Task C
Rapid and low-cost in-situ building vulnerability assessment

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AUTH, Thessaloniki, Greece

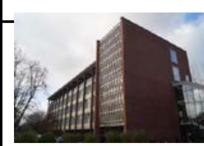
(September-October 2015)

Faculty of Philosophy

Administration building

School buildings, Cologne, Germany

(November-December 2015)

NN	School		General information
1	Humboldt-Gymnasium		Year of construction - 1956 Number of schoolchildren - 1200 Structural system – mixed, RC, masonry
2	Alfred-Müller-Armack Berufskolleg		Year of construction - 2007 Number of pupils – 3000 (800) Structural system – masonry shear walls
3	Henry-Ford-Realschule		Year of construction – ca. 1965 Number of schoolchildren - 850 Structural system – mixed, RC, masonry
4	Berufskolleg Ehrenfeld		Year of construction – ca. 1960 Number of schoolchildren - not specified Structural system – mixed, RC, masonry
5	Otto-Lilienthal-Schule		Year of construction - 1969 Number of schoolchildren – not specified Structural system – mixed, RC, masonry
6	Gymnasium Thusnelda-straße		Year of construction - 1960s Number of schoolchildren - 843 Structural system – mixed, RC, masonry
7	Gymnasium Kreuzgasse		Year of construction – not specified Number of schoolchildren - 979 Structural system – mixed, RC, masonry

School buildings, Cologne, Germany

RC frame, masonry in-fill and shear walls

Mixed: RC, masonry

Masonry shear walls

Mixed: RC, masonry

School buildings, Cologne, Germany

Mixed: RC, masonry

Mixed: RC, masonry

RC frame, in-fill walls, shear walls

shear wall, masonry

L'Aquila, Italy

(May-June 2016)

Dynamik
Statik

SIBYL

Knowledge levels and corresponding methods of analysis (EN 1998-3:2005)

	KL1: Limited knowledge	KL2: Normal knowledge	KL3: Full knowledge
Geometry	From original outline construction drawings with sample visual survey or from full survey	From original outline construction drawings with sample visual survey or from full survey	From original outline construction drawings with sample visual survey or from full survey
Details	Simulated design in accordance with relevant practice and from limited in-situ inspection	From incomplete original detailed construction drawings with limited in-situ inspection or from extended in-situ inspection	From original detailed construction drawings with limited in-situ inspection or from comprehensive in-situ inspection
Material	Default values in accordance with standards of the time of construction and from limited in-situ testing	From original design specifications with limited in-situ testing or from extended in-situ testing	From original test reports with limited in-situ testing or from comprehensive in-situ testing
Analysis	Linear analysis methods, either static or dynamic	Linear or nonlinear analysis methods, either static or dynamic	Linear or nonlinear analysis methods, either static or dynamic

Structural survey and data collection

- **design documentation (if available)**
- **simulated design** (site-specific construction technology)
- **limited in-situ inspection**
  - **visual survey**
  - **vibration measurements**
  - **non-destructive in-situ testing**

The information to be collected for the structural modeling includes :

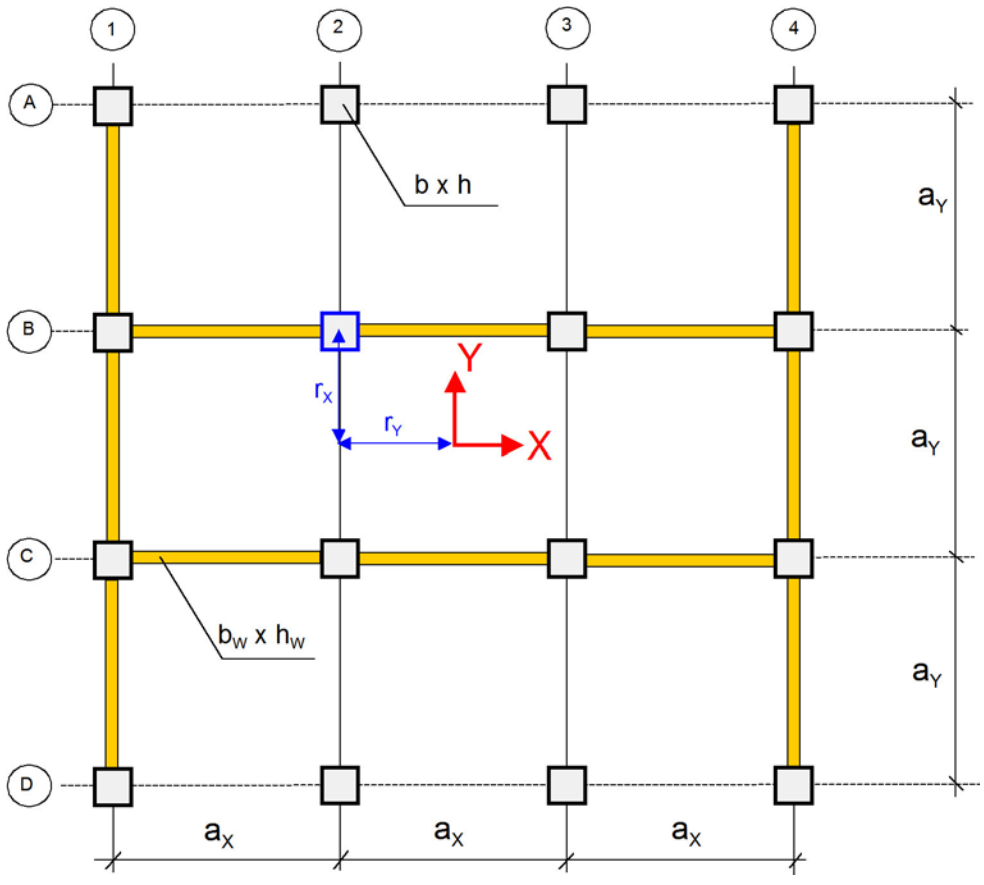
- **current physical condition** of the structural elements and possible presence of damage or degradation;
- **geometry** (including overall structural geometry and member sizes, possible geometrical distortions or deficiencies);
- **structural details** (presence and amount of steel reinforcement in columns, beams and walls and depth of concrete cover);
- **mechanical properties** of construction materials (in particular, concrete strength and elasticity modulus, steel yield strength, ultimate strength and ultimate strain).

Even if the original documentation is available, in-situ inspection, first of all, should check correspondence between the available drawings and the actual state of the existing structure.

Data needed for the modelling and vulnerability assessment

No.	Data type	Ranking
1	Lateral load-resisting system and material of bearing structures	1
2	Overall dimensions and shape of the building	1
3	Presence and location of separation joints	1
4	Presence of irregularities (physical or geometrical / in plan or in elevation)	1
5	Dimensions and location of structural elements (columns, walls, slabs)	1
6	Cross-sections of the structural members and their material properties (strength, elastic moduli, specific density)	1
7	Year of construction (modification)	2
8	Occupancy of the building	2
9	Non-structural elements and other building components, which can contribute to the stiffness and/or mass distribution	2
10	State of the preservation of the building (structural system)	2
11	Depth and type of foundation	2
12	Local soil conditions	2
13	Position of the building with respect to the neighboring buildings	2

Data needed for the modelling and vulnerability assessment



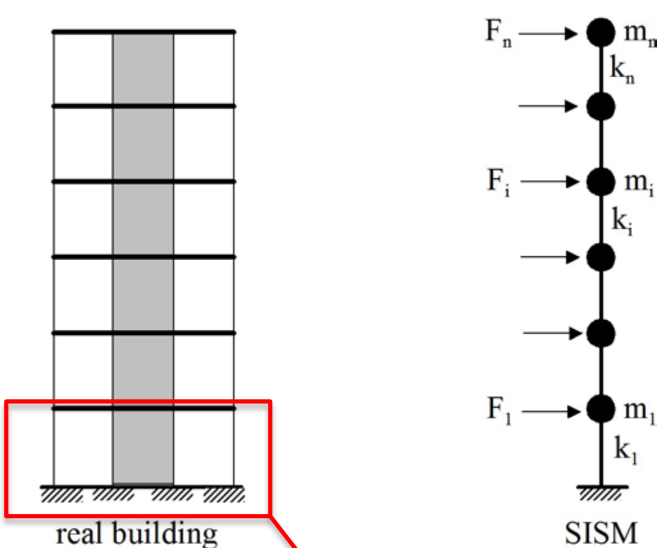
Structural members

- Columns
- Girders
- Walls
- Slabs

with their

- Position
- Dimensions
- Material properties

Simplified integral structural model (SISM)



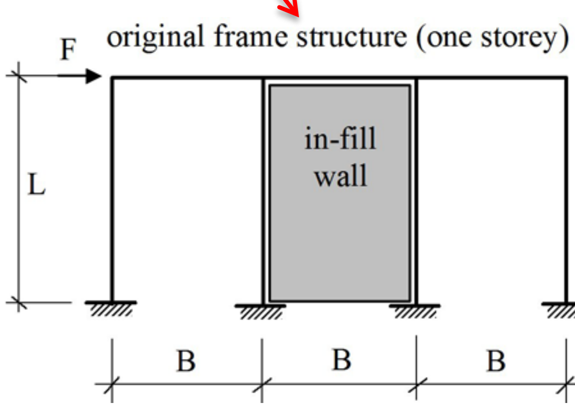
Stiffness matrix $\boldsymbol{K} = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 \\ -k_2 & k_2 + k_3 & -k_3 \\ 0 & -k_3 & k_3 \end{bmatrix}$

