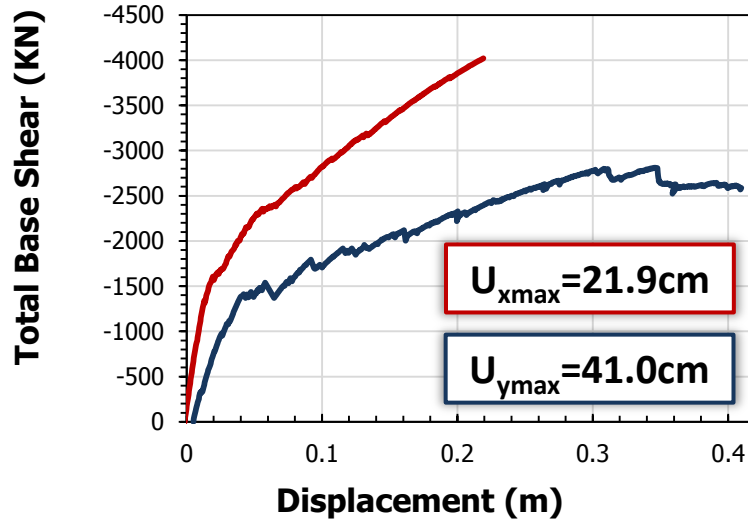
C10

C6

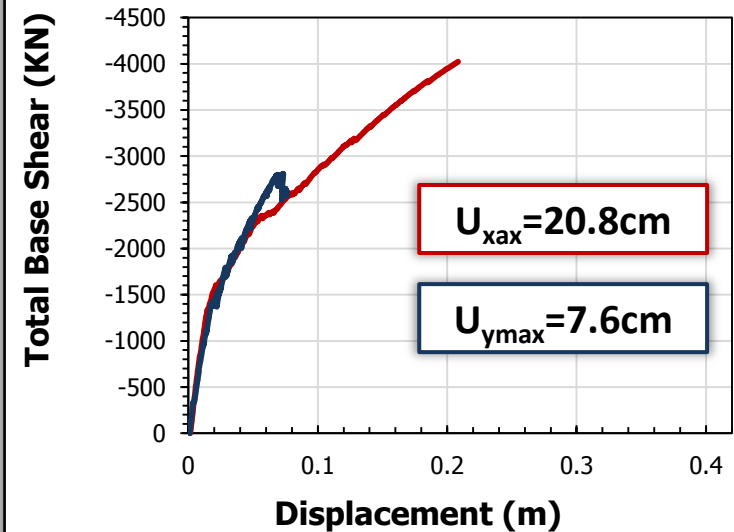
- ✓ Total base shear versus displacement
- ✓ Control point C6 and C10 located at top floor level

— longitudinal
— transverse

Column C10



Column C6



Future work

- **Faculty of Philosophy building**
 - ✓ **Further investigation of the updating procedure**
 - ✓ **Inelastic numerical modeling of the updated finite element models**
- **Derivation of building-specific fragility curves**
 - ✓ **Selection of seismic records based on site – specific hazard (seismic disaggregation)**
 - ✓ **Nonlinear dynamic analyses**



Thank you !!!

