16TH EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING THESSALONIKI 18 - 21 JUNE 2018

UNIVERSITÀ DEGLI STUDI DI TRENTO

Structural health monitoring for seismic protection of structure and infrastructure systems

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3.The author deeply acknowledges the financial support from the European Union through:

- the SERA project (Project Reference: 730900) for the smart city activities; MEMSCON) FP7-NMP, MONICO) FP7-SME-2007; and several agreements between the Autonomous Province of Trento, Italy and the University of Trento.

MOTIVATIONS

- Structural health monitoring (SHM) and damage identification (DI) nowadays represent important tools in structural engineering.

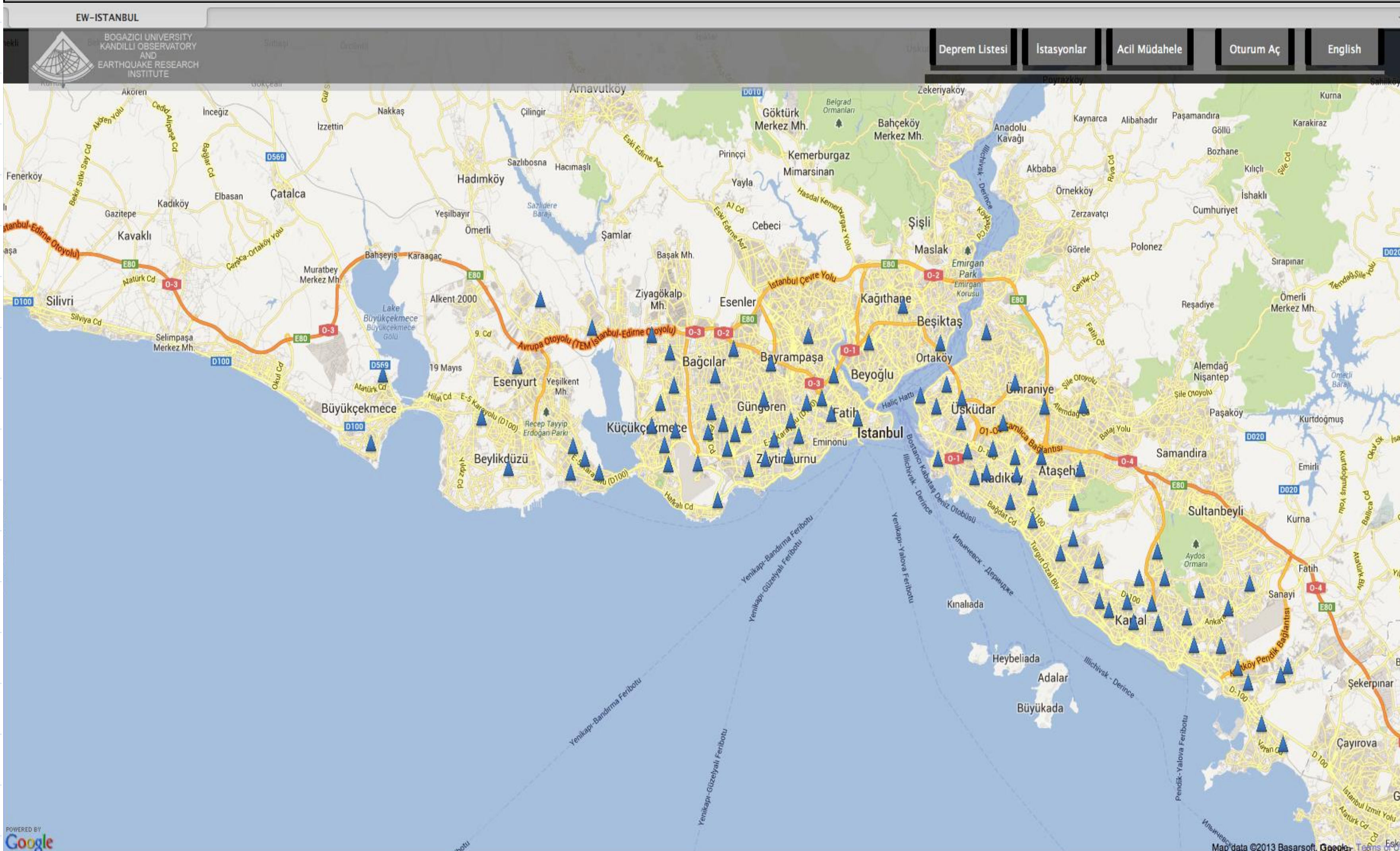
- SHM can be defined as a process of implementing in situ, non-destructive sensing and performing analysis of structural characteristics in order to identify if damage has occurred, define its location, estimate its severity and evaluate its consequenc-es on a structure residual life (Huston, 2011)

- It is becoming more and more popular because offers several advantages

    - Reduction of inspection costs
    - Better understanding of the behavior of structures and infrastructure under dynamic loads,
    - Seismic protection of the structural response
    - Understading of the evolution of damage
    - Support on post-earthquake scenarios and support rescue operations

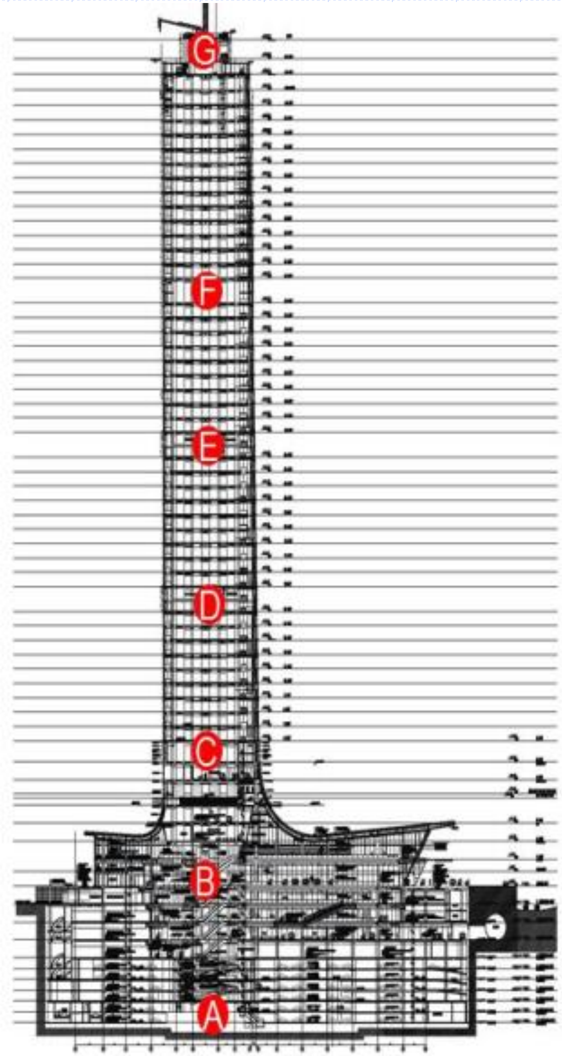
Huston, D. (2011), Structural Sensing, Health Monitoring, and Performance Evalua-tion, CRC Press, Taylor and Francis.

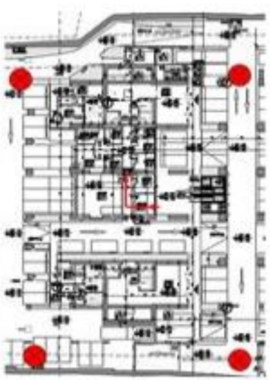
Istanbul Earthquake Rapid Response Network (+200 stations)
(http://www.ew-istanbul.com/Stations.aspx)



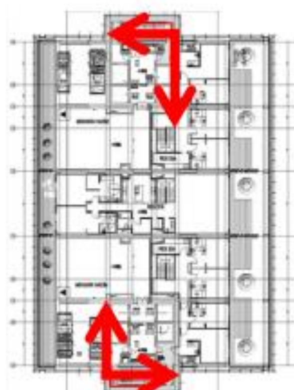
SHARING OF EARLY WARNING SIGNALS

Case Study #1 of SERA: Tall buldings in Istanbul





Level: A
30 channels

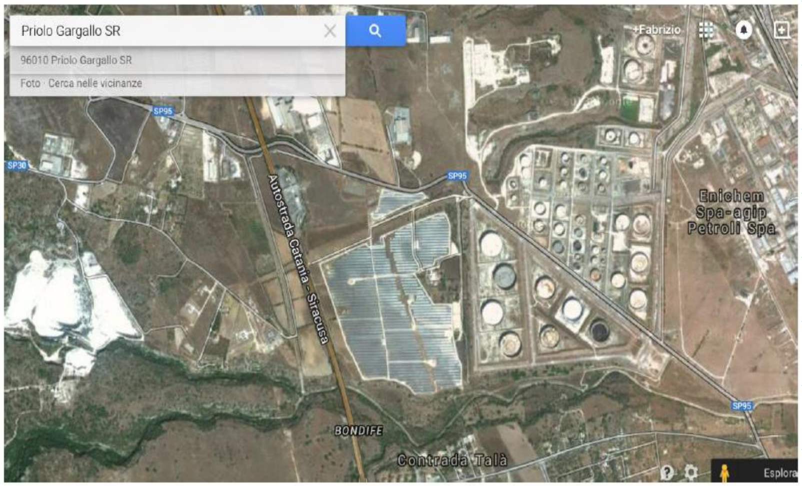


Levels: B-G

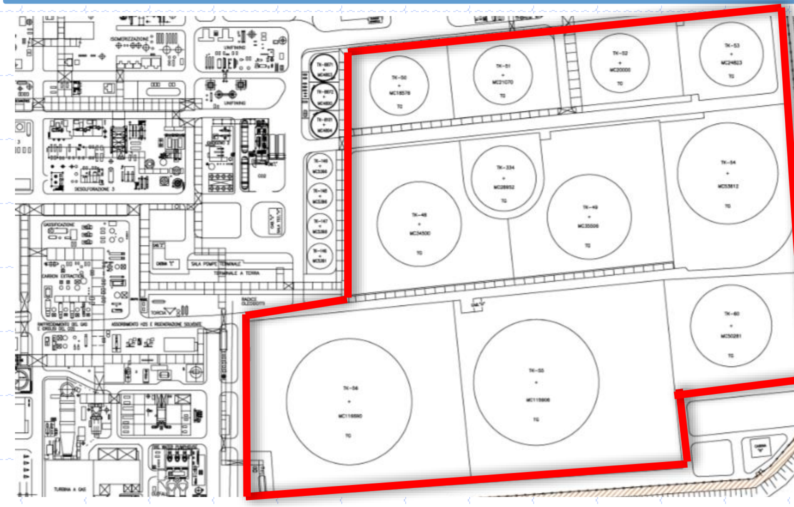
Total of

CASE STUDY #2 OF SERA - PRIOLO GARGALLO (SR) - ITALY

SITE PRIOLO GARGALLO (SR) ITALY



TANK FARM SELECTED



CHARACTERISTICS OF TANKS

Content : Crude oil

	TK1	TK2	TK3	TK4	TK5	TK6	TK7	TK8	TK9	TK10	TK11
Diameter (m)	37.96	37.96	37.96	41.26	54.86	41.26	54.86	65.4	81.46	81.46	54.86
Liquid Level (m)	11.3	11.3	11.3	12	15.3	12	15.3	10	21.6	21.6	15.3
Height (m)	14	14	14	15	18	15	18	14	25	25	18
Yielding strength (MPa)	345	345	345	345	345	345	345	345	345	345	345
Shell equiv. thick. (m)	0.013	0.013	0.013	0.013	0.0185	0.013	0.0185	0.014	0.026	0.026	0.0185
Shell base thick. (m)	0.02	0.02	0.02	0.02	0.0295	0.02	0.0295	0.0295	0.04	0.04	0.0295
Annular plate thick. (m)	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.016	0.016	0.008

ACOUSTIC EMISSION AND REMOTE SENSING FOR LEAKAGE DETECTION IN PROCESS PLANT PIPELINES

- Industrial process plants are an important source of hazard for environment and communities. The safety level can benefit from the adoption of SHM systems.

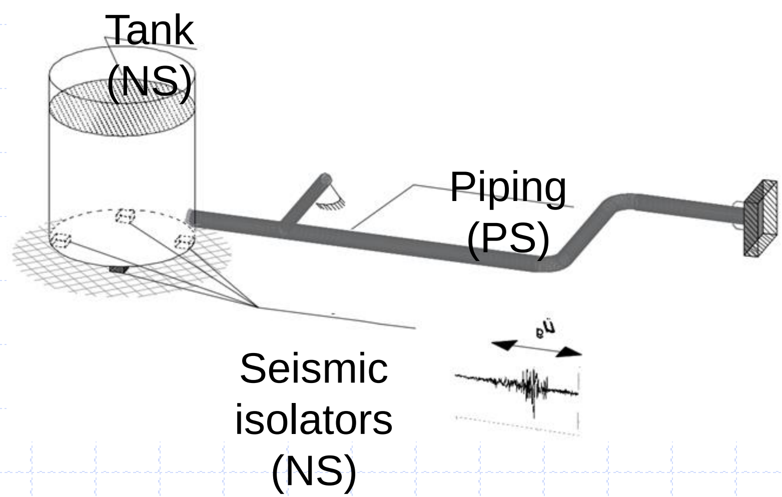
- LOSS OF CONTAINEMENT of hazardous substances from pipelines when subjected to natural hazards, i.e. earthquakes, can cause serious damages as in Na-Tech events.