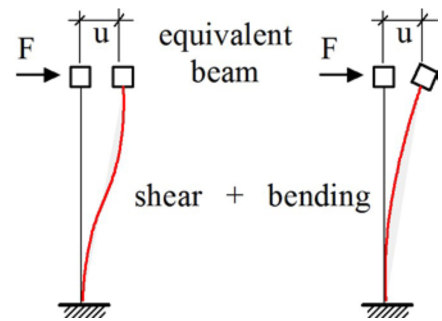
Mass matrix $\boldsymbol{M} = \begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix}$

Modal analysis: $(\boldsymbol{K} - \boldsymbol{\Omega}\boldsymbol{M})\boldsymbol{\Phi} = \boldsymbol{0}$

Comparison: measurements vs. calculation

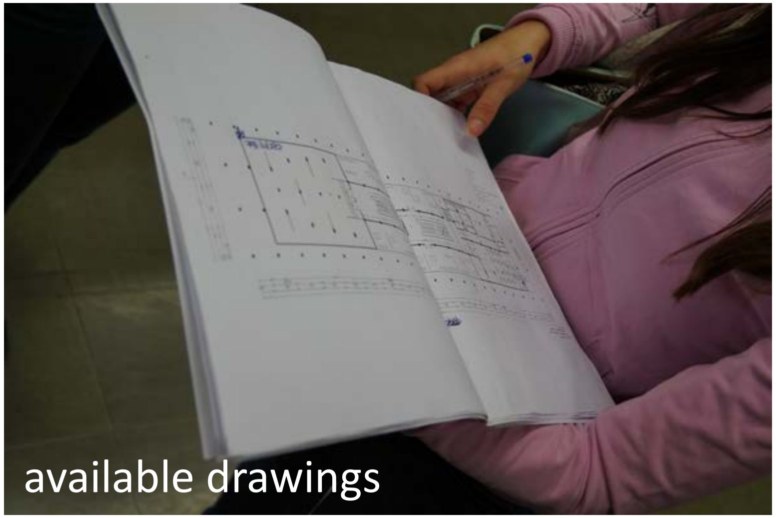
Each story will be replaced by an equivalent beam element with stiffness k_i and mass m_i (both bending and shear deformations are into account)





Dynamik Statik SIBYL

Data collection tools and methods


available drawings

measuring tape

Reinforcement detector


Laser distance meter

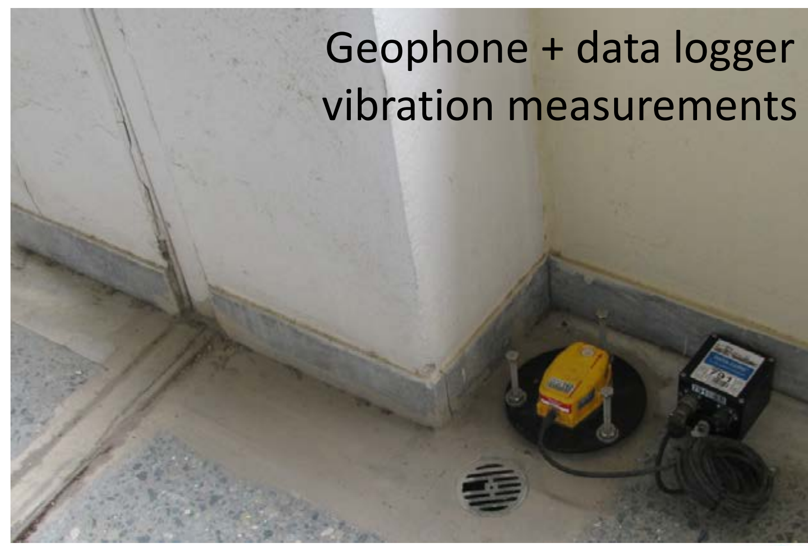
Data collection tools and methods

Distance meter on tripod

NDT tools

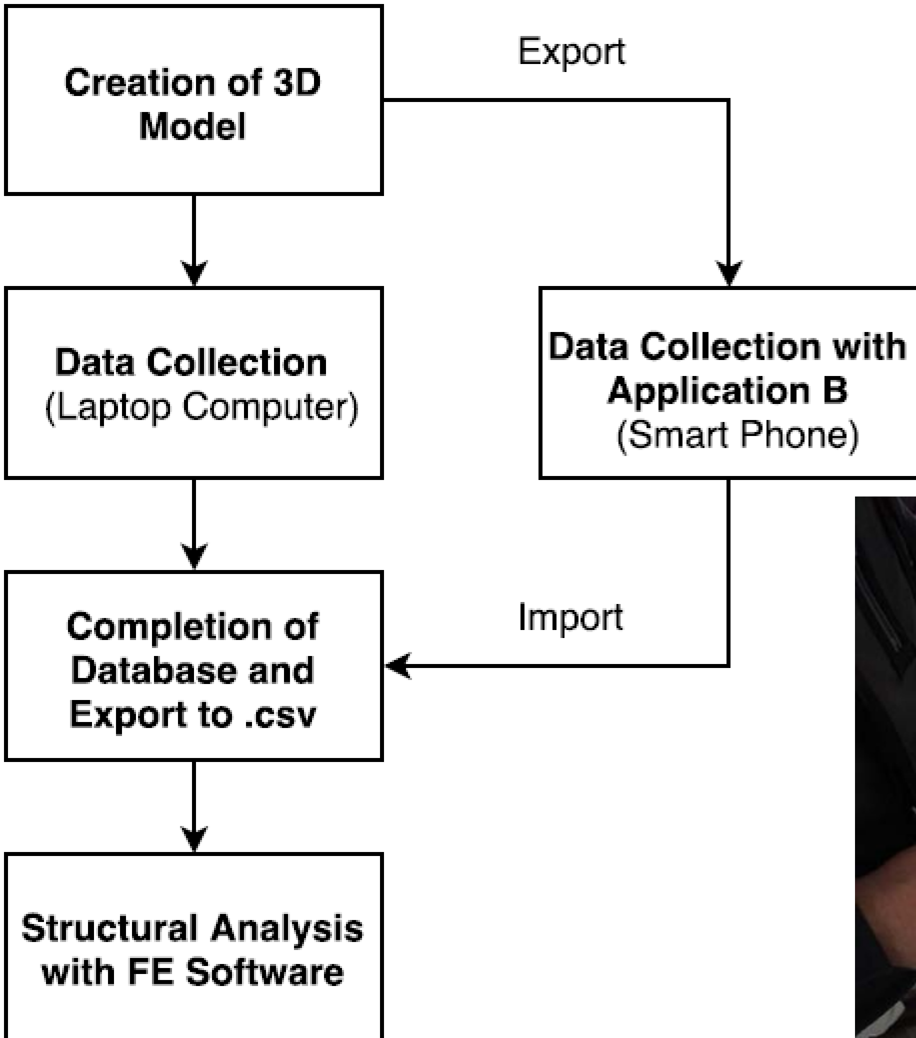
Schmidthammer rebound test

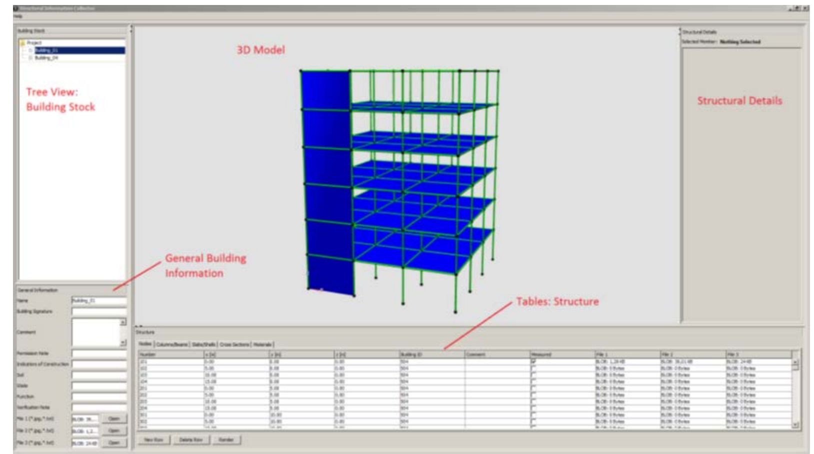
Ferroscan: reinforcement location

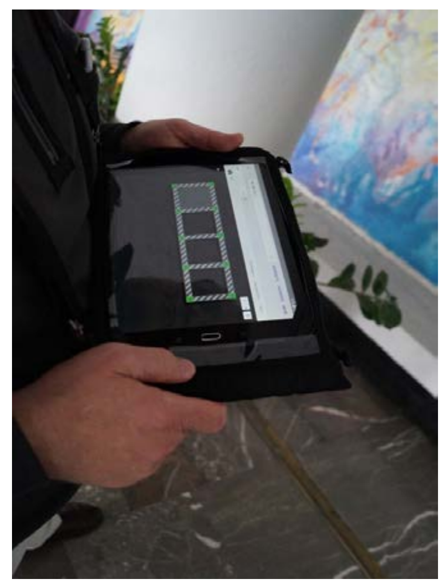


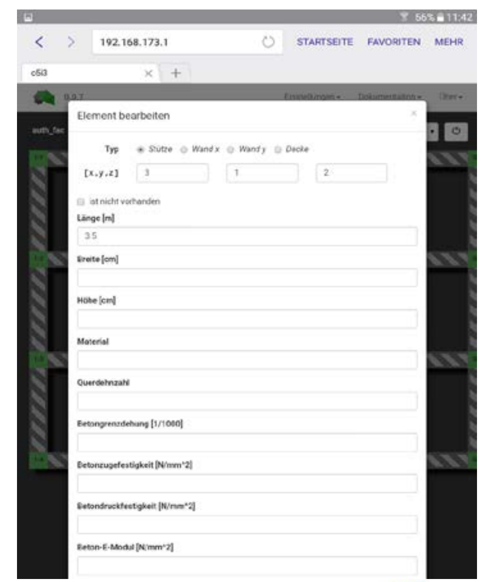
Geophone + data logger vibration measurements

