



POLITECNICO
MILANO 1863

Data analysis for mechanical system identification

Introduction: recalling MATLAB basics

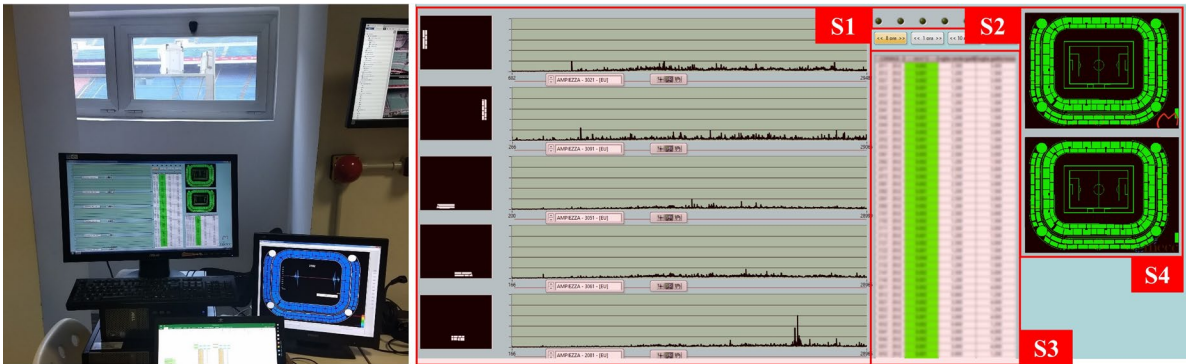
F. Lucà – francescantonio.luca@polimi.it

Vibration Measurements – Meazza stadium