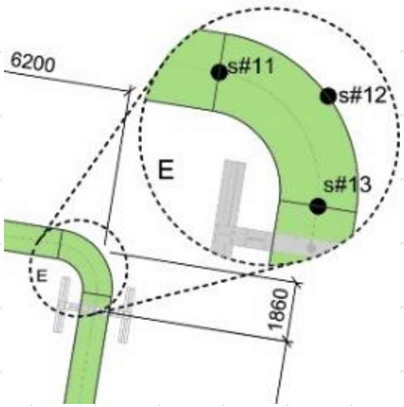
- Within the European project SERA a test campaign will be carried out @UNITN on a realistic tank-piping system subjected to seismic loading.

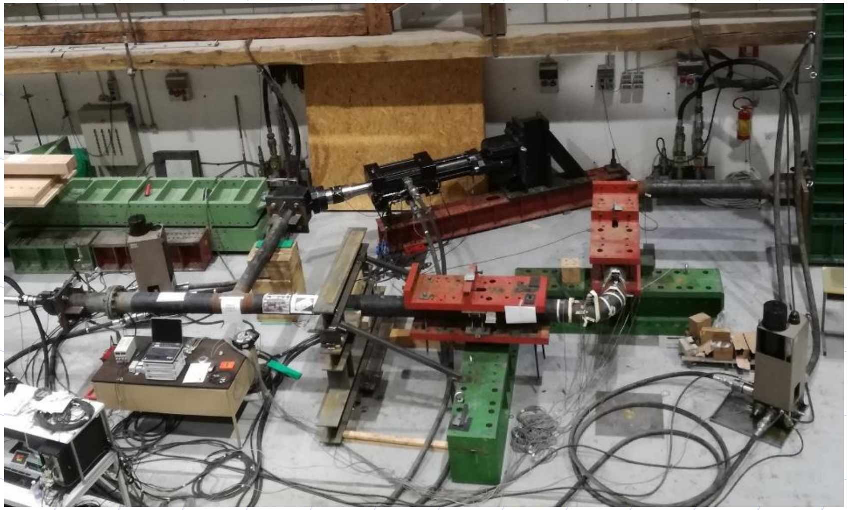
- The experimental campaign has two main goals:
  - Investigate the seismic performance of a realistic tank-piping system with artificial seismic signals.
  - **The adoption of AE PZT sensors** to detect **loss of containement from pipeline elbow components**, both in a classical and in a remote sensing (wireless) configuration.

EXPERIMENTAL SETUP

The experimental setup is composed by a physical substructure, i.e. a pipeline, and a numerical substructure, i.e. a steel tank, simulated by an actuator

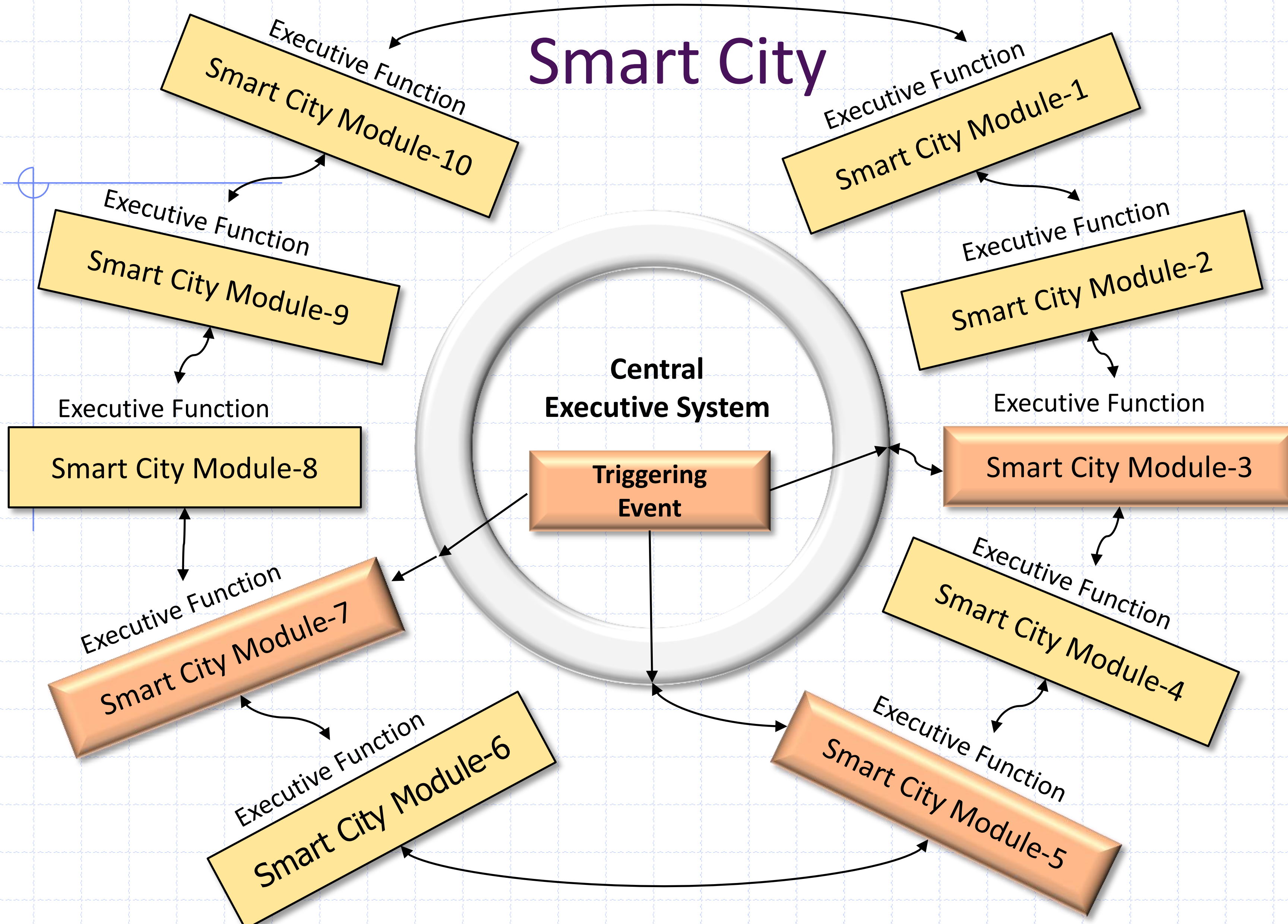






Details of location of a PZT triplet for crack detection/localization.
Typical strain gauges on the elbow

SERA Smart-City Concept



SERA Smart-City Concept/Cntd

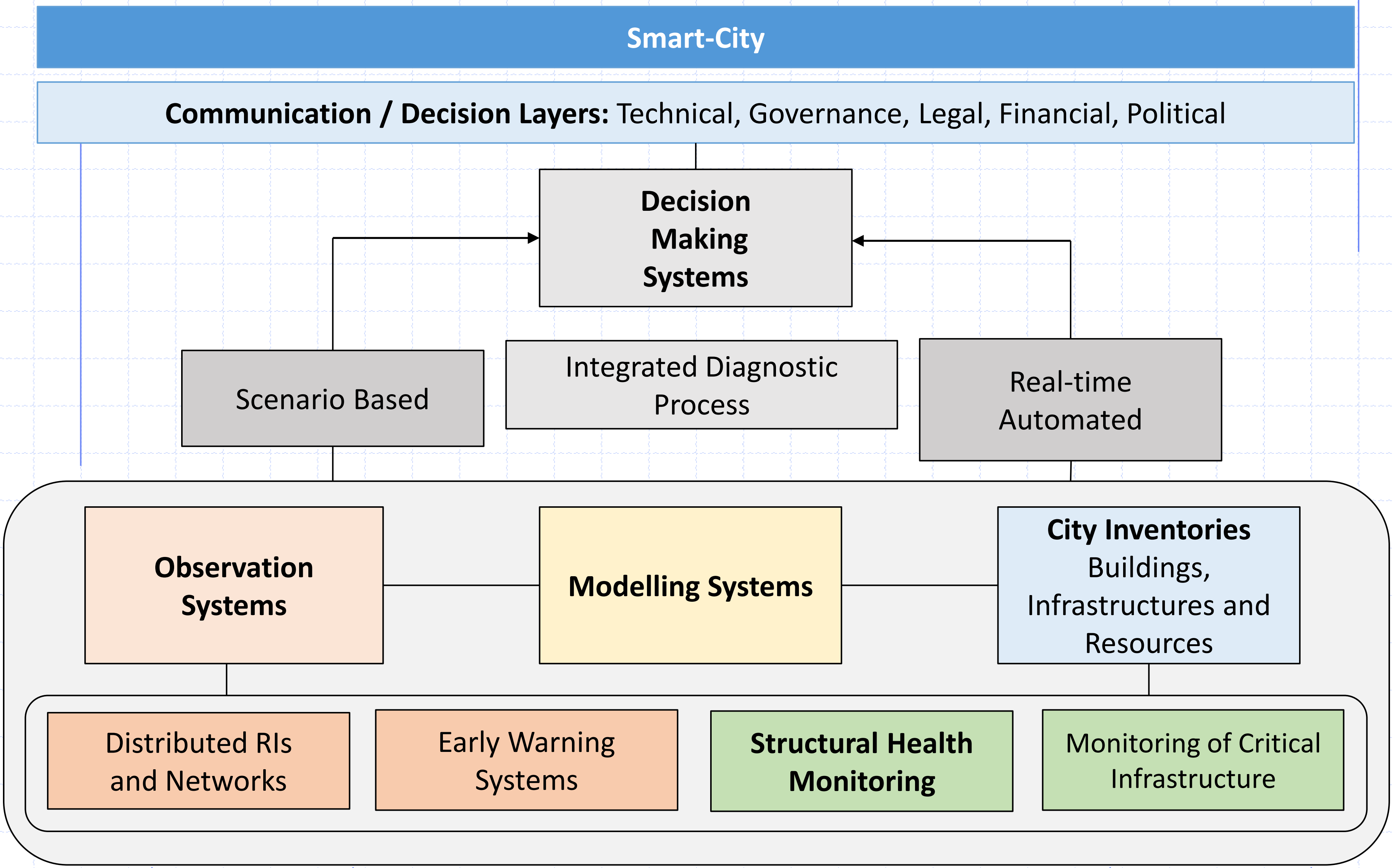


TABLE OF CONTENTS

SOME SENSORS in the MEMSCON EU project (11 partners from 7 countries)

MISSION

Development of a reliable and cost-effective **monitoring system** to be integrated in **new RC buildings** for their protection against seismic events and settlement.

OBJECTIVES

(i) development of a **wireless sensor network (WSN)**, including the conception of new dedicated microelectromechanical systems (**MEMS)** instruments for **both strain and acceleration measurements.**

(ii) development of a **Decision Support System (DSS)** for remote data processing, structure condition assessment and for maintenance planning.

VALIDATION

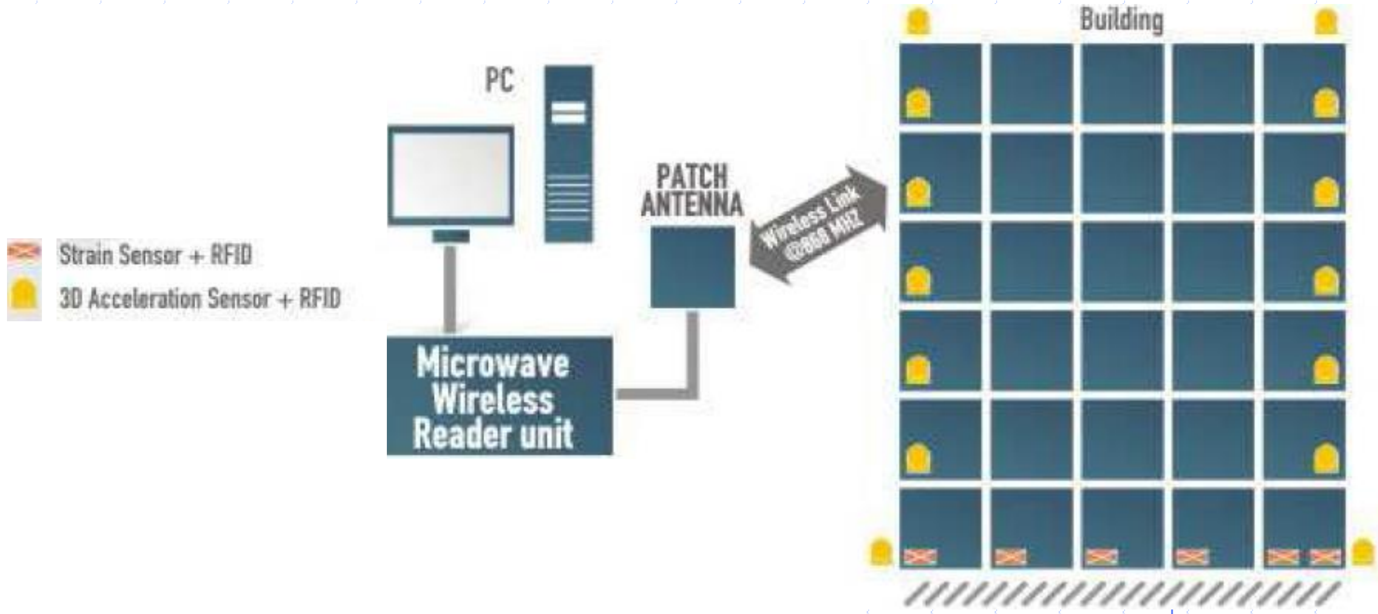
The products have been **validated** both in the **laboratory** and in on-site applications.