Data collection tools and methods









Data collection tools and methods

Microsoft Excel sheets

	A	B	C	D	E	F	G	H	I	J
1	Building									
2	Nfl	5	Length X	33.6	E-Modul	30000	Poisson's ratio	0.2		
3	H	5.8	Length Y	25.5	Alpha	1				
4	Input									
5	**grid of columns**									
6	Number of Floor	Total number of columns in x-direction	Total number of Columns in y-direction	Center dis-tance in x	Center dis-tance in y	x-width	y-width	Diameter (if round, else 0)	start-coordinate x	start-coordinate y
7										
8										
9	**No uniform grid of colums**									
10	Number of Floor	x-coordinate	y-coordinate	x-width	y-width	diameter (if round)				
11										
12										
13	**Core**									
14	Number of Floor	x-coordinate (center)	y-coordinate (center)	x-width	y-width	wall thickness x	wall thickness y			
15										
16										
17	**Walls**									
18	Number of Floor	coordinate x1	coordinate y1	coordinate x2	coordinate y2	wall thickness				
19										
20										
21	floor	Number of columns	Number of cores	number of shells						
22	1	32	1	0						
23	2									
24	3									
25	4									

Building | 1st Floor | 2nd Floor | 3rd Floor | 4th Floor | 5th Floor

Data collection tools and methods

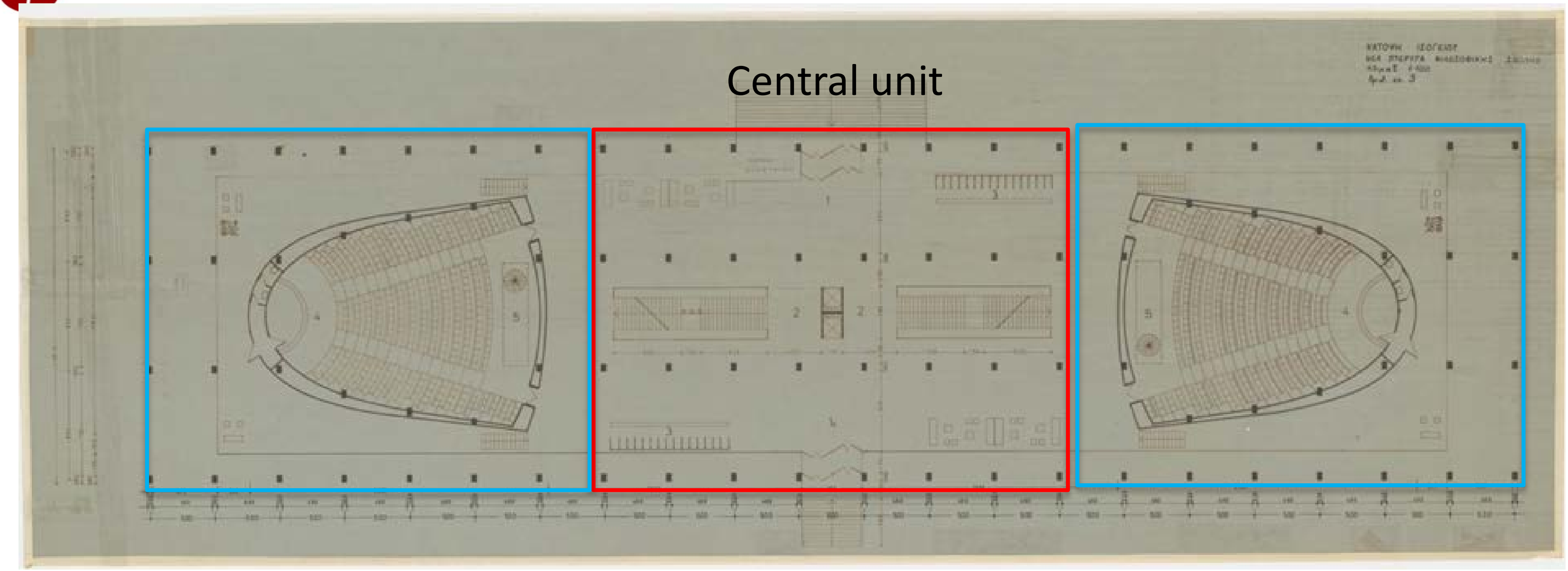
Microsoft Excel sheets: floor information

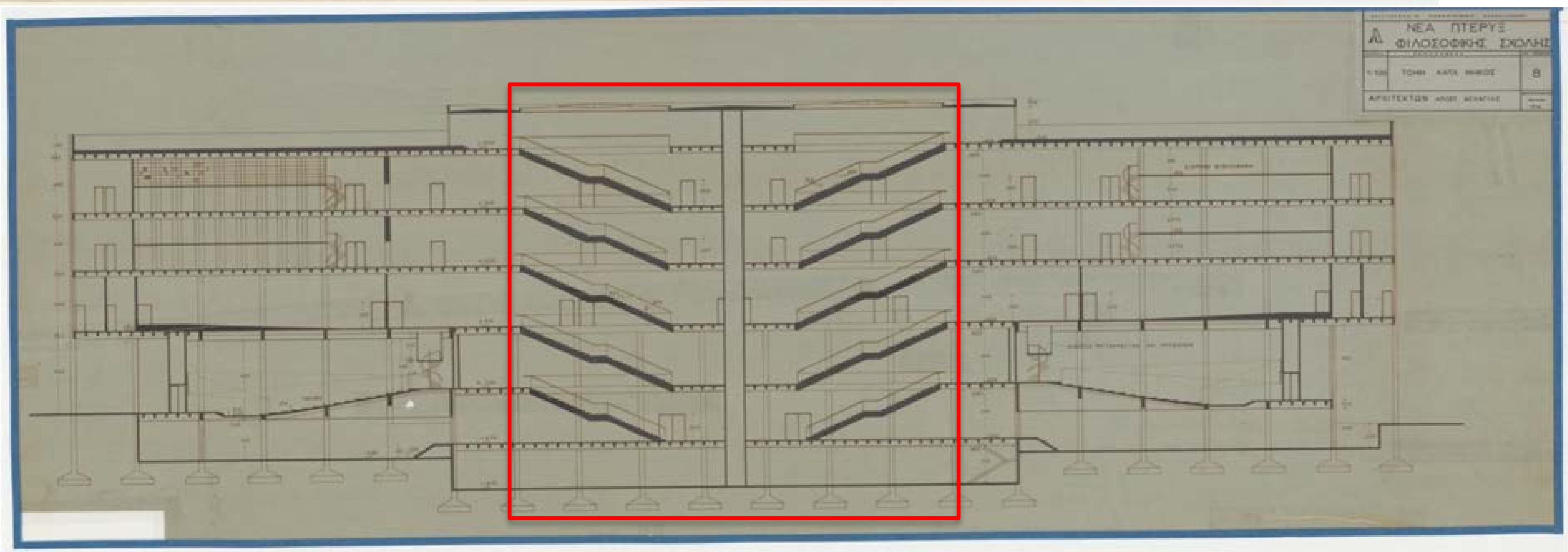
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	1st Floor																
2	Querschnitts fläche gesamt	Ixges	Iyges	Xs	Ys	Xm	Ym	Ixges	Iyges		Delete empty rows		Nco	Nk	Ns		
3	13.08	2.6344	0.8061	16.8	12.75	16.8	12.75	1454.1544	1084.5561				32	1	0		
8	Stützen												Nx	Ny	Bx	By	
9	nco	x	y	bx	by	r	A	Ix	Iy	ex	ey		8	4	4.8	8.5	
10	1	0	0	0.5	0.75	0	0.375	0.01757813	0.0078125	16.8	12.75		kuu	1487.3			
11	2	4.8	0	0.5	0.75	0	0.375	0.01757813	0.0078125	12	12.75		kff	16696			
12	3	9.6	0	0.5	0.75	0	0.375	0.01757813	0.0078125	7.2	12.75		kpp	595862			
13	4	14.4	0	0.5	0.75	0	0.375	0.01757813	0.0078125	2.4	12.75		kuf	4313.3			
14	5	19.2	0	0.5	0.75	0	0.375	0.01757813	0.0078125	2.4	12.75		kfp	3418			
15	6	24	0	0.5	0.75	0	0.375	0.01757813	0.0078125	7.2	12.75						
16	7	28.8	0	0.5	0.75	0	0.375	0.01757813	0.0078125	12	12.75		1487.3	4313.3	0	1	0.00269
17	8	33.6	0	0.5	0.75	0	0.375	0.01757813	0.0078125	16.8	12.75		4313.3	16696	3418	0	-0.0007
18	9	0	8.5	0.5	0.75	0	0.375	0.01757813	0.0078125	16.8	4.25		0	3418	595862	0	4E-06
19	10	4.8	8.5	0.5	0.75	0	0.375	0.01757813	0.0078125	12	4.25						
20	11	9.6	8.5	0.5	0.75	0	0.375	0.01757813	0.0078125	7.2	4.25		371.74	Stiffness x-direction			
21	12	14.4	8.5	0.5	0.75	0	0.375	0.01757813	0.0078125	2.4	4.25						
22	13	19.2	8.5	0.5	0.75	0	0.375	0.01757813	0.0078125	2.4	4.25		kuu	4860.7			
23	14	24	8.5	0.5	0.75	0	0.375	0.01757813	0.0078125	7.2	4.25		kff	45988			
24	15	28.8	8.5	0.5	0.75	0	0.375	0.01757813	0.0078125	12	4.25		kpp	527586			
25	16	33.6	8.5	0.5	0.75	0	0.375	0.01757813	0.0078125	16.8	4.25		kuf	14096			
26	17	0	17	0.5	0.75	0	0.375	0.01757813	0.0078125	16.8	4.25		kfp	2102.1			
27	18	4.8	17	0.5	0.75	0	0.375	0.01757813	0.0078125	12	4.25						
28	19	9.6	17	0.5	0.75	0	0.375	0.01757813	0.0078125	7.2	4.25		4860.7	14096	0	1	0.00185
29	20	14.4	17	0.5	0.75	0	0.375	0.01757813	0.0078125	2.4	4.25		14096	45988	2102.1	0	-0.0006
30	21	19.2	17	0.5	0.75	0	0.375	0.01757813	0.0078125	2.4	4.25		0	2102.1	527586	0	2.3E-06
31	22	24	17	0.5	0.75	0	0.375	0.01757813	0.0078125	7.2	4.25						
32	23	28.8	17	0.5	0.75	0	0.375	0.01757813	0.0078125	12	4.25		539.26	Stiffness y-direction			
33	24	33.6	17	0.5	0.75	0	0.375	0.01757813	0.0078125	16.8	4.25						
34	25	0	25.5	0.5	0.75	0	0.375	0.01757813	0.0078125	16.8	12.75						
35	26	4.8	25.5	0.5	0.75	0	0.375	0.01757813	0.0078125	12	12.75						
36	27	9.6	25.5	0.5	0.75	0	0.375	0.01757813	0.0078125	7.2	12.75						

