Ingenieria Sismica : Evolucion del conocimiento y sus reflejos en las Normativas

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Synopsis

- Soil Mechanics and Soil Dynamics
- Main Geotechnical Earthqu. problems
- Focus on Local Seismic Response (with Code references)
- Overview on RSL in Near-Fault conditions

Geotecnica (Mecanica de suelos)

Granular materials (solid particles, void full of air and/or water, degree of saturation)

Grain size ….
Coarse grained soils
Fine grained soils

Permeability
Coarse soils $k = 10^{0} \div 10^{-2}$ cm/s
Fine soils $k = 10^{-8} \div 10^{-9}$ cm/s

«SANDY soils» **DRAINED** behaviour **«D»**
«CLAYEY soils» **UNDRAINED** behaviour **«ND»**

CIVIL ENGINEERING problems
Deformation (e.g. foundation settlements)
Failure (safety against collapse)

Dinamica de suelos y Ingenieria Geotecnica Sismica

Dynamic behaviour of soils (small, medium and large deformations … failure)

Small deformations – In situ tests (e.g. DH, CH, MASW)

Seismic Codes : Vs (or VR measurement)

Medium-Large deformations – Laboratory tests (not common in practise)

Seismic Codes : no mandatory
(literature curves)

Dinamica de suelos y Ingenieria Geotecnica Sismica

Dynamic behaviour of soils (small, medium and large deformation … failure)

Soil – Seismic Wave dynamic interaction

Small-Medium deformations ***e.g. Local seismic response***
e.g. Foundation Kinematic Interaction

Large deformations ***e.g. Liquefaction (sandy soils)***
e.g. Landslides, foundation collapse

CIVIL ENGINEERING problems
Deformation (e.g. settlements, lateral displacements)
Failure (*PBD : Peformance based design !!!*)

Dinamica de suelos y Ingenieria Geotecnica Sismica

Soil – Seismic Wave dynamic interaction

Small-Medium deformations ***e.g. Local seismic response***

INTRODUCTION

Engineering science develops from the observation of natural phenomena that happen

We try to interpret and simulate them by means of physical and mathematical approaches

Hence we have to check if our theoretical approaches are effective, by means of experimental verification

- **OBSERVATION of Natural Phenomena**
- **THEORETICAL SIMULATION**
- **EXPERIMENTAL VERIFICATION**

Traditional well studied Earthquakes :

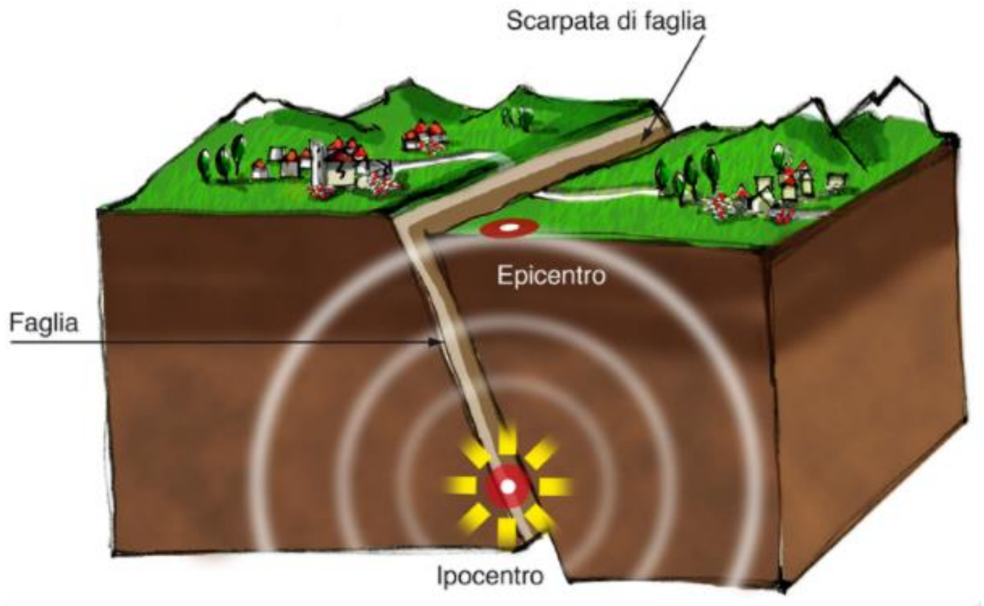
FAR-FAULT Earthquakes (FF)

Earthquake phenomenon

Deep tectonic plates tends to move relatively : High stress accumulation !

When the stresses reach a «limit» value, a failure phenomen takes place.

The released energy propagates as seismic waves, from the focus all over around, even towards the free surface: **EARTHQUAKE** !!!



The source fault is sometimes visible on the surface.

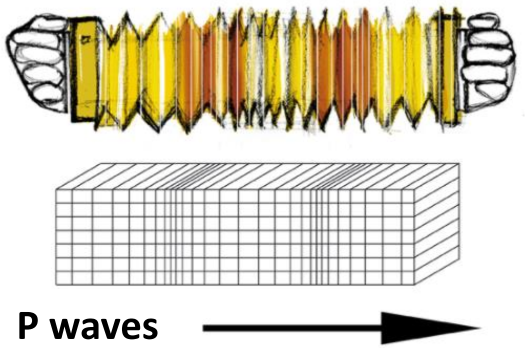
Seismic waves propagation

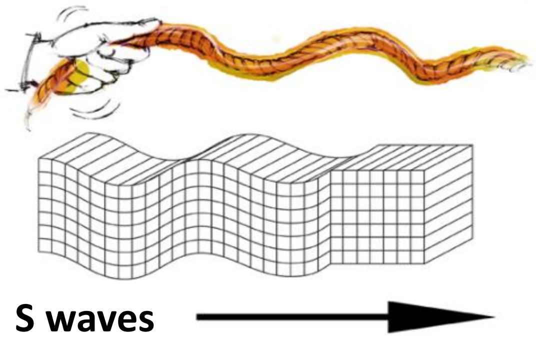
body waves

Onde P *Primae*: vibration in the direction of propagation

Onde S *Secundae:* vibration in the direction orthogonal to the direction of propagation

acordeòn

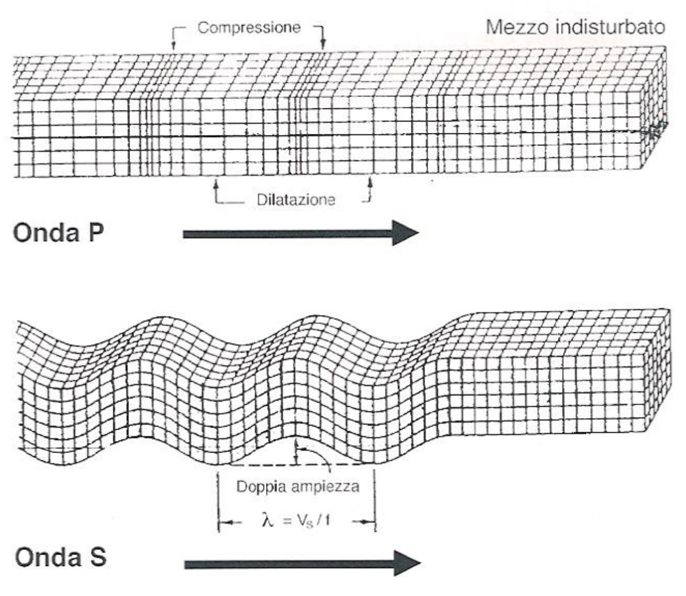




- **P waves are faster than S waves (about 1.7 times).**
- **When the P and S waves reach the surface, they generate Superficial waves.**

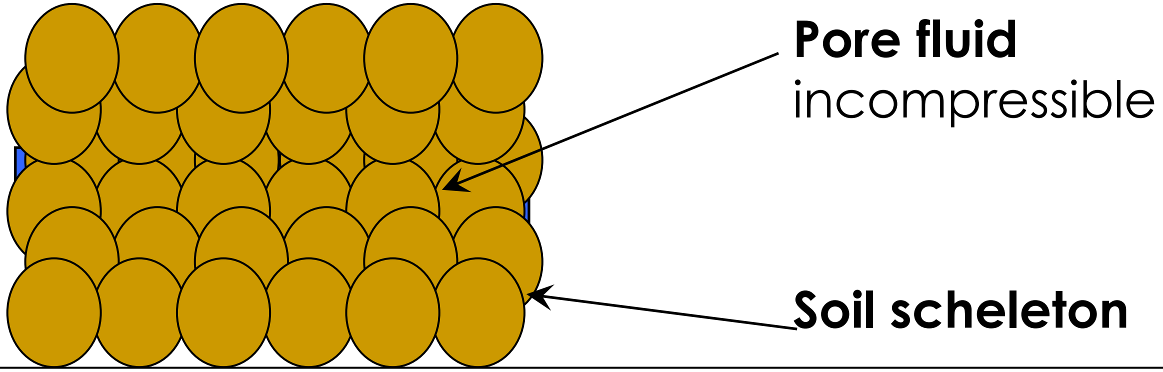
P and S waves

- Earthquake and sesimic waves
- **Moto sussultorio/ondulatorio**
- **S waves and shear stiffness Go**



➢ Measurement methods (geophisical and geotechnical)

➢ Saturated soil



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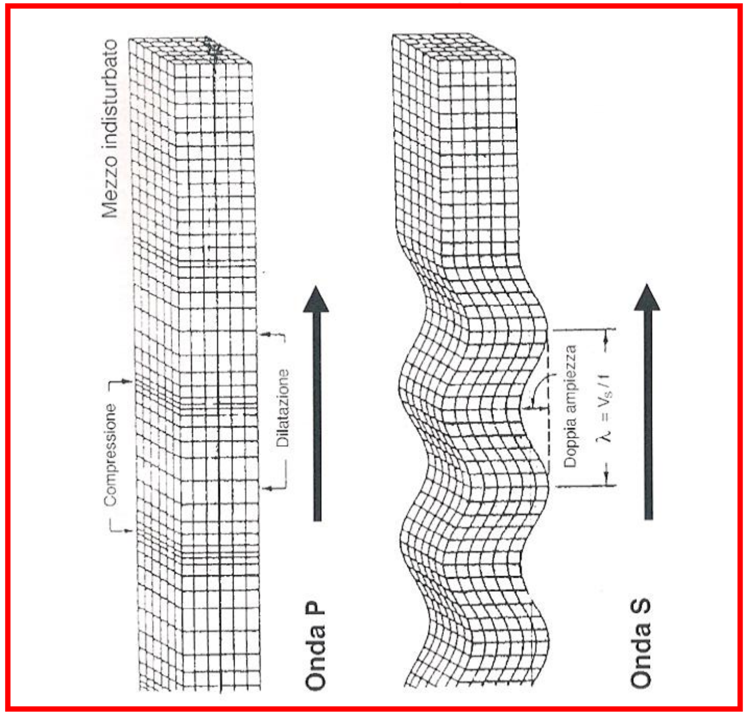

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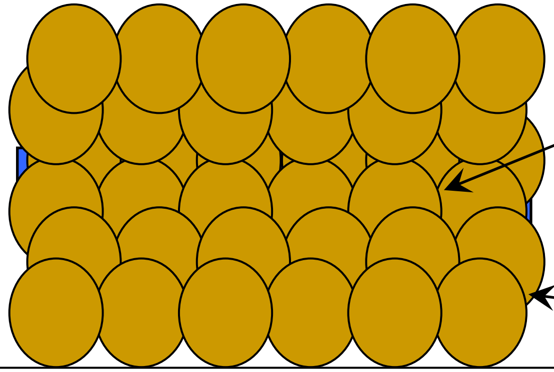
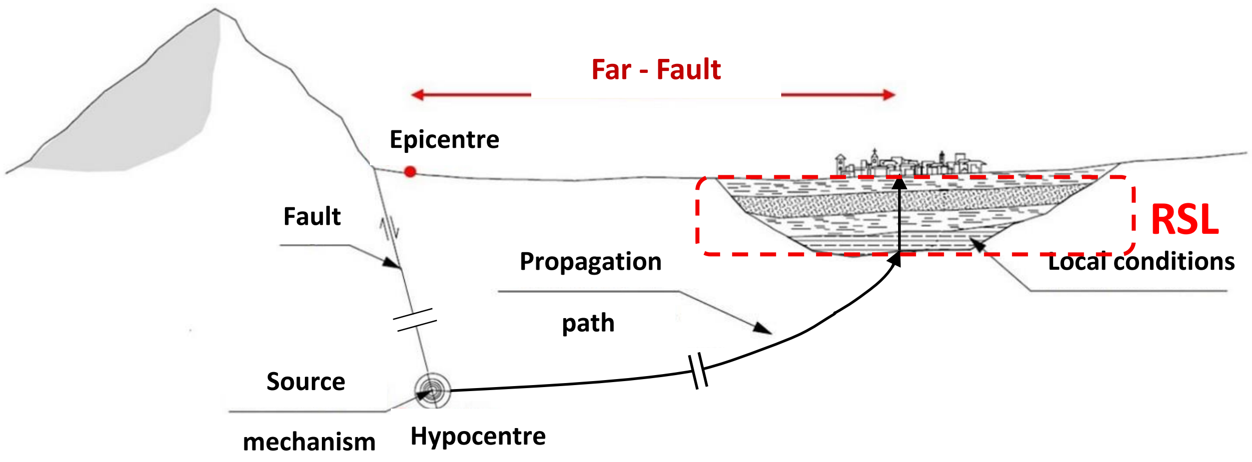


FAR-FAULT condition

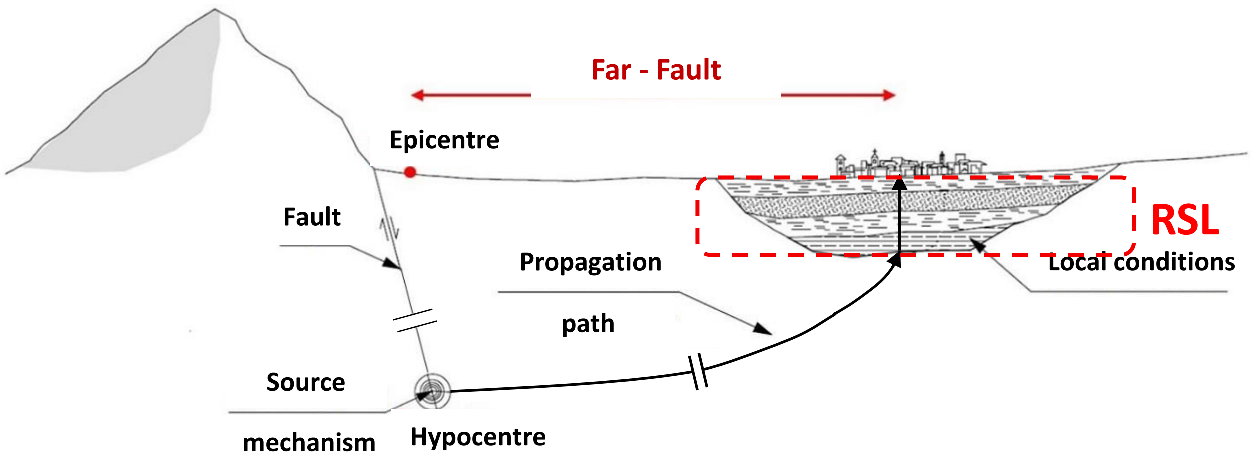
FAR FIELD



- ❖ P and S waves emerge on the surface with vertical propagation direction
- ❖ P waves arrive first (vertical earthquake), S waves arrive later (undulatory earthquake)
- ❖ **Vertical accelerations rather smaller than the horizontal ones**
- ❖ Main frequency content - P waves: 5-10 Hz , S waves: 2-5 Hz

