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Seismic vulnerability of existing schools

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Acknowledgments

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- Authors would like to thank the **BIMgroup LAB of Politecnico di Milano** and the **Municipality of Melzo** for sharing the BIM model used in this research.

Motivations and Objectives

European Research Council
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- Most of the schools in Italy were built **before the introduction of structural design standard for seismic areas**

- Approximately **25,000 buildings are therefore not adequate** to current standards

- This research aims to implement a methodology to evaluate **vulnerability index** of existing buildings

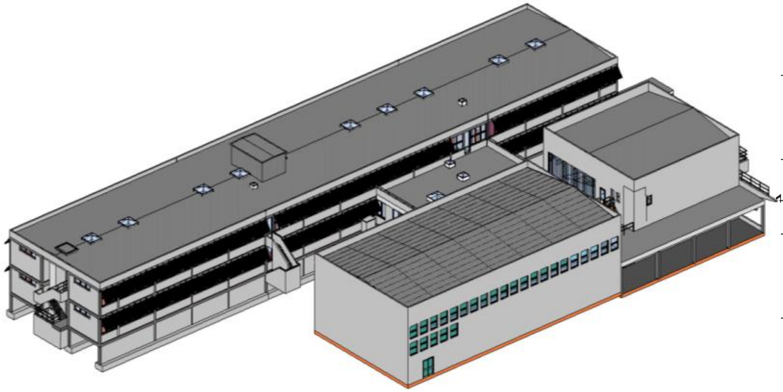
Introduction

❑ The "**Mascagni School**" is a **RC building** located in Melzo (MI) built in **1976**. The school consists of **three separated structures** (classes, gym and canteen)

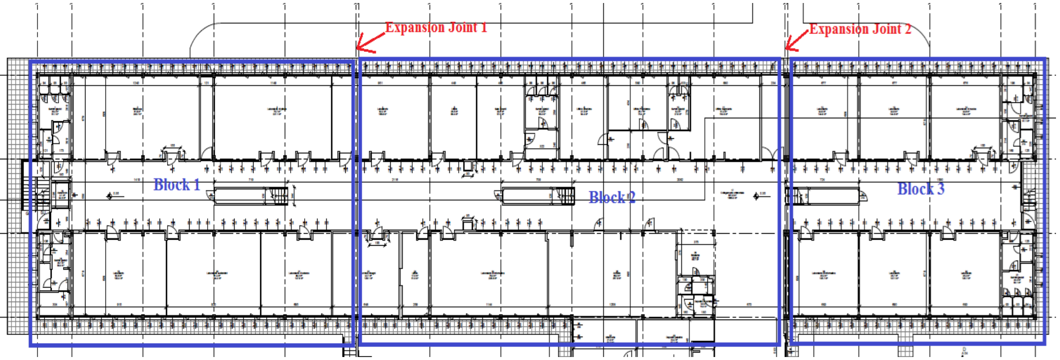
Buildings overall view

Classrooms

Gym

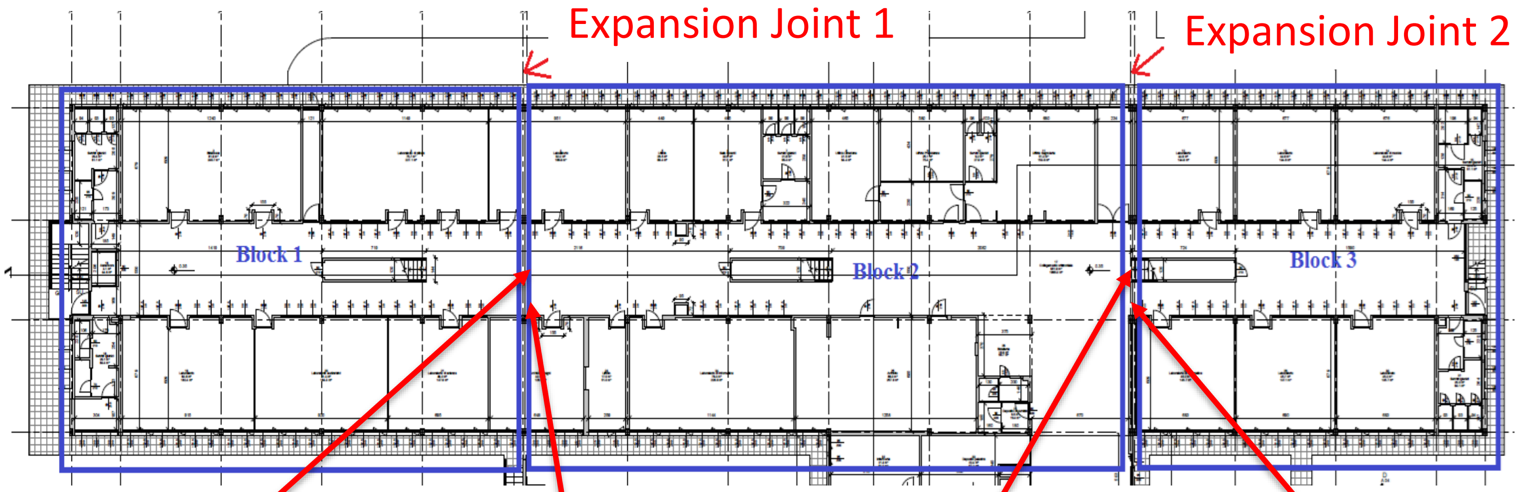


BIM model



Plan view

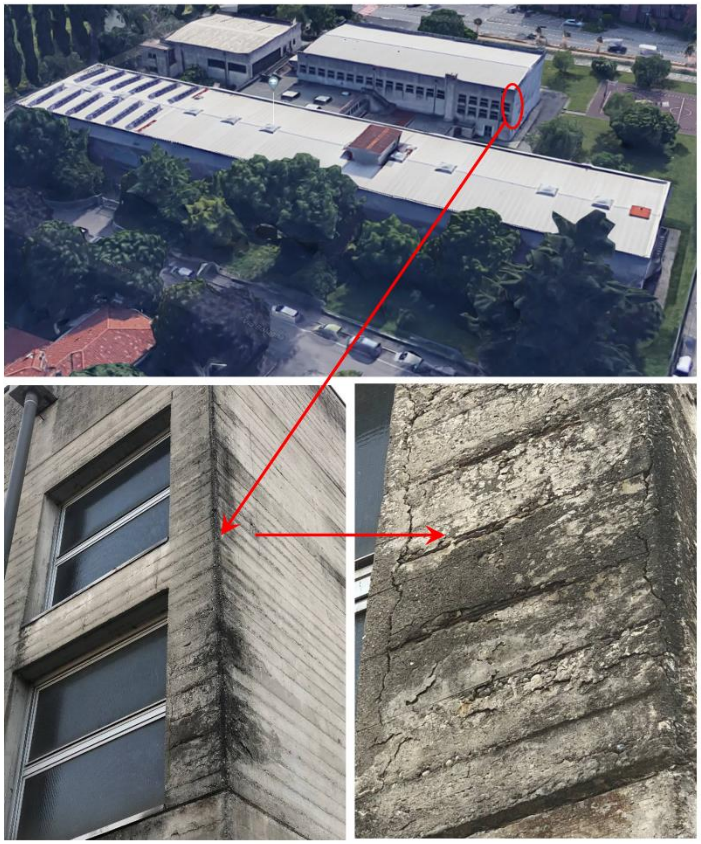
Visual inspection



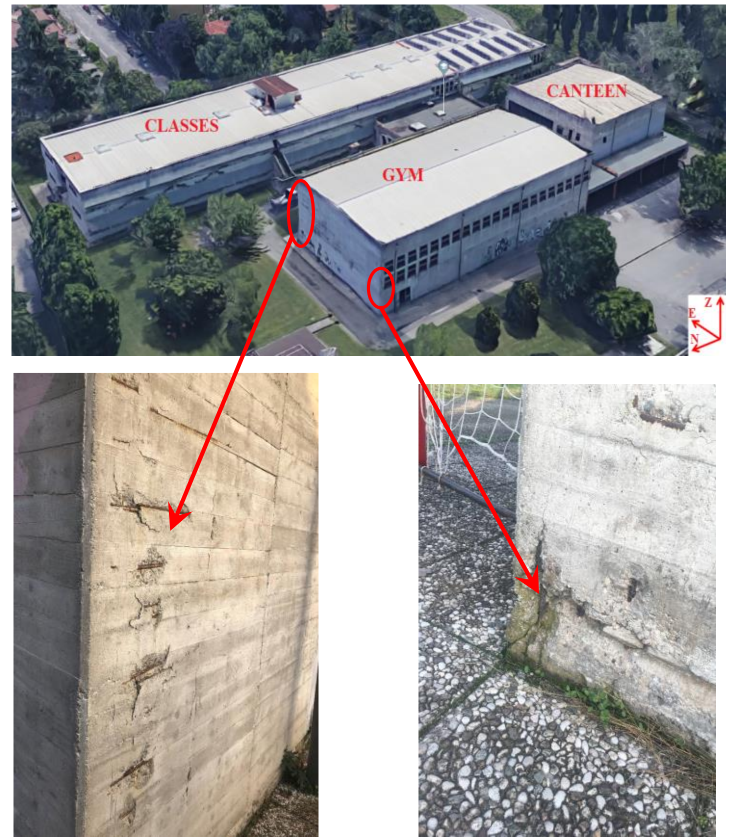



Joints visual inspection in the school basement

Visual inspection



Superficial concrete deterioration

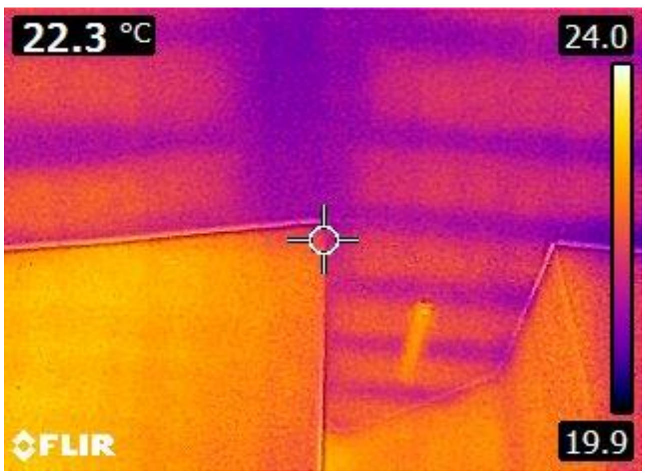


Reinforcement corrosion and concrete crack

Non destructive test

❑Test with Thermal camera

The concrete elements (blue areas) have a lower temperature with respect to the masonry elements, lighting systems and aluminum ventilation elements (orange and yellow areas).