Building | 1st Floor | 2nd Floor | 3rd Floor | 4th Floor | 5th Floor

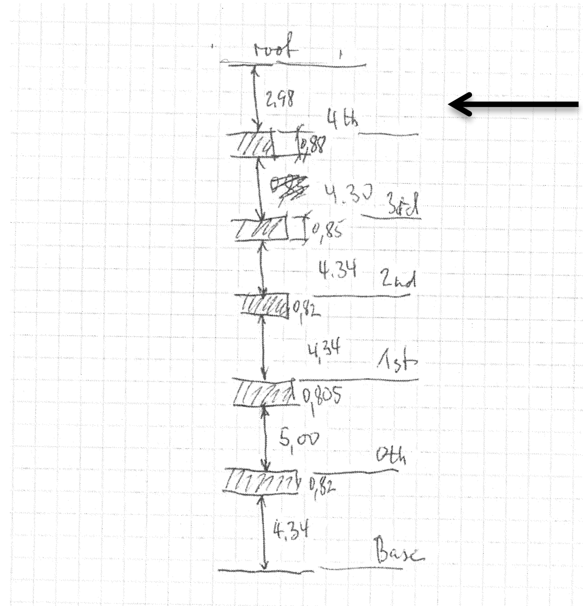
Case study: The building of the Faculty of Philosophy, AUTH

Original design drawings



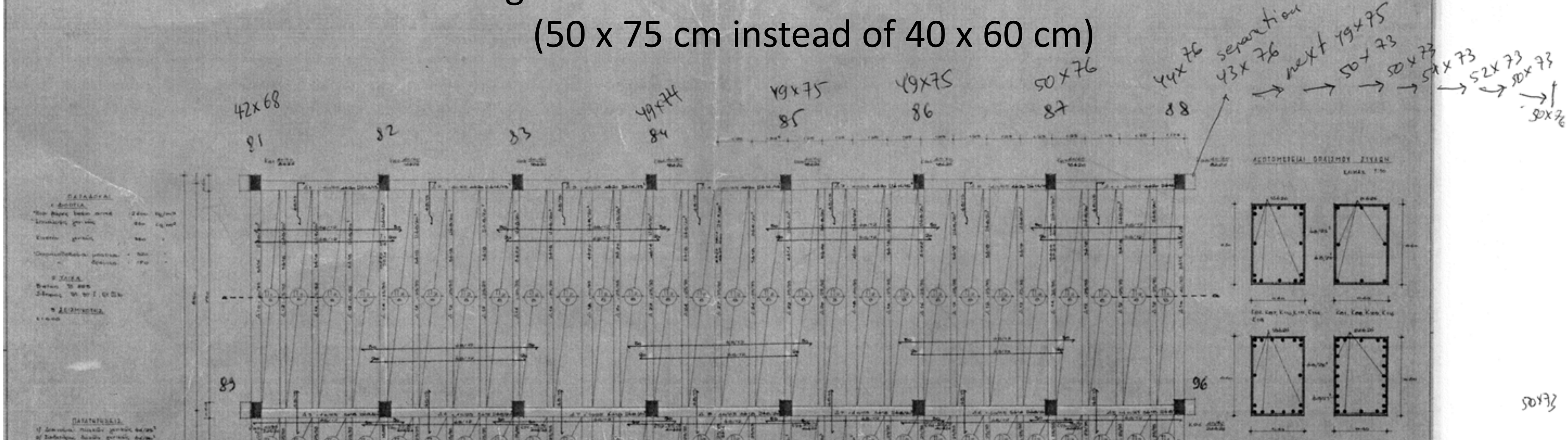


In-situ structural survey and data collection



One additional floor detected

Considerable changes in cross-sectional dimensions of structural elements (50 x 75 cm instead of 40 x 60 cm)

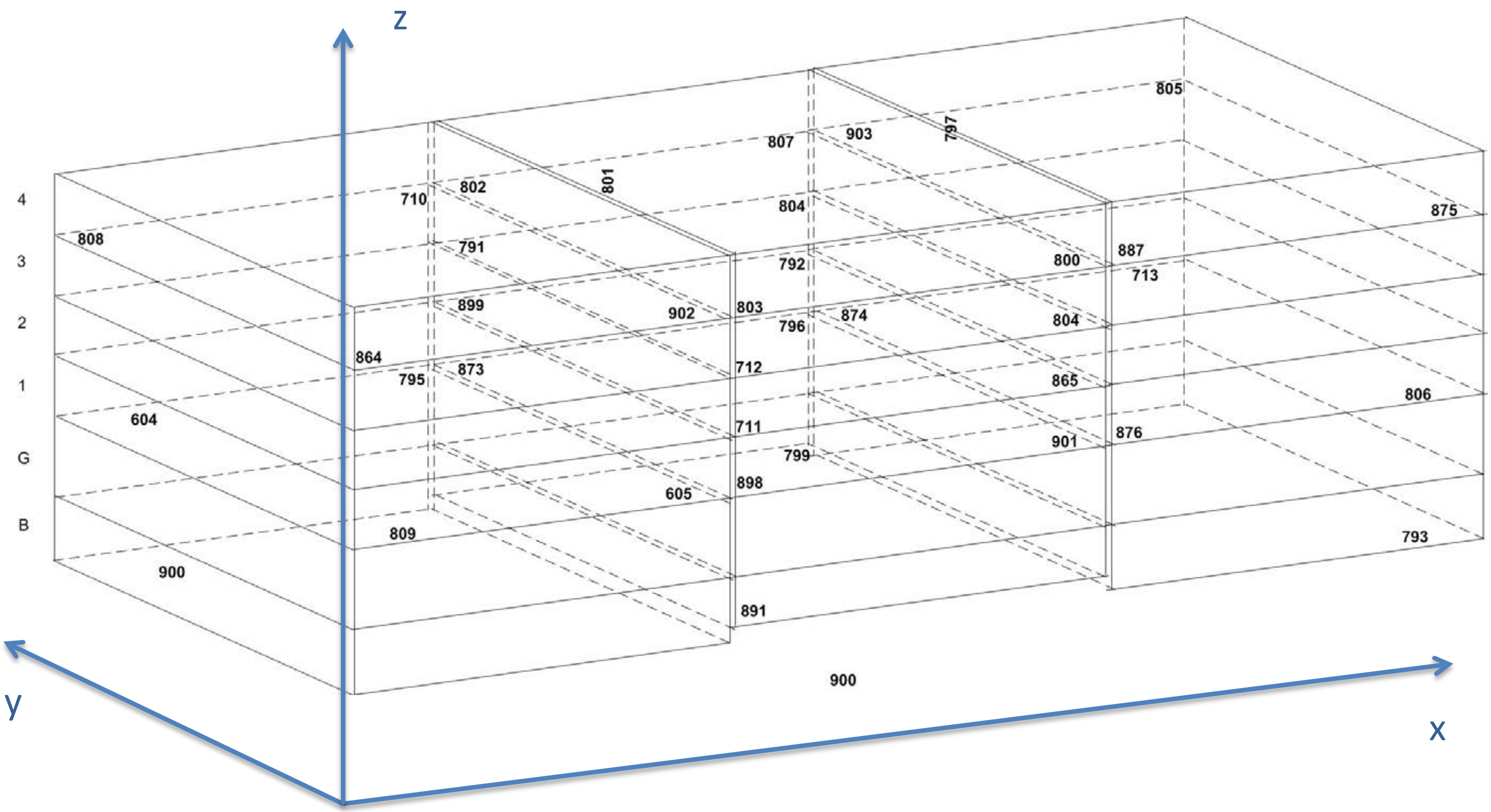


Ambient vibration measurements, system identification and modal analysis for the building of the Faculty of Philosophy