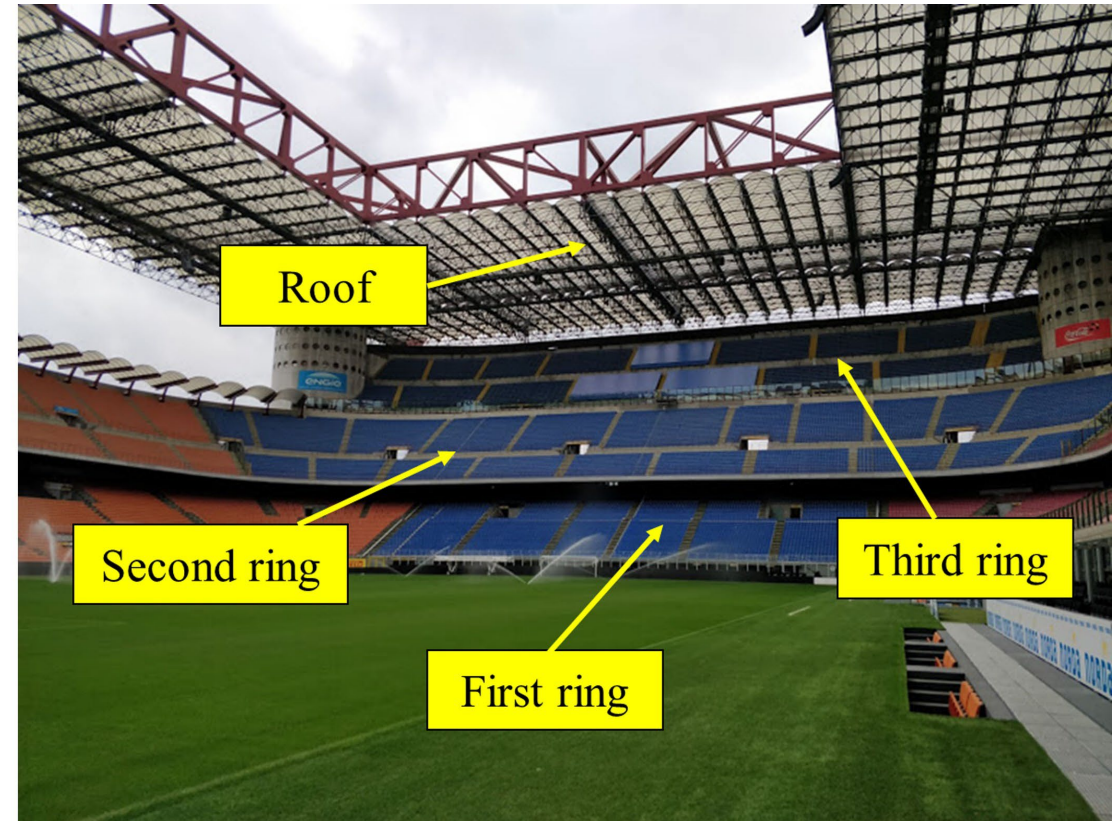
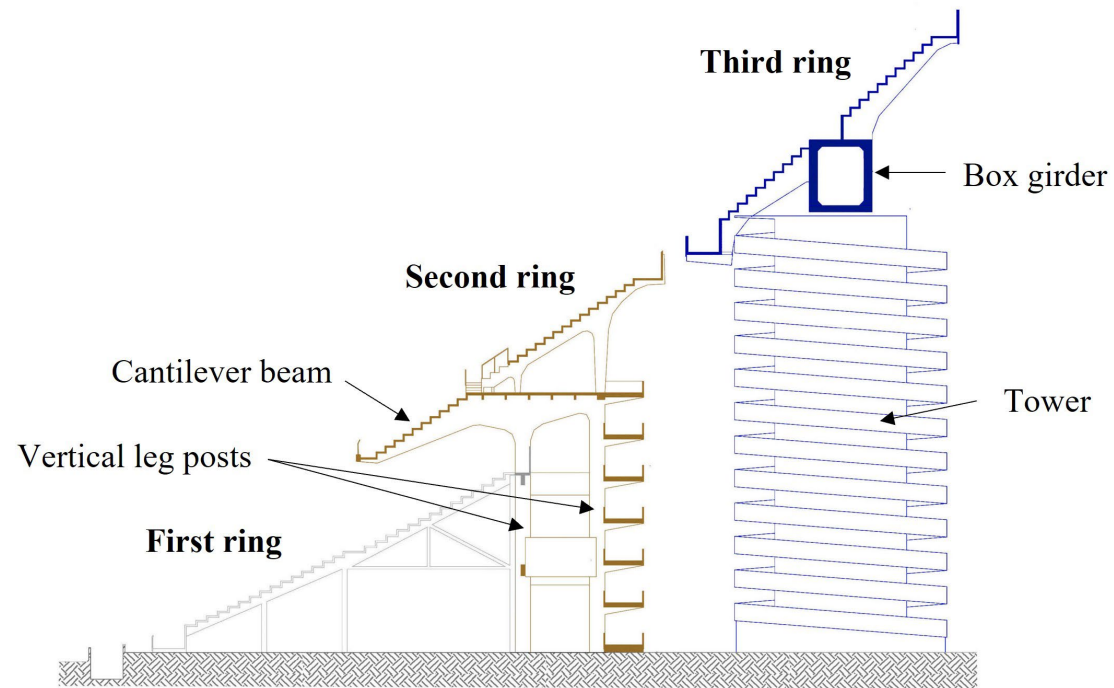
The group of Measurements and Experimental Techniques of the Mechanical department is in charge of the structural monitoring of the G. Meazza stadium since 2003.