FAR-FAULT condition

F A R F I E L D

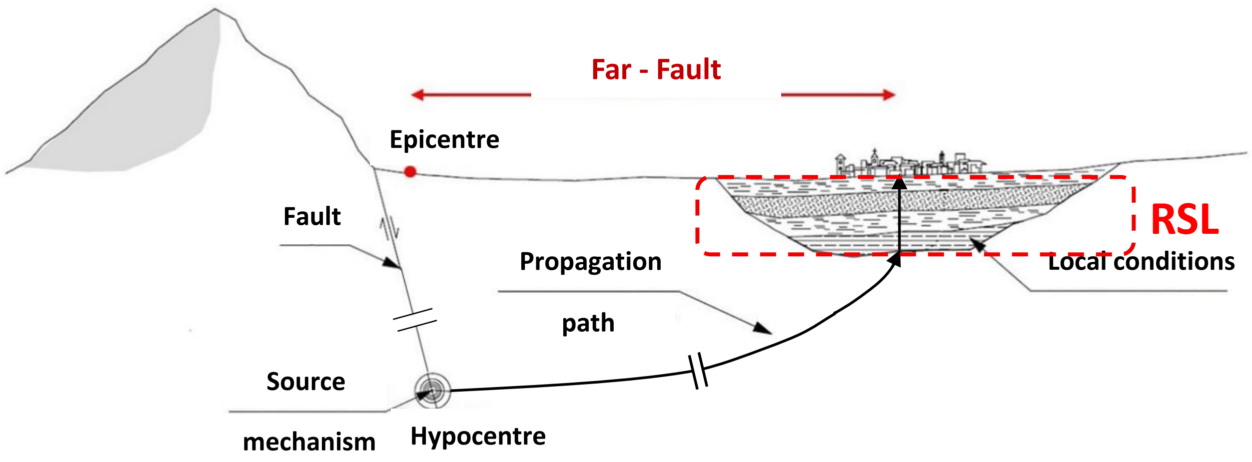


In traditional seismic engineering studies, therefore, the earthquake is schematized as:

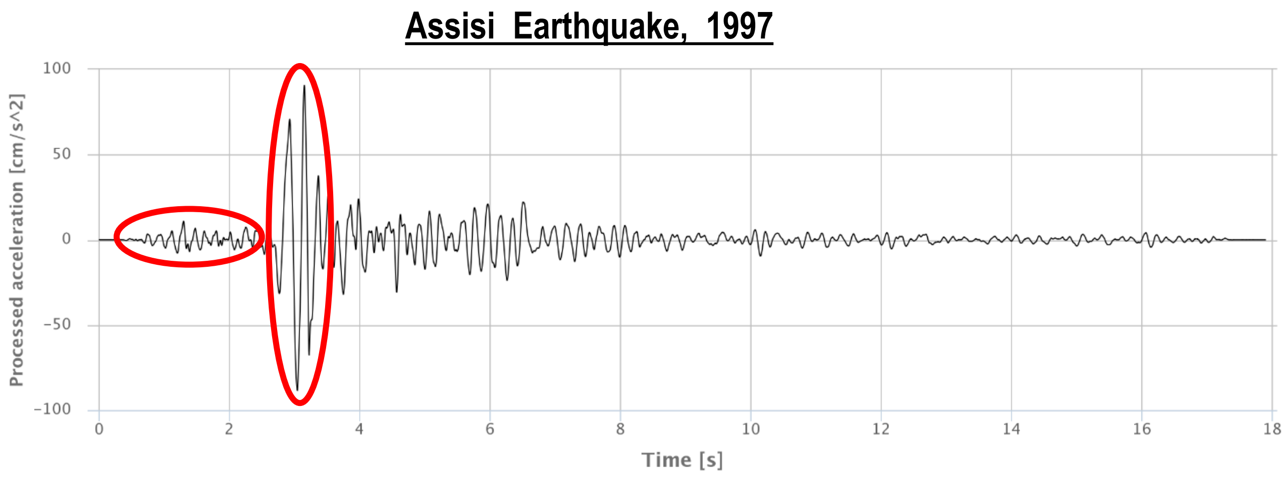
- **vertical propagation of only S waves**
- **the soils are essentially characterized by their G shear stiffness (and horizontal period T)**
- **the actions on the structures are exclusively horizontal actions**

FAR-FAULT condition

F A R F I E L D



Seismic Code: This is the kind of earthquake that, up to now, is accomplished in all the National and International Codes !

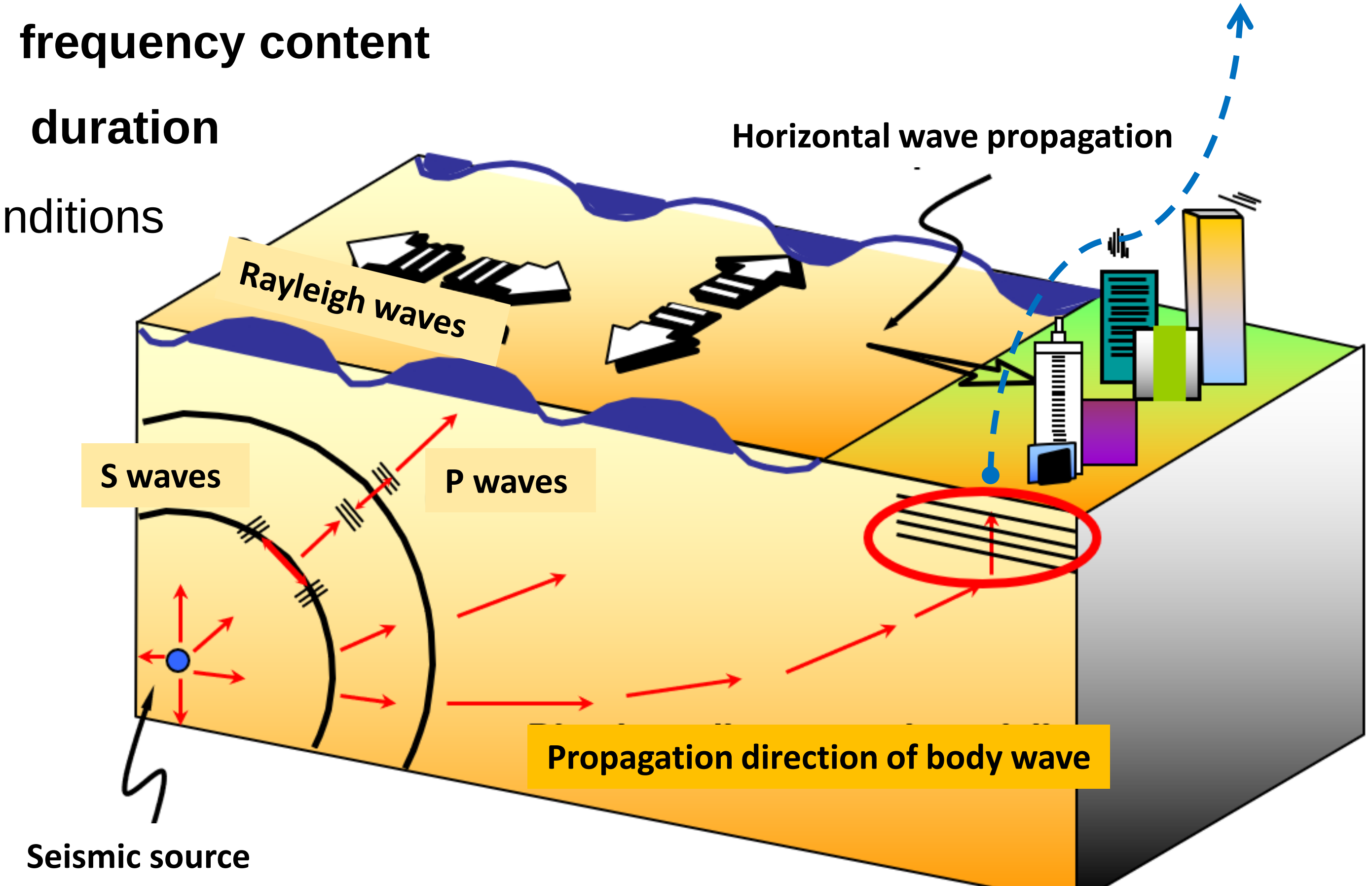

Assisi Earthquake, 1997
Processed acceleration [cm/s^2]
100
50
0
-50
-100
0
2
4
6
8
10
12
14
16
18
Time [s]

Local Seismic Response (*always in Far-Fault conditions*)

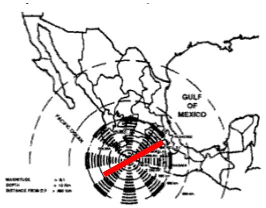
Modification of :
- **amplitude**
- **frequency content**
- **duration**