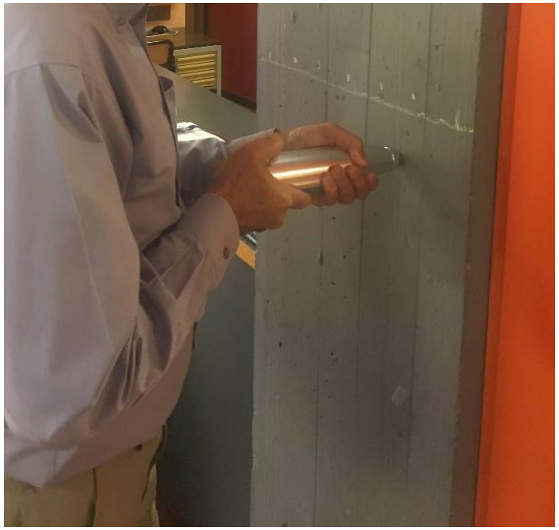


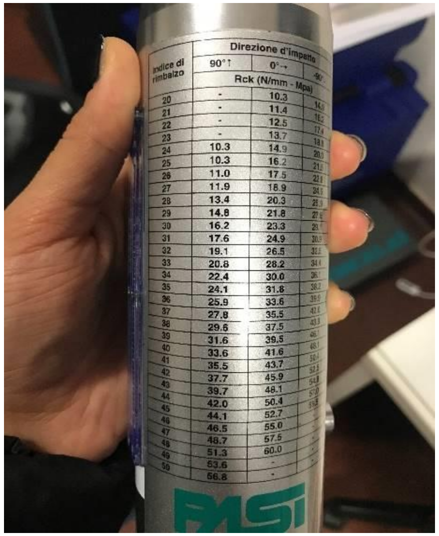
Constructional elements identification using thermal camera

Non destructive test

❑Sclerometric Test

The results show that the average resistance of the columns is equal to 31,5 MPa: To create a FE models, the concrete class C25/30 was used neglecting the deterioration of the concrete.





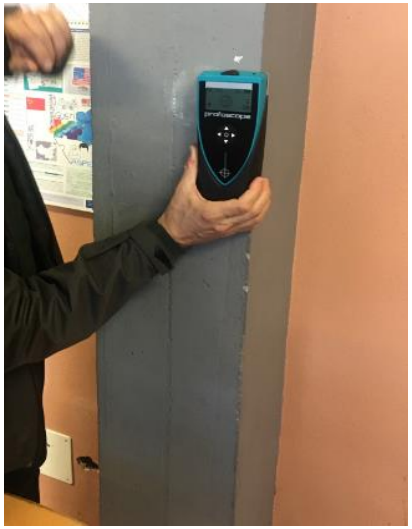
Rebounded value	R_{ck} [N/mm^2] 0° →	
31	24.9	TOP
30	23.3	
35	31.8	
33	28.2	
37	35.5	MIDDLE
34	30.0	
35	31.8	
34	30.0	
35	31.8	BOTTOM
37	35.5	
38	37.5	
36	33.6	

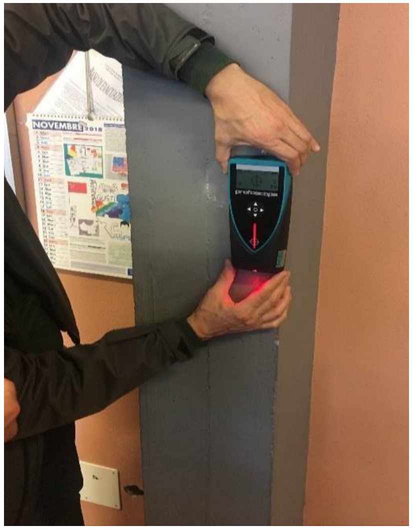
Data acquisition with sclerometer, instrument conversion table, sample of obtained values

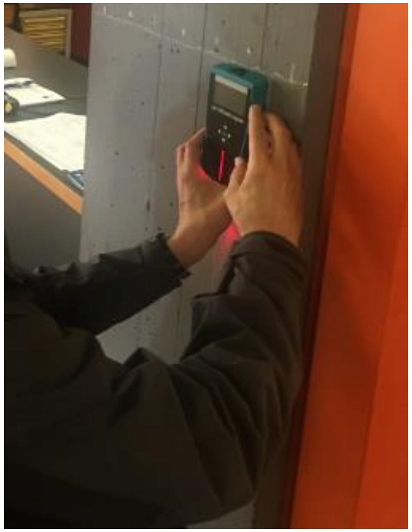
Non destructive test

❑Test with pacometer

Pacometer was used to get information about the reinforcement inside the columns, such as location, cover and size of steel reinforcement bars.







Measurements with pachometer

	Number of longitudinal bars (long side)	Number of longitudinal bars (short side)	Diameter of longitudinal bars [mm]	Inter axis [mm]	Cover [cm]	Stirrups diameter [mm]	Stirrups spacing [cm]
Column 25x50 cm	7	3	18	6	4	10	15
Column 30x50 cm	7	3	18	6	4	10	15
Beam 70x28 cm	8	-	20	8	3	10	16

Columns and beam reinforcement detail resulted from pachometer test

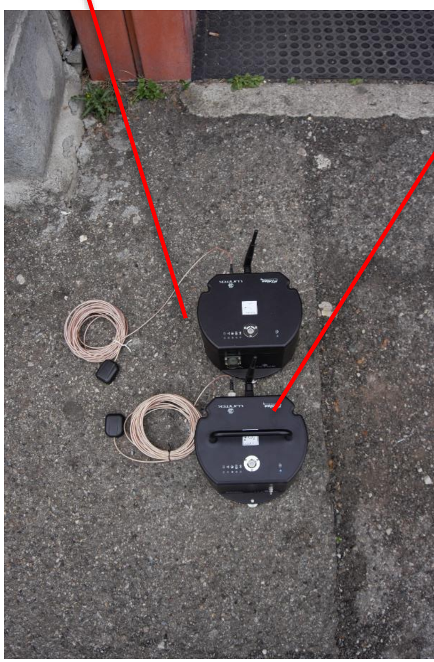
Dynamic monitoring

A campaign of experimental investigations was conducted to identify the dynamic behavior of the main building

→ Ambient vibration tests

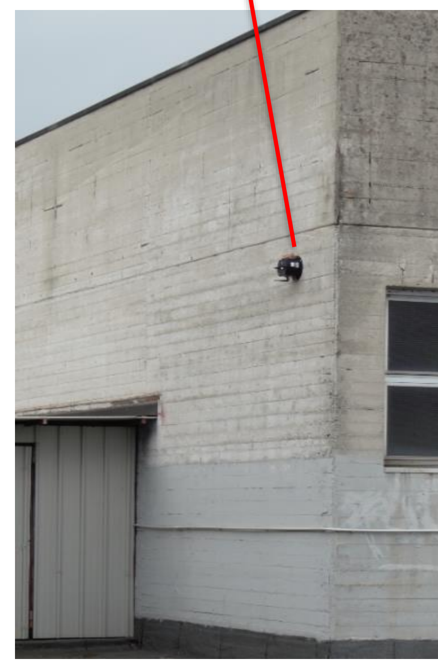
→ Forced vibration tests

Force balance accelerometer MEMS Accelerometer



Vibrodyne

Accelerometer positioning



Identification Algorithms

- Two **output-only identification methods** are used to identify the structure frequencies for the **ambient vibration test**:

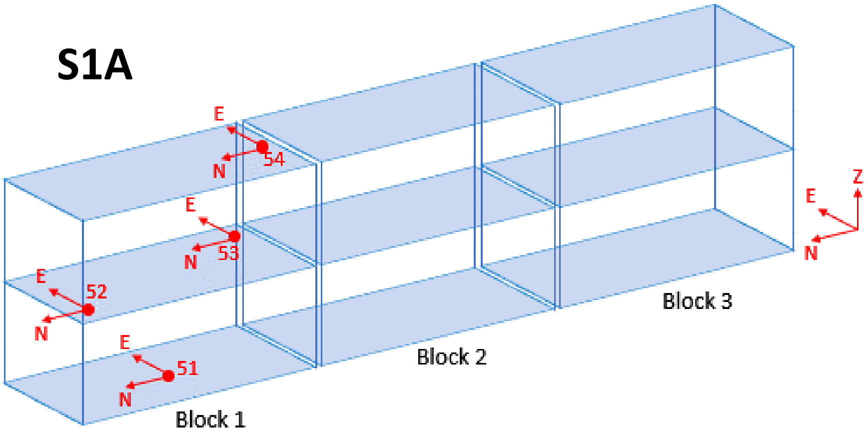
  - **Frequency Domain Decomposition (FDD)**
  - **Random Decrement Technique (RDT)**

- **Frequency Response Function (FRF) method** is used to process **Vibrodyne tests**