What we will see:

- Description of the structure
- The reason of the involvement of the Politecnico di Milano
- The proposed solution



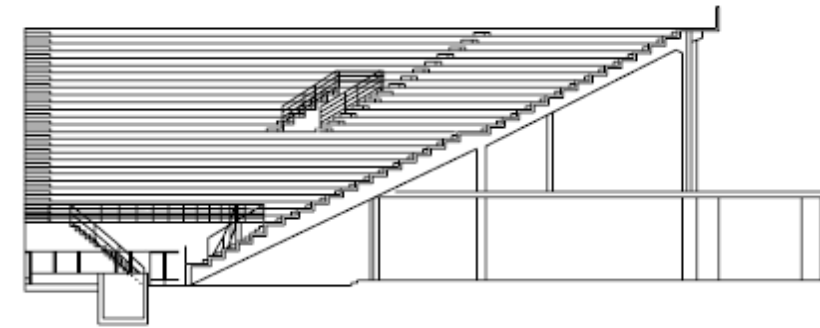
Meazza Stadium



Meazza Stadium – 1st ring

The first ring was built in 1927: it is the oldest structure, and allowed to reach the capacity of 35000 seats.

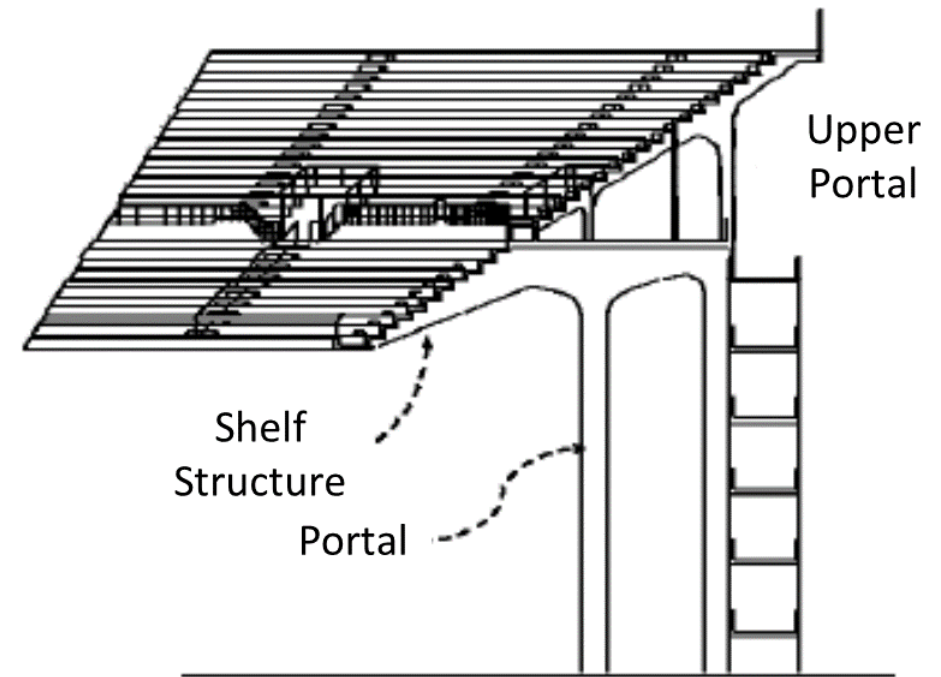
- Very stiff



Meazza Stadium – 2nd ring

The second ring, built in 1955, is a shelf structure supported by a series of portals. It improved the stadium capacity up to 55000 seats.

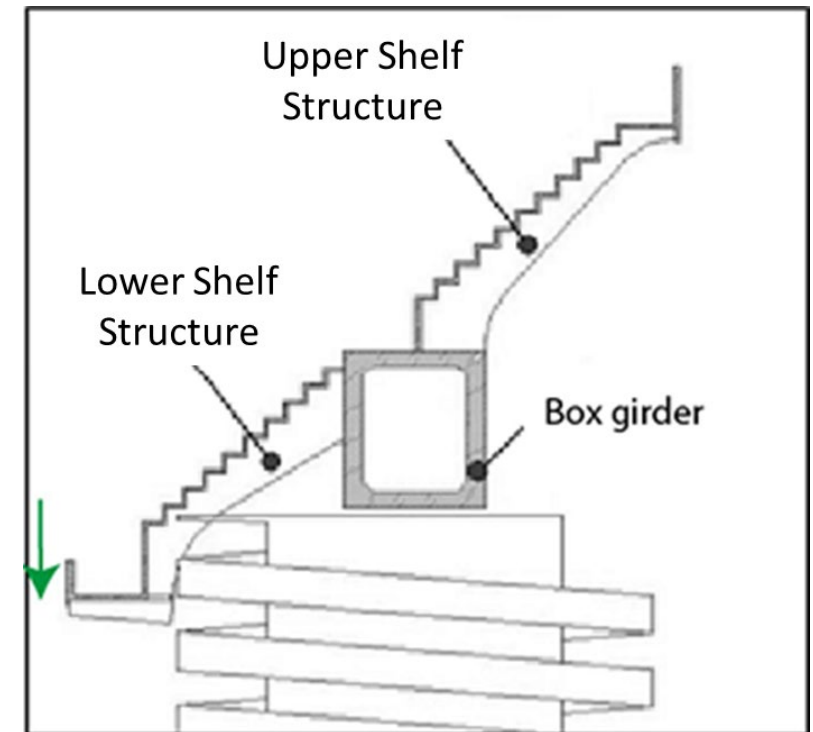
- It is subjected to considerable vibrations in horizontal and vertical directions



Meazza Stadium – 3rd ring

The third ring was finished in 1990. It is composed of shelf structures suspended on box girders, which are sustained by towers.