due to local soil conditions

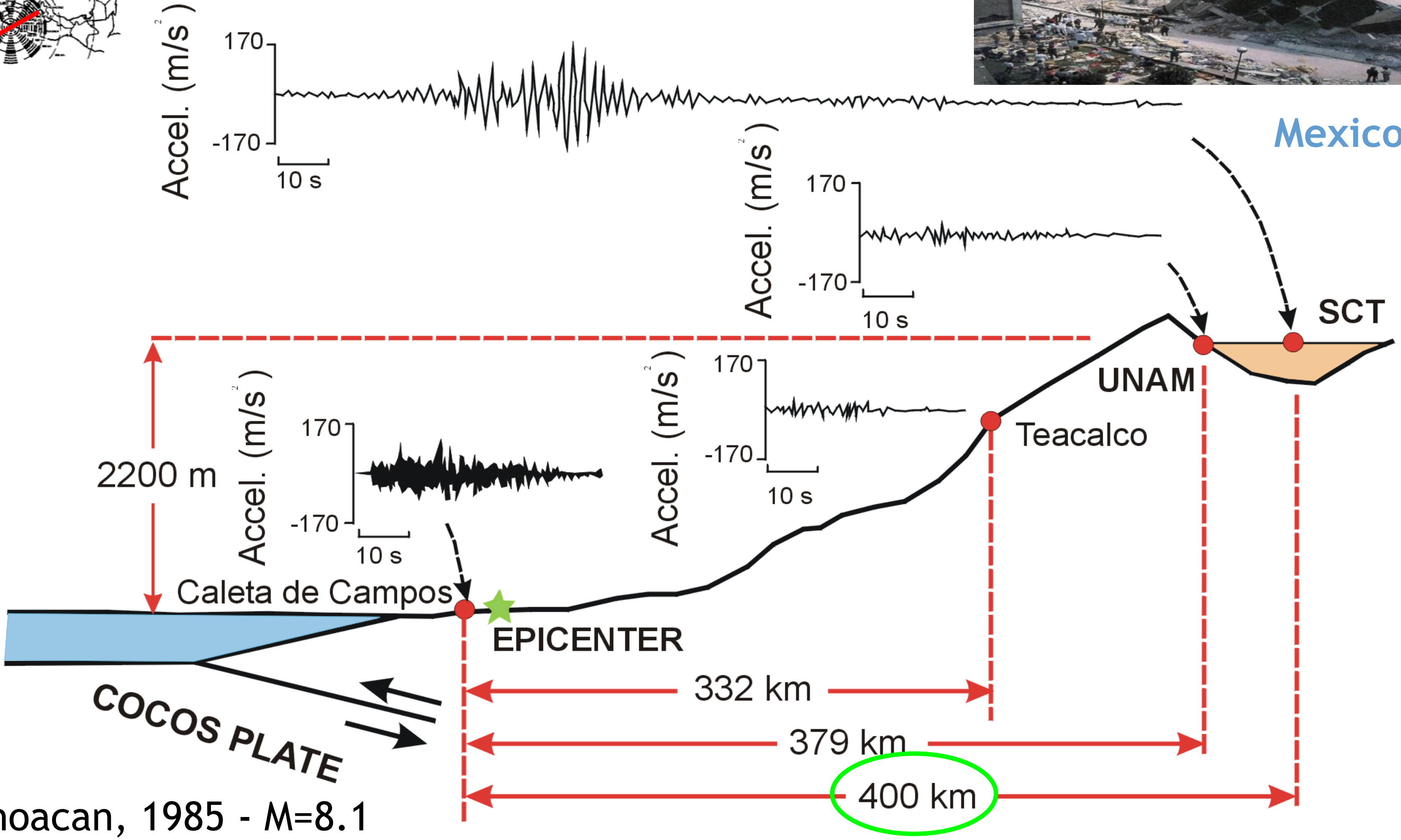
Microzonation



LOCAL SEISMIC RESPONSE :
Experimental evidence



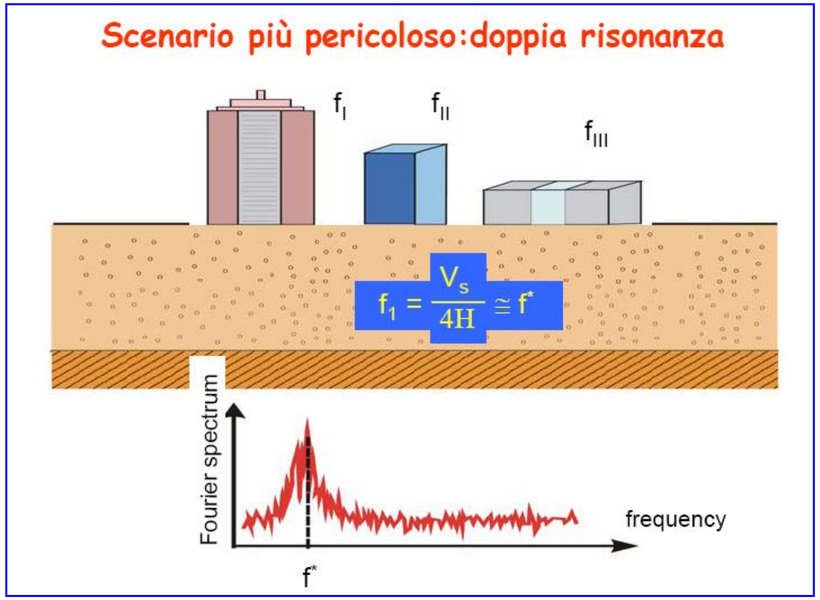
Mexico City

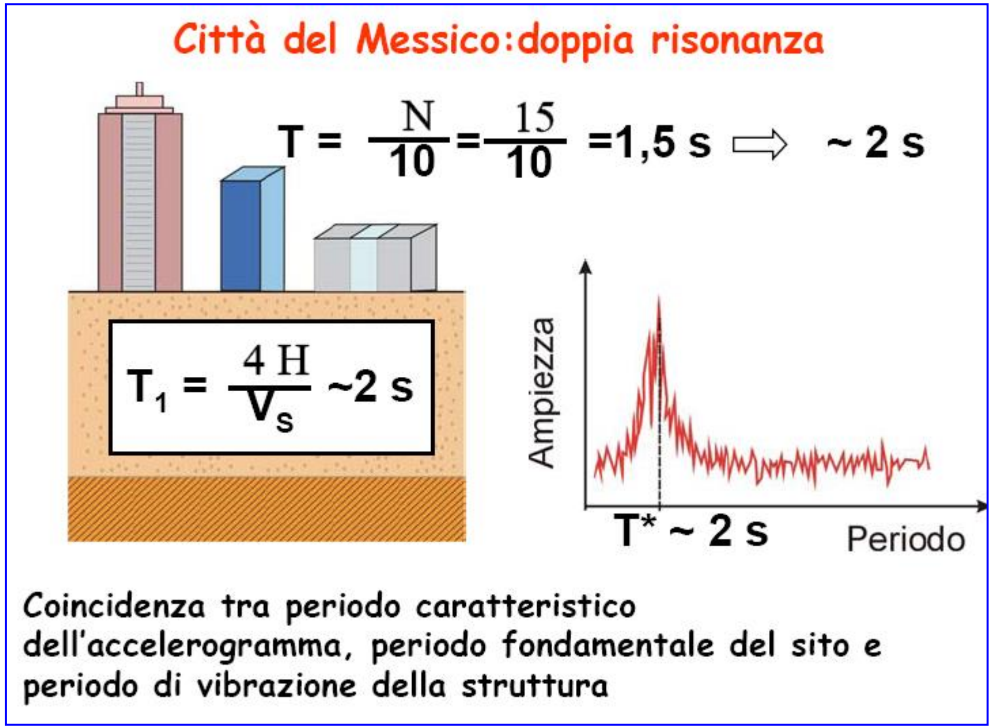


Michoacan, 1985 - M=8.1

RESONANCE Phenomena

Seismic waves – soil - structure Resonance

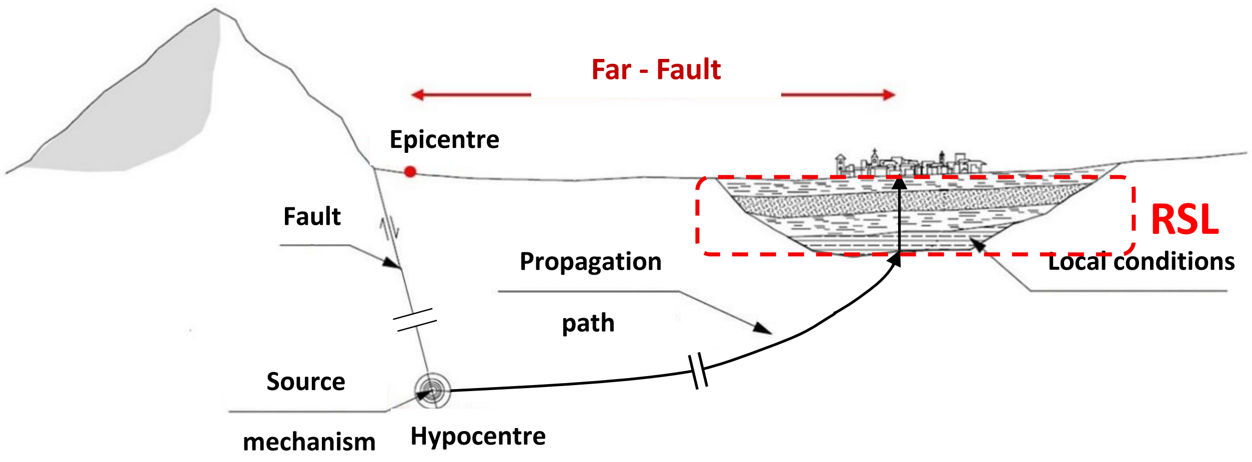




Seismic Code: "T" is always the main horizontal period of the structure !

SEISMIC CODES: Evaluation of the Local Seismic Response

F A R F I E L D

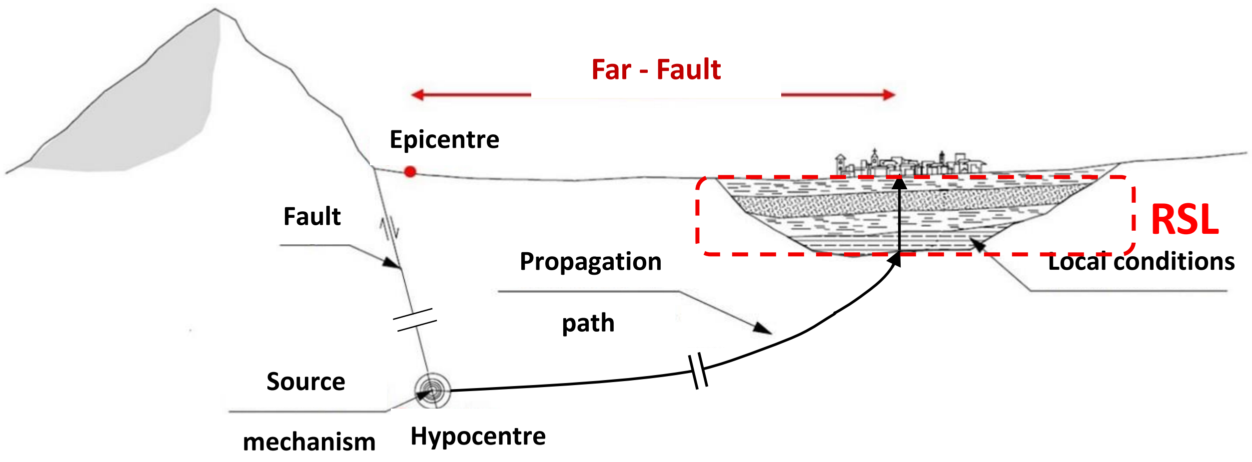


True RSL – Analysis of propagation of vertical SH waves, coming up from the bedrock (or a stiff soil with Vs ≥ 800 m/s)

Simplified RSL - Amplification factors Ss for different soil categories (5+2), based on subsoil equivalent shear wave velocity

SEISMIC CODES: Evaluation of the Local Seismic Response

F A R F I E L D



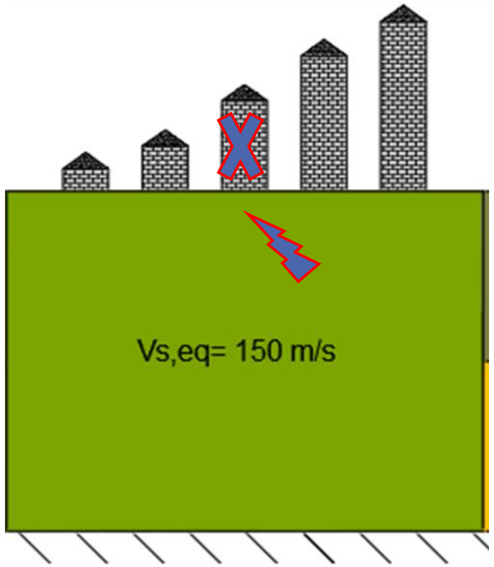
Simplified RSL : Two main observations

FIRST - Soil categories should not be based on $V_{S,30}$ but on $V_{S,eq}$ when the bedrock is within the first 30 m (see NTC2018)

SECOND - Soil categories are valid only for deposits with <u>stiffness constant or incresing with depth</u> (NEGLECTED IN THE PRACTICE)!!!

Effect of Soil Stiffness sequence for three subsoils having the same $V_{s,30}$

$$V_{S,eq} = \frac{H}{\sum \frac{H_i}{V_{S,i}}} = 150\,\frac{m}{s}$$



f_H=1.25 Hz

$T_H = 4H/V_S = 0.80$ s

N_{piani}=8

Effect of Soil Stiffness sequence for three subsoils having the same $V_{s,30}$

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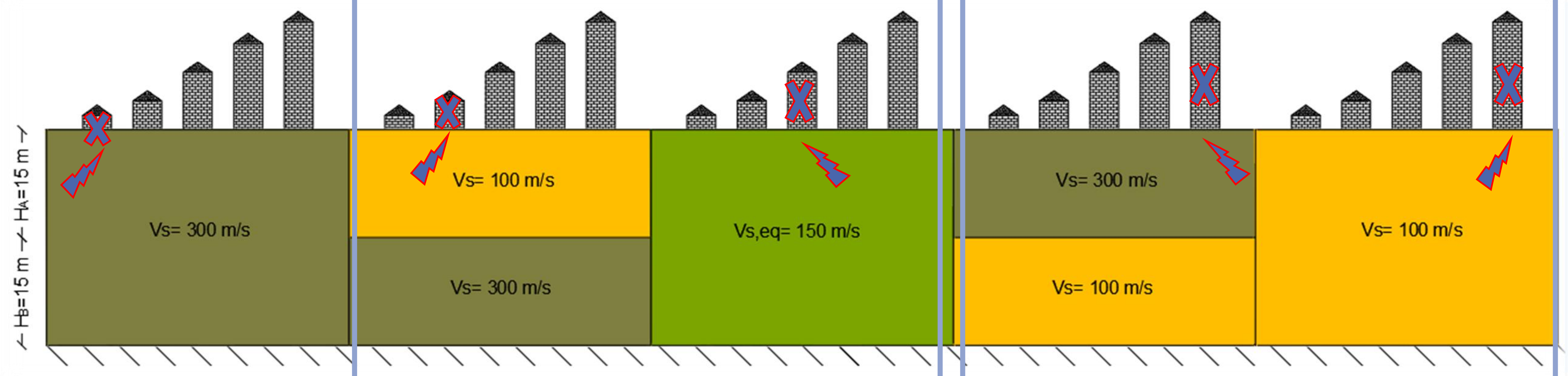


f_H=2.50 Hz	f_H=1.47 Hz	f_H=1.25 Hz	f_H=0.89 Hz	f_H=0.83 Hz
T_H=0.40 s	T_H=0.68 s	$T_H = 4H/V_s$ = 0.80 s	T_H=1.12 s	T_H=1.20 s
N_{piani} = 4	N_{piani} ~ 7	N_{piani}=8	N_{piani} ~ 11	N_{piani}=12

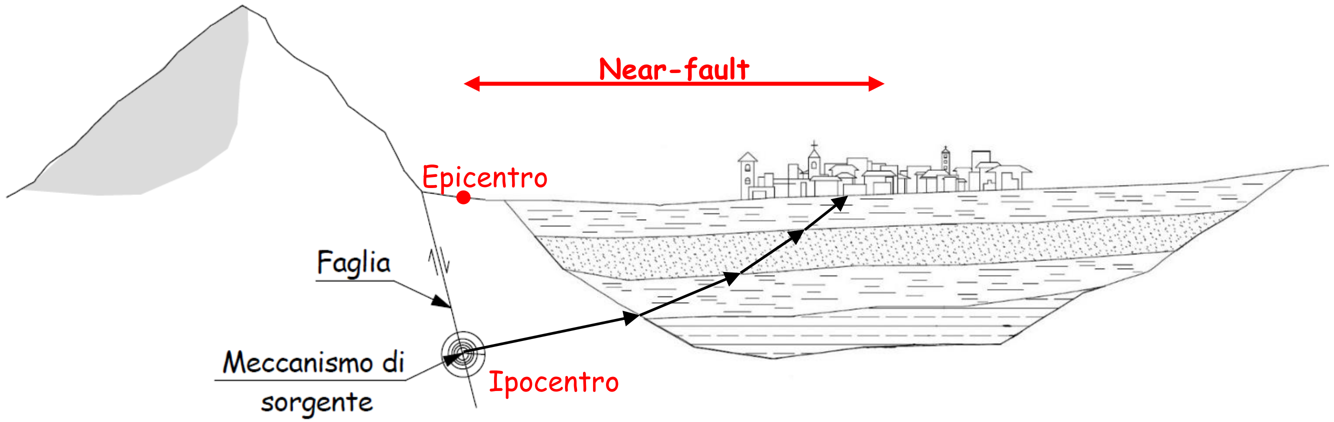
Traditional well studied Earthquakes,

accounted for in national and international seismic codes :

FAR-FAULT Earthquakes (FF)

What happens in

NEAR-FAULT condition ???



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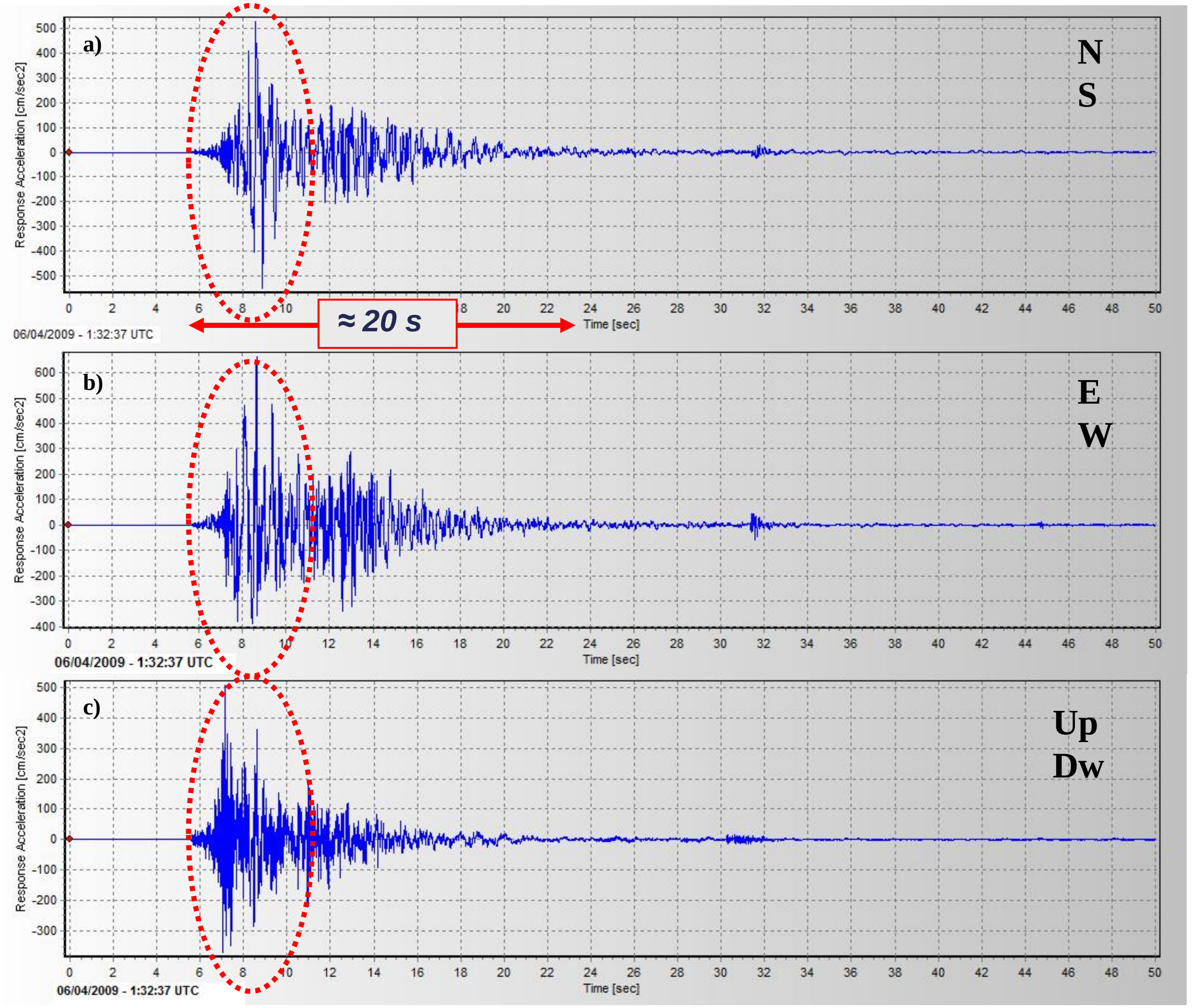
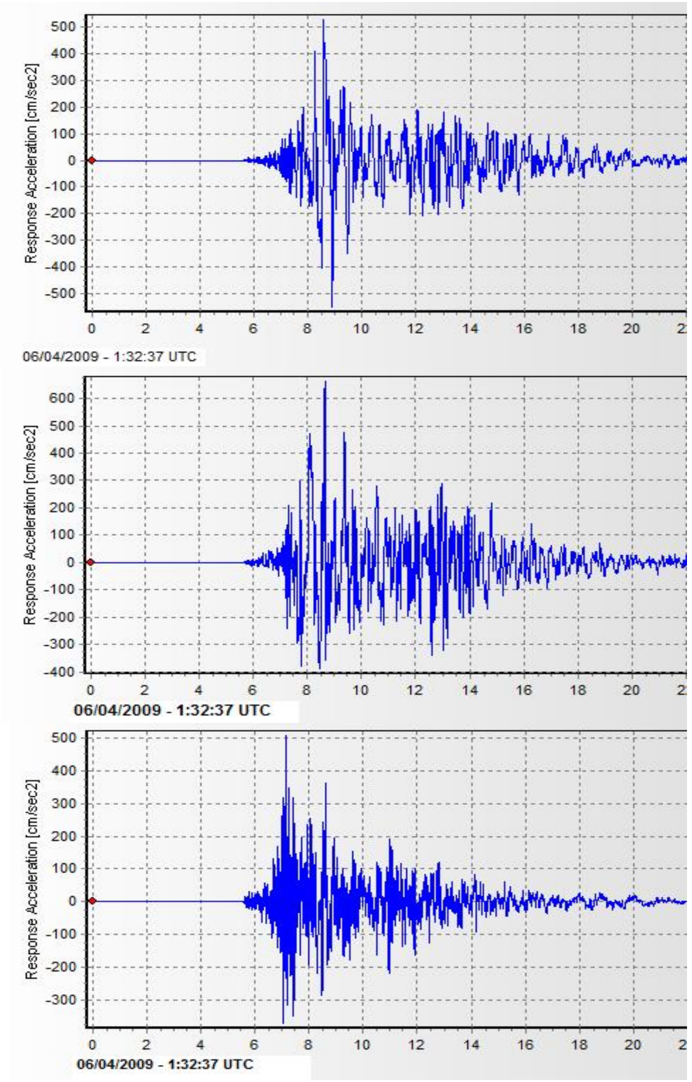
- **EXPERIMENTAL VERIFICATION**