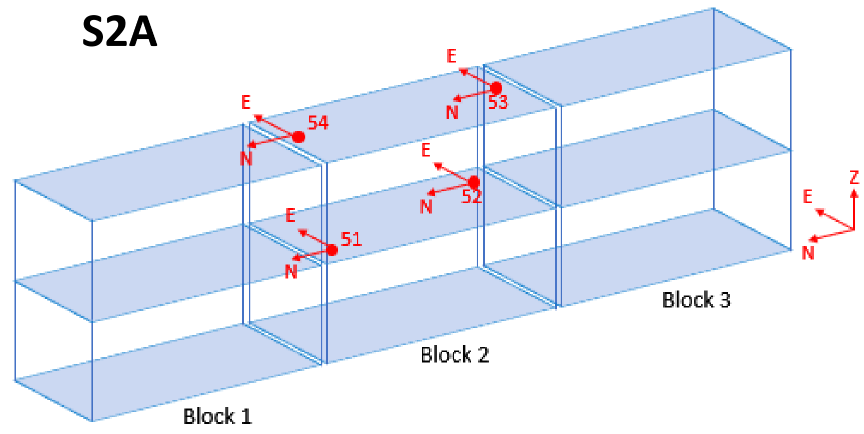
Accelerometers configurations

Classrooms

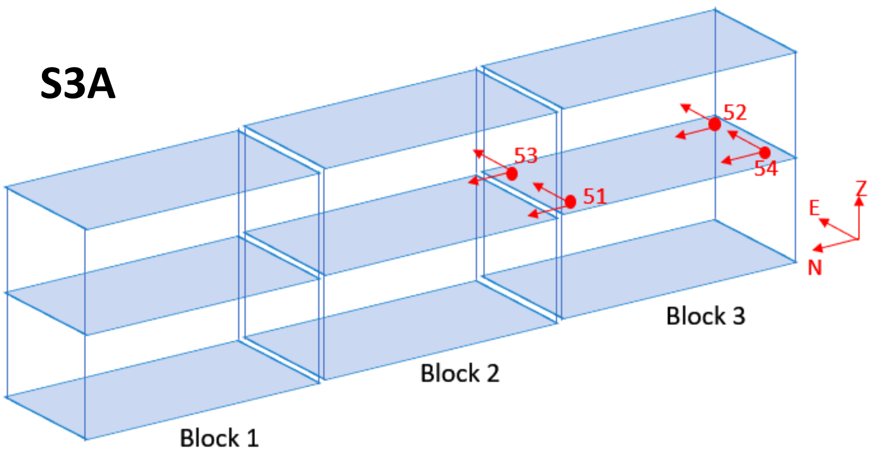
S1A



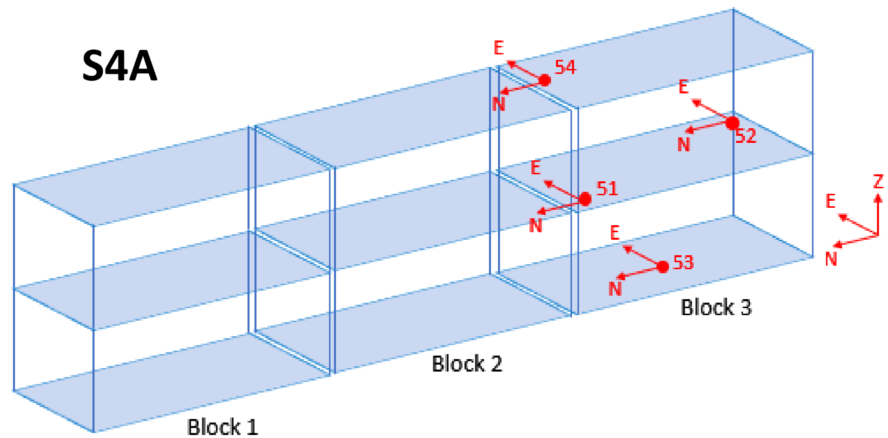
S2A



S3A



S4A



Main classes building configurations used to record the signals with ambient vibration

Accelerometers configurations

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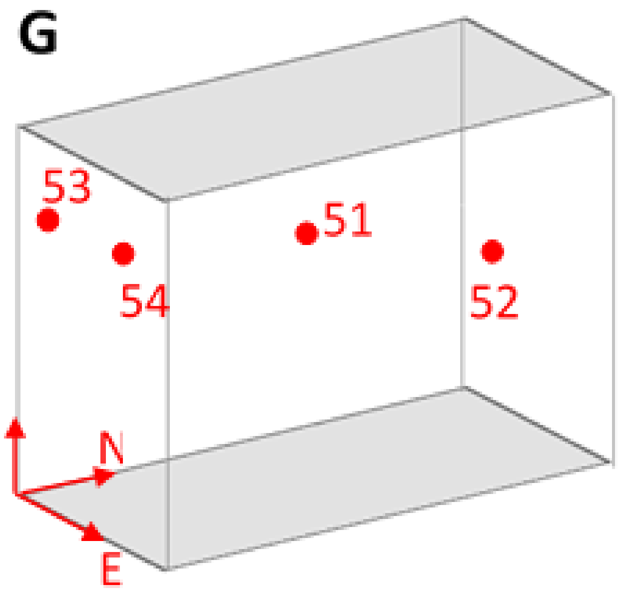
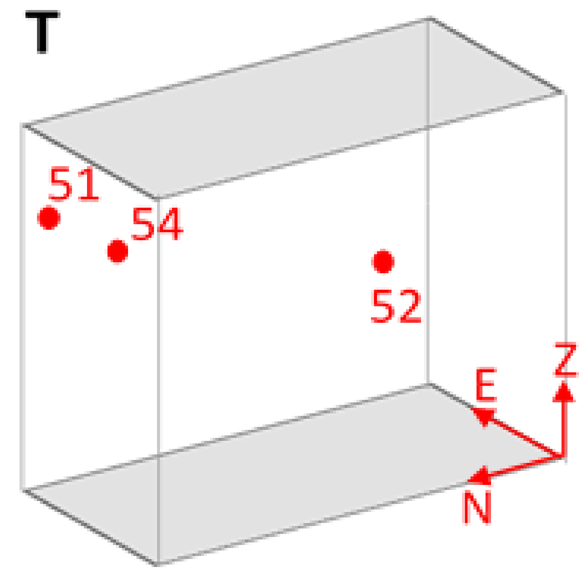
Gym



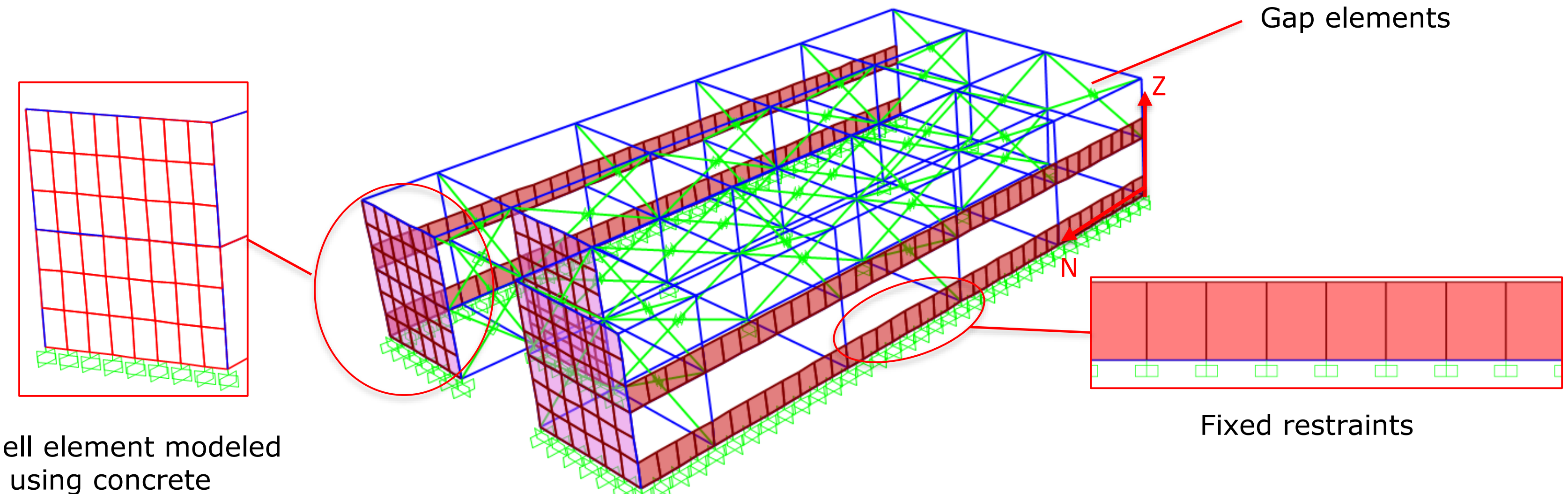
Auditorium



Main classes building configurations used to record the signals with ambient vibration

FE models and calibration

- FE models are prepared and calibrated (freq. & mode shapes)
- E.g. Classrooms Block 1



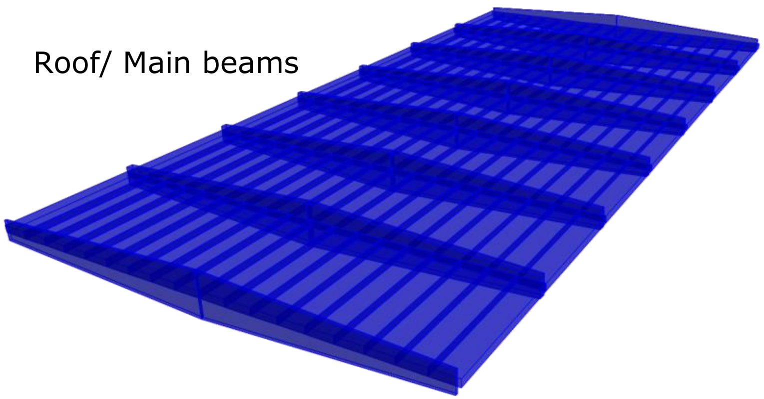
Shell element modeled by using concrete perimeter walls