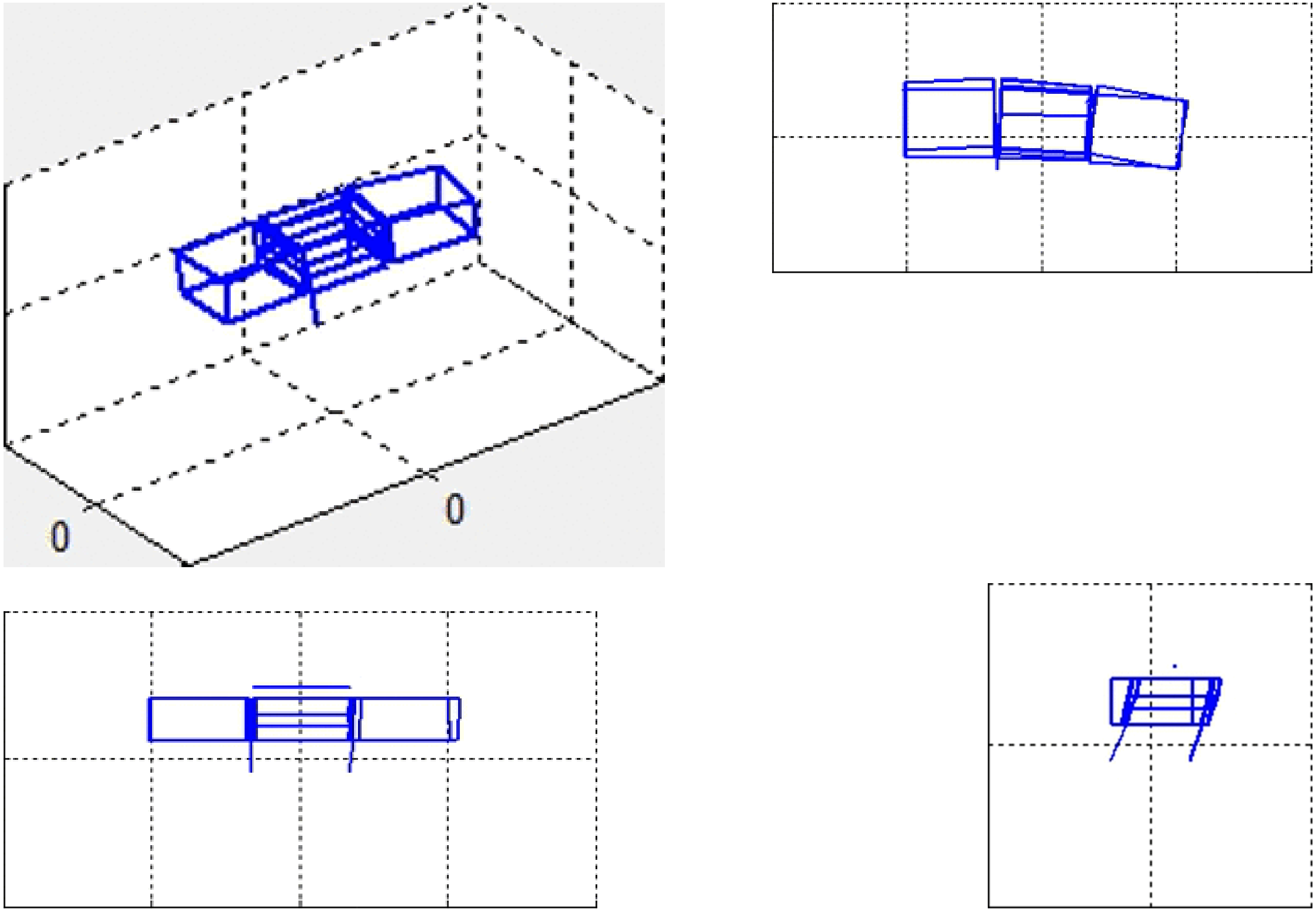
Ambient vibrations are recorded using seismic stations, each of them composed by a 24 bit DSS-CUBE3 digitizer connected to a 4.5Hz three-component geophone. The sampling rate is set to 400 Hz and the timing is provided by a build-in GPS.
The identification of the eigenfrequencies and mode shapes is performed by use of the MACEC software on the base of time intervals of 180 s duration.

Spatial arrangement of the sensors

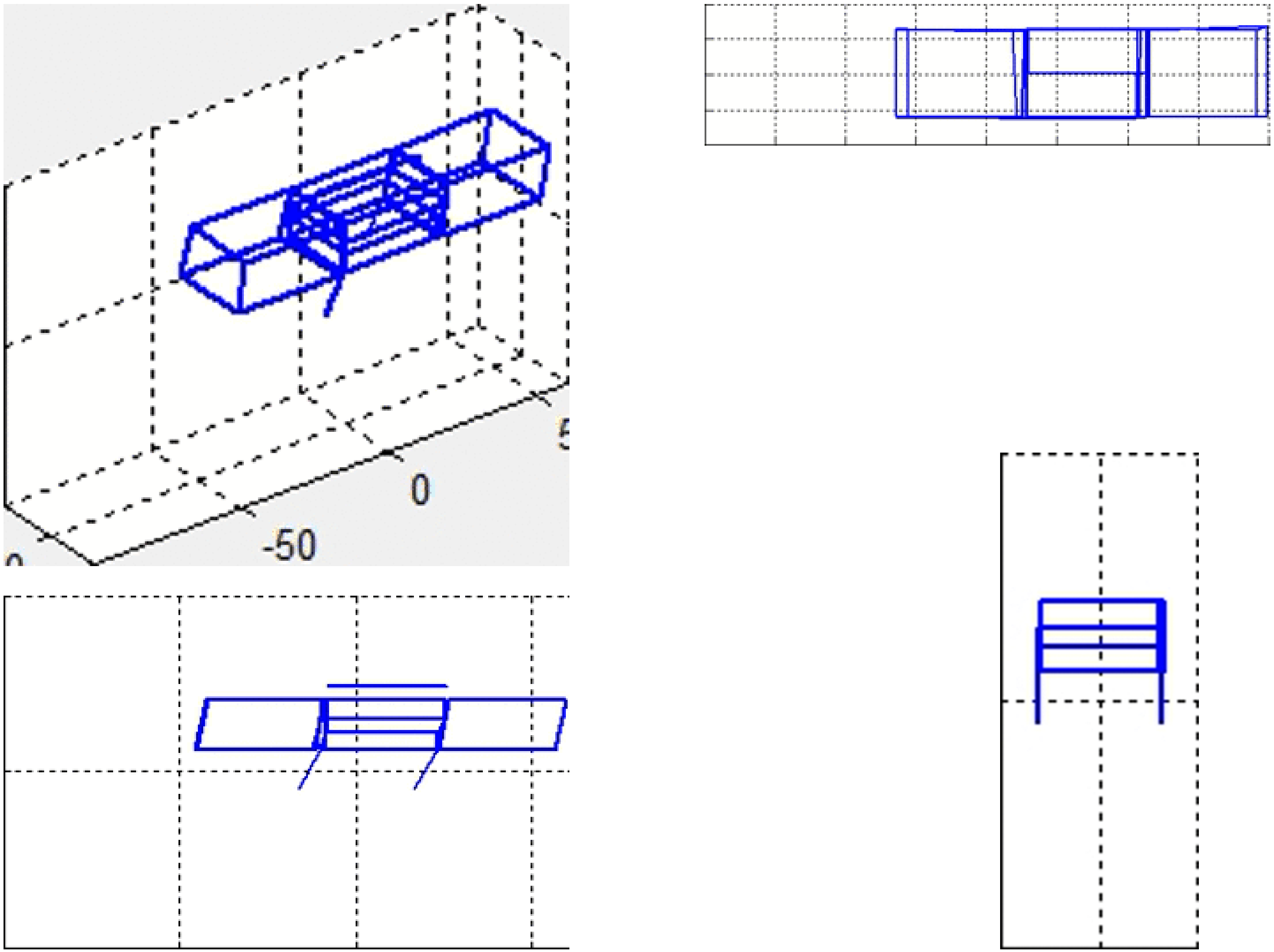
Minimum set: 1 on the ground, 2 on the roof/top