L'Aquila, 2009 April 6

L’Aquila Earthquake, 2009: Time Histories of acceleration at AQV *(42.377N;13.344E)*
Station epicenter distance 4.8 km





April 6, 2009 L'Aquila earthquake

NEAR-FAULT EARTHQUAKES

STRUCTURAL DAMAGE

2009 L'Aquila Earthquake

Examples of Damage to due to high vertical component of ground motion

L'Aquila 2009 – Residential buildings with damage due to high vertical seismic actions

2009 L'Aquila Earthquake

Examples of Damage to due to high vertical component of ground motion

L'Aquila 2009 – Residential buildings with damage to bow-windows under high vertical seismic actions

2009 L'Aquila Earthquake

Examples of Damage to due to high vertical component of ground motion

L'Aquila 2009 – Residential buildings with damage to intermediate floors <u>because of their higher frequency vibration modes</u>

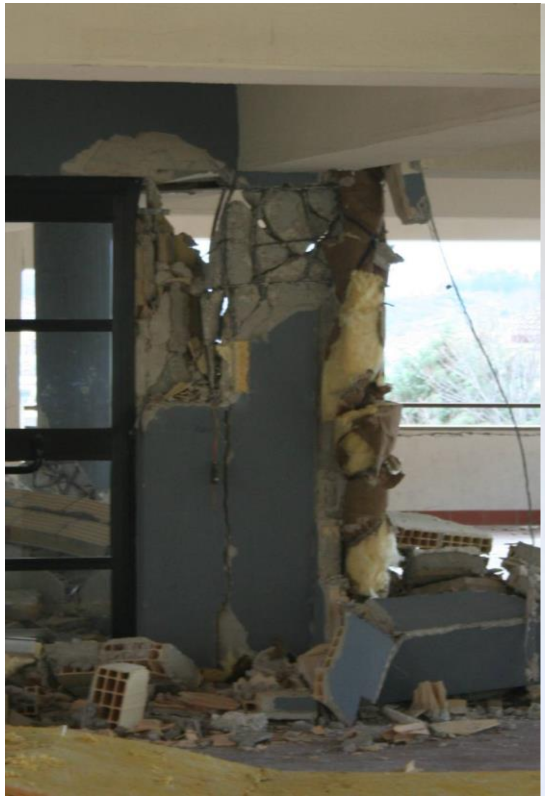
2009 L'Aquila Earthquake

Columns

Failure at column top section (circular & rectangular).

Stirrups spacing (certainly!) greater than 200mm.

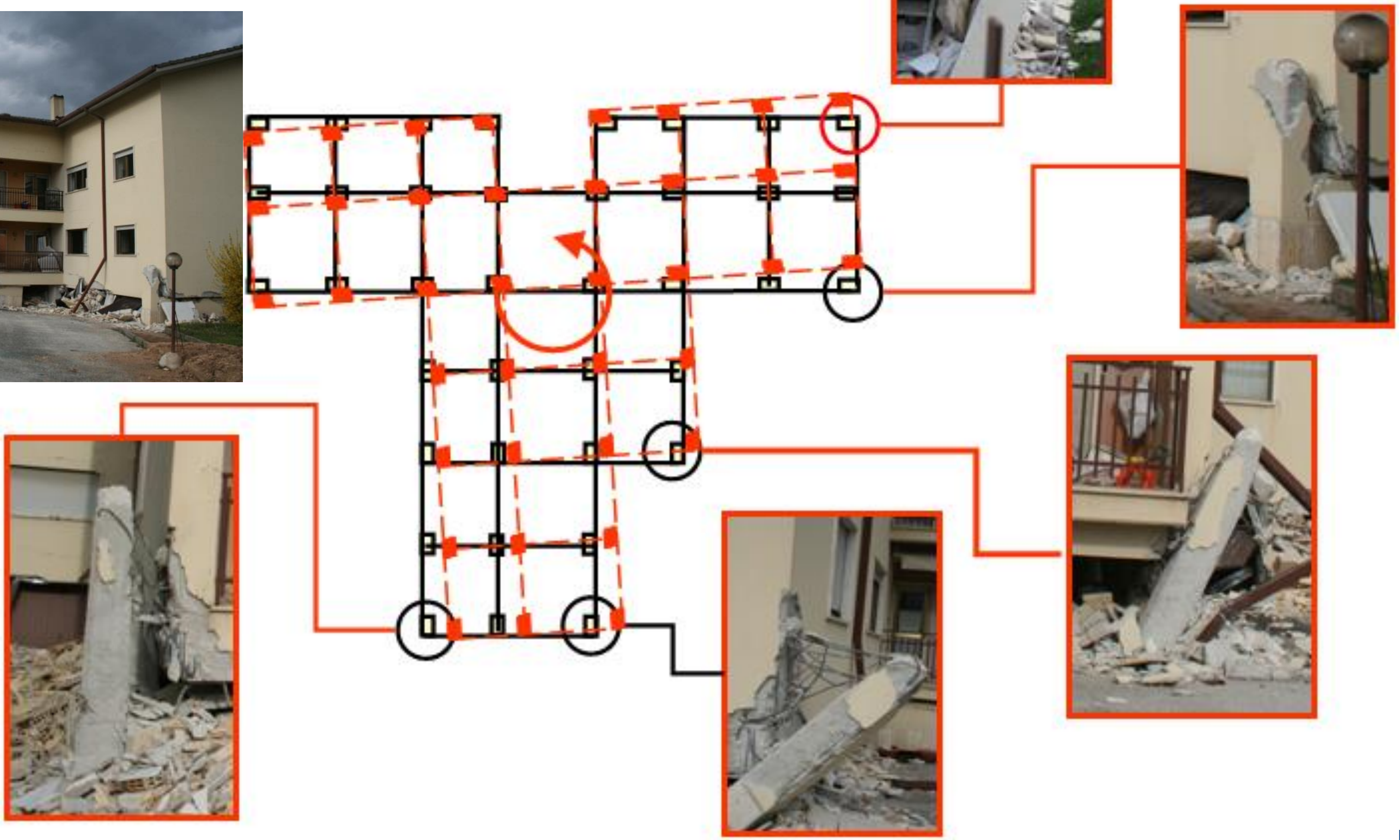
Inadequate concrete mix and compression strength

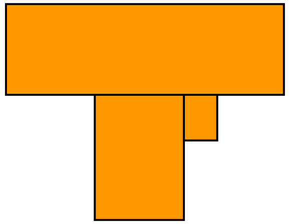


2009 L'Aquila Earthquake

Examples of Damage to due to high vertical component of ground motion

Pettino Building : System Global-Collapse





2009 L'Aquila Earthquake

Pettino Building : System Global-Collapse

2016-17 Italia Centrale Earthquake - Accumoli

Examples of Damage
to due to
high vertical component
of ground motion

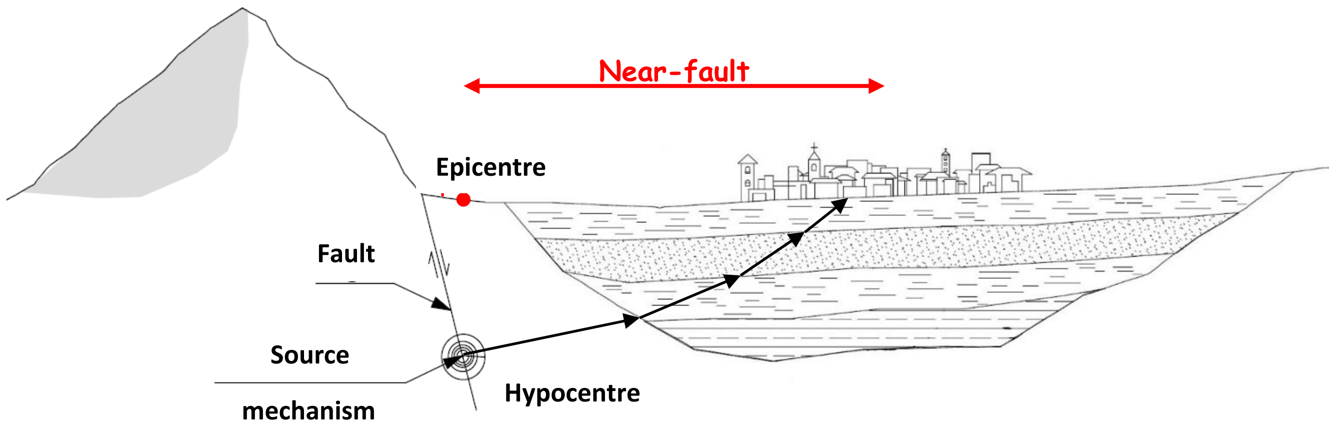
2016-17 Italia Centrale Earthquake - Accumoli

2016-17 Italia Centrale Earthquake - Amatrice

2016-17 Italia Centrale Earthquake - Amatrice

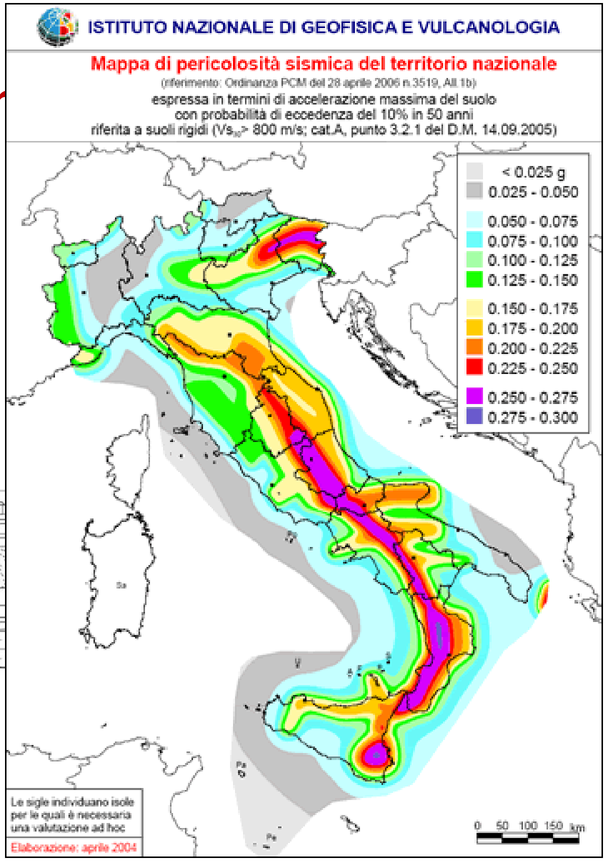
NEAR-FAULT condition

NEAR FAULT

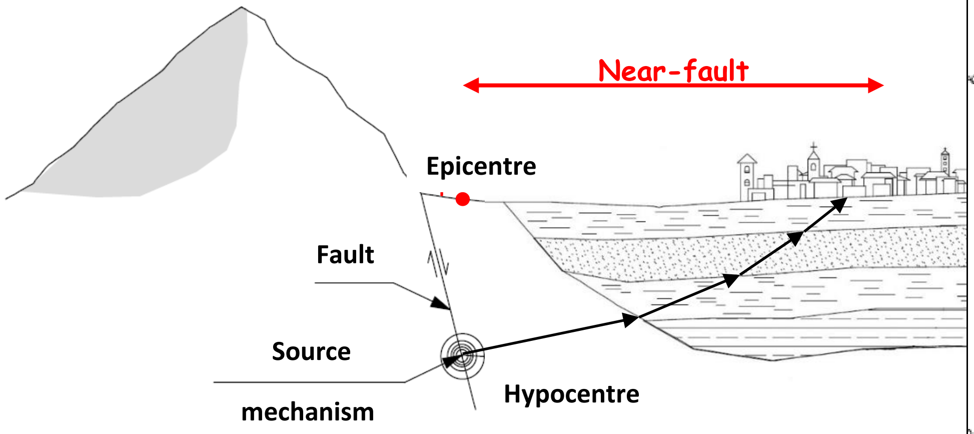


- P and S emerge on the surface with inclined direction ⟶ contribute to both horizontal and vertical oscillations
- P waves and S waves arrive almost simultaneously ⟶ combined motion
- Comparable values of vertical and horizontal accelerations
- Frequency content of horizontal and vertical motions are similar (from low to higher frequencies)

NEAR-FAULT conditio



N E A R F A U L T



It is evident, therefore, that <u>the traditional approach of seismic engineering,</u>

as propagation of S waves only in the vertical direction

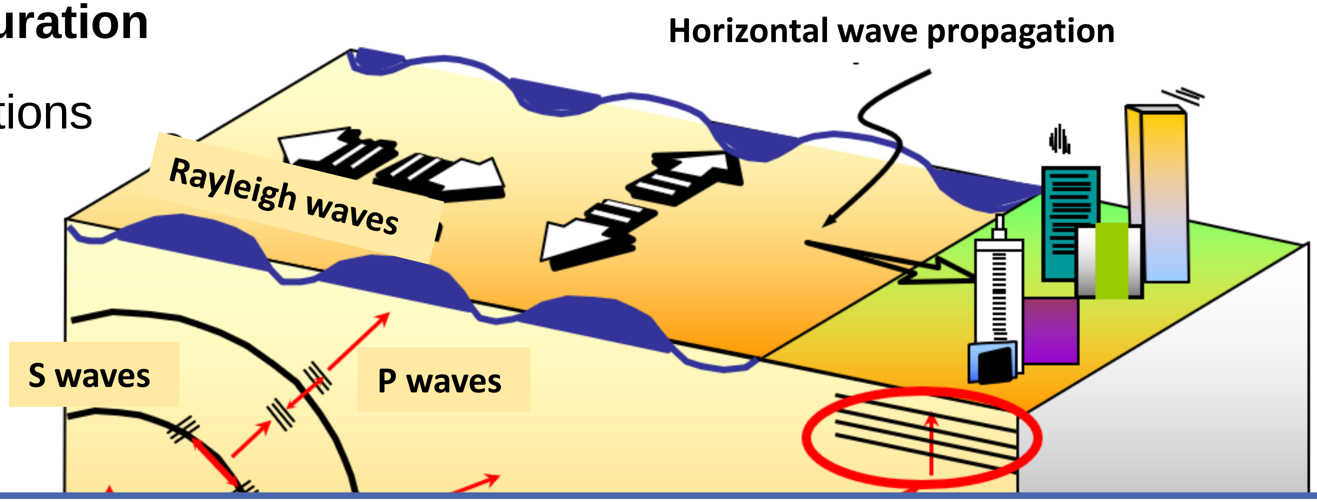
(hence only horizontal motion),

<u>is very far from what occurs in near-fault conditions</u>

Local Seismic Response (*always in Far-Fault conditions*)