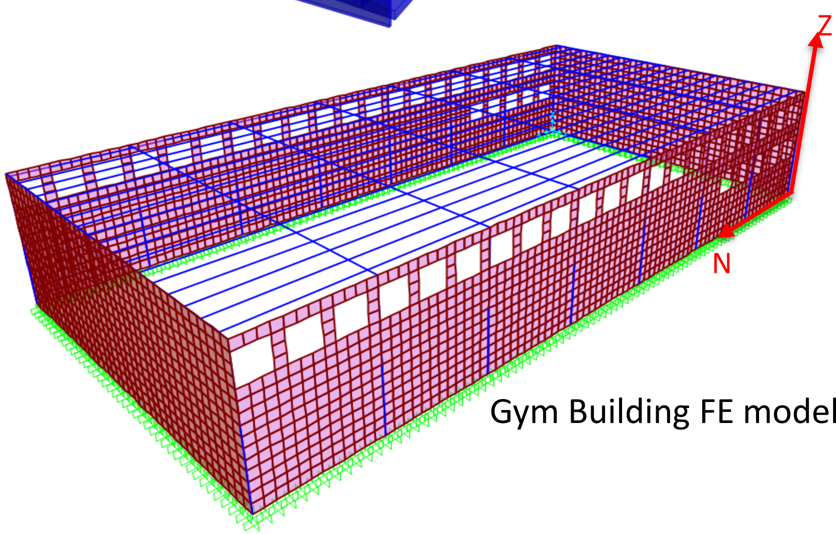
Main Building FE model

FE models and calibration

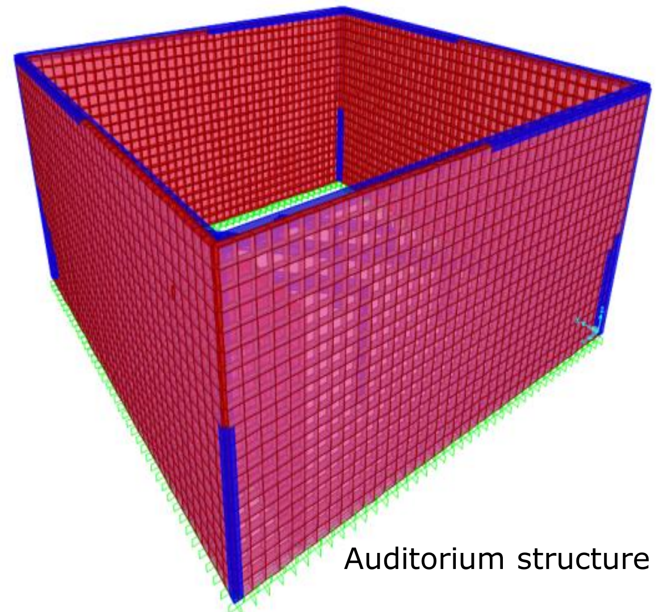
❑Gym and Auditorium FE Model

Roof/ Main beams





Gym Building FE model



Auditorium structure

FE models and calibration

❑FE model nonlinearity

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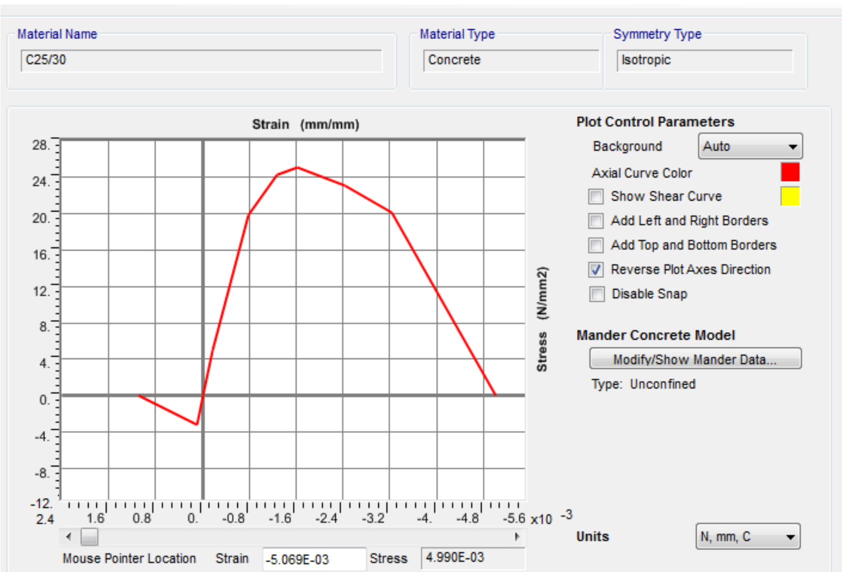
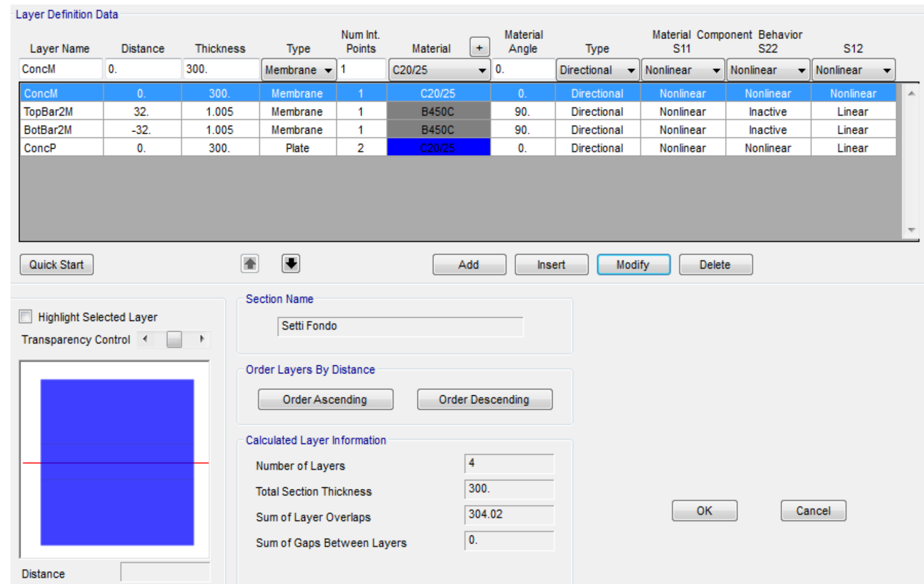
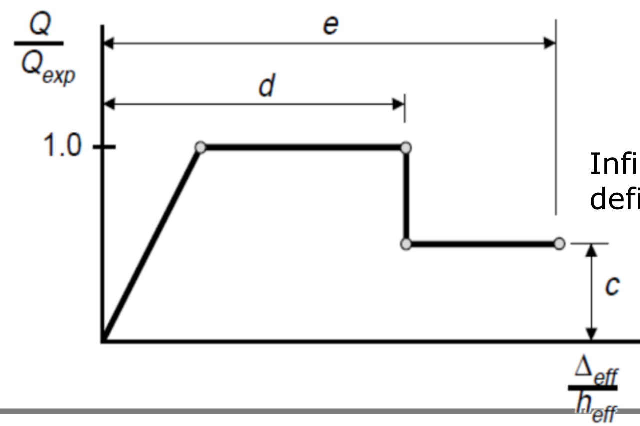
Material nonlinearity



Shell element nonlinearity





Infill wall nonlinearity definition (FEMA 273)

Output-Only methods Result

Mode shapes - Block 1

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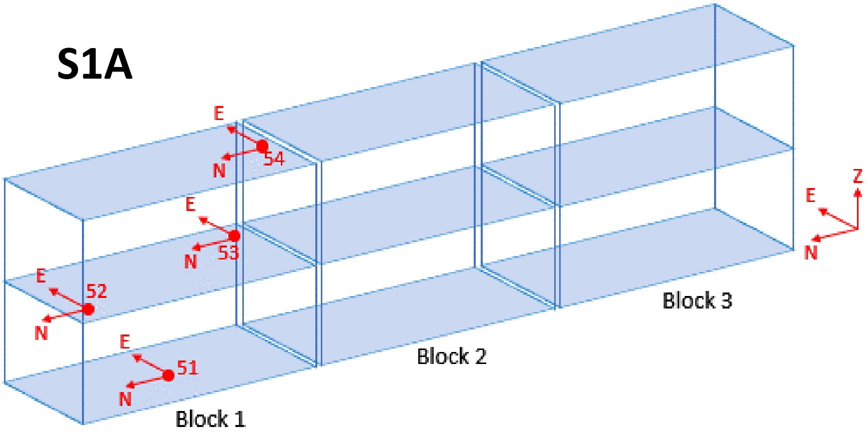
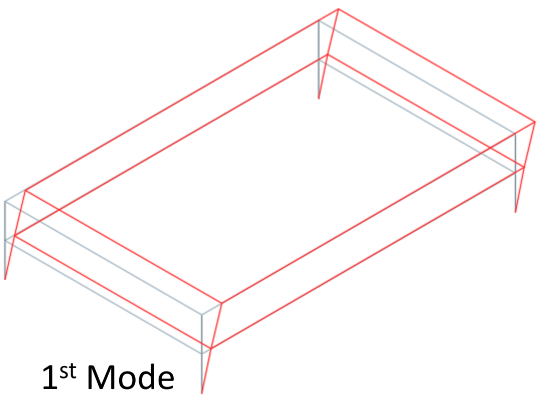
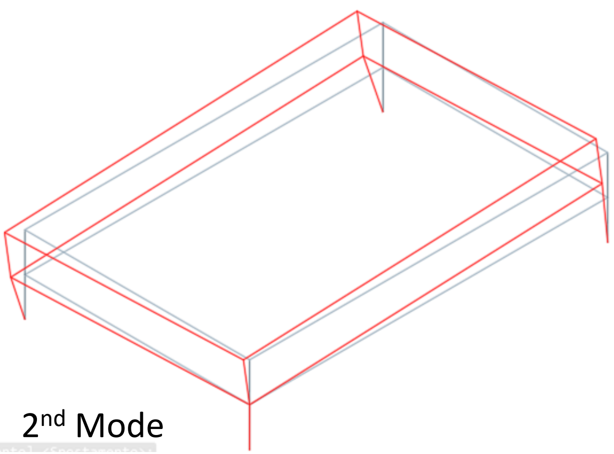
S1A



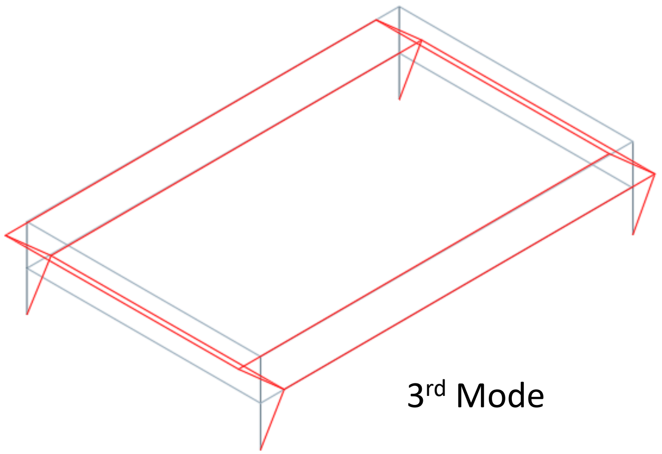
	Modes	FDD [Hz]	RDT [Hz]
S1A (1st block)	*1st mode*	5,33	5,30
	2nd mode	6,38	6,50
	3rd mode	13,40	13,34



1st Mode



2nd Mode



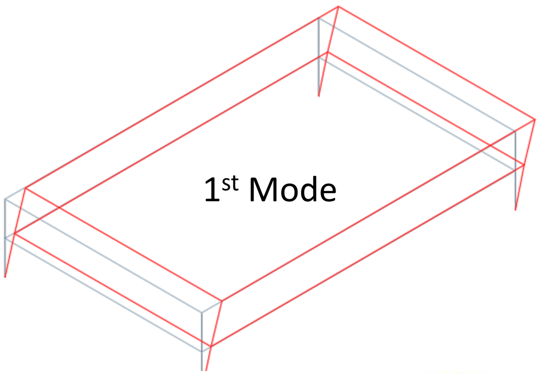
3rd Mode

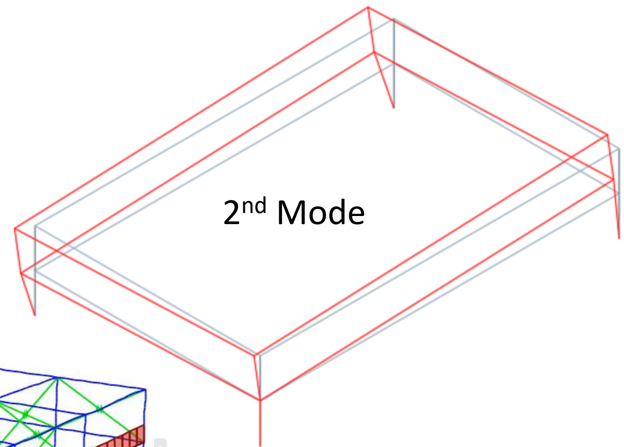
FEM Result
Block 1

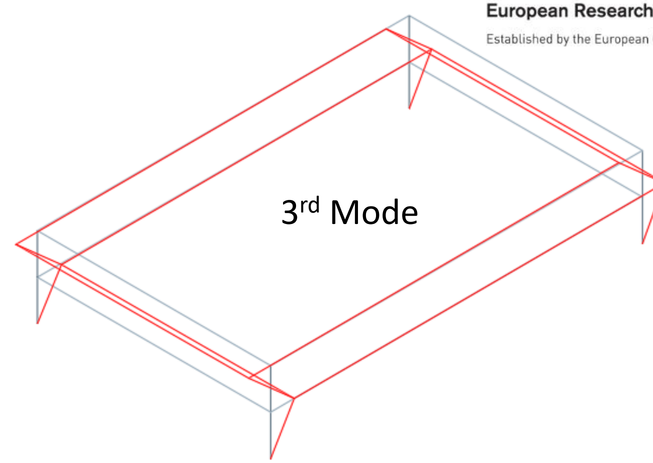
	Modes	FDD [Hz]	RDT [Hz]	FEM [Hz]	Participating mass ratio
S1A (1st block)	*1st mode*	5,33	5,30	5,40	0,91
	2nd mode	6,38	6,50	6,40	0,52
	3rd mode	13,40	13,34	13,20	0,97