WSN scheme

The system includes a **wireless network** within the building and a base station linking the building to a remote centre for data interpretation.

Strain measurements are collected at the **lowest level** of the building, to estimate the vertical column loads and any strain variation due to settlement;

Horizontal acceleration is measured by dedicated nodes at **each level** during an earthquake, allowing an analysis of the seismic response of the whole structure.



MEMSCON WIRELESS ACCELEROMETER

SPECIFICATIONS

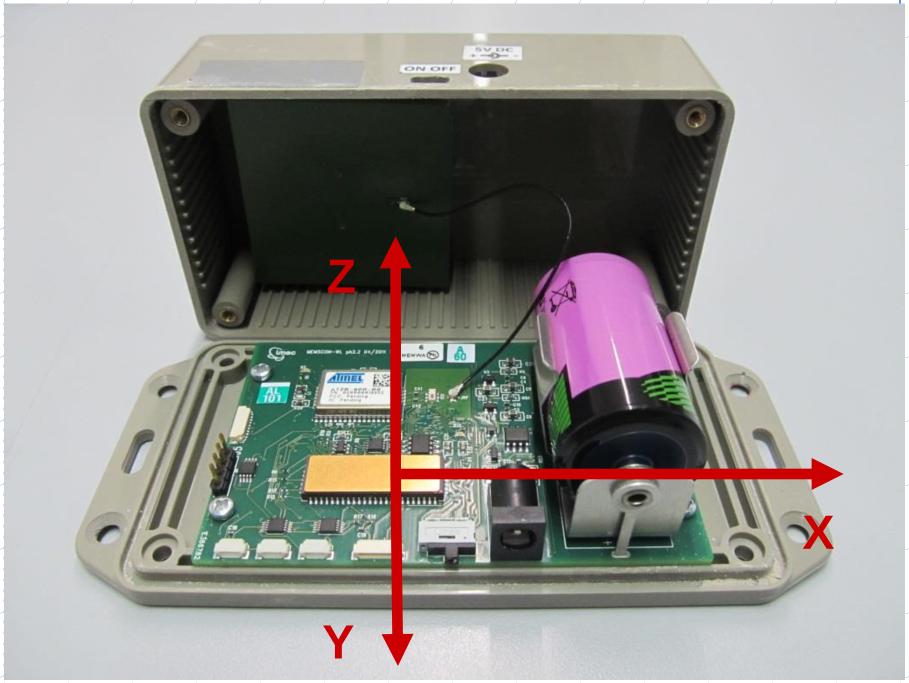
Tri-axial MEMS capacitive accelerometer

Sampling rate: **200Hz**

Resolution: **16bit**

Range: from -**2g** to +**2g**
(from -20m/s2 to +20m/s2)

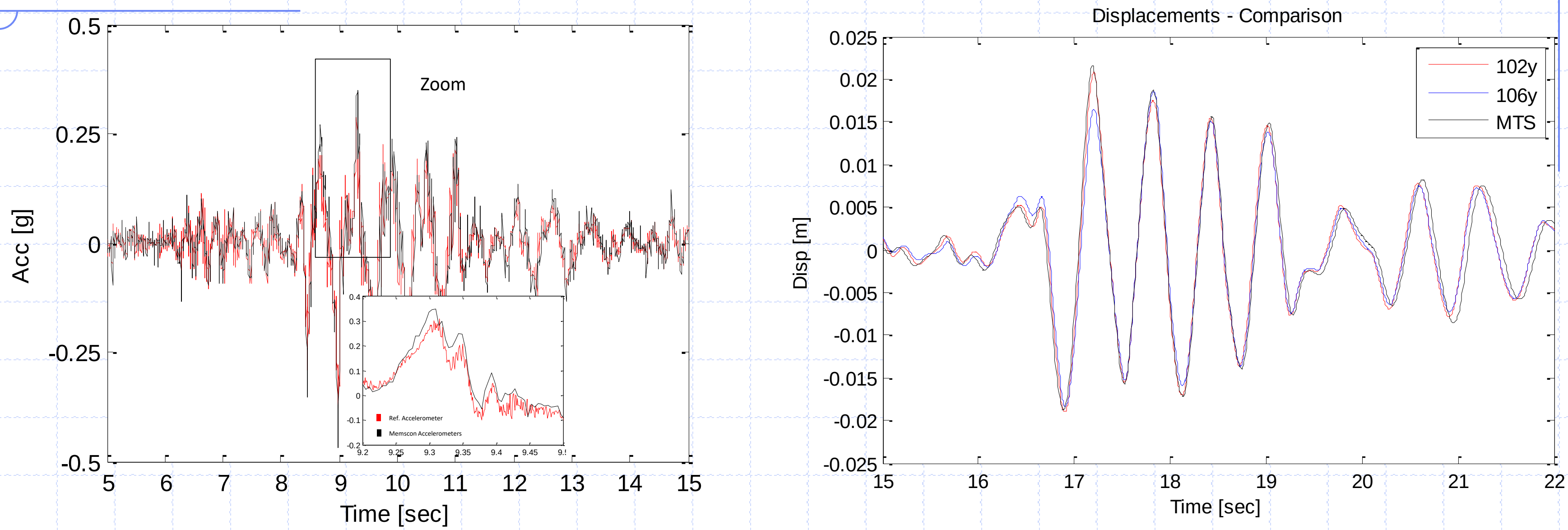
Sensitivity: **170-300 mV/g**



LABORATORY VALIDATION @UNITN http://lpms.dicam.unitn.it/

- **AIM:** to assess the reliability of the whole Memscon system, different tests on a **3D** concrete **frame were carried out**
- To estimate axial load redistribution, strain monitoring during frame construction was carried out.
- Seismic monitoring was performed during earthquake loadings

EXAMPLE OF DYNAMIC RESPONSE



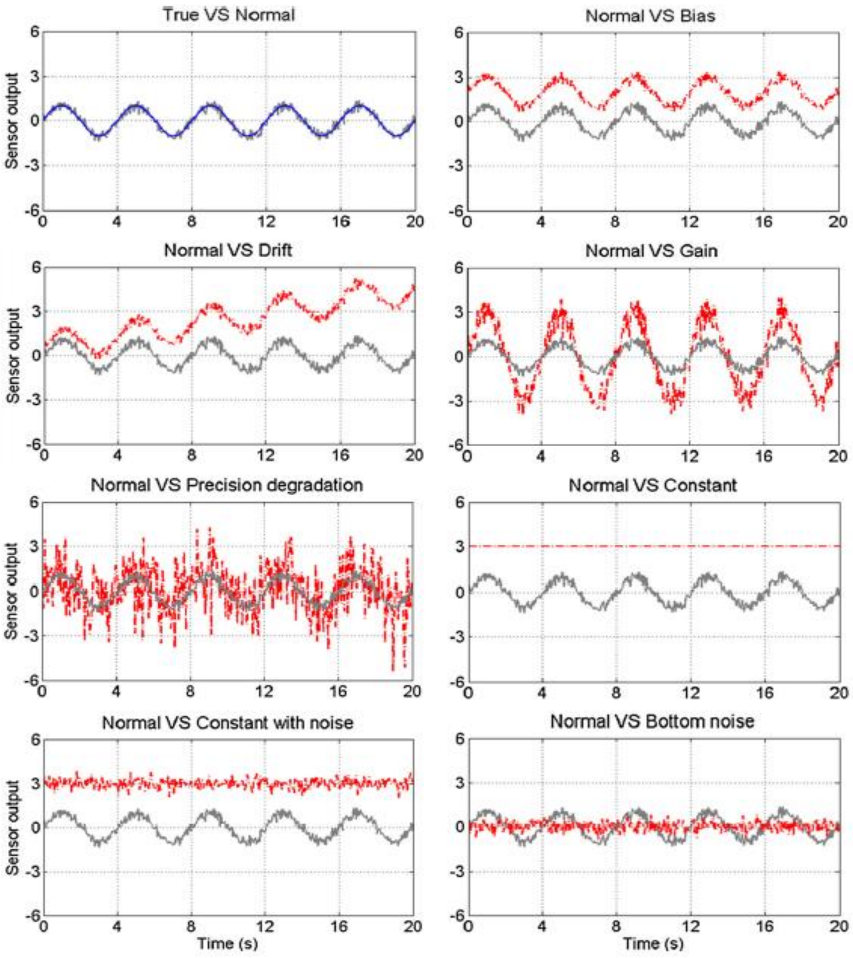
- The **comparison with reference accelerometers** shows that Memscon accelerometers are suitable to record earthquake responses, **with RMS scatter < 20 mg w.r.t. the reference response.**
- The comparison **between horizontal displacements** recorded at the actuator level and the one estimated by double integration of **MEMSCON acceleration measurements exhibits an error < 0.5 mm**

SENSOR FAULT TYPES

- A sensor is considered to be faulty when its measurements display unacceptable deviations from the true values of a measured variable

$$x(t) = x^*(t) + w(t)$$

- 7 typical sensor fault types: bias, drift, gain, precision degradation, complete failure 1 (constant), complete failure 2 (constant with noise) and complete failure 3 (bottom noise).



Yi et al. 2017

Yi T-H, Huang H-B, Li HN (2017). Development of sensor validation methodologies for structural health monitoring: A comprehensive review. Measurement, 109, 200-214.

VALIDATION METHODOLOGIES

- **Sensor fault detection:** determine whether a **potential** fault has occurred.

2 phases:

  - definition of a normal-work condition
  - evaluation of a sensor fault detection index

$$\lambda_n = \ln \frac{f_1(x_1)}{f_0(x_1)} + \ln \frac{f_1(x_2)}{f_0(x_2)} + \cdots + \ln \frac{f_1(x_n)}{f_0(x_n)}$$

- **Sensor fault isolation:** Several fault isolation methods have been developed in recent years:
  - contribution analysis
  - missing variable approach
  - probability quantification

- **Sensor fault reconstruction:** sensor fault reconstruction follows as the structural response measured by this sensor contains important information:
  - optimization-based
  - regression-based
  - robust denoising-based

DYNAMIC IDENTIFICATION TECHNIQUES

Dynamic identification is the problem of determining a structure's model (e.g. a system of equation) from information about inputs and responses measured during dynamic tests and is a typical inverse problem. In linear fields, dynamic identification often reduces to an experimental modal analysis. Techniques may operate in the time, frequency or joint time-frequency domain.

- **Frequency domain**
  - Welch PSD, FDD etc
  - Ewins-Gleeson
  - Dobson
  - Kennedy-Pancu
  - Spectral Multimatrix
- **Time domain**
  - ARMA and TARMA
  - NExT
  - PRTD
  - ERA
  - Random Decrement
  - OKID
  - Subspace
- **Time-frequency domain**
  - Time-Frequency Instantaneous Estimators (TFIE)
  - Wavelet indicators etc.

DYNAMIC IDENTIFICATION TECHNIQUES/Cntd

One of the promising algorithm is the **N4SID algorithm** is member of the direct subspace system identification methods family, which estimate the state-space model directly from an arbitrary set of **input and output sequences** by solving a least square problem.

- A reference FE models is set assuming to be linear, elastic and isotropic material
- Material properties are deduced from the results of destructive and non-destructive tests to carry on the structure based on in situ tests and visual inspections
- A preliminary calibration of the FE models is done by reconciling the analytical modal responses with the experimental modal response

DYNAMIC IDENTIFICATION TECHNIQUES

As a rule, the following steps were used for the modal updating procedure:

(1) discretization of the FE models in homogeneous zones, in order to reduce the number of updating variables

(2) minimization of the error function, by updating the most influential parameters so that the analytical modal model would match the experimental modal model

$$\varepsilon(\mathbf{p}) = \sum_{i=1}^{m}\left[\alpha\left(\frac{f_{ai}(\mathbf{p}) - f_{ei}}{f_{ei}}\right)^2 + \beta\left(\frac{\sqrt{1 - MAC_i(\mathbf{p})}}{MAC_i(\mathbf{p})}\right)\right].$$

MAC is the modal assurance criterion

EARTHQUAKE ENGINEERING & STRUCTURAL DYNAMICS
Earthquake Engng Struct. Dyn. 2017; **46**:2399–2417
Published online 8 May 2017 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/eqe.2910

Amplitude dependence of equivalent modal parameters in monitored buildings during earthquake swarms

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[2]*SATM, School of Aerospace, Transportation and Manufacturing, Cranfield University, Cranfield, UK*

The Seismic Observatory for Structures (OSS)

- The Seismic Observatory for Structures (OSS), founded at the end of the 1990s by the Italian Department of Civil Protection (DPC), is a nation-wide network for the permanent monitoring of the seismic response of more than 100 strategic public buildings in Italy.