Modification of :
- **amplitude**
- **frequency content**
- **duration**

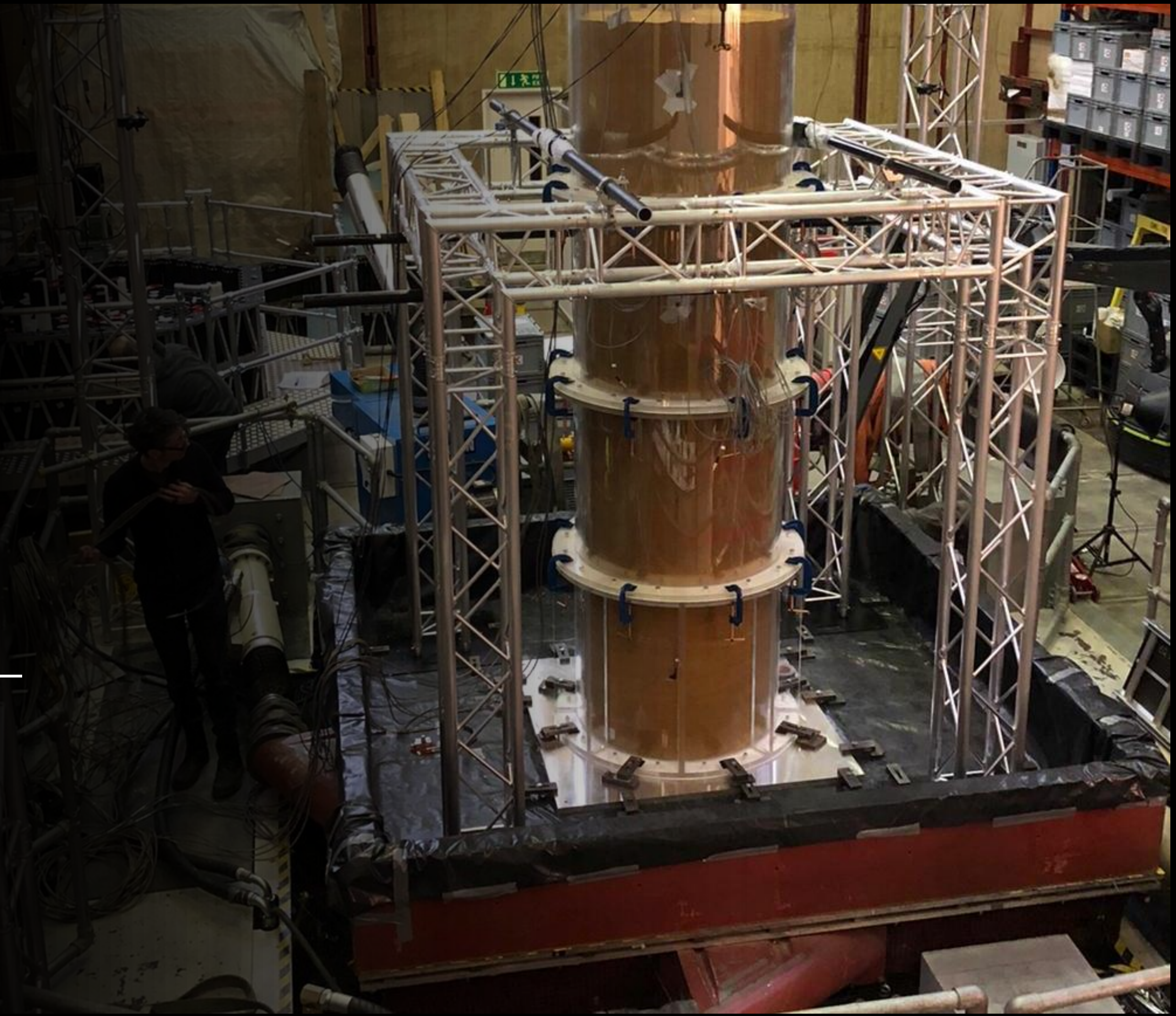
due to local soil conditions



What happens in Near-Fault Conditions ?

(Soil response to ***Vertical Accelerations*** *too … vertical period* T_V *and Amplification)*

Conferencia:
Lecciones sobre
terremotos recientes en
áreas cercanas a fallas



Lessons from
recent earthquakes in
near-fault areas

Armando L. Simonelli

SEISMOLOGY AND EARTHQUAKE ENGINEERING RESEARCH INFRASTRUCTURE ALLIANCE FOR EUROPE
SERA

SERA Seismology and Earthquake Engineering Research Alliance for Europe

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SHAking Table Testing for Near Fault Effect Evaluation

(*SHATTENFEE*)

Lead User Prof. **Armando Lucio Simonelli**

University of Sannio (Italy)
School of Civil Engineering
Department of Engineering

Università degli Studi del Sannio

Project SHATTENFEE

PROPOSING RESEARCH TEAM & HOSTING TA FACILITY

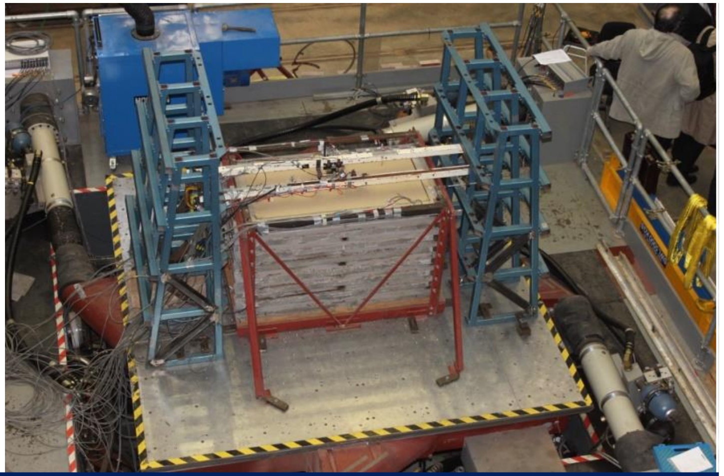
PROPOSING RESEARCH TEAM

- University of Sannio – Italy
- National Technical University of Athens - Greece
- University of Trento - Italy
- Norwegian Geotechnical Institute - Norway
- University of Lisbon – Portugal
- University of the West of England

HOSTING TA FACILITY

BLADE
Bristol Laboratory
for Advanced
Dynamic Engineering
University of Bristol
UK

SERIES PROJECT "PILESI", 2009



Project SHATTENFEE

PROPOSING RESEARCH TEAM & HOSTING TA FACILITY

PROPOSING RESEARCH TEAM

- **University of Sannio – Italy**

  Armando Lucio Simonelli

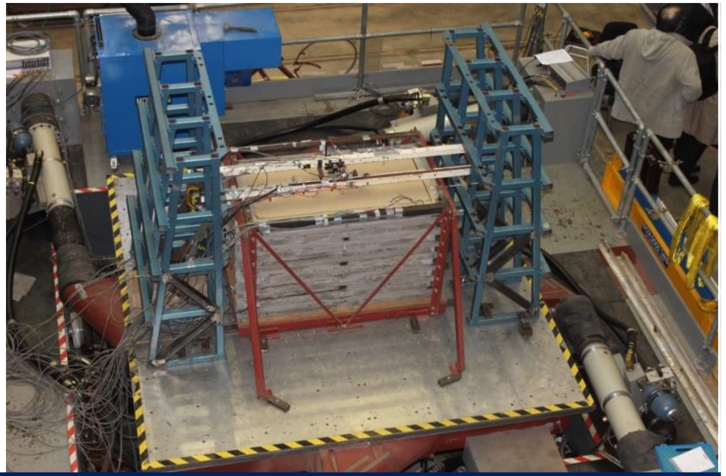
  Augusto Penna

  Luigi Di Sarno

HOSTING TA FACILITY

BLADE
Bristol Laboratory for Advanced Dynamic Engineering
University of Bristol
UK

SERIES PROJECT "PILESI", 2009



Project SHATTENFEE - Summary

Recent surveys conducted after destructive earthquakes demonstrated that, i… near fault (NF) conditions, combined vertical and horizontal motions caused unusual and po… …rstood damage to geotechnical and structural systems.

In Near Fault areas earthquake ground motions are significantly i…

- *the short distance from the fault;*
- *the seismic waves' incidence direction (gen…*

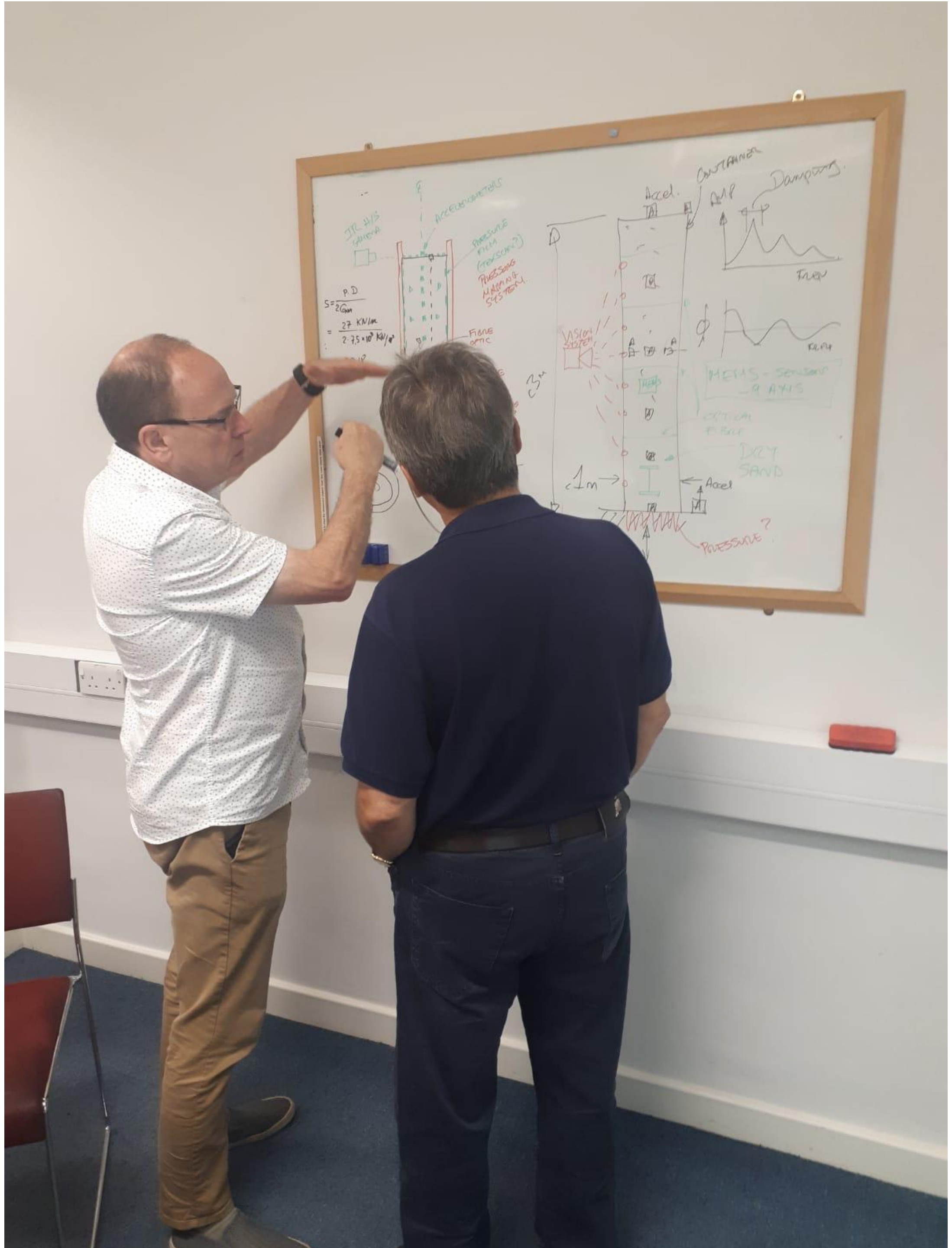
As a result:

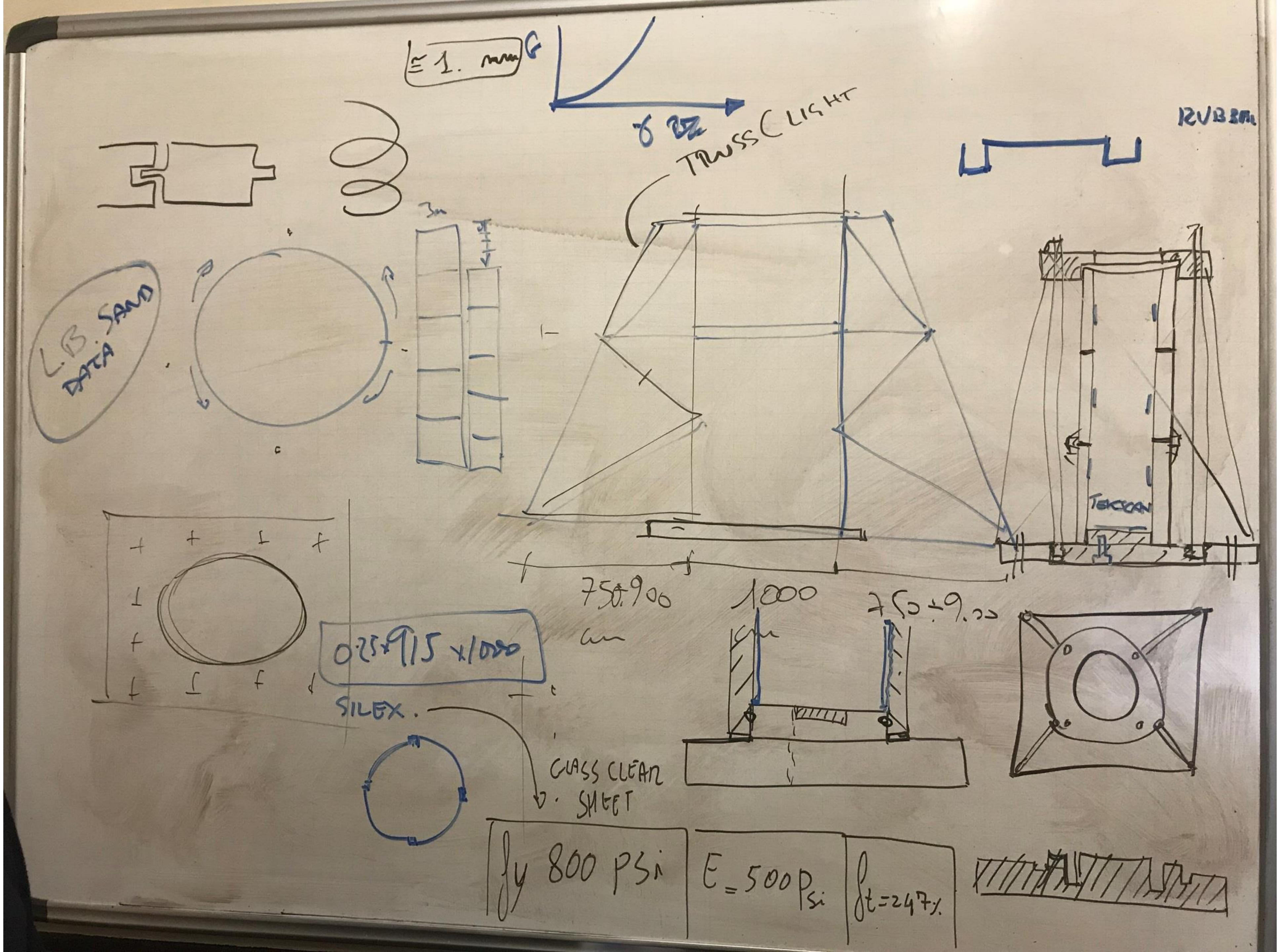
- *the time delay between comp…*
- *horizontal and vertical … …zed by similar frequency contents, becaus…*
- *horizontal … …f the same magnitude;*
- *seism… …d tend to exceed the values provided by*