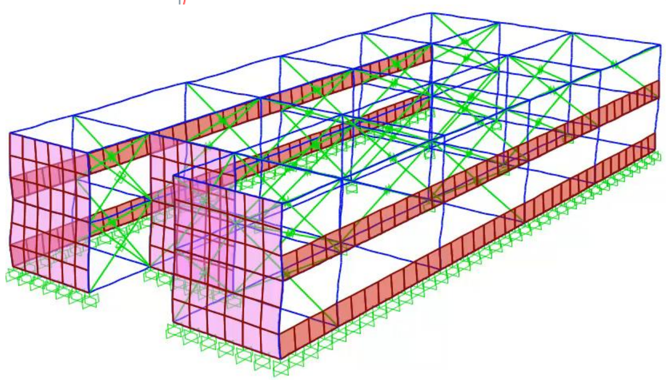
FEM Result

Block 1

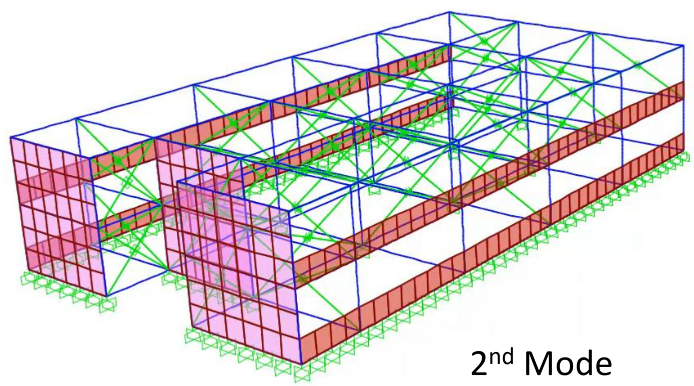




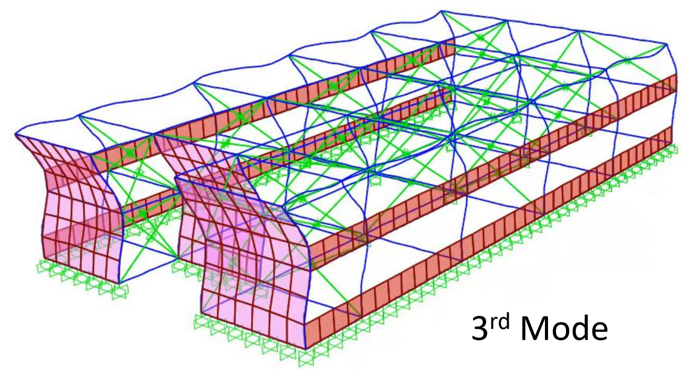




1st Mode



2nd Mode

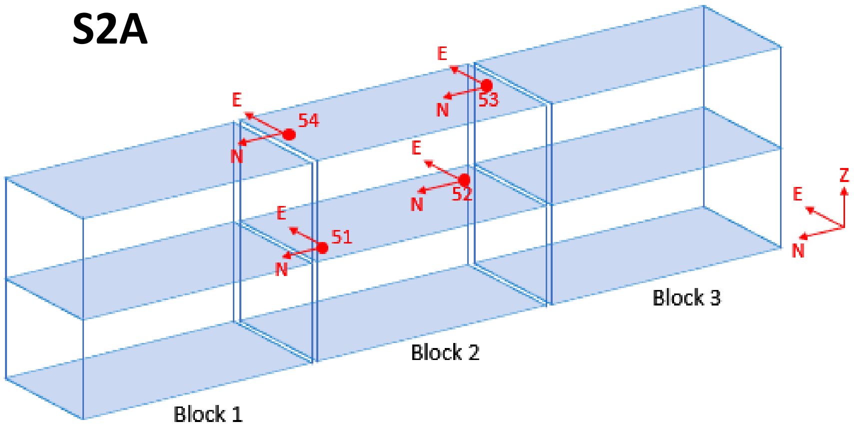


3rd Mode

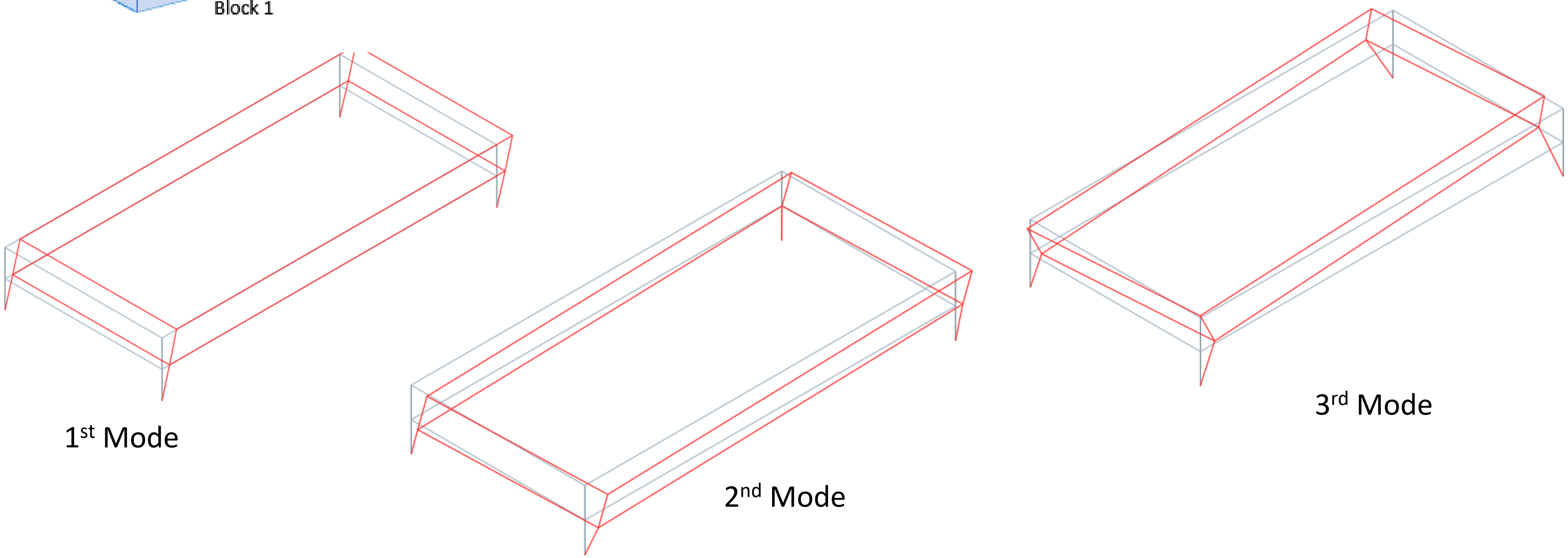
Output-Only methods Result

Mode shapes - Block 2

S2A



	Modes	FDD [Hz]	RDT [Hz]
S2A (2nd block)	*1st mode*	5,30	5,39
	2nd mode	6,30	6,40
	3rd mode	7,25	7,34

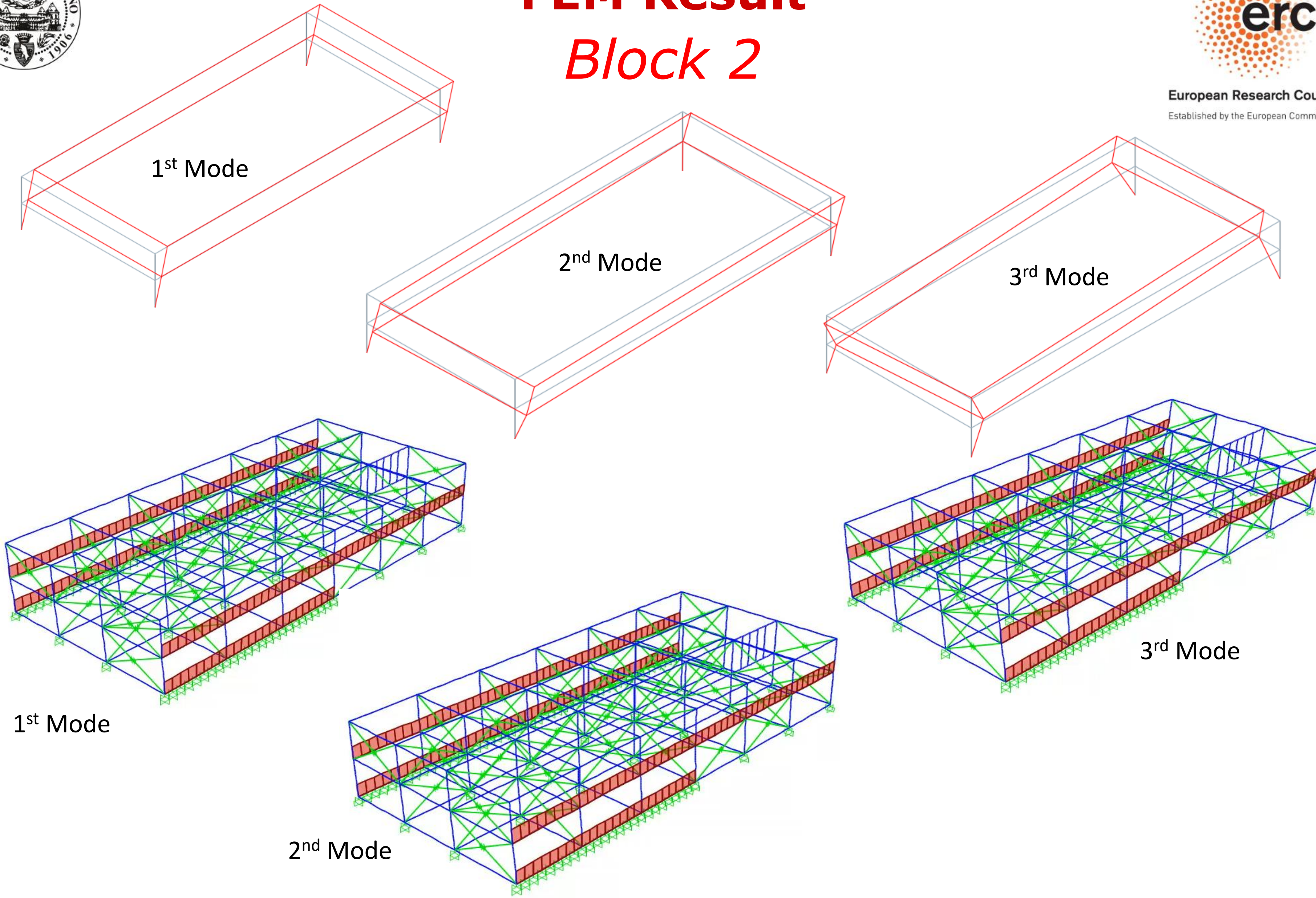


FEM Result
Block 2

	Modes	FDD [Hz]	RDT [Hz]	FEM [Hz]	Participating mass ratio
S2A (2nd block)	*1st mode*	5,30	5,39	5,40	0,96
	2nd mode	6,30	6,40	6,30	0,67
	3rd mode	7,25	7,34	7,10	0,63