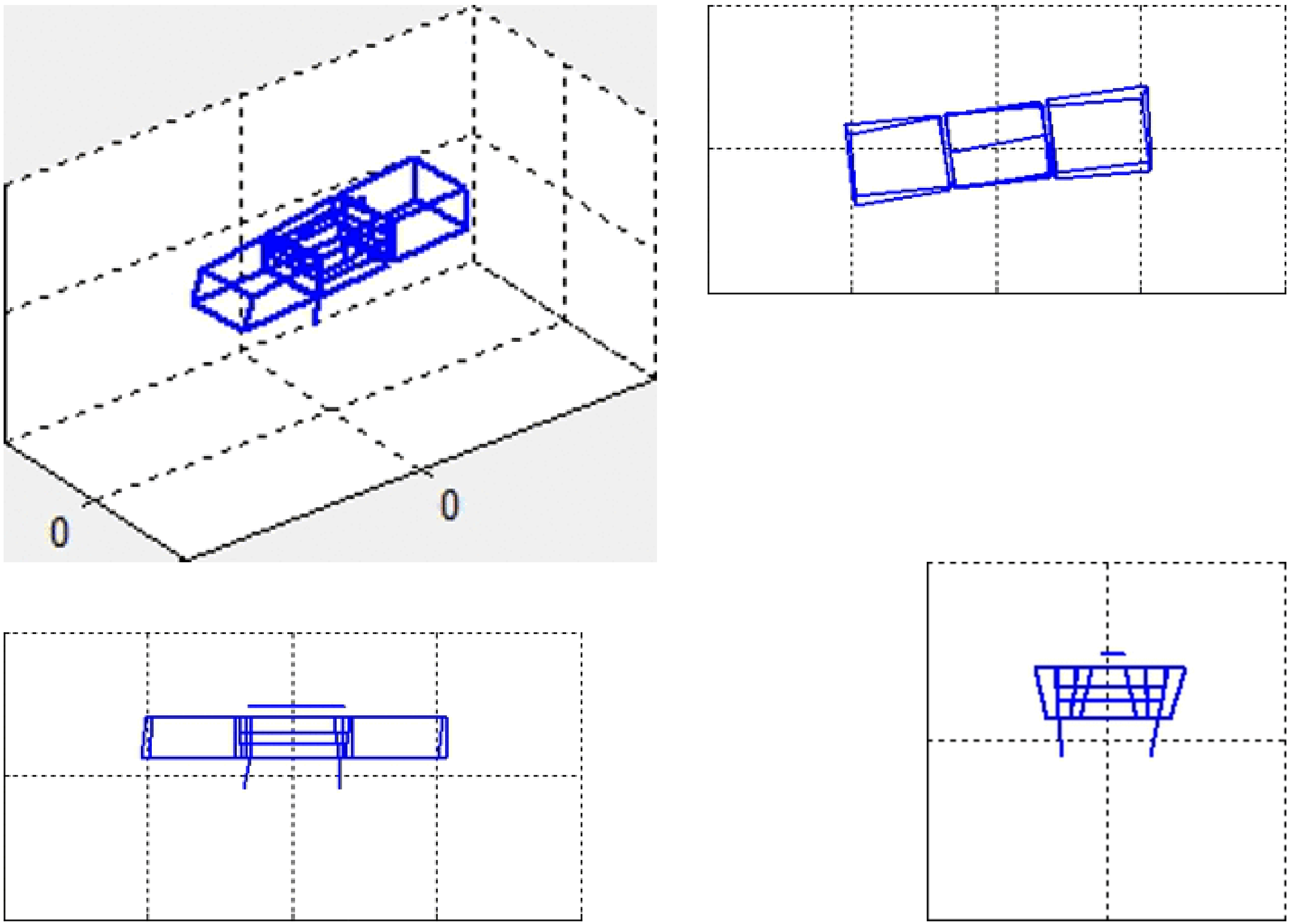
1st mode (f=1.60 Hz)



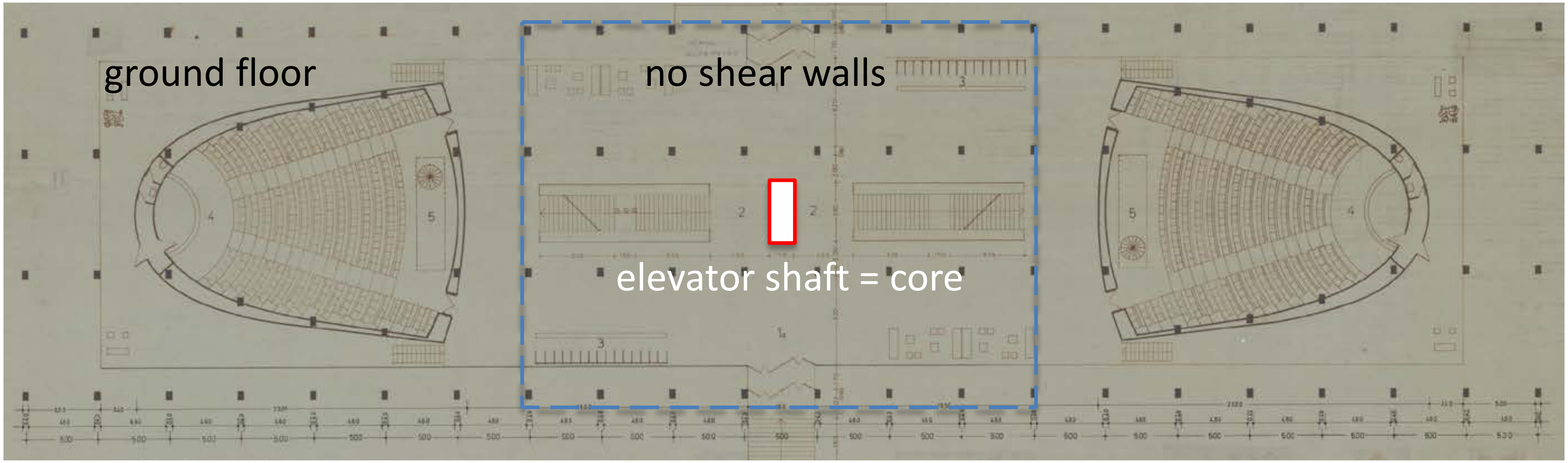
2nd mode (f=1.72 Hz)

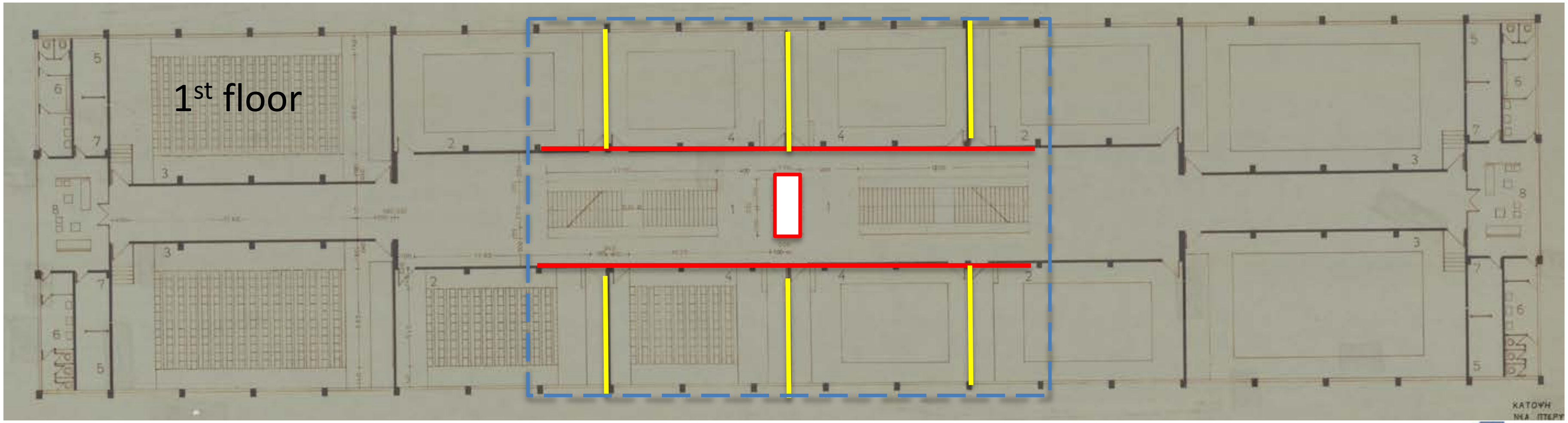


3rd mode (f=1.76)