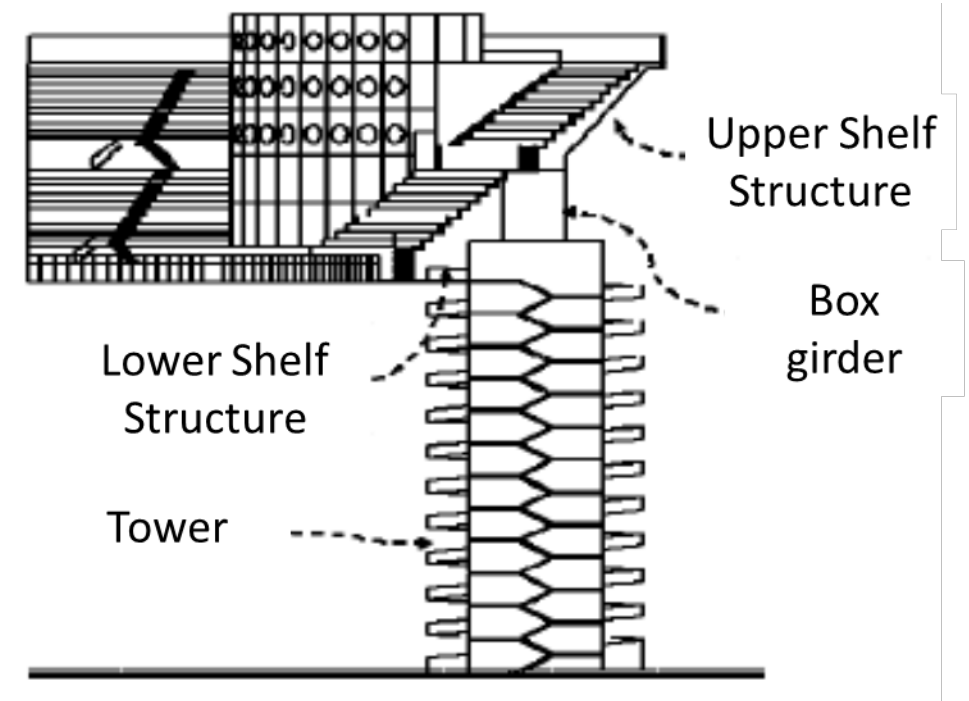
- It undergoes to considerable vibrations in vertical direction.



Meazza Stadium – 3rd ring

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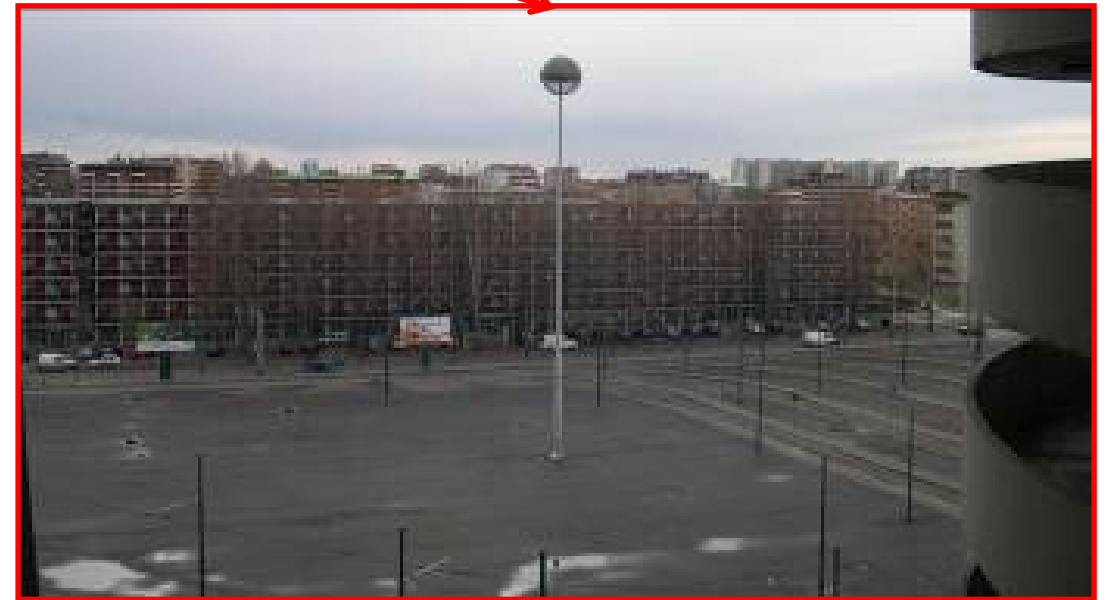
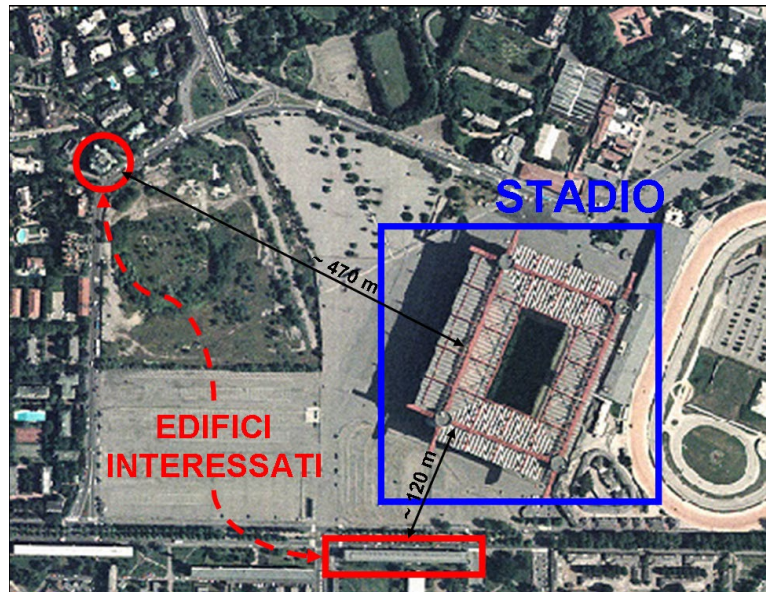
- It undergoes to considerable vibrations in vertical direction.