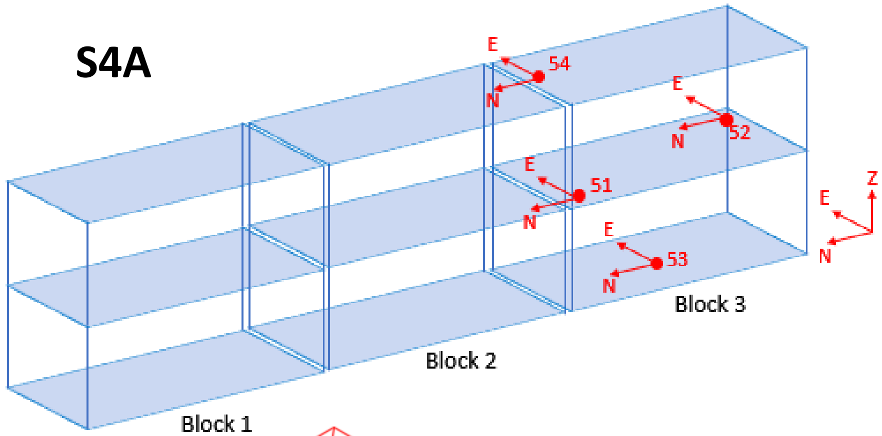
FEM Result

Block 2

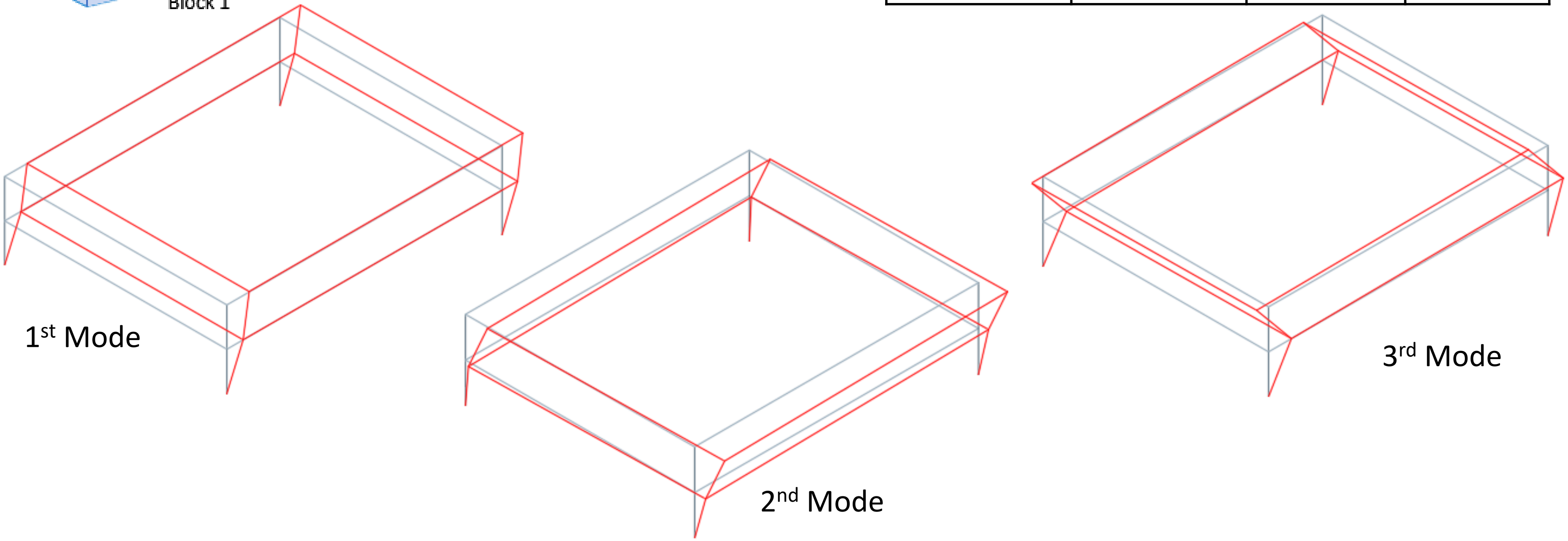


Output-Only methods Result

Mode shapes - Block 3



	Modes	FDD [Hz]	RDT [Hz]
S4A (2nd block)	*1st mode*	5,32	5,24
	2nd mode	7,57	7,49
	3rd mode	11,17	11,24



FEM Result
Block 3

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	Modes	FDD [Hz]	RDT [Hz]	FEM [Hz]	Participating mass ratio
S4A (2nd block)	*1st mode*	5,32	5,24	5,30	0,94
	2nd mode	7,57	7,49	7,60	0,54
	3rd mode	11,17	11,24	11,9	0,99

FEM Result

Block 3

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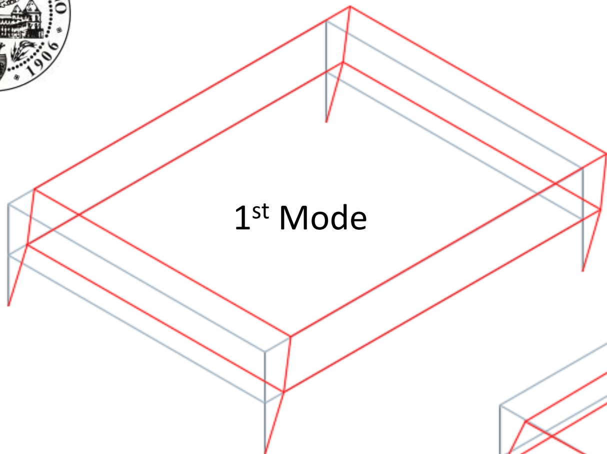
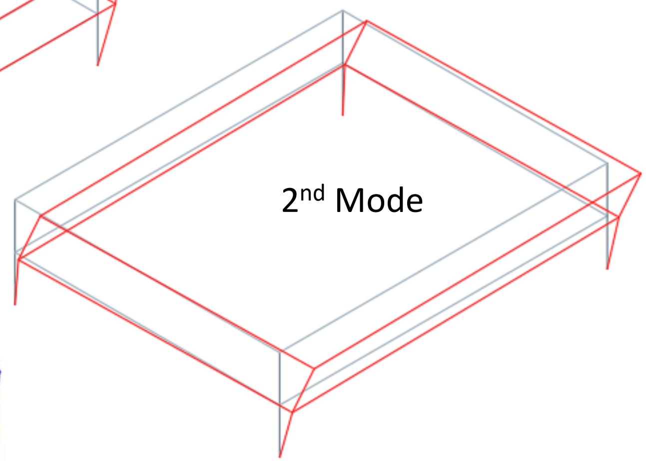
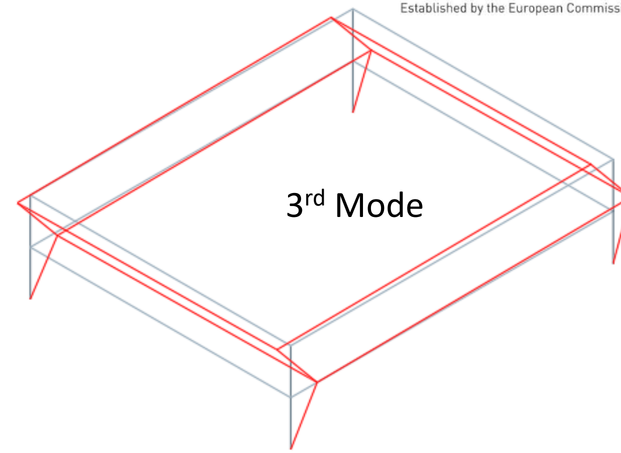
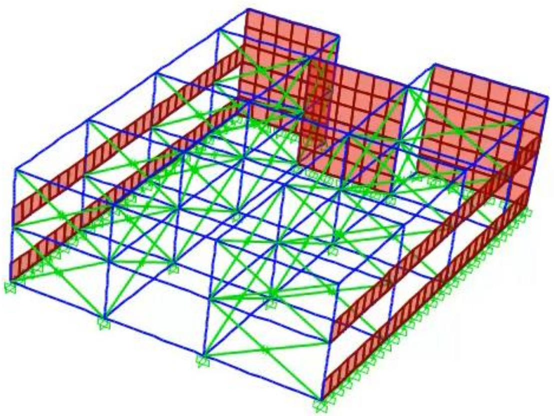
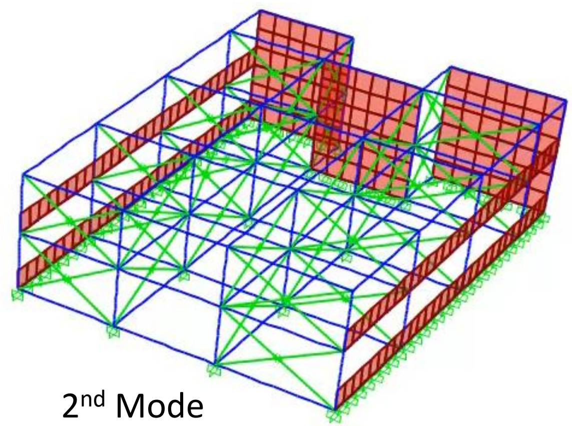