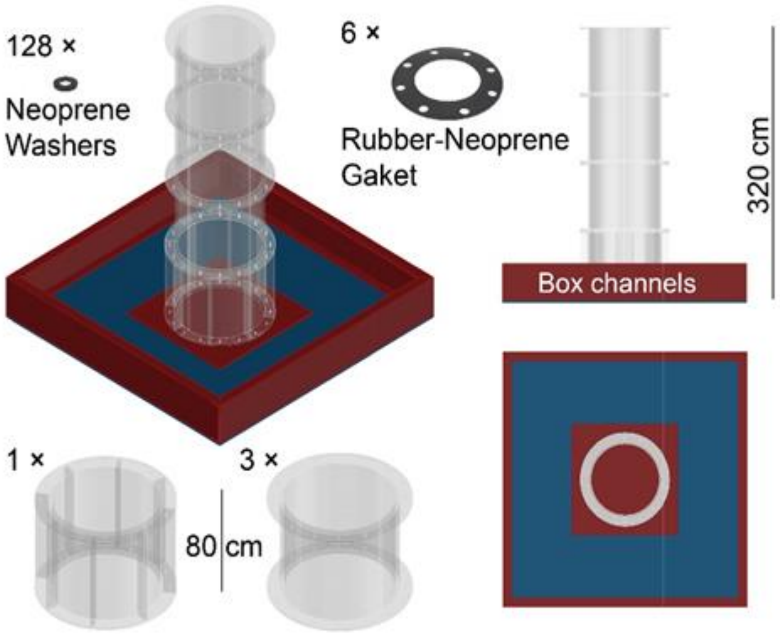
Dynamic identification of soil response under vertical input motion

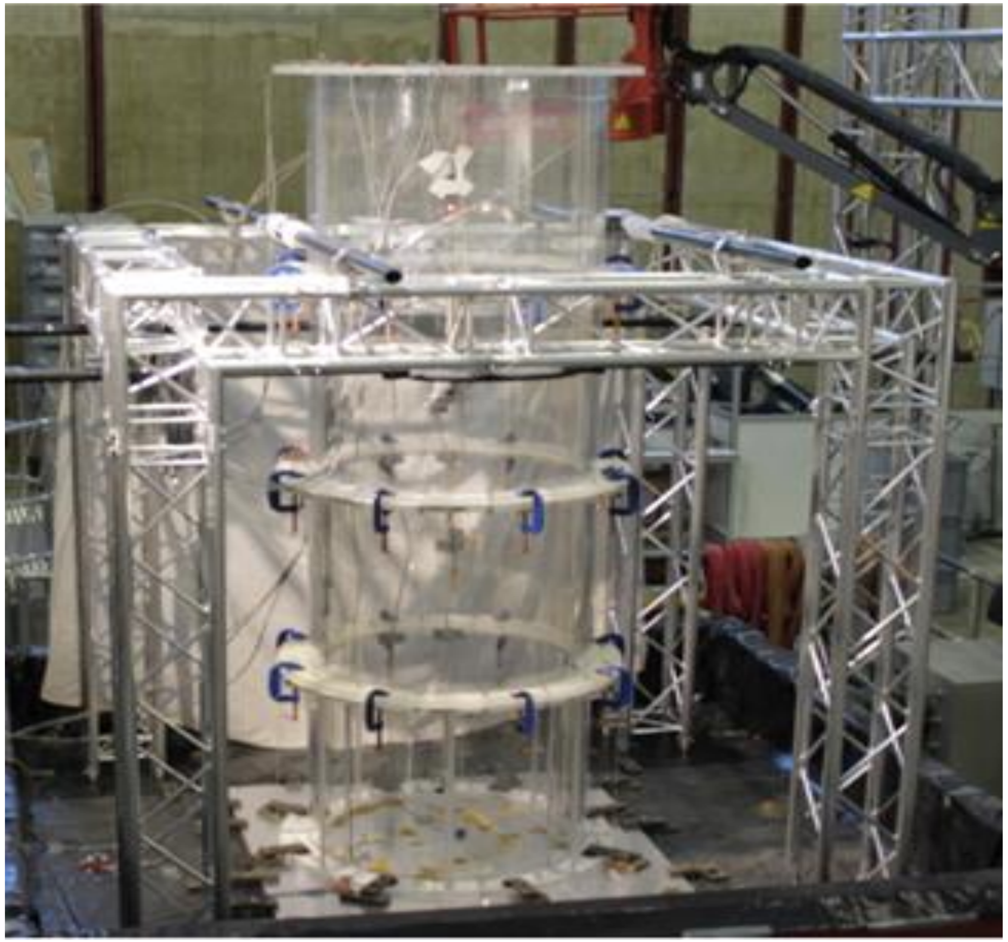
Littl… …ects on SSI systems, so this project will focus on this aspe… …e overall problem.
The ve… …a typical soil deposit, with and without the presence of a foundation system a… …d oscillator, will be explored experimentally on the 6-DoF shaking table at Bristol Un… …g a new soil container specifically designed for vertical wave propagation.

In particula… the vertical dynamic response characteristics, e.g. the period of vertical vibration, damping coefficient, and effect of soil non-linearity and excitation characteristics (e.g., harmonic, impulse, seismic), will be investigated experimentally and numerically to provide fundamental insight and guide further research and code of practice development.

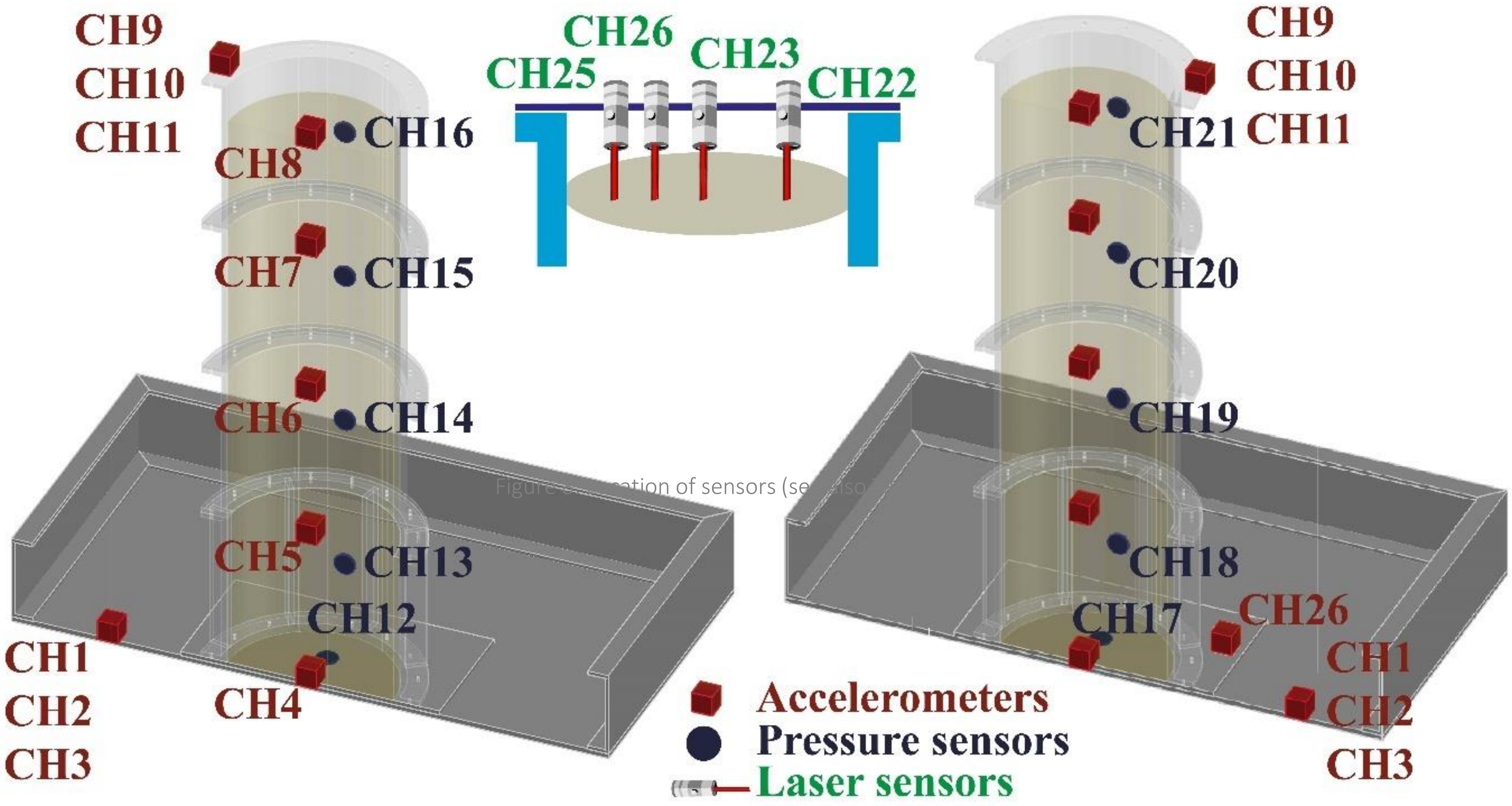

Accel.
CONTAINER
MEMS - SENSORS
9 AXIS
DRY
SAND
Accel


≤ 1. mm
L.B. SAND
DATA
3m
TEKSCAN
750÷900
1000
750÷9.00
0.25×915 ×1000
SILEX.
GLASS CLEAN
SHEET
fy 800 psi
E = 500 psi
ft = 247%