- The OSS network aims at providing, in the aftermath of an earthquake, a rapid estimation of the seismic damage suffered by the monitored buildings and, plausibly, by similar neighbouring constructions, helping DPC in planning and managing emergency activities

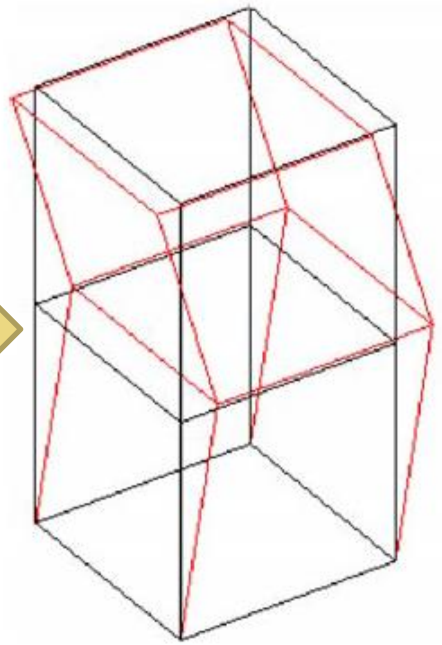
105 strategic buildings

A few dams

Secondary sub-network, comprising 300 buildings

The Seismic Observatory for Structures (OSS)

MONITORING OF STRATEGIC BUILDINGS



MODAL PARAMETER DEVIATION

VS

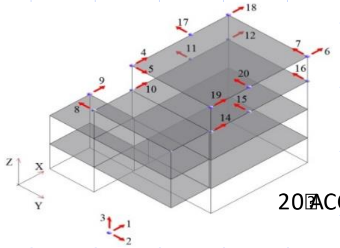
DAMAGE

simple and direct relationships between modal parameter deviations

Practical usability of data collected by the OSS network during seismic events

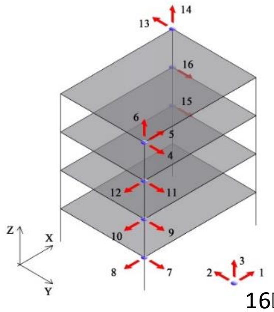
The Seismic Observatory for Structures (OSS)

DESCRIPTION OF THE CASE STUDIES



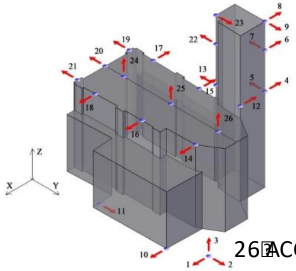
20 ACCELEROMETERS

CITY HALL OF S.ROMANO IN GARFAGNANA



16 ACCELEROMETERS

HOSPITAL OF CASTELNUOVO DI GARFAGNANA



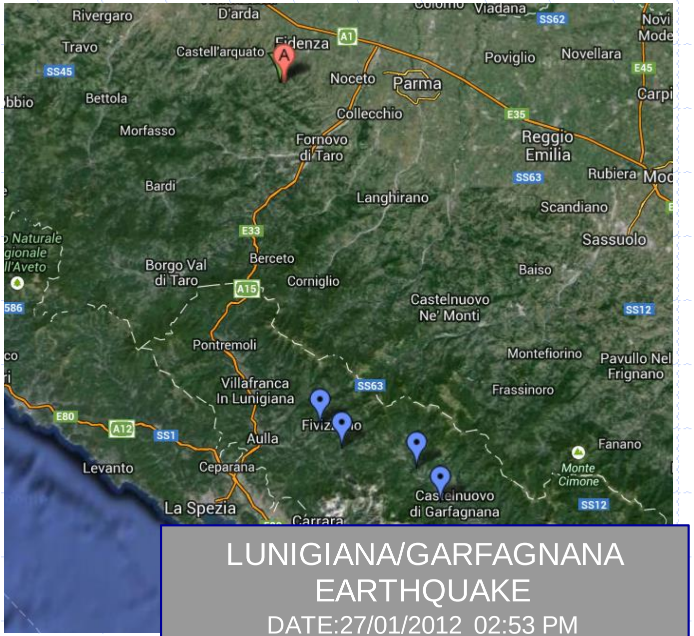
26 ACCELEROMETERS

SENSORS

ReLUIS-DPC 2010-2013

FOR EACH BUILDING:

- FEM MODEL;
- DYNAMIC IDENTIFICATION USING THE ACCELERATION DATA RECORDED DURING SEISMIC EVENTS
- FEM MODEL UPDATING



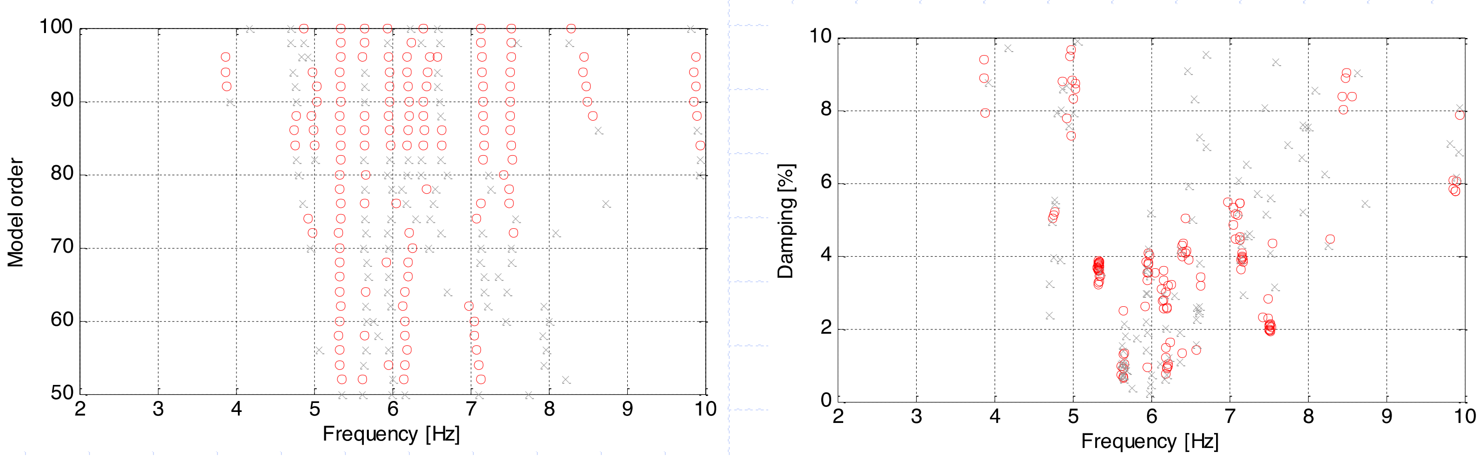
LUNIGIANA/GARFAGNANA EARTHQUAKE
DATE:27/01/2012 02:53 PM
MAGNITUDE:5.4 (RICHTER SCALE)

The Seismic Observatory for Structures (OSS)

IDENTIFICATION ALGORITHM

N4SID algorithm is member of the direct subspace system identification methods family, which estimate the state-space model directly from an arbitrary set of input and output sequences by solving a least square problem.

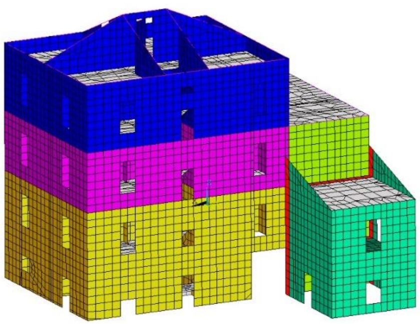
For each data set a state-space system was identified by using an ***input-output methodology*** belonging to the general subspace state-space system 4SID identification family, you can found a detailed description in the works **by Van Overschee and De Moor.** Moreover, an extended review of the theoretical principles of 4SID and its application to support-excited structures has recently been proposed by Kim et al. For the purpose of this research, the specific N4SID implementation of the algorithm was applied.

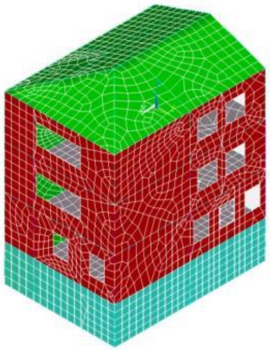


27/01/2012 earthquake: (a) Stabilization diagram ("x": unstable mode; "o": stable mode); (b) Frequency-damping clustering diagram for the SR building.

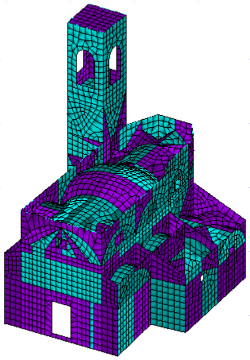
The Seismic Observatory for Structures (OSS)

IDENTIFICATION OF THE CASE STUDIES





- MONO-DIMENSIONAL BEAM ELEMENTS FOR THE REINFORCED CONCRETE FRAME STRUCTURE
- BI-DIMENSIONAL SHELL-TYPE ELEMENTS FOR THE FLOOR SLABS
- LINEAR ELASTIC AND ISOTROPIC MATERIALS



- BI-DIMENSIONAL SHELL-TYPE ELEMENTS
- LINEAR ELASTIC AND ISOTROPIC MATERIALS

Mode	SR	HC	CC
	f [Hz]	f [Hz]	f [Hz]
1	6.7	4.6	2.5
2	7.5	7.0	3.2
3	9.0	8.3	5.4

IDENTIFIED MODAL FREQUENCIES (FROM OSS TESTS, 2000)

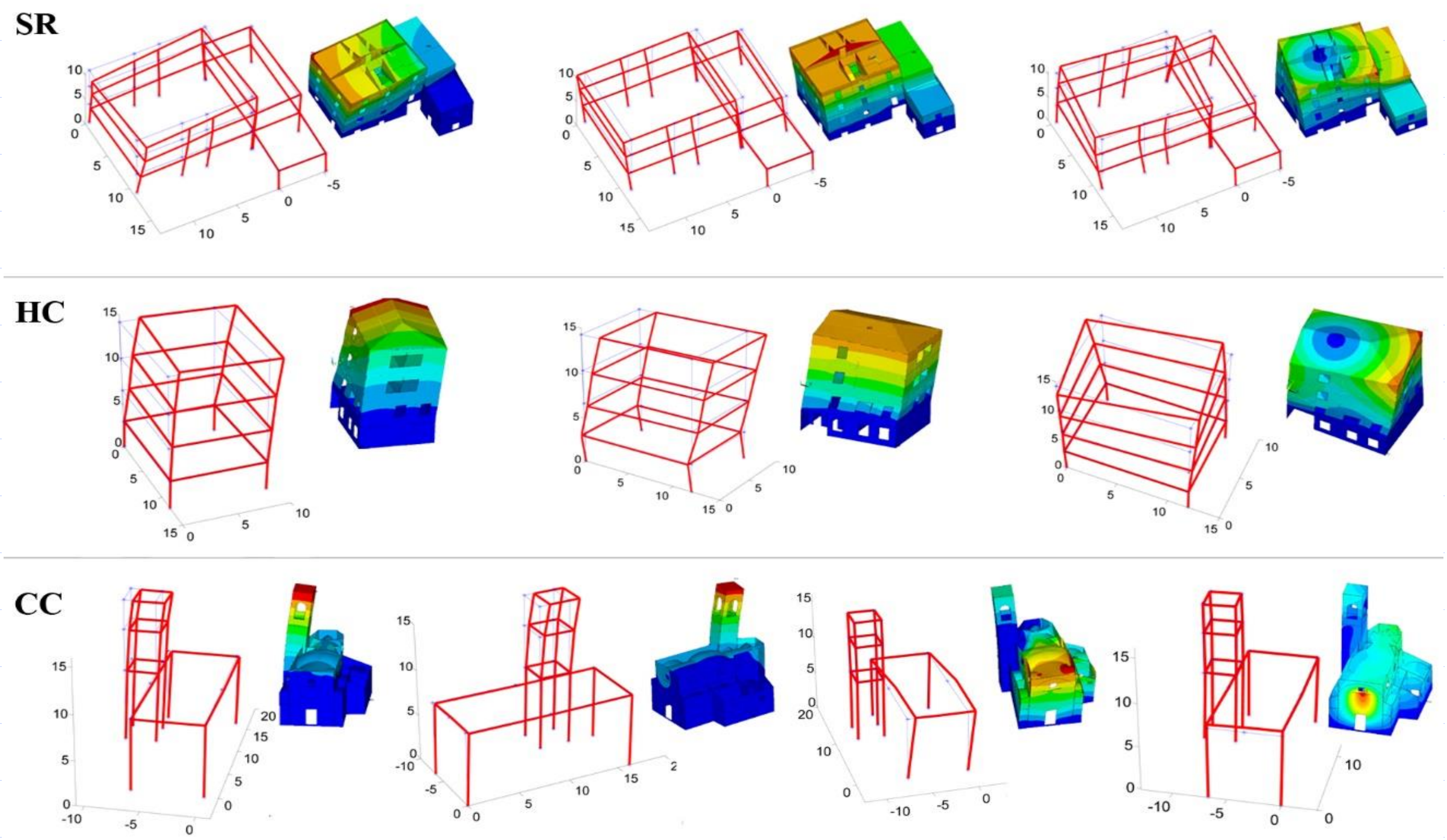
Minimization of the Error

$$e(\mathbf{p}) = \sum_{i=1}^{m}\left[a_i\left(\frac{f_{ai}(\mathbf{p})-f_{ei}}{f_{ei}}\right)^2 + b\,\frac{\sqrt{1-MAC_i(\mathbf{p})}}{MAC_i(\mathbf{p})}\right]$$

$$\mathrm{MAC}(\Phi_1,\Phi_2)=\frac{|\Phi_1^H\Phi_2|^2}{|\Phi_1^H\Phi_1||\Phi_2^H\Phi_2|}$$