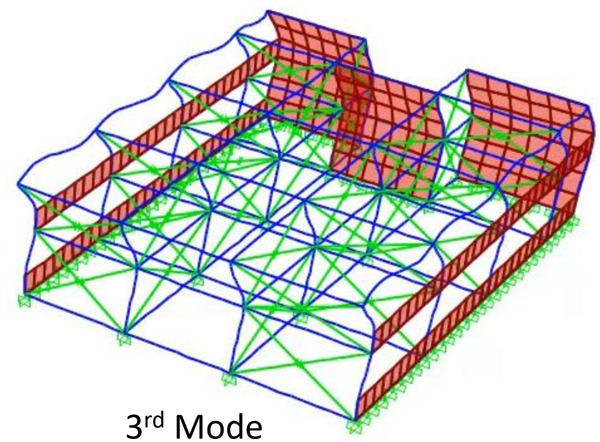




1^{st} Mode



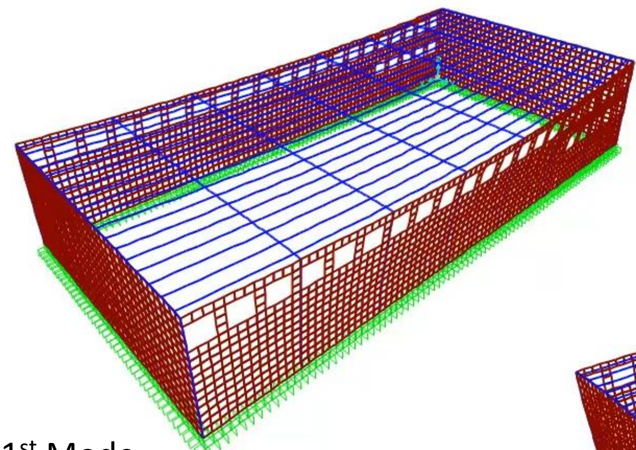
2^{nd} Mode



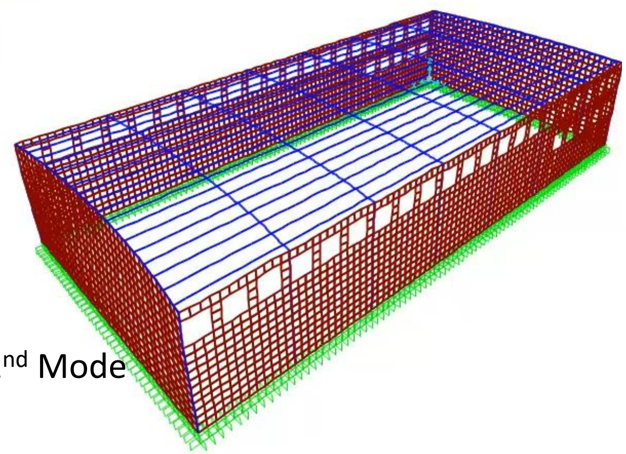
3^{rd} Mode

FEM Result
Gym buidling

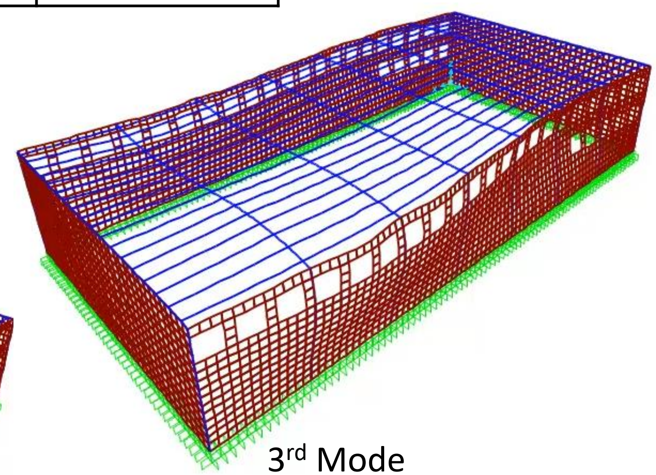
	Modes	FDD [Hz]	RDT [Hz]	FEM [Hz]	Participating mass ratio
GYM	*1st mode*	4,60	4,64	4,55	0,55
	2nd mode	7,10	7,10	7,27	0,57
	3rd mode	10,00	10,04	10,8	0,26



1st Mode



2nd Mode

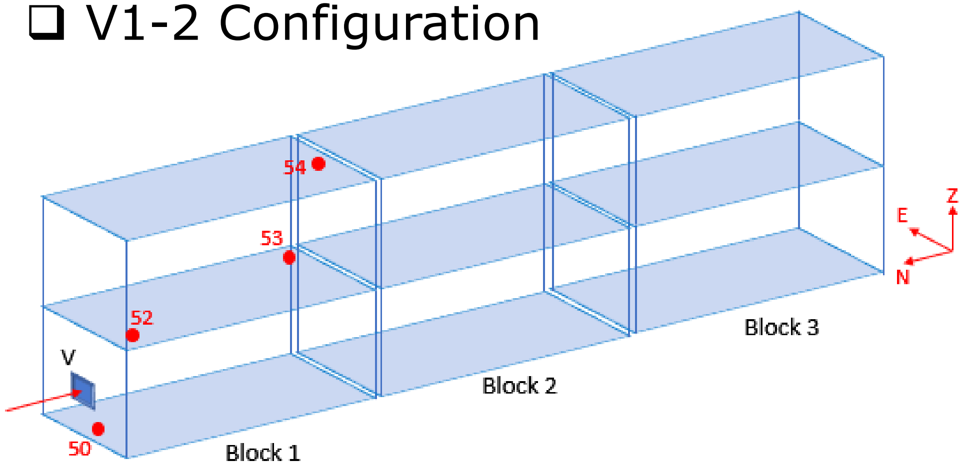


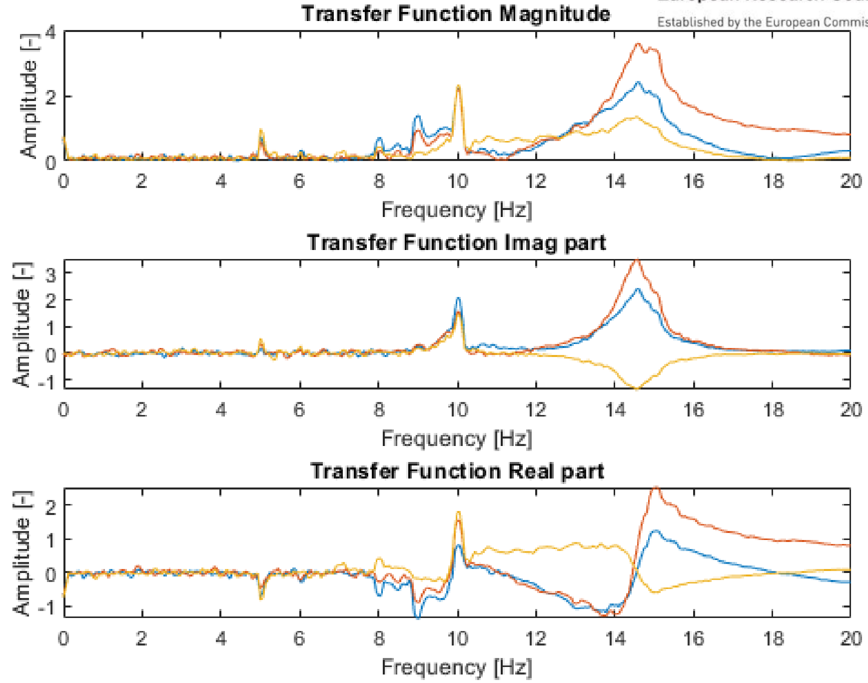
3rd Mode

Gym Building mode shapes

Results of vibrodyne test
Block 1

- V1-2 Configuration





		FRF Freq [Hz]	Damping [%]	Mode Shape	Damping Average [%]
V1-2 (1st block)	**North Direction**	5	[1,09 1,02 1,02]	[0,1726 0,3459 0,5486]	1,04
		10	[0,93 0,93 0,93]	[2,0624 1,5417 1,4339]	0,93
		14,61	[3,83 3,73 4,29]	[2,3892 3,4352 -1,3046]	3,95

(Block 1 FDD: 5.3, 9.75 and 13.4 Hz)

Vulnerability index

- Vulnerability index ζ_E is evaluated by:

$$\zeta_E = \frac{S_a}{S_d}$$

S_a: maximum bearable seismic action of the structure

S_d: maximum seismic action that would be used in the design of a new building with the same characteristics (LSC - limit state of collapse)

- Static non-linear analyses (pushover) and incremental dynamic non-linear analyses, were performed.

Results: nonlinear static analysis

1st and 3rd blocks

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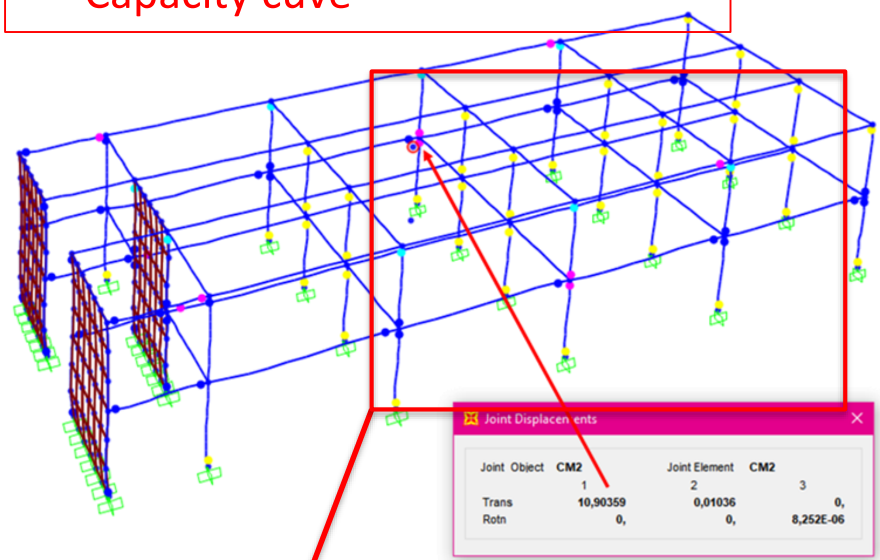
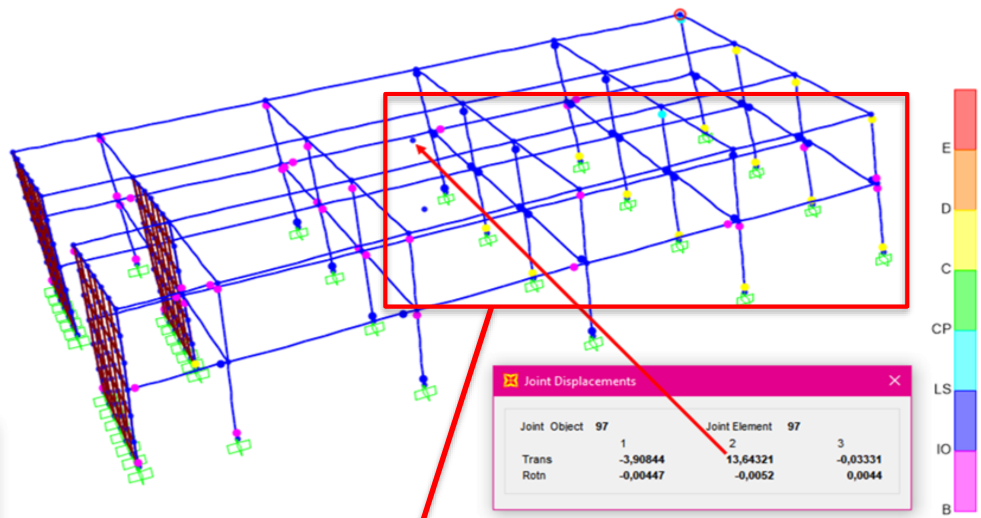
Two different lateral load patterns (x and y) were applied to perform pushover analysis up to point of collapse (according to NTC2018)