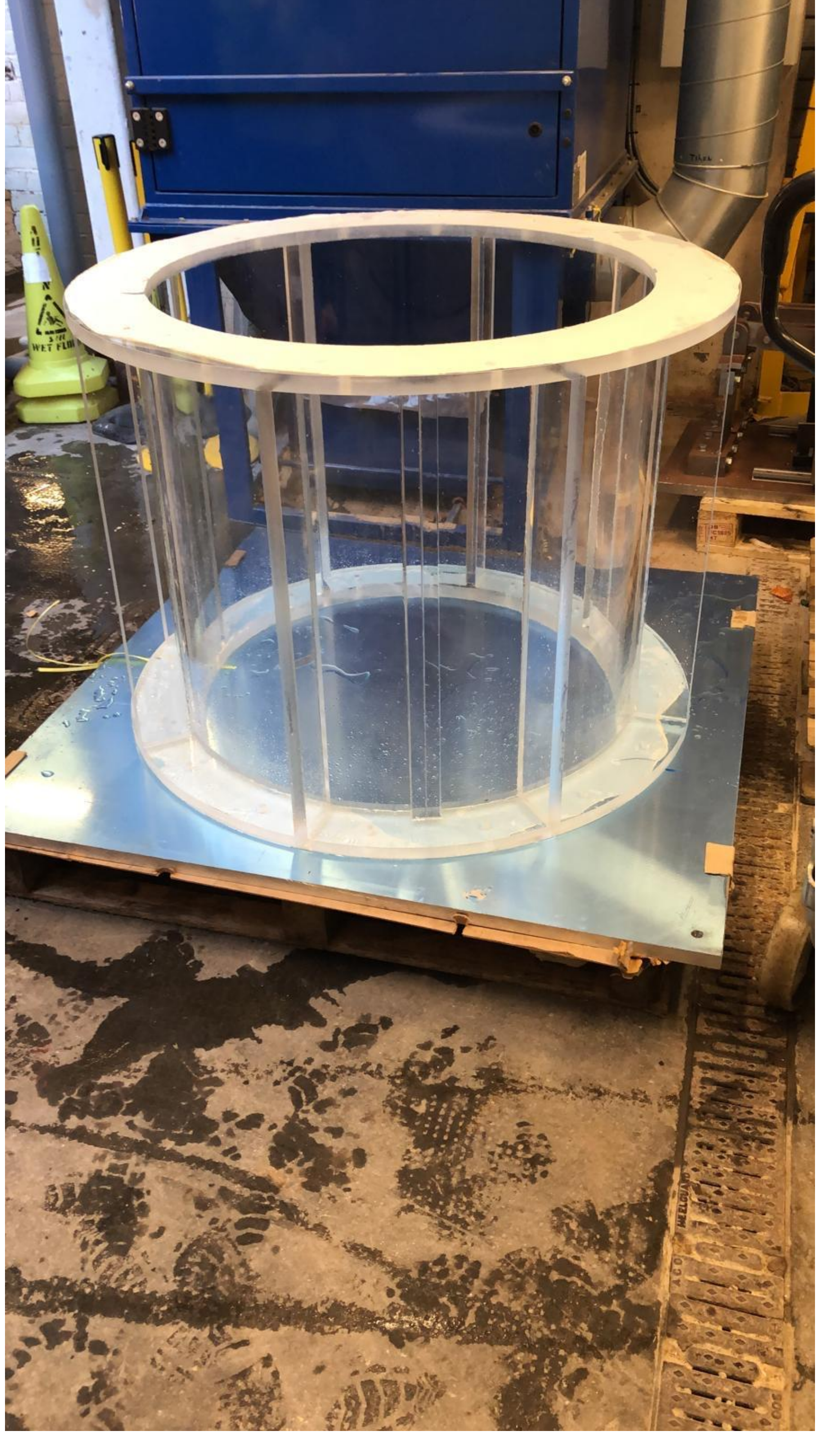


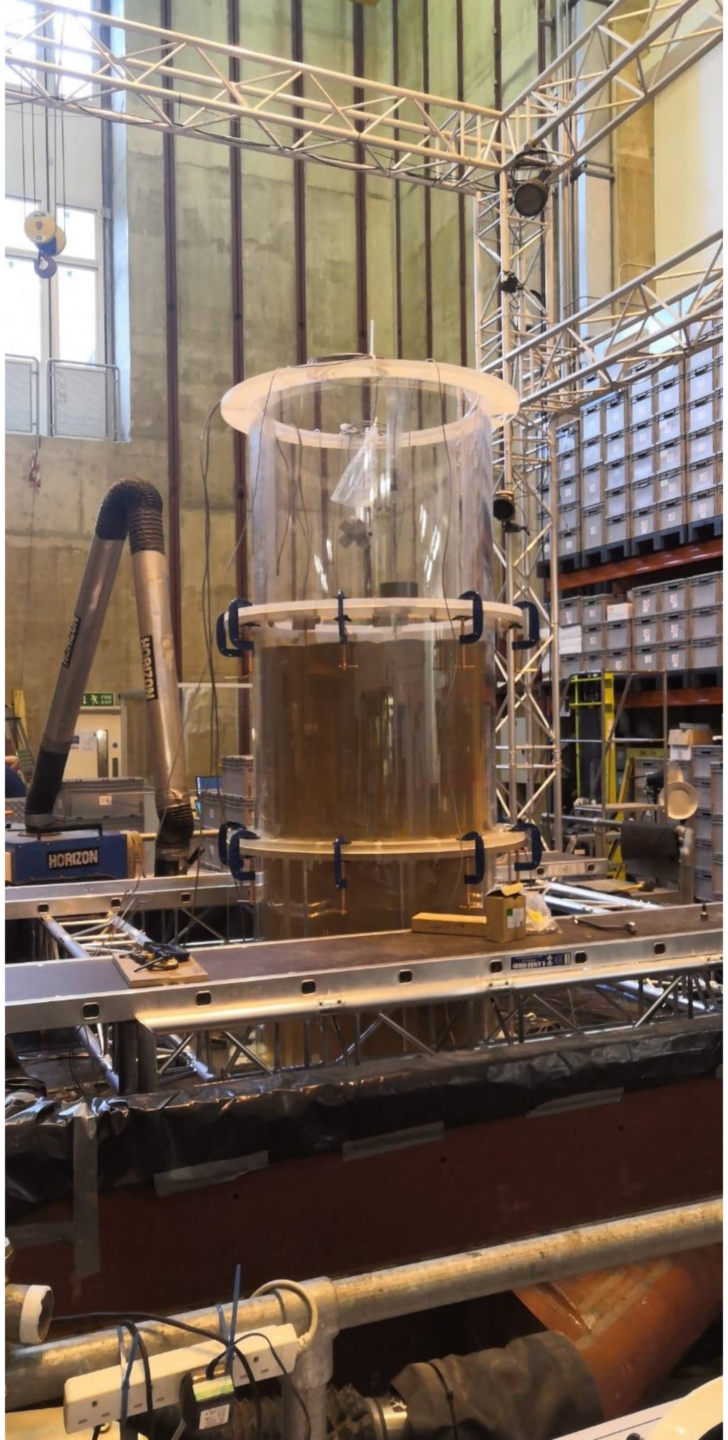


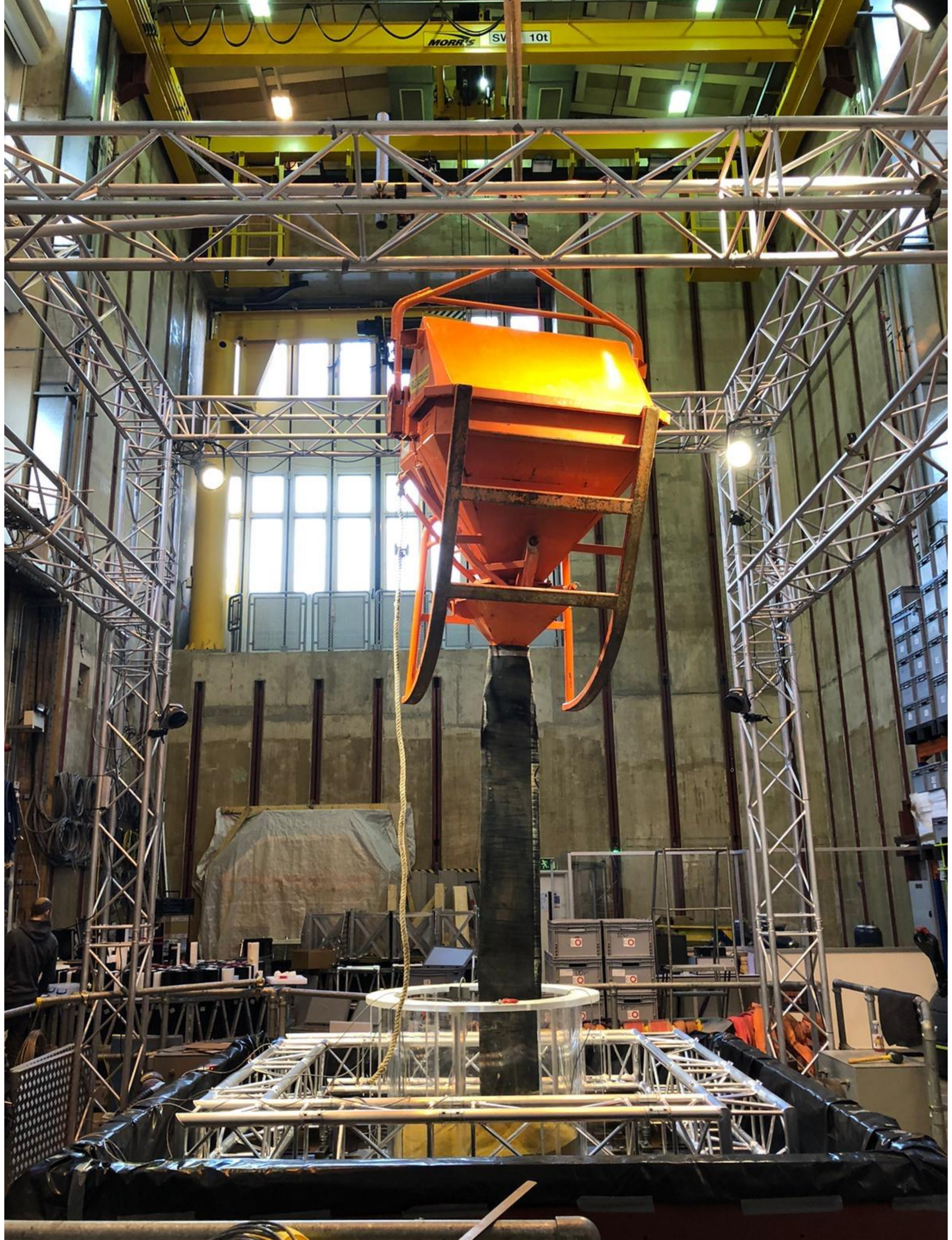
Sketch of the container elements and photo of the whole container located on the table

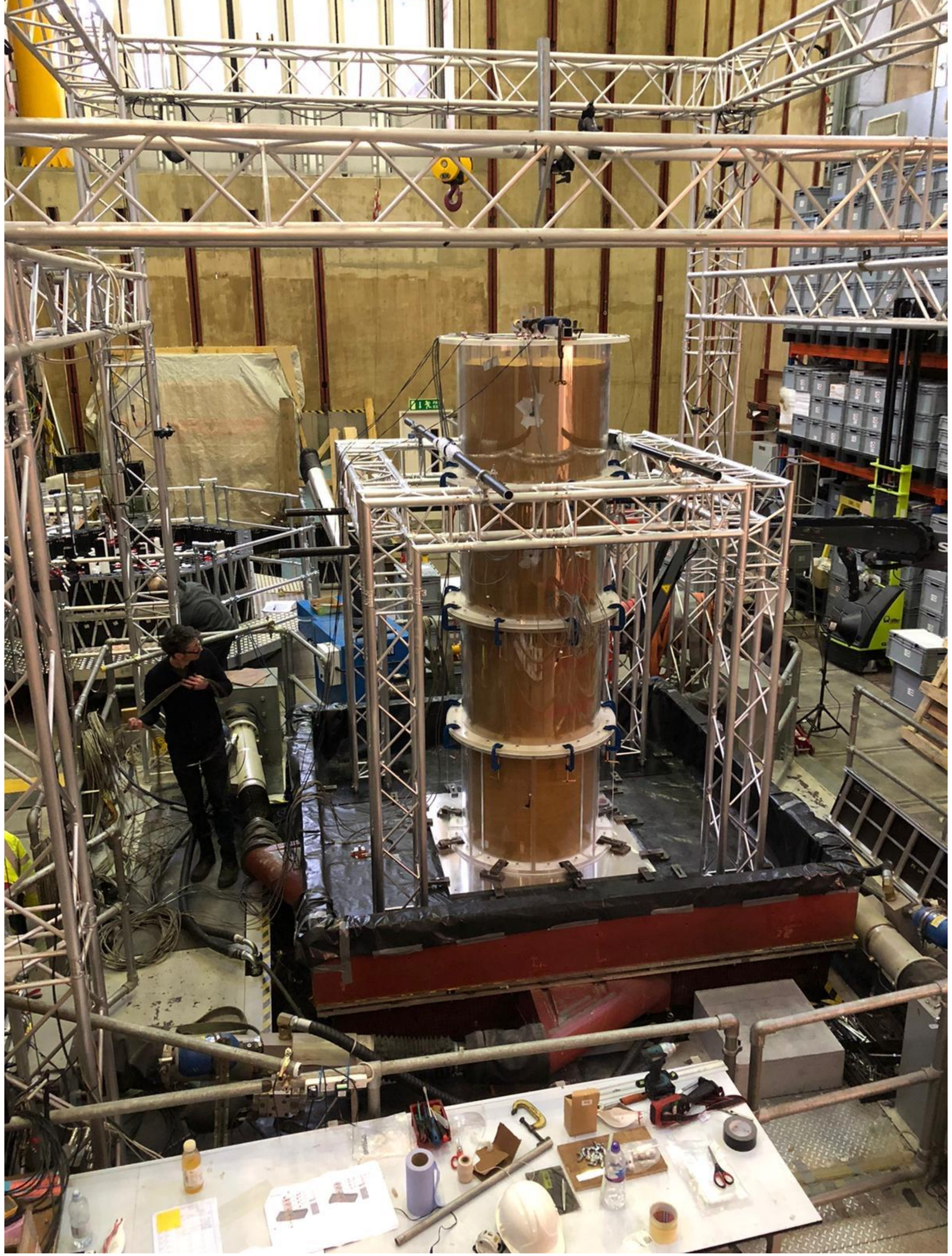


Location of sensors



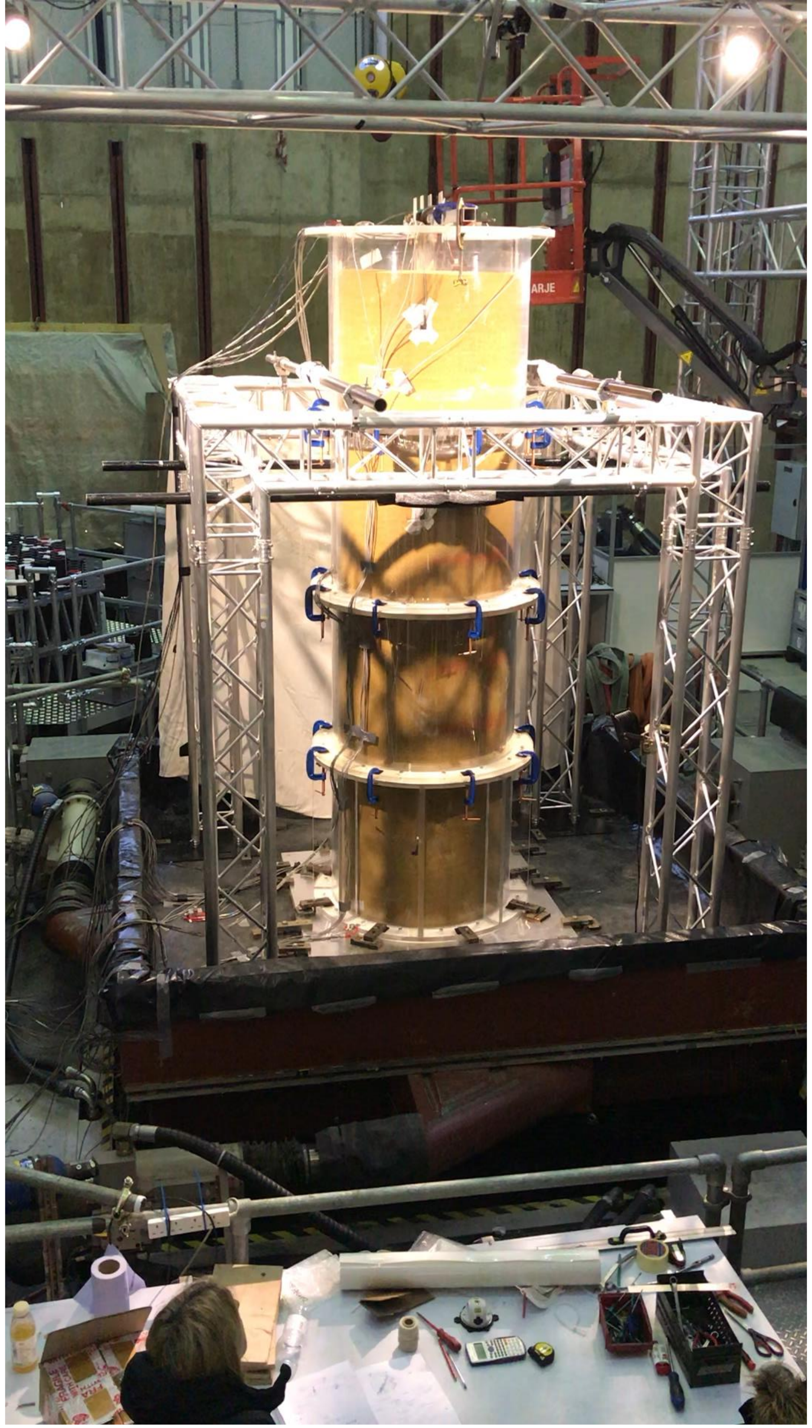

HORIZON

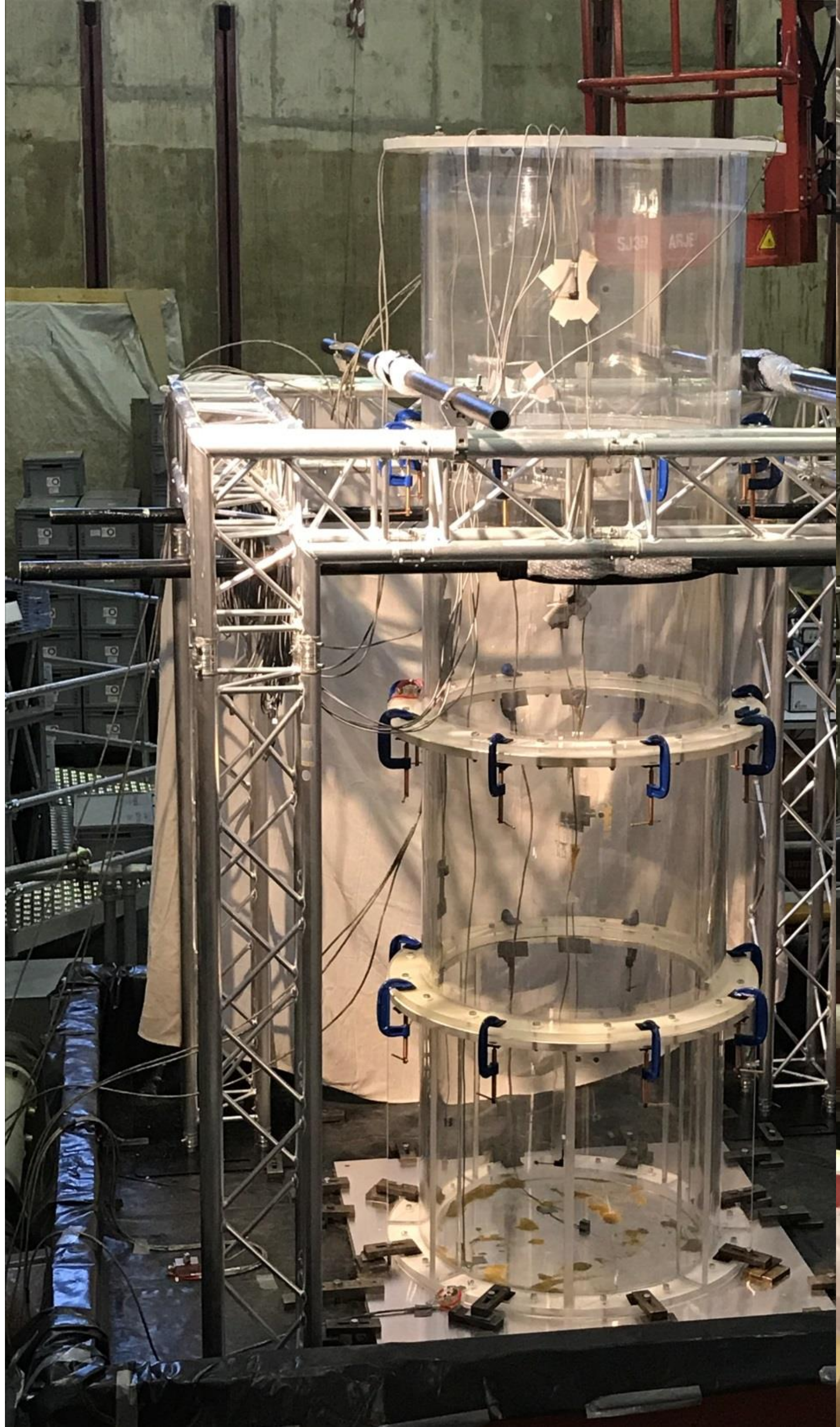



SJ30 ARJE



HORIZON


CYLINDER
1
CYLINDER
1





Future effects of such research studies

On the Codes (*… later ?*)**:**

- **Data-base of seismic input motions in NF conditions**
- **Local Seismic Response in NF conditions**
- **Seismic design actions in Near-Fault areas**

On technology developments :

- **Seismic base isolation systems in NF conditions**
- **Soil treatments for reduction of vertical motion amplification**

Final Goal

SEISMIC PREVENTION !!!