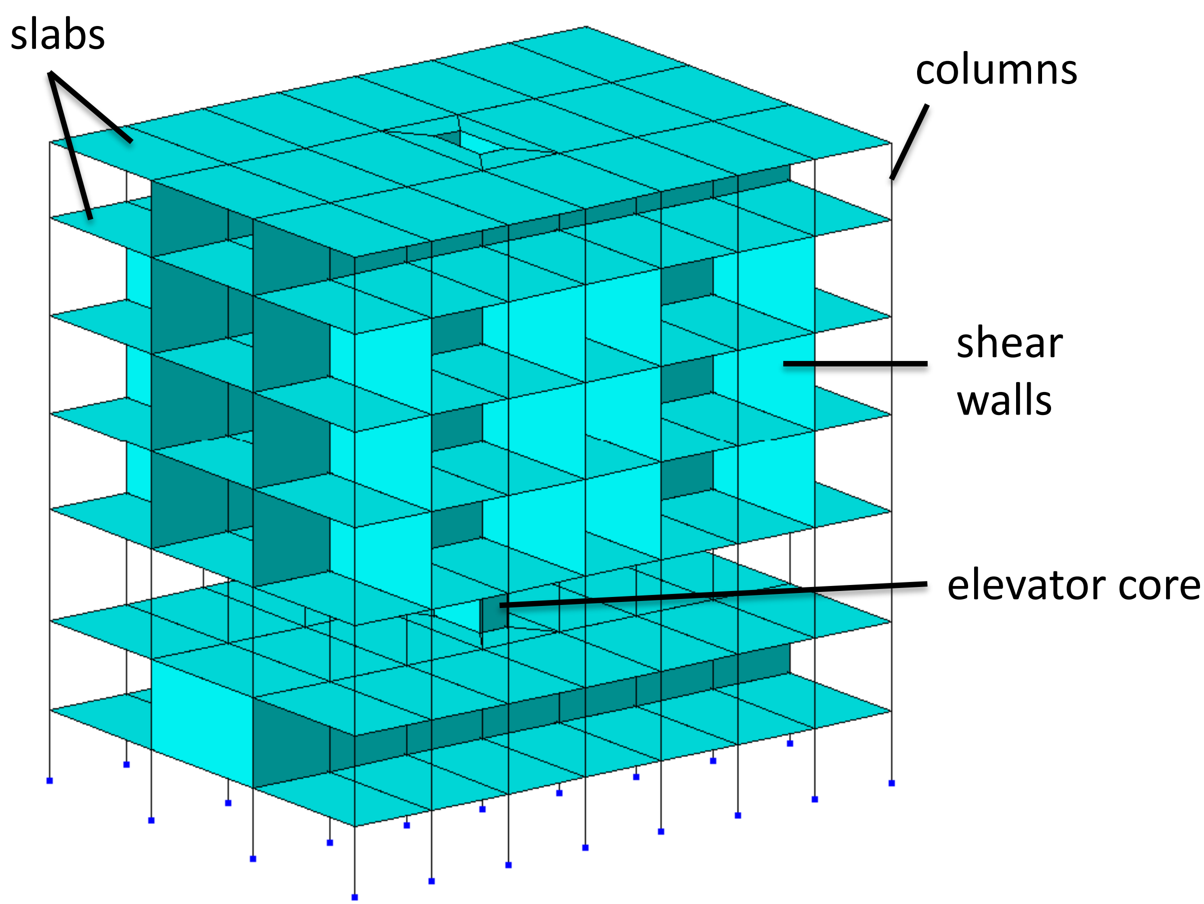


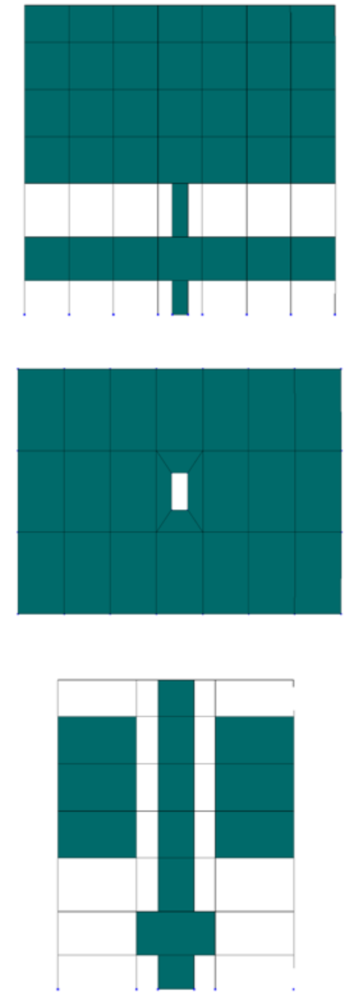
Relevant structural members





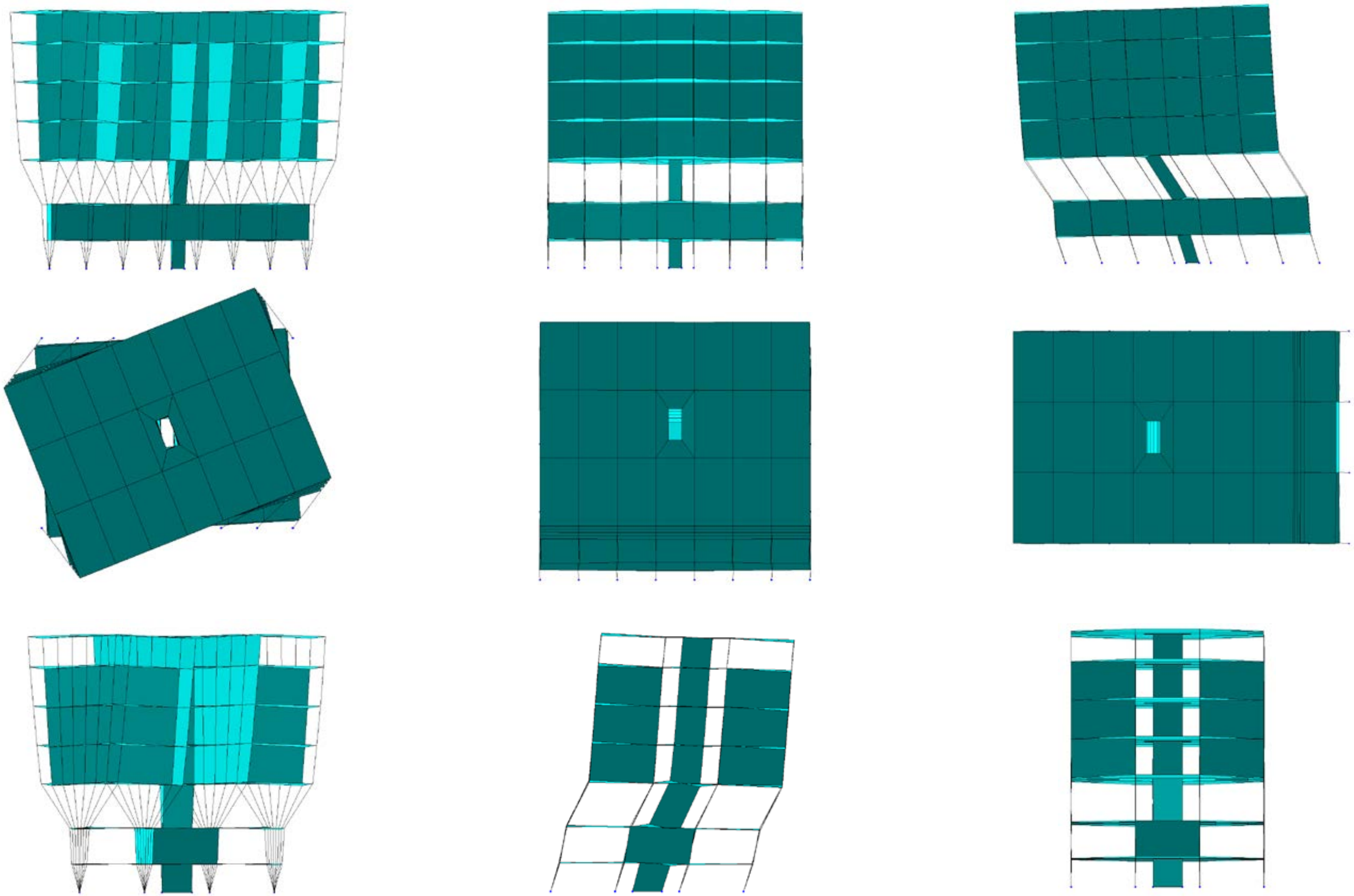
Simplified FEM Modelling
for demonstration of structural behavior