The Seismic Observatory for Structures (OSS)

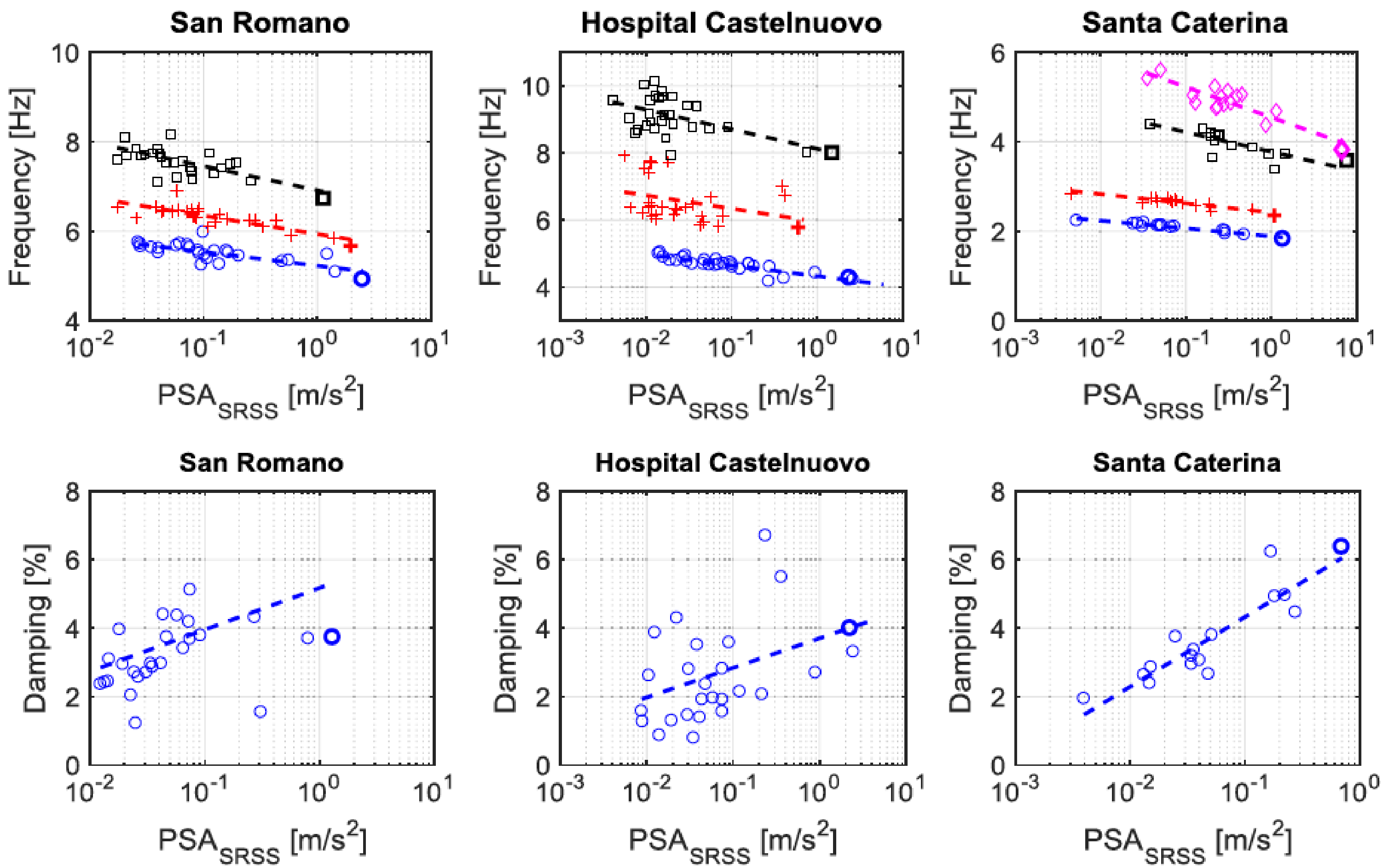
IDENTIFICATION OF THE CASE STUDIES



Identified and numerical mode-shapes

The Seismic Observatory for Structures (OSS)/Cntd

IDENTIFICATION OF THE CASE STUDIES



seismic wandering of the modal frequencies

first mode damping ratios

The Seismic Observatory for Structures (OSS)

IDENTIFICATION OF THE CASE STUDIES

Case		Frequency vs PSA_{SRSS}			Damping vs PSA_{SRSS}		
		θ_0	θ_1	R^2	θ_0	θ_1	R^2
SR	1st mode	5.211	-0.155	0.505	4.936	0.598	0.115
	2nd mode	5.910	-0.181	0.669	5.337	0.983	0.343
	3rd mode	6.796	-0.281	0.439	5.166	0.717	0.270
HC	1st mode	4.330	-0.137	0.785	3.602	0.393	0.168
	2nd mode	6.096	-0.129	0.086	2.546	-0.044	0.006
	3rd mode	8.099	-0.269	0.260	3.062	0.040	0.004
CC	1st mode	1.896	-0.077	0.921	6.428	1.023	0.810
	2nd mode	2.506	-0.072	0.818	4.549	0.550	0.681
	3rd mode	3.955	-0.115	0.623	3.375	-0.696	0.098
	4th mode	4.921	-0.148	0.769	3.398	-0.061	0.024

Because, according to the OSS surveys none of the building was seriously damaged by the seismic swarm, the prevalent cause leading to the variation of modal properties has to be the interaction between the structure and the soil–foundation system.

The Seismic Observatory for Structures (OSS)/Cntd

Secondary School “De- Gasperi-Battaglia”, Norcia, Italy

Built during the 60‘, it was included in the strategic buildings list of OSS and equipped with a specific monitoring system composed by 11 accelerometers (5 uniaxial, 5 biaxial and 1 free field)

The Seismic Observatory for Structures (OSS)

Secondary School "De- Gasperi-Battaglia", Norcia, Italy

The building was retrofitted by dissipative Bracings (BRB)

The Seismic Observatory for Structures (OSS)

Secondary School “De- Gasperi-Battaglia”, Norcia, Italy

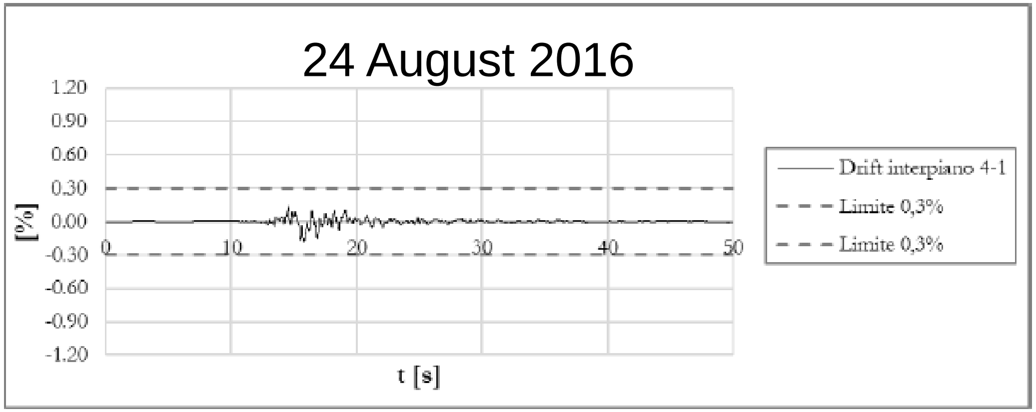
24 August 2016

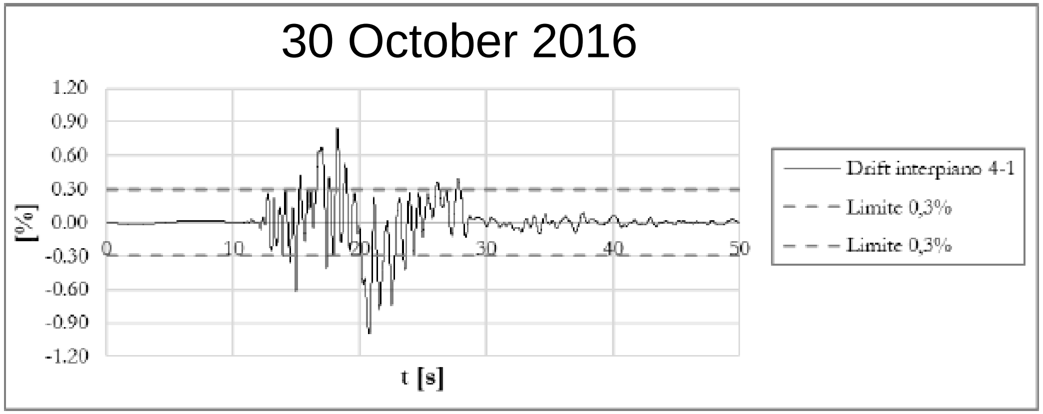
30 October 2016

The building was slightly damaged during the 2016 Central Italy Earthquake, where the damage was mainly developed in the secondary elements

The Seismic Observatory for Structures (OSS)

Secondary School “De- Gasperi-Battaglia”, Norcia, Italy





The monitoring system was also useful to identify the level of damage exceedance in the damaged elements (infills)

A MONITORING SYSTEM BASED ON ACCELERATION AND TILT MEASUREMENTS IN ITALY

Following major earthquakes it is critical to identify **as soon as possible** which building can be used and which cannot in case of **aftershocks**

Damage evaluation is done by **on site visual inspections** but they are **time-consuming** and often **subjective**

Monitoring systems can: i) **limit time** required for damage evaluation: ii) provide immediate information about **usability**; provide **objective data** on structural responses

Emilia earthquake (DPC, 2013)	
Surveys	39000
Usable / **Damaged**	**36%** / **64% (14000** / **25000)**
Economic loss	12.4 billion euro
Economic loss for industry	5.4 billion euro (**3,1 billion** due to a **halt in production**)

STRATEGIES FOR THE ESTIMATION OF STRUCTURAL DAMAGE

- Monitoring systems based on **changes of structural parameters**: **comparison** of structural **dynamic characteristics, e.g. frequency values, mode shapes, modal damping values before** and **after** an earthquake

- For simple structures, the monitoring systems can be based on **structural damage related** to seismic displacement demand, in particular the Interstory Drift Ratio (**IDR**)

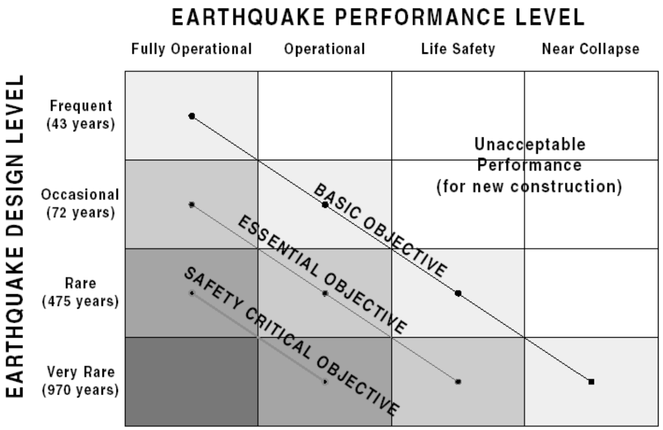
- **Displacement calculations from acceleration data only** present two fundamental issues:
  - i) total loss of information about structural residual displacements, thus about **residual interstory drift (RID);**
  - ii) underestimation of peak deformation, i.e. of the peak interstory drift (PID).