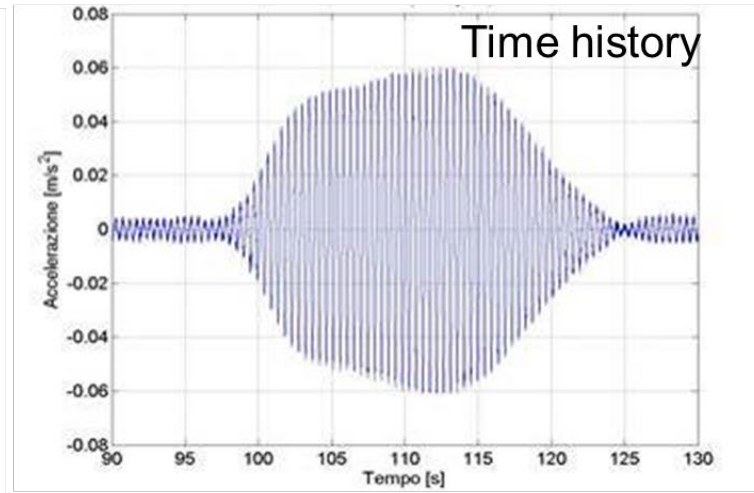
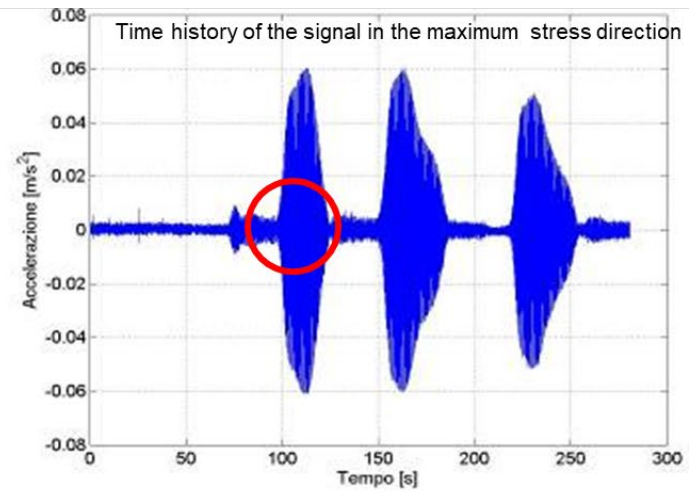
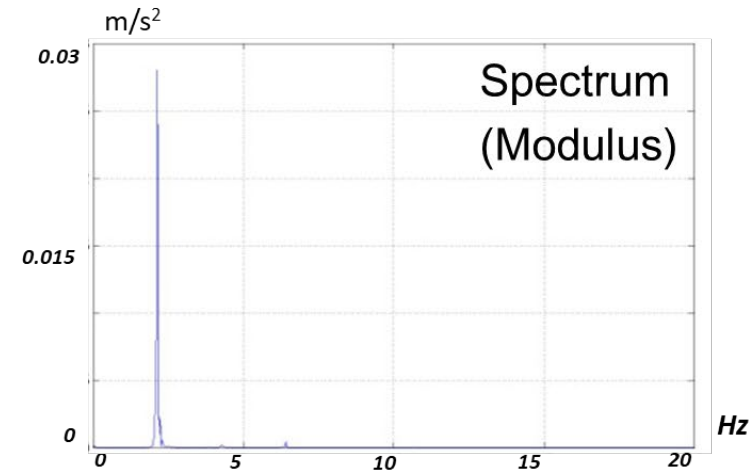
Original Problem: significant vibration level in surrounding buildings



Involved Buildings



First investigation: measurement of the vibration level in the involved buildings