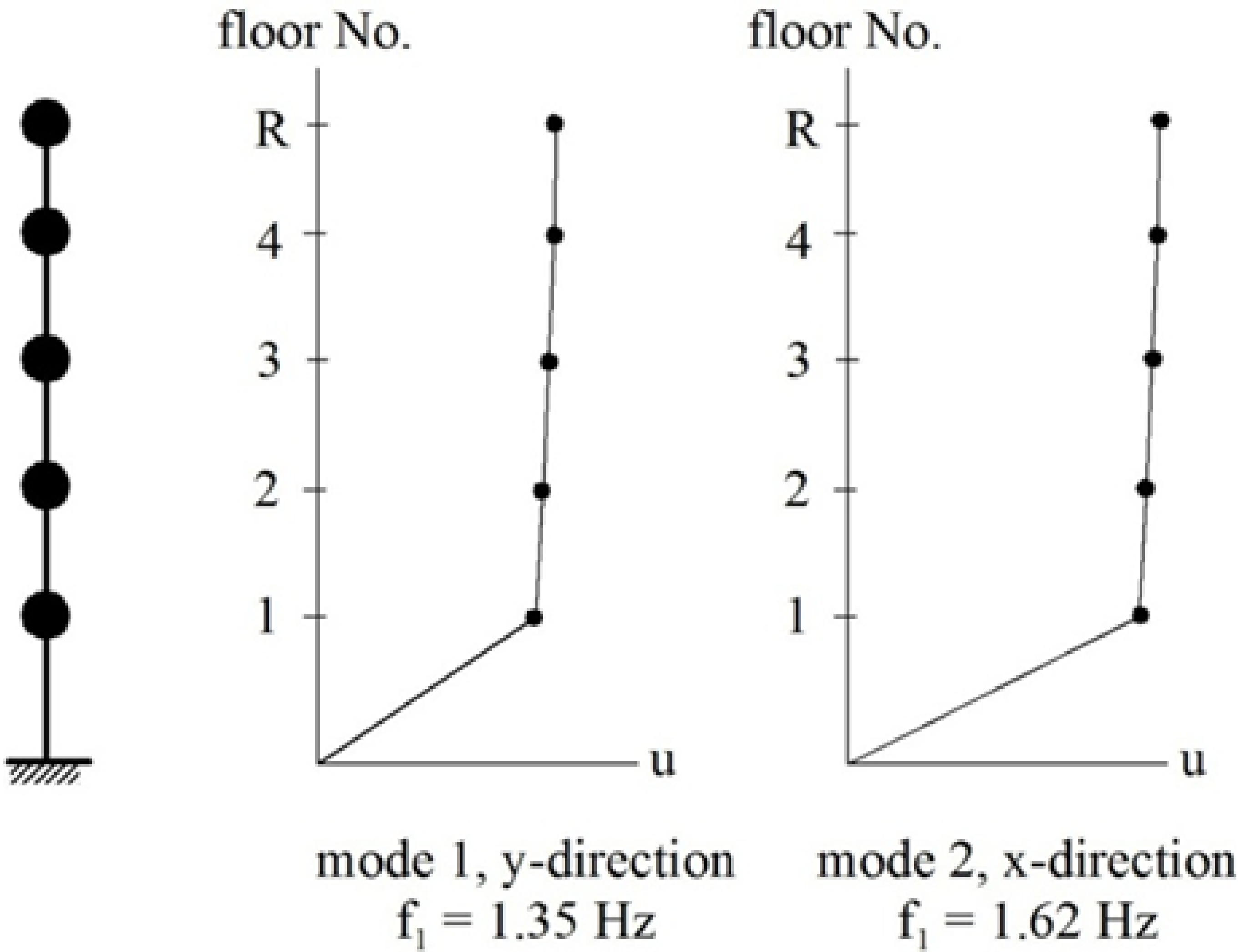
Only essential structural members are included

Mode shapes (comparison with OMA)



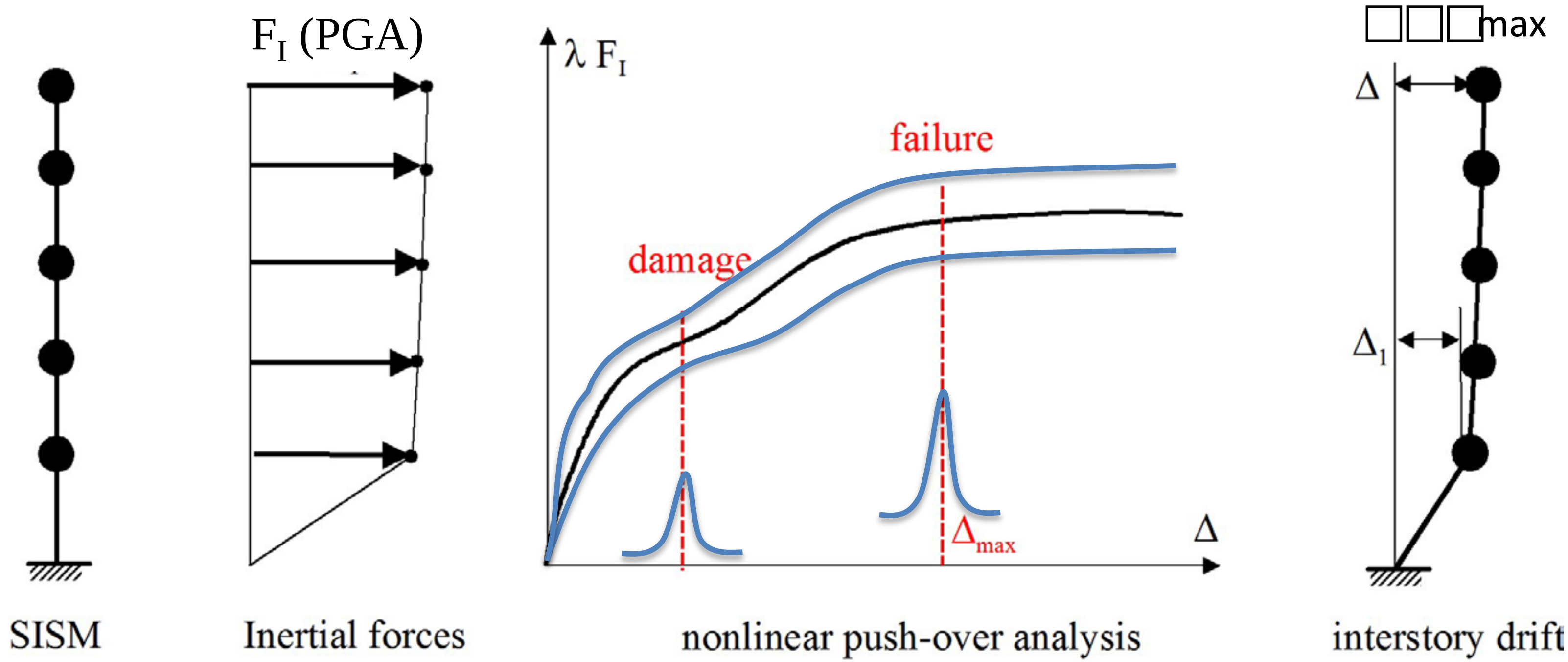
f=1.37 Hz	f=1.83 Hz	f=1.94 Hz
f=1.76 Hz	f=1.60 Hz	f=1.72 Hz

Model validation by use of vibration measurements



measured f = 1.60 Hz f = 1.72 Hz

Nonlinear push-over analysis and damage states

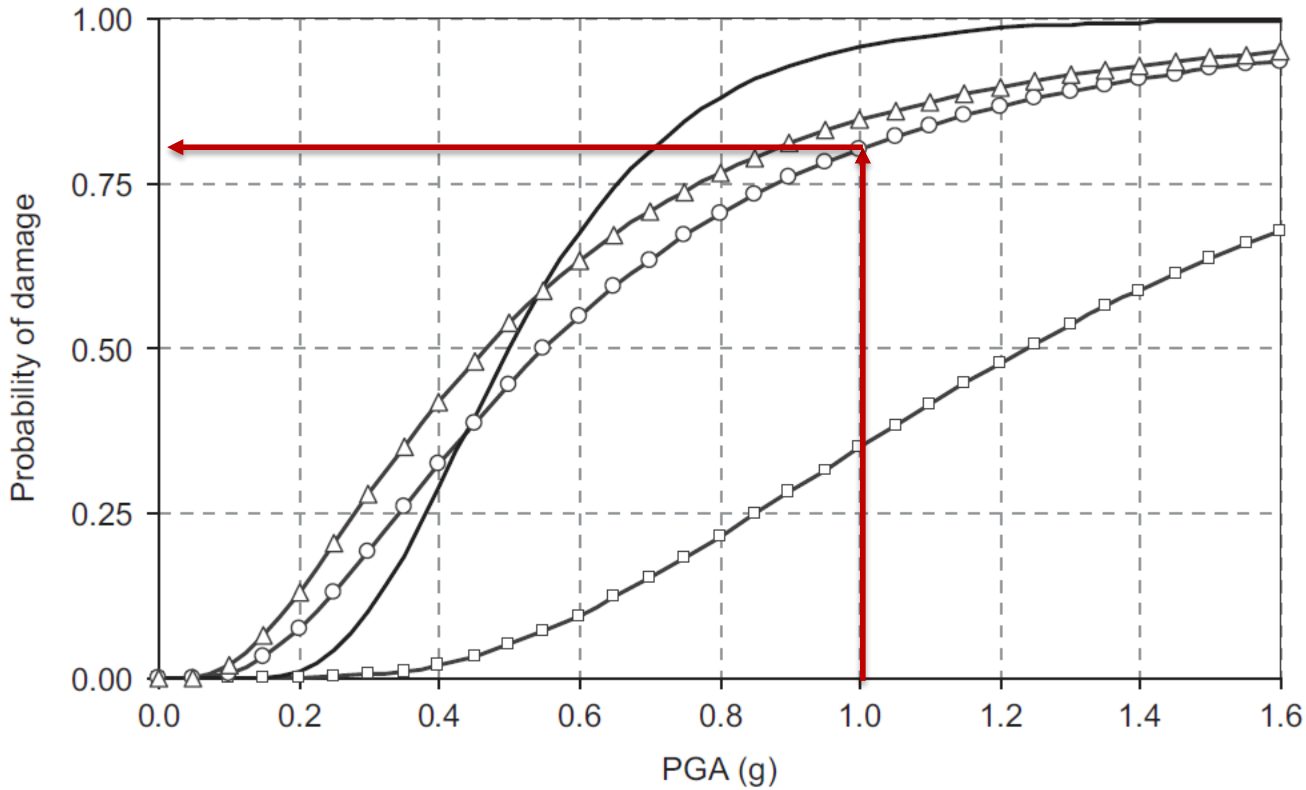


TUB **GFZ** **TUB** **AUTH**

The variation of structural properties according in the framework of Monte-Carlo simulation provides a statistical scatter of interstory drift, which is necessary to calculate

→ Fragility curves

Fragility curves



http://www.sibyl-project.eu/

Thanks for your attention