- The authors developed a sensing bar within I-KUBED (http://www.i-kubed.com/) suitable for seismic SHM

A MONITORING SYSTEM BASED ON ACCELERATION AND TILT MEASUREMENTS

- **Goal**: development of a monitoring system that provides **IDR** as a **state variable** basing on a kinematic model and able to:
  - provide floor accelerations;
  - provide real time IDR;
  - provide residual IDR;

  without the need of double integration and, therefore, filtering



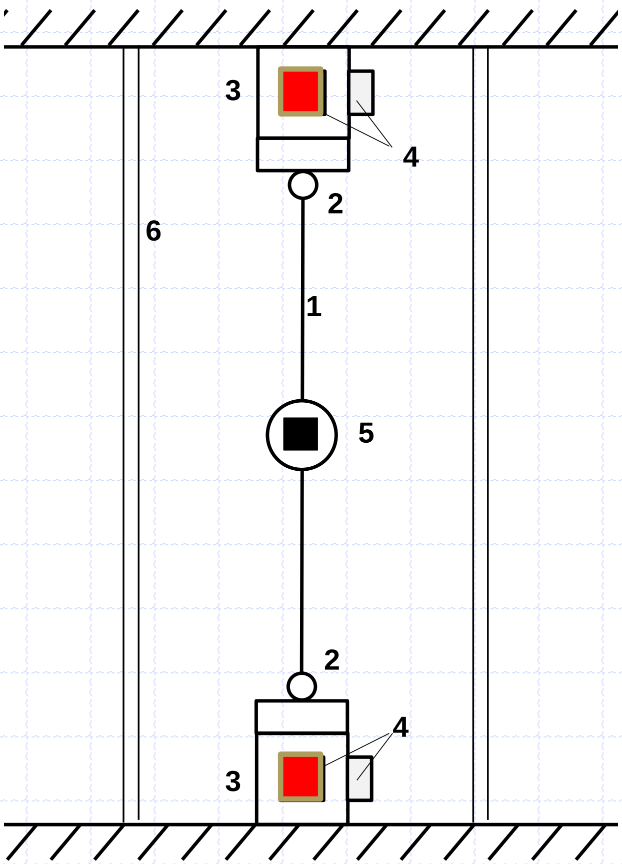
Design Objectives for buildings (SEOAC Vision, 2000) Performance objectives (Bertero & Bertero, 2002)

Table I. Example of quantification of the performance objectives (POs).

EQ performance level	EQ design level Return period (years)	Structural damage		Non-structural damage (1)		Contents damage (1)	
		Local DM index	Cond. fail. prob. (2)	IDI	Cond. fail. prob. (2)	Floor accel.	Cond. fail. prob. (2)
Fully operational	43	0.20	40%	0.003	40%	0.6*g*	40%
Operational	75	0.40	30%	0.006	30%	0.9*g*	30%
Life safety	475	0.60	25%	0.015	25%	1.2*g*	25%
Near collapse	970	0.80	20%	0.020	20%	1.5*g*	20%

(1) For control of non-structural and contents damage, it may be necessary to limit a combination of IDI, floor velocity and floor acceleration (and even jerk for frequent EQGMs).
(2) Conditional probabilities of limit state exceedence given earthquake ground motions with the considered return period occurs.

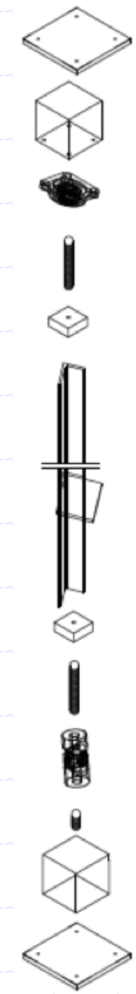
PATENTED sensing bar



1) hinged bar
2) joints
3) accelerometer stand;
4) accelerometer

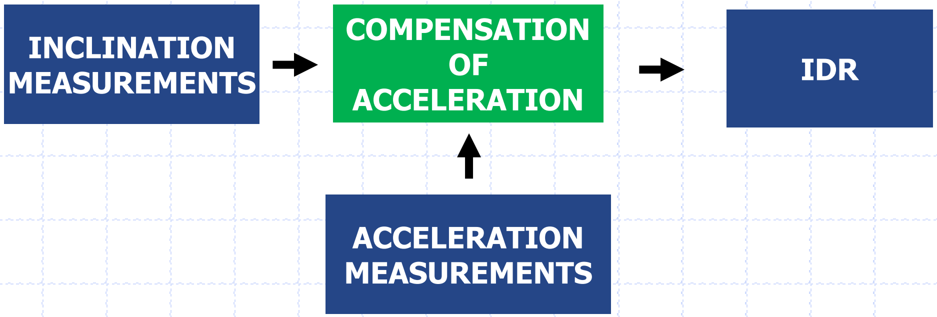
5) Inclinometer

6) Protective case

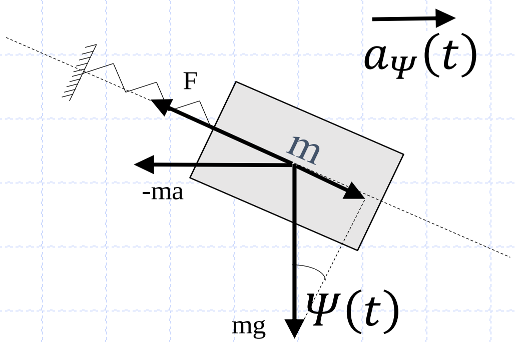


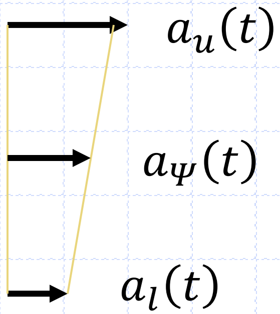
MODEL

- Kinematic model



- Compensation of accelerations applied to the inclinometer





$$\Psi(t) = \sin\alpha(t) + \frac{a_{\Psi}(t)}{g}$$

$$a_{\Psi} = a_u + (a_l - a_u)\frac{(H - H_{\Psi})}{H}$$

SYSTEM PROTOTYPE

2 Storeys

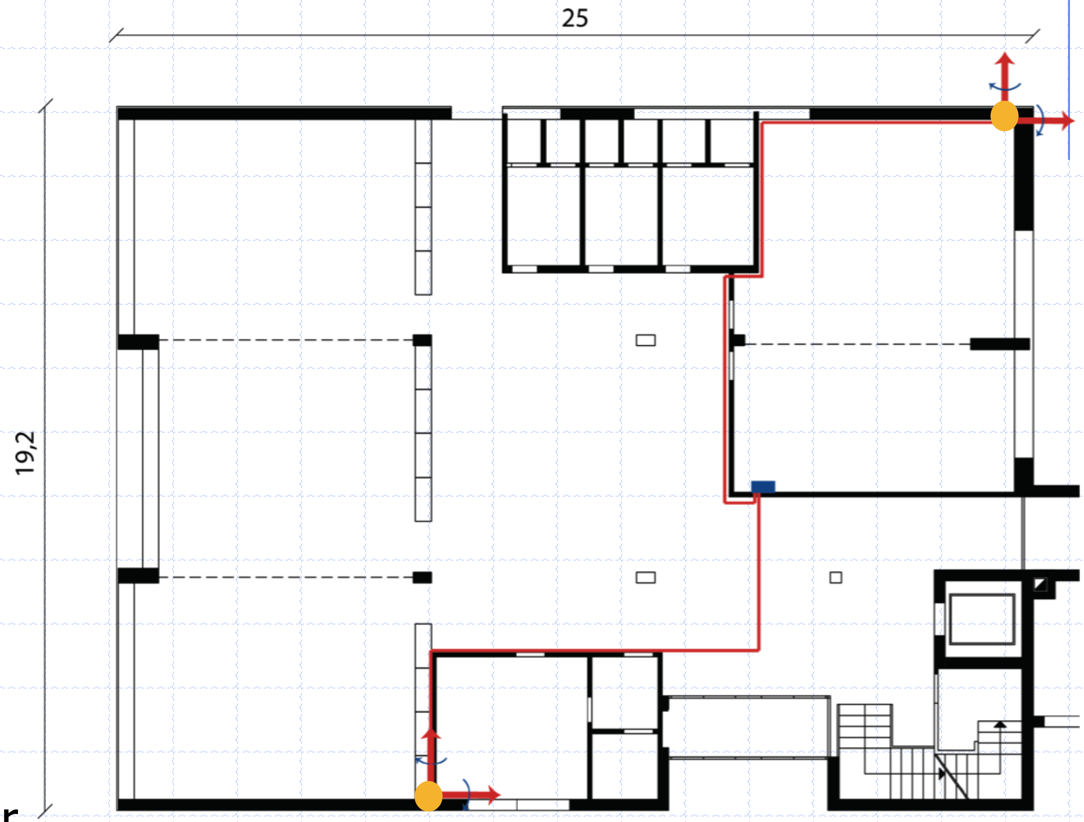
School building (Trentino)

Sensing bars: 2 per floor

Rack

Sensing bar

Wires

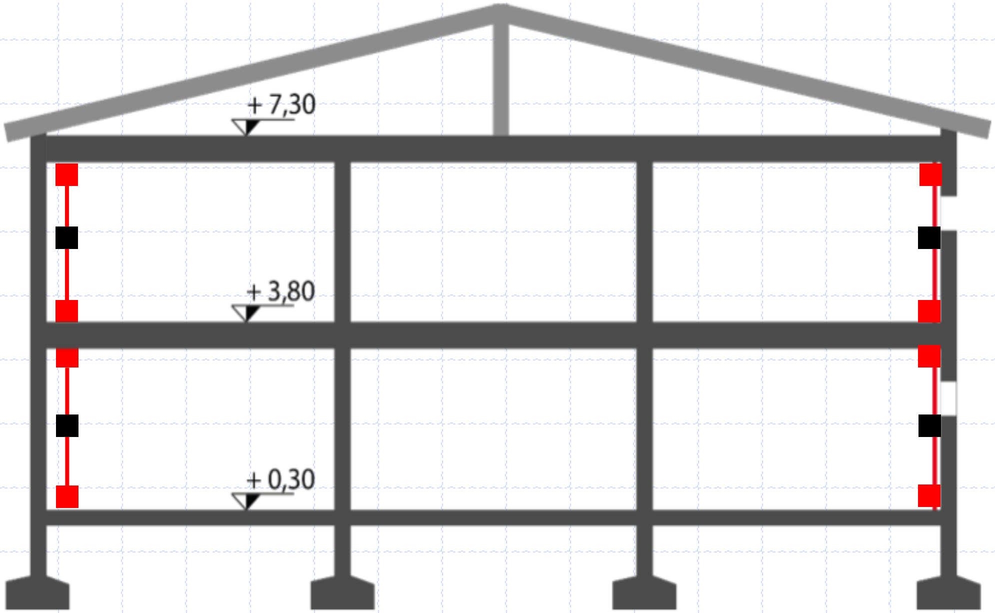


OBSERVATIONS

- **Observations: 1) inclination – range +- 35 mrad**

  2) accelerations - range +- 2 g**;**

- **Number and location: 2 per floor (4** accelerations+ **2** inclinations)

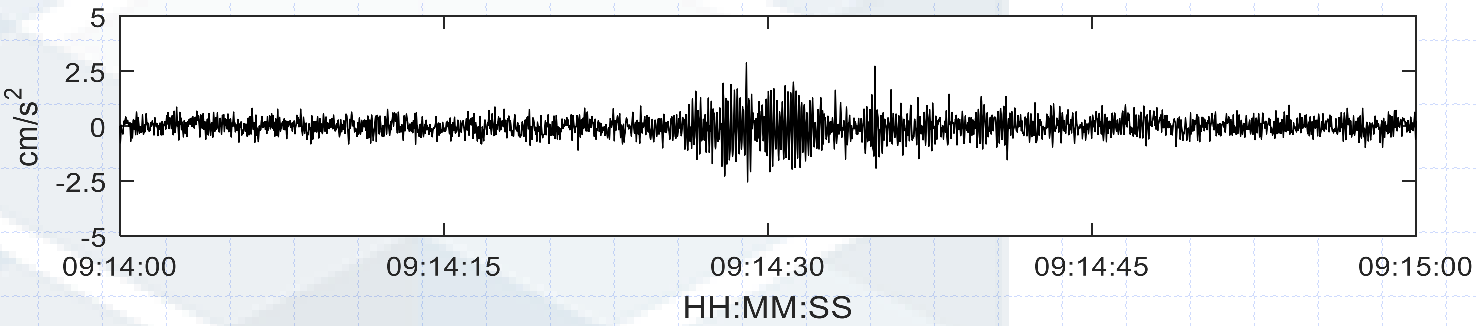


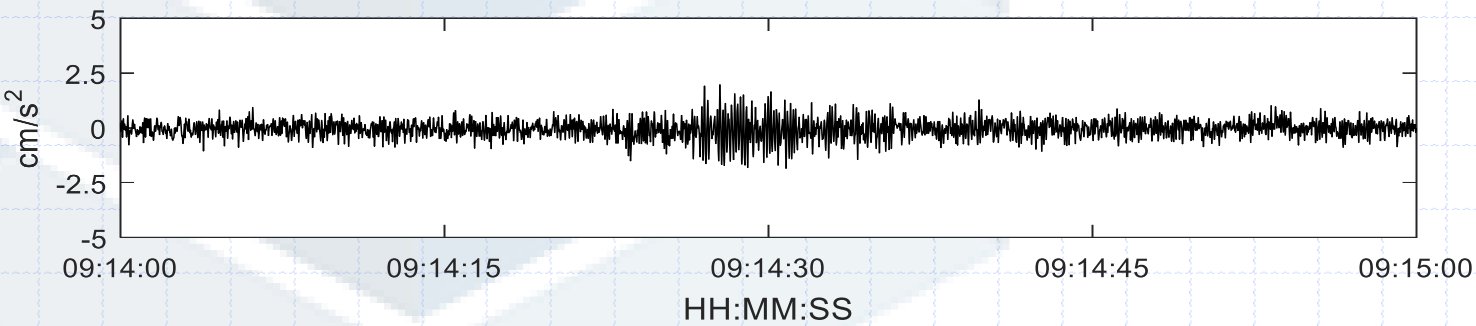
■ **bi-axial accelerometer**

■ **bi-axial inclinometer**

PIEVE DI BONO DATA FOR VALLARSA EARTHQUAKE

Data	Ora	Epicentro	Latitudine (SM)	Longitudine (SM)	Magnitudo	Profondità (km)
09/02/2017	09:14:08	Vallarsa	45.7815	11.1588	3.6	11.3