First investigation: measurement of the vibration level in the involved buildings

The time and frequency domain analysis of the acquired acceleration signals showed:

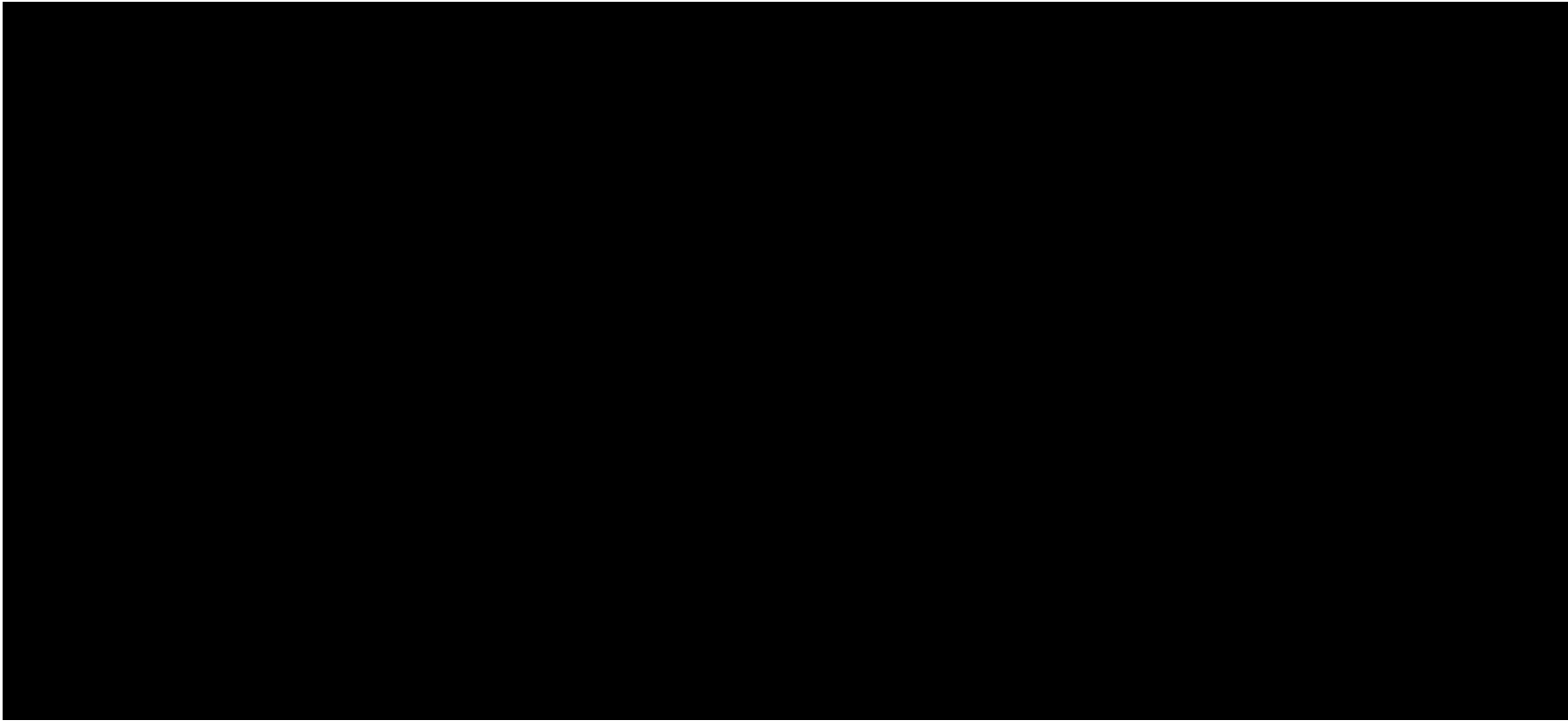
- a harmonic motion at 2.2 Hz
- different acceleration level in different directions: $z/x = 1/4$
- same concert for 3 nights \Rightarrow same phenomenon

Which could be the cause of this behavior?

- Sub-woofer?
- Other?