Collapse is identified considering:
- Plastic hinges development
- Capacity cuve



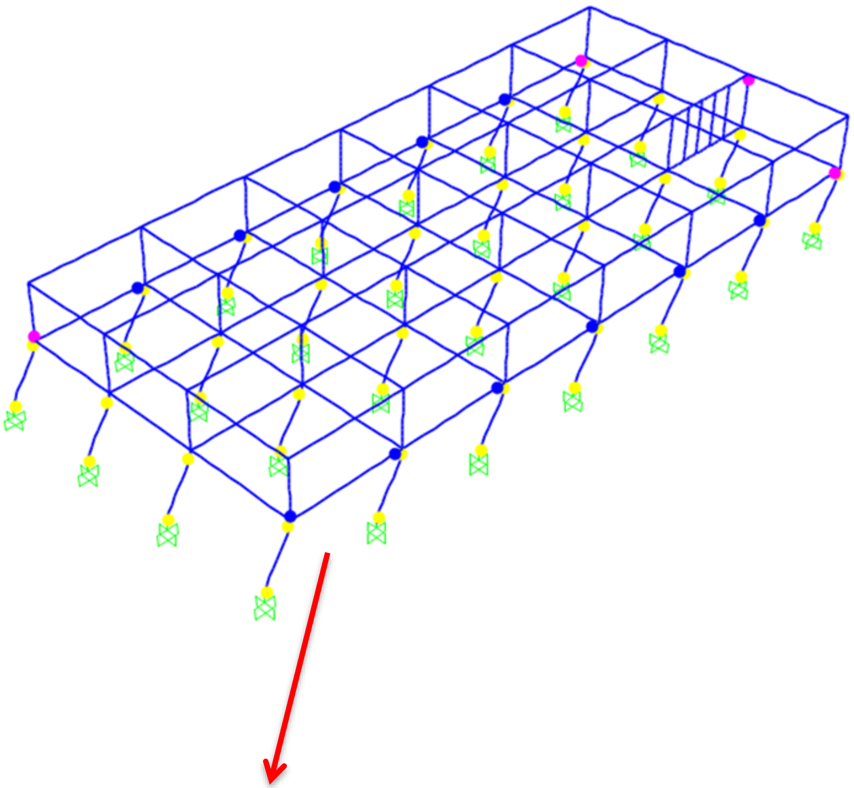


Block 1; Partial collapse – pushover analysis in y-direction

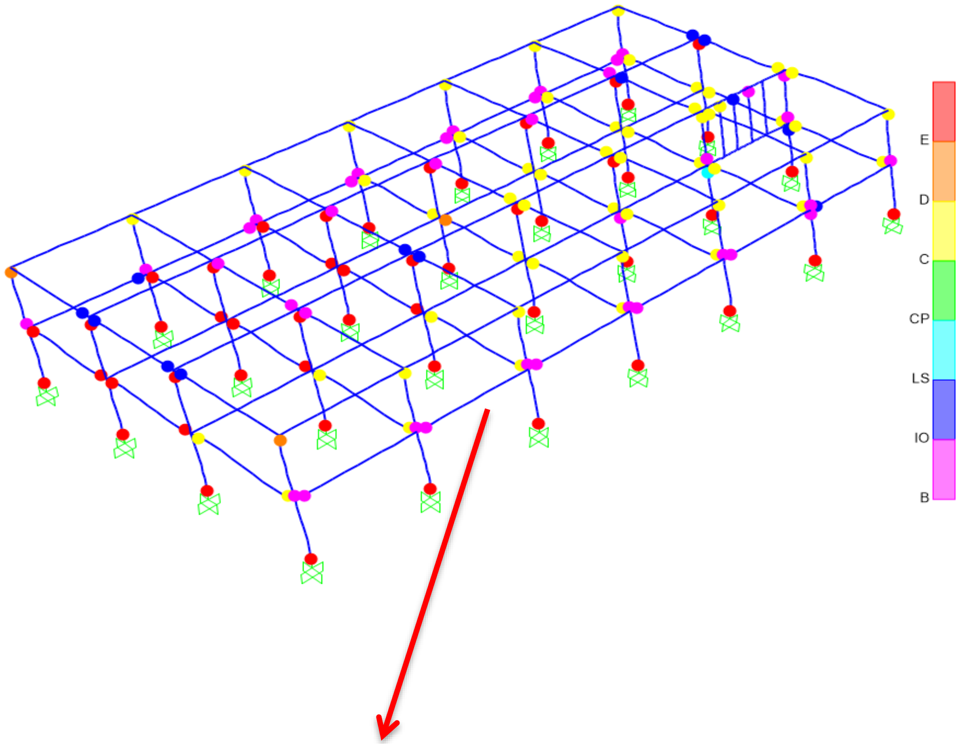
Block 1; Partial collapse – pushover analysis in x-direction

Results: nonlinear static analysis

Central block



Block 2; Soft story mechanism–
pushover analysis in x-direction



Block 2; global story mechanism–
pushover analysis in y-direction

Results: nonlinear static analysis

Pushover curves

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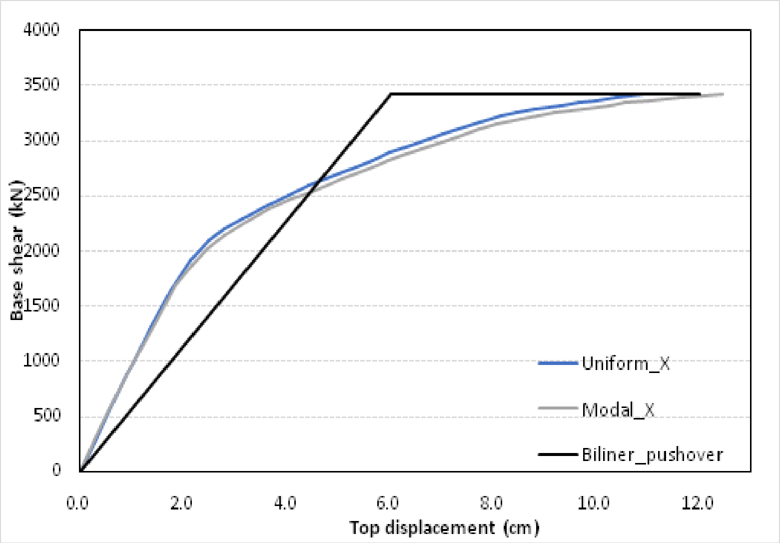
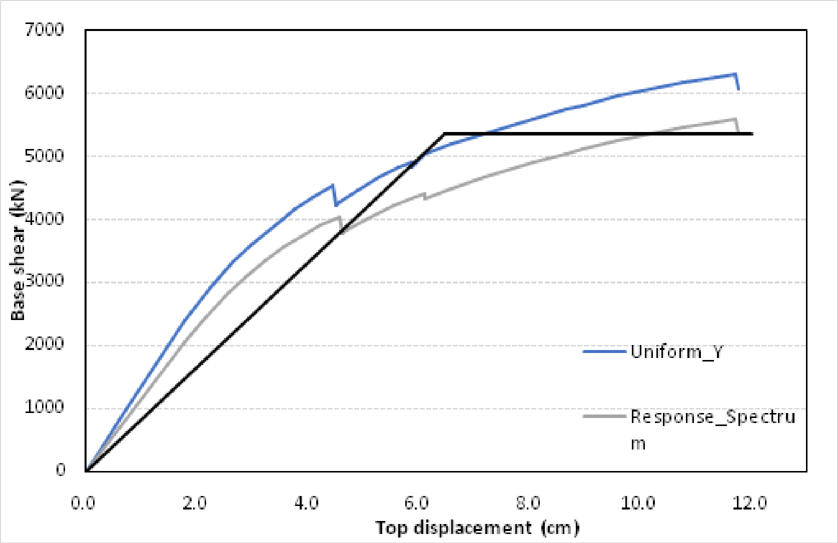
Acceleration associated with maximum capacity: the **ratio** between the **maximum force** (collapse mechanism) and the **participating mass** in considered direction

Block 1- X direction



Block 1- y direction



Results: vulnerability index

Pushover analysis

Vulnerability index for classroom building in x direction

	F_{max} [kN]	Sa [g]	S_d [g]	ζ_E
Blocco 1	3420	0,36	0,155	2,34
Blocco 2	2650	0,25	0,155	1,66
Blocco 3	2540	0,42	0,155	2,75

Vulnerability index for classroom building in y direction

	F_{max} [kN]	Sa [g]	S_d [g]	ζ_E
Blocco 1	5370	0,54	0,303	1,78
Blocco 2	3920	0,39	0,303	1,30
Blocco 3	3180	0,51	0,303	1,70

Design acceleration *Sd* → design spectra (LSC) for the site of Melzo (MI) - NTC2019

Nonlinear dynamic analysis

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- **Only block 1 is here presented**

- **Maximum inter-storey drift associated with the collapse state (LSC) → 4% (FEMA 273)**

- An **iteration procedure** is used → **incremental dynamic analysis** → maximum bearable acceleration

- 7 accelerograms compatible with LSC spectra → both H directions

Results: vulnerability index

Nonlinear dynamic analysis

- The maximum bearing capacity performing non-linear time history analyses → **0.371 g**

- Considering design spectra (LSC) acceleration for site of Melzo → **0.155 g in X** and **0.303 g in Y**)

- Vulnerability indexes → **2.39 in the x** direction and **1.22 in y** direction → **Compatible** with **pushover**

Conclusions

- The research proposes a **reasonable methodology that can be applied for the assessment of the seismic vulnerability** coefficient of existing structures as schools

- It can be a **useful support tool for decision-makers** to effectively evaluate **priorities and interventions**

Thanks for your attention

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