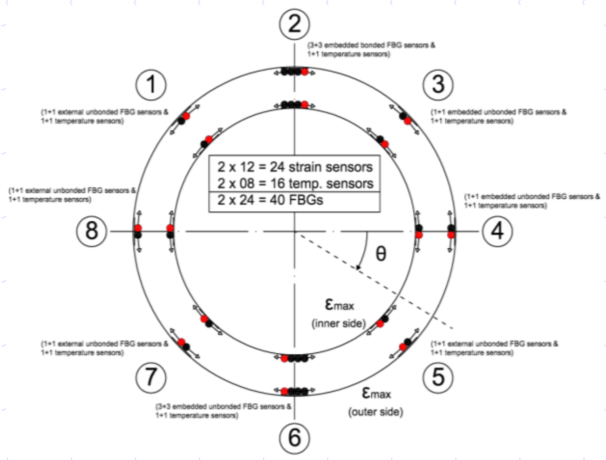


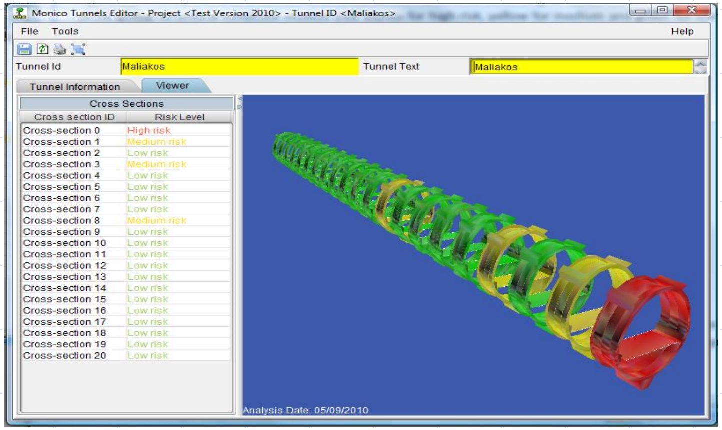
Sistema	Max accelerazione [mg]
Scuola materna Pieve di Bono - Prezzo	3.39

SHM of INFRASTRUCTURE SYSTEMS
FBG SENSOR SYSTEM FOR MONITORING THE EARTHQUAKE RESPONSE OF TUNNEL LINIGS

- The **MONICO EU PROJECT:** to develop a Decision Support System capable of estimating current structural conditions and damage at the monitored areas in tunnel cross-sections as well as the overall structural condition of new tunnels

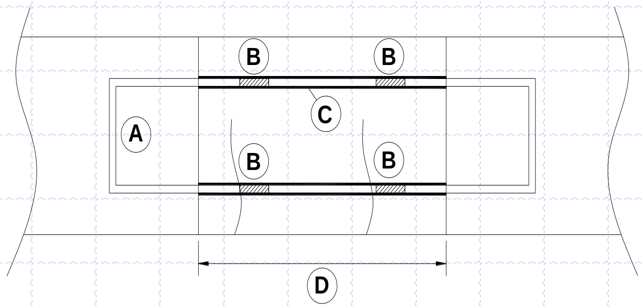
- Investigation of the capabilities of **Fibre Bragg Grating (FBG)** sensors in monitoring the inelastic response of new circular concrete tunnel linings, subjected to seismic events.



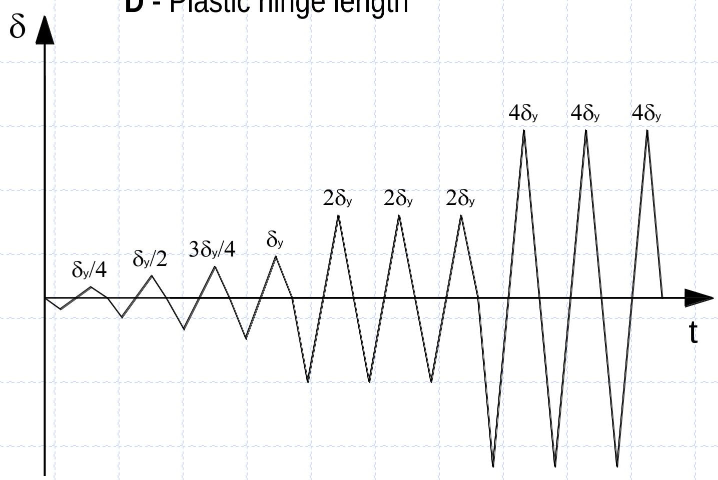


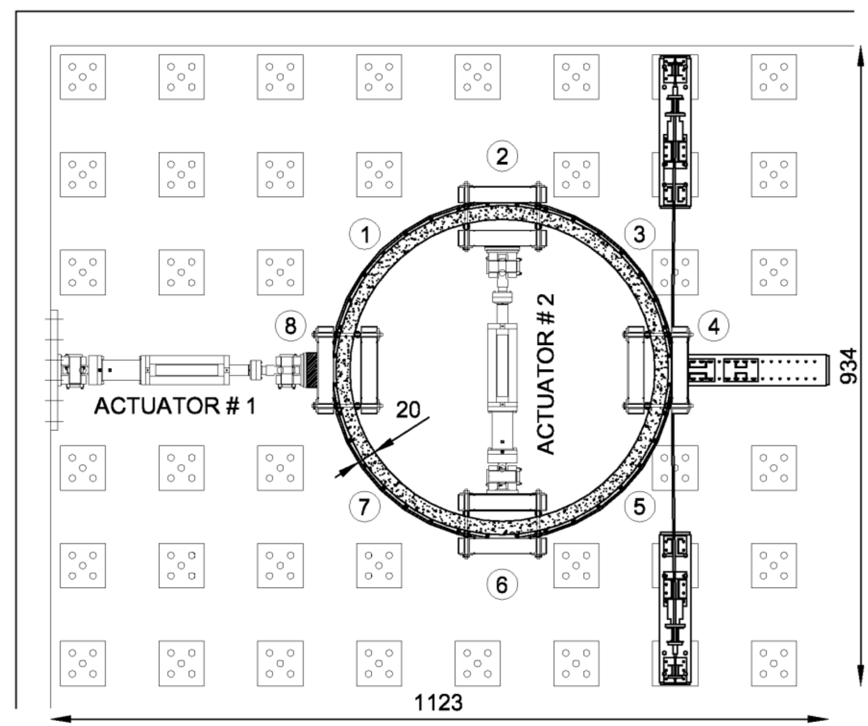
TEST PROGRAMME ON THE SUBSTRUCTURE

- The experimental programme of the specimens was divided into two parts:
  a) tests on substructures of the tunnel lining representative of concrete sections;
  b) tests on a full-scale specimen representative of the whole tunnel lining.

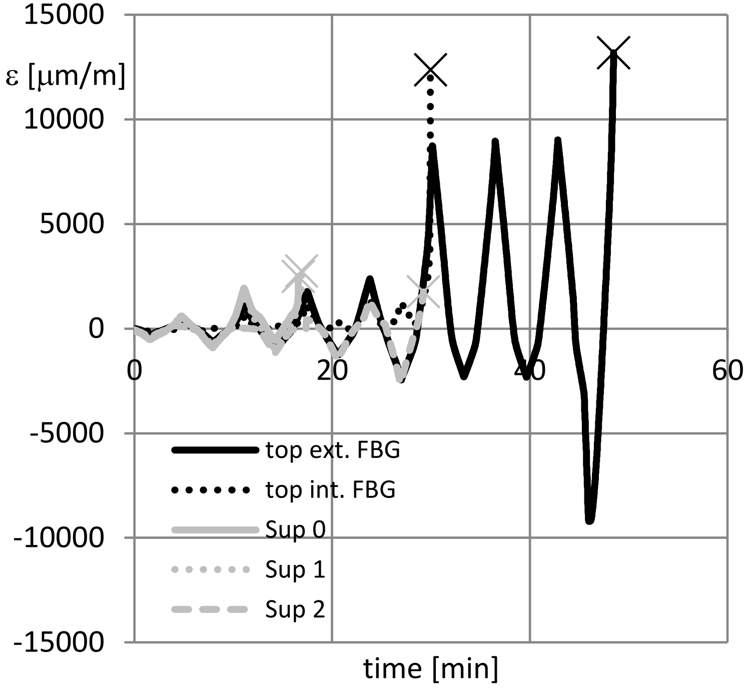


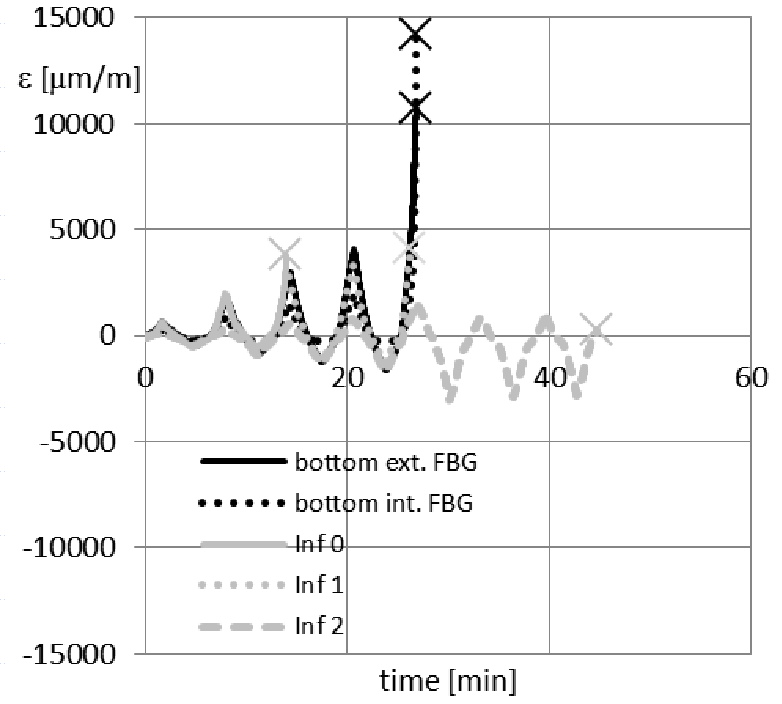
A - Stirrup where FBGs are attached on
B - FBGs
C - Material to prevent bond
D - Plastic hinge length





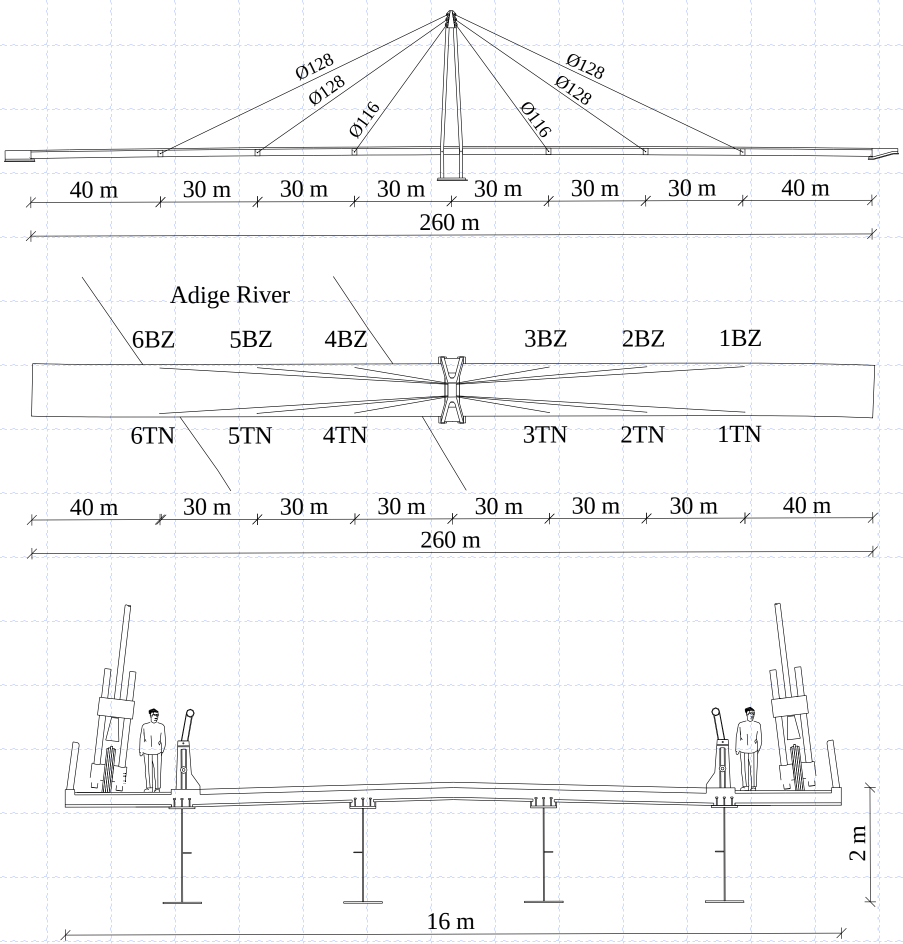
FBG RESULTS AND COMPARISON WITH STANDARD DEVICES





- External FBG fibres approach a maximum value of about 0.6%
- Internal FBG fibres reached a maximum value of 1.2%

SHM OF THE PONTE ADIGE CABLE-STAYED BRIDGE



- **Length**: 260 m overall.
- **Construction**: 2006–2008.
- **Deck cross section**: 4 “I” section steel beams of 2m depth, bearing a 25 cm-thick concrete slab.
- **12 stay cables**, 6 per deck side, anchored every 30 m.
- **Bridge tower**: 4 pylons 45 m tall, located at the center of the span.