Origin of the phenomenon

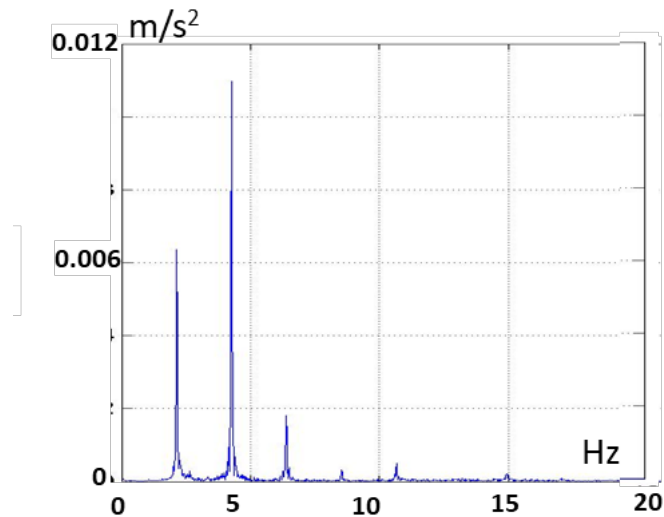
Forced motion of the structure induced by the synchronized motion of the audience at the rhythm of the music



Origin of the phenomenon

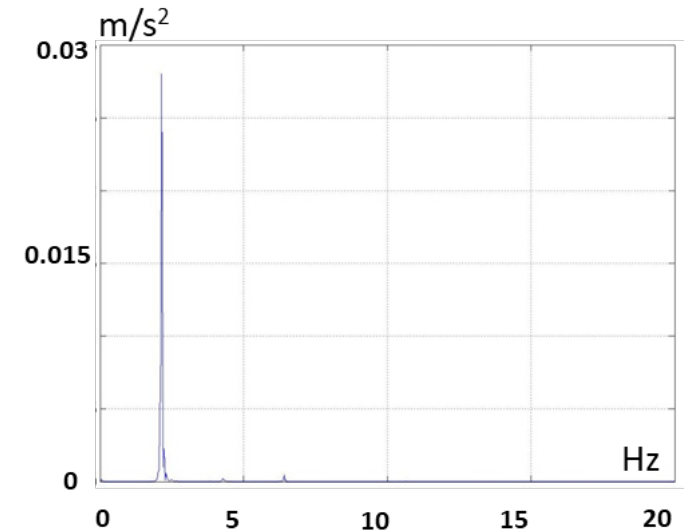
Problem: forced motion of the structure induced by the synchronized motion of the audience at the rhythm of the music

Accelerometer at the base of the tower



x 5
→

Accelerometer in the residential building



The synchronized motion of the people coincides with the resonance frequency of the stands (approximately 2.2 Hz). The ground transmits the force to the building, where accelerometers detect the same harmonic motion.

Well-known example of human-structure interaction

Nuremberg stadium



Proposed solution: permanent and continuous vibration monitoring system

Accelerometers

- Servo accelerometers
- High sensitivity
- Low noise floor

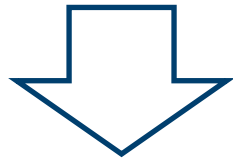


Acquisition system

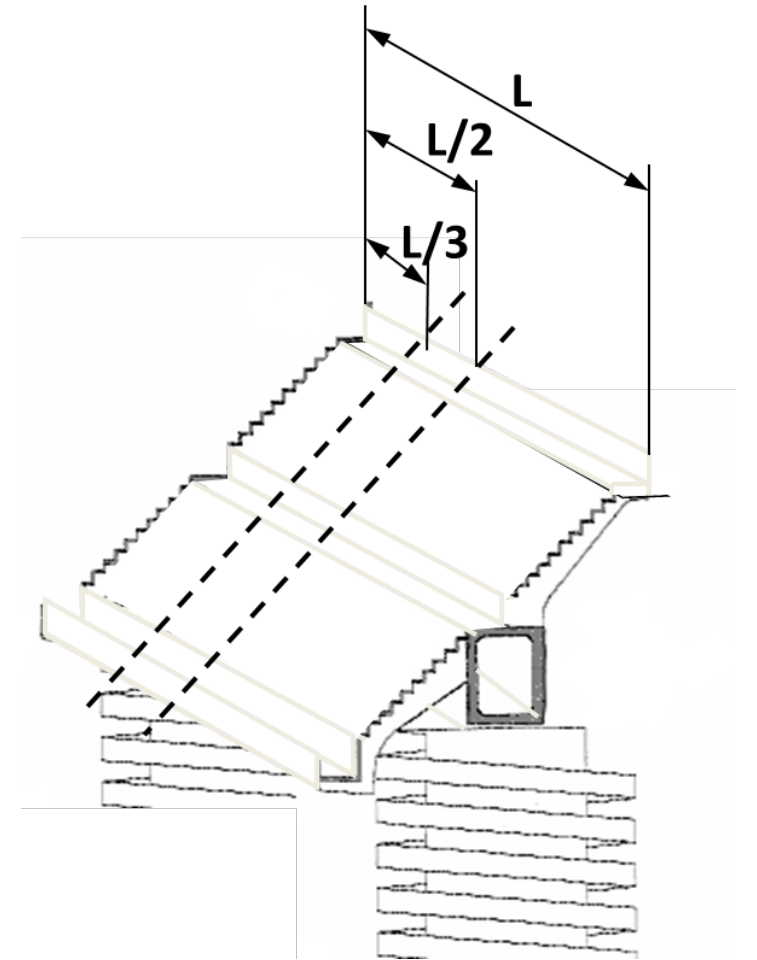
- Redundant
- 16 bit in order to guarantee a high resolution
- Anti-Aliasing filters