Prevision of earthquake, alone, is not sufficient !

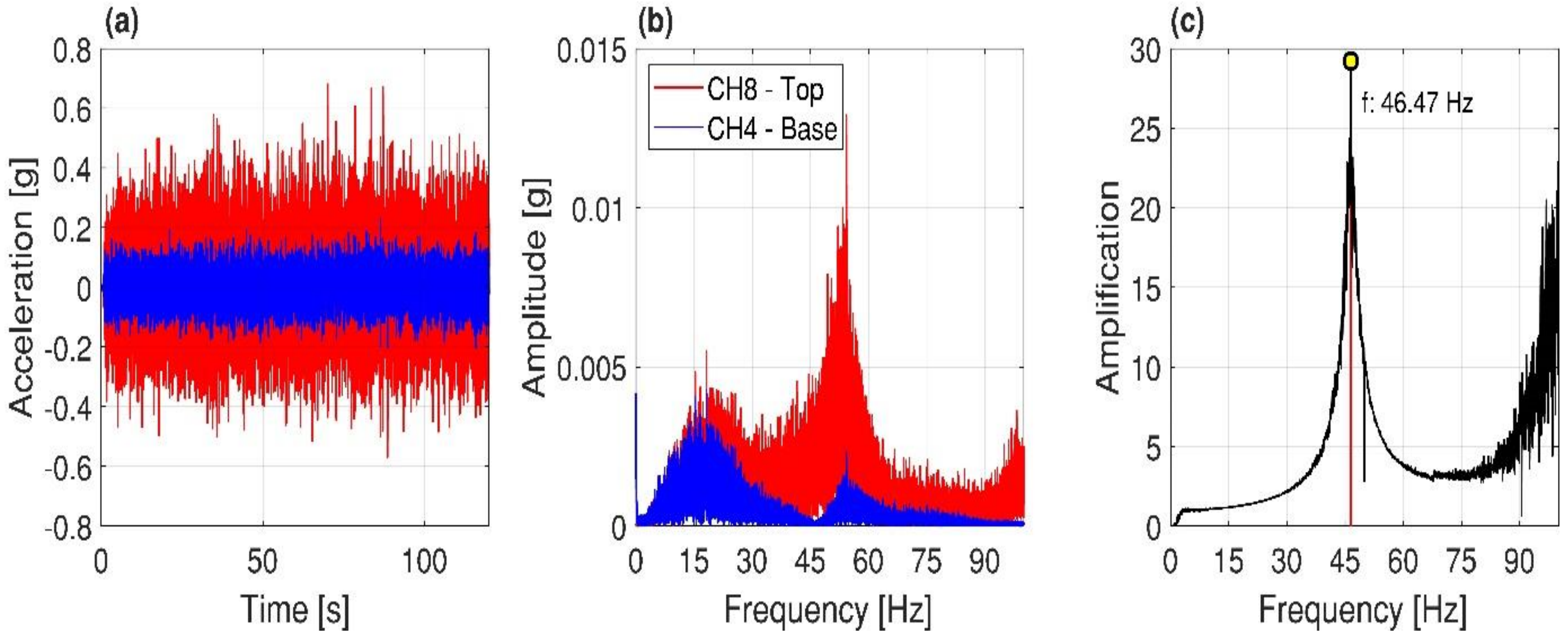
Further, up to now, we are not very able in seismic prevision …


Muchas gracias por su atencion

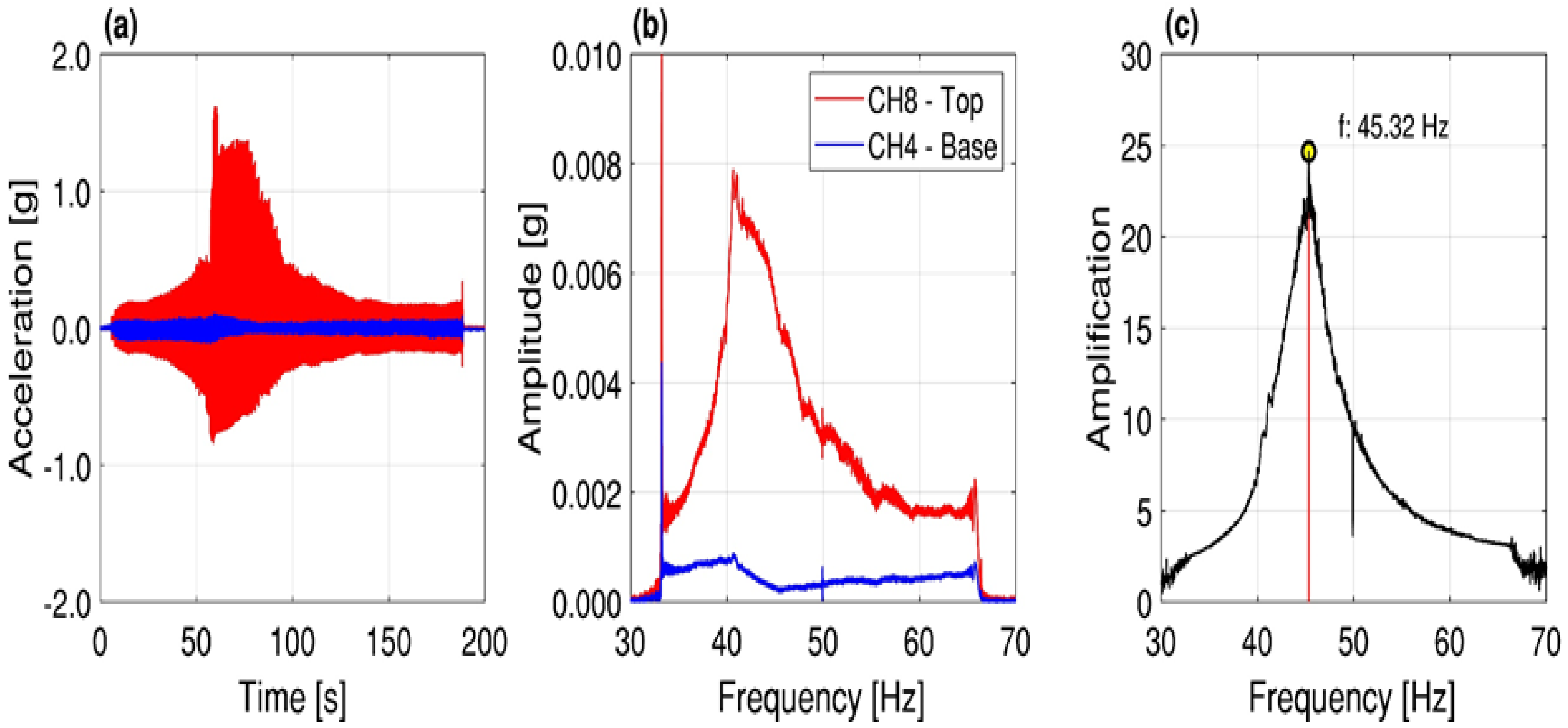
Project SHATTENFEE

Phase 1 – Data Analysis

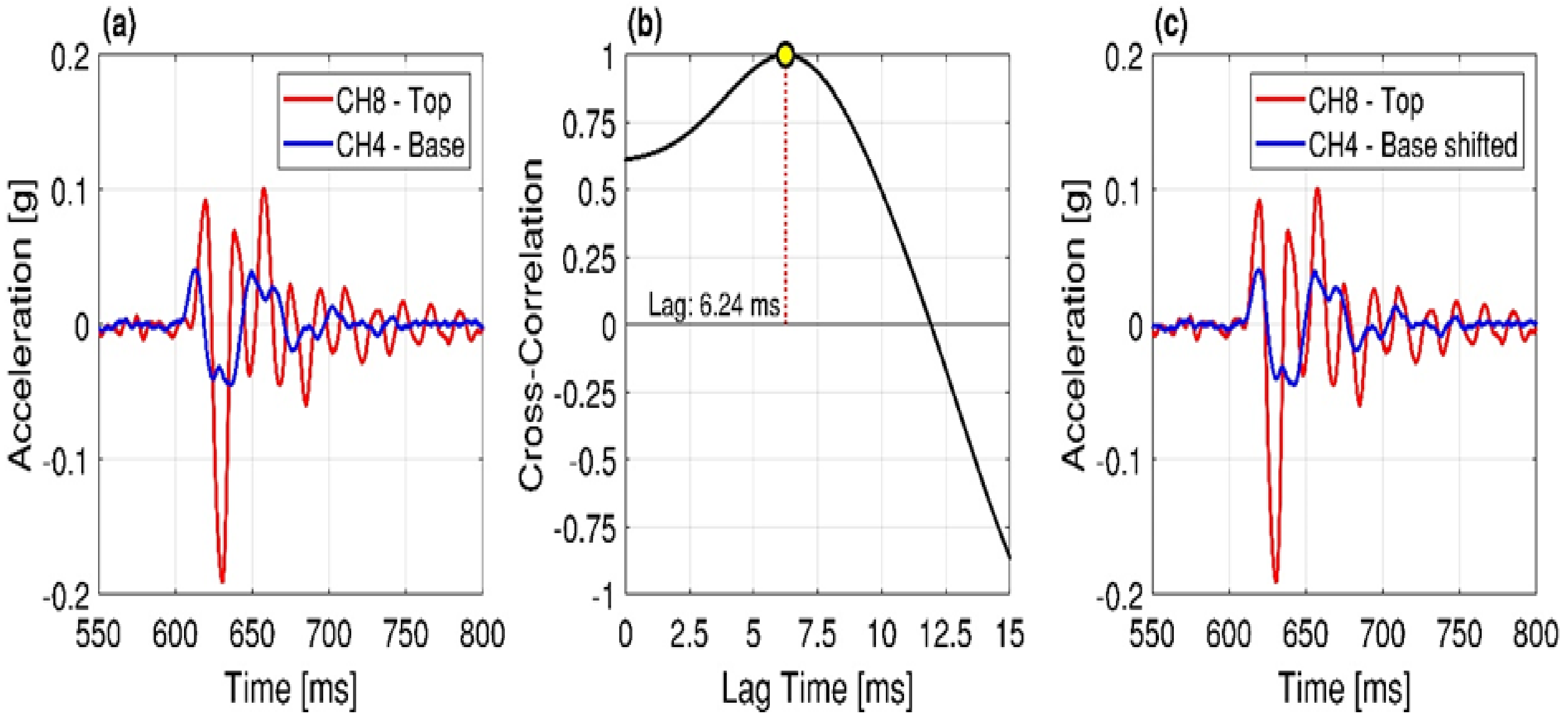
Some preliminar results



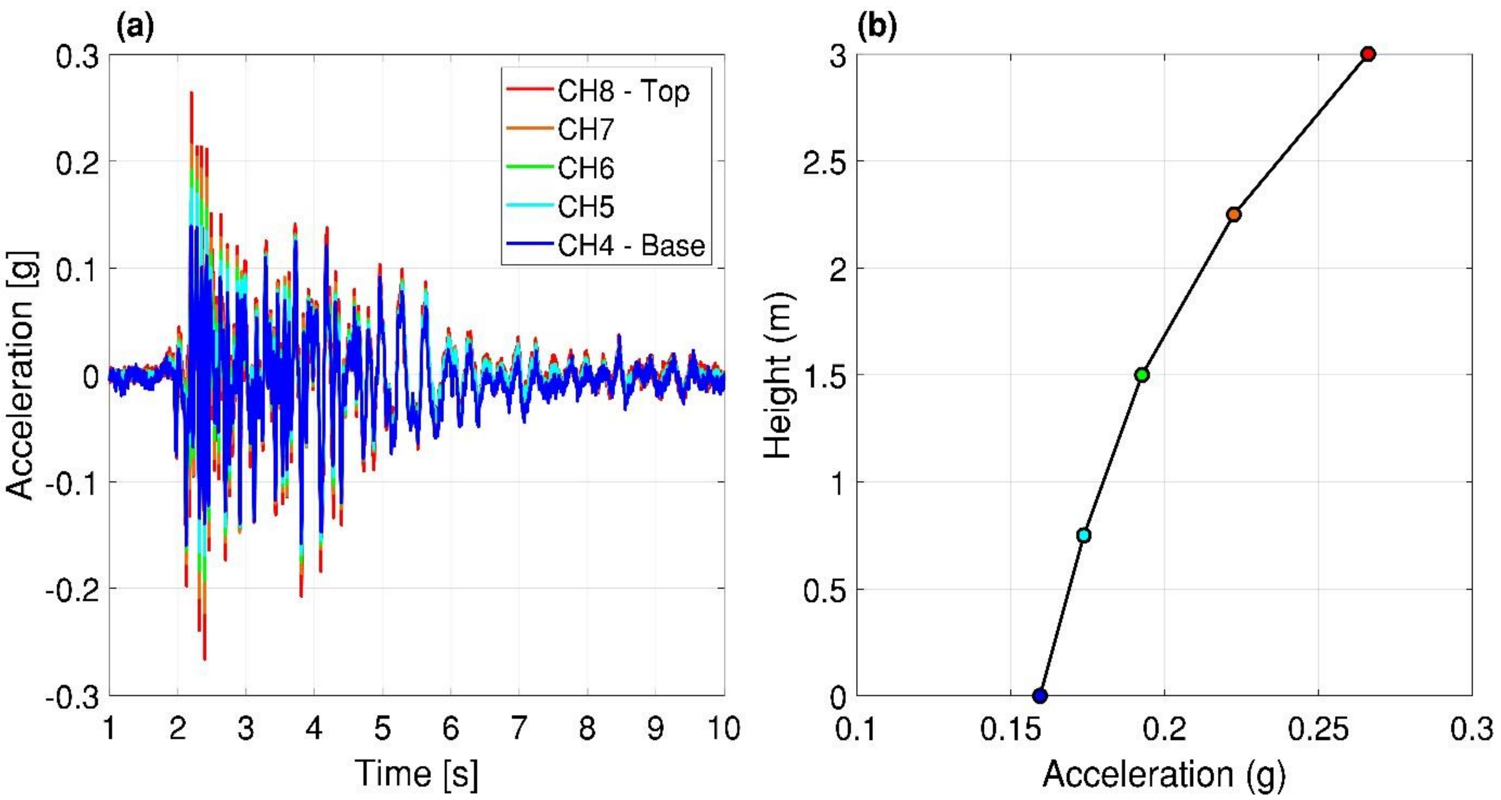
Example of fundamental vertical frequency determination - TEST 25: noise input motion, amplitude 0.05 g, duration 120 sec - (a) Acceleration time-histories at the base (CH4) and top (CH8) of the soil model; (b) Fourier spectra of the two signals; (c) Amplification function and determination of the main frequency f



Example of fundamental vertical frequency determination - TEST 30: sweep function, amplitude 0.05 g, frequency range 33-66 Hz; duration 200 sec - (a) Acceleration time-histories at the base (CH4) and top (CH8) of the soil model; (b) Fourier spectra of the two signals; (c) Amplification function and determination of the main frequency f



Example of compression wave velocity (Vp) measurement – TEST 30: pulse function, amplitude 1 mm; duration 100 sec - (a) Acceleration time-histories at the base (CH4) and top (CH8) of the soil model; (b) Cross-Correlation function and determination of the time delay (travel time); (c) Representation of the shifted acceleration time histories base shifted



Example of vertical acceleration amplification - TEST 45: L'Aquila 2009 earthquake (AQK station, UP component): input accelerogram scaled to a total duration of 20 sec (here only the first 10 sec window is represented)- (a) Acceleration time-histories along the soil height: at the base (CH 4), at intermediate levels (CH. 5, 6 and 7) and on the top of the soil model (CH 8); (b) Maximum acceleration values recorded at each level, from the base to the top