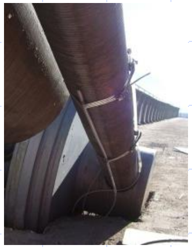
MONITORING REQUIREMENTS AND CONCEPTS

Requirements

- Need for independent measurements of load and strain for each cable
- Cable unloading do not allowed by owner
- Sensors used to acquire measurement during a seismic event

Elongation

- 2m gauge lenght FBG-FOS on each cable
- 0.6m gauge lenght FBG-FOS on three anchorages



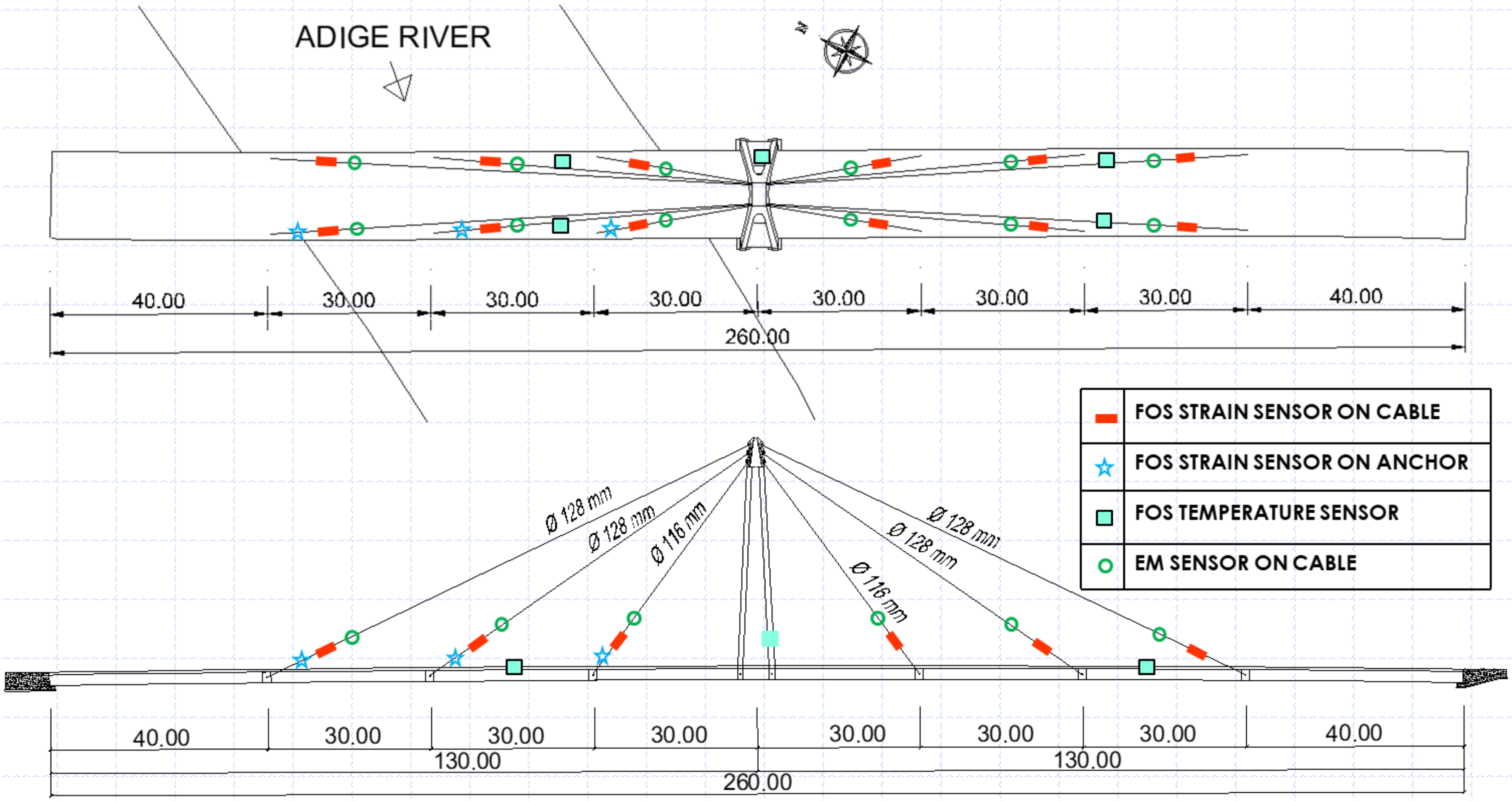
Load

- Elasto-Magnetic sensors on each cable

Temperature

- FBG thermometers and thermistors on each cable
- 4 FBG thermometers embedded in the concrete slab

MONITORING SYSTEM LAYOUT



MONITORING SYSTEM LAYOUT

- Dynamic data acquisition take place whenever required, at any frequency up to 500Hz.
- The system can also be used in the case of an earthquake. The FBG system records the cable elongations during a seismic event.
- The accuracy of the instruments is 5μ strains and 0.5C for temperature, while the range of measurement is ±5‰ strain and -20° C to + 60 ° C for temperature.
- FBG sensors measure only changes of strain between two states: as a result, every measurement defines the difference with respect to the value at the time of installation.

CONCLUSIONS

- The ultimate target of SHM is the ability to monitor a structure throughout its working life in order to reduce maintenance requirements and subsequent downtime, also caused by seismic loadings
- Systems subjected to earthquake excitations may exhibit strong nonlinearities
- We have reviewed some sample cases taken from buildings and infrastructures, and we have analysed some aspects related to the implementation of sensors and SHM systems
- We need SHM systems endowed with DSS based on systems identification and/or non-destructive damage evaluation algorithms to rapidly process data and capable of fulfilling the ultimate goals of estimating capacity and service life of structures and infrastructure systems

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Thank you very much for your attention!

Any question?

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Any question?

Department of Civil, Env. & Mechanical Engineering

University of Trento, Trento, Italy

USE OF MEMS FOR BUILDING MONITORING: MEMSCON PROJECT

11 partners from 7 countries

- Universities
- Companies
- Consultants

C2V concept to volume

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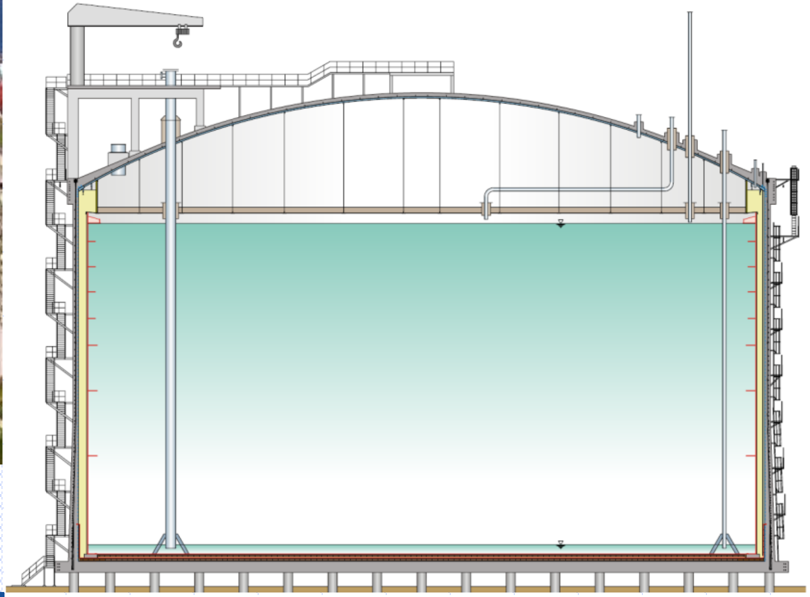
Case Study #3 of SERA – Process plants in Sicily (I)

- ***A liquified natural gas (LNG) plant***

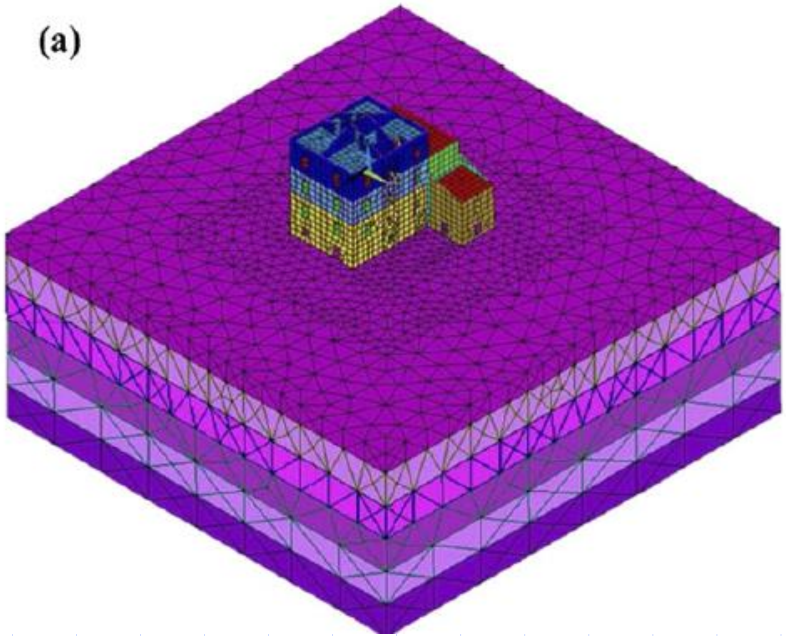


The refrigerated liquified gas (RLG) tank

A liquified natural gas (LNG) plant

The Seismic Observatory for Structures (OSS)

MODEL CONSIDERING SOIL–STRUCTURE INTERACTION AND SEISMIC WANDERING

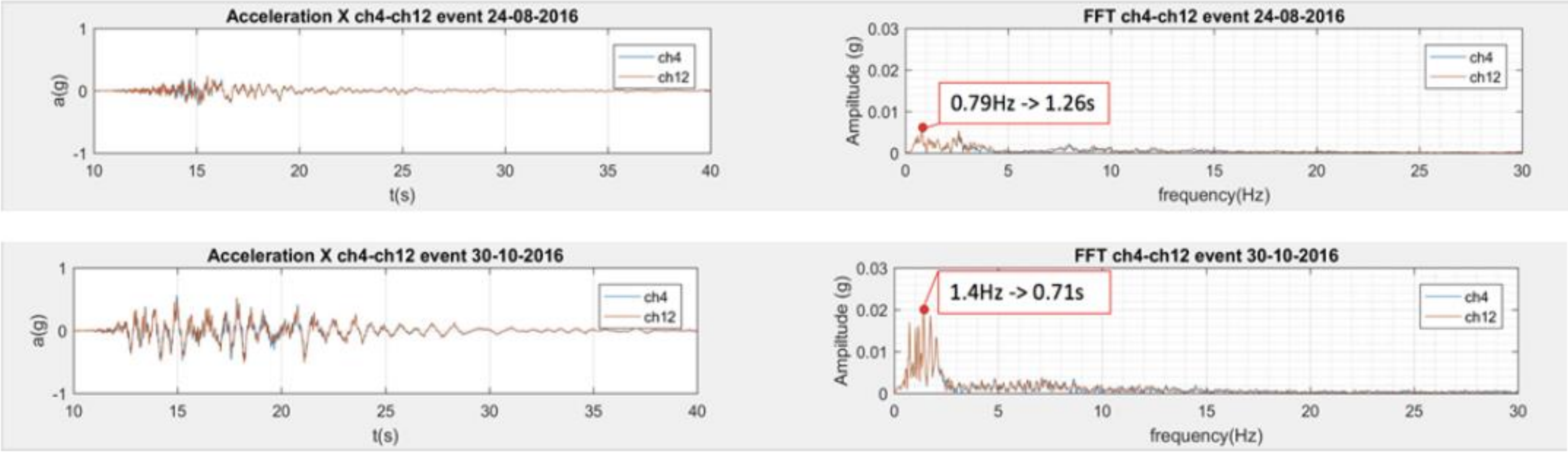


- In a first step, the elastic parameters of the building and of the soil have been calibrated against the experimental frequencies and modal shapes identified from the seismic response (2013)

- In a second updating phase, the identification results for the SR building have been used to perform an automatized procedure of model updating for each different value of experimental frequencies

The Seismic Observatory for Structures (OSS)

Secondary School “De- Gasperi-Battaglia”, Norcia, Italy



Most of the sensors during the earthquake sequence of 24 August and 30 October shown a limited variation of the frequency peak, which clearly demonstrate the limited damage to which the building was subjected to.