Test set-up: sensors layout

The quality and completeness of the information that can be obtained from the monitoring system is highly dependent on the sensors layout. For this reason, the choice of the measurement points on the structure is fundamental: they must be placed in order to measure the highest vibration levels and all the main modes of the structure.



Two sensors for each shelf and for each box girder, in each of the underlined sections

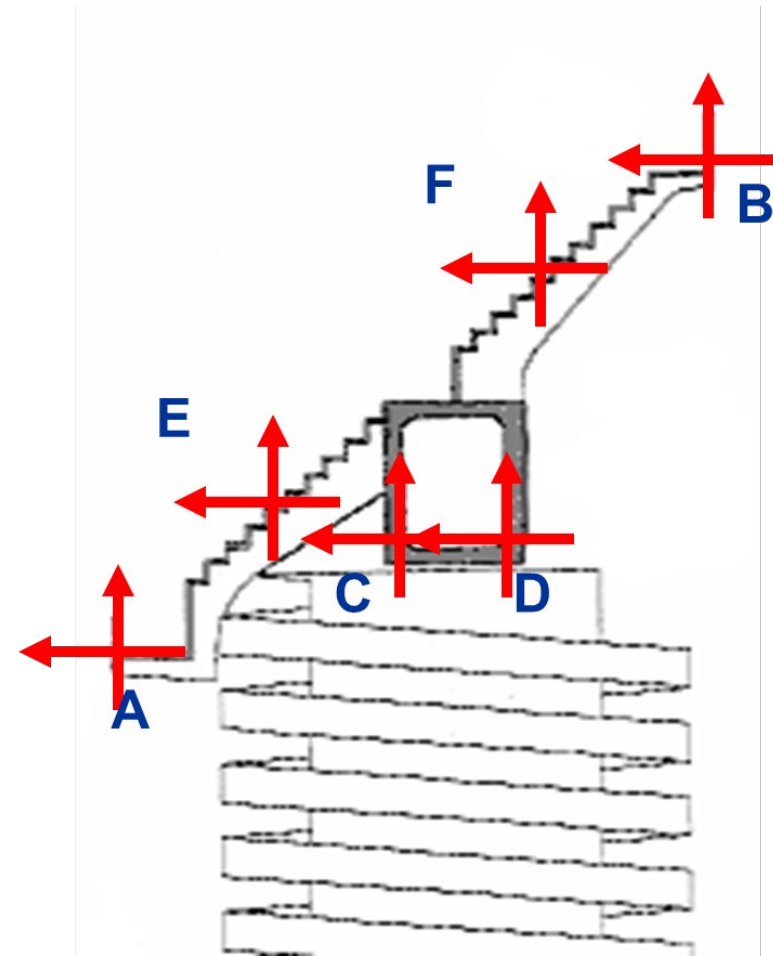


Sensor layout for each section

C



A



Laboratory 1: to do list

Write a MATLAB program in a script file that implements the following instructions (the in-built functions that could be used are suggested in *blue*):

- 1) Displays a dialog window to choose the file to open (*uigetfile*)
- 2) Loads the file (*cd, load*)
- 3) Defines how many signals there are in the loaded file (*size*)
- 4) Derives the sampling time dt knowing the sampling frequency (variable name “fsamp”)
- 5) Transforms the signals (V) in engineering units (EU) using the accelerometers sensitivity values (**V/EU**) (variable name: “sens”)
- 6) Builds the time axis using a for loop (*for*) and defining directly the time vector
- 7) Plots the signals in the time domain (*plot, subplot*)
- 8) Displays on the graphs a grid, the legend and the axis title (*grid, legend, xlabel, ylabel, title*)

Laboratory 1: to do list

- 9) Calculates the maximum (using *max* and a recursive cycle), the minimum (*min*), the mean (*mean*), the standard deviation (*std*) and the RMS value for all the channels.
- 10) Displays on the time histories plot the values calculated in the previous point as lines (*yline*).
- 11) Saves in a text file (*.txt) all the values of the quantities calculated at point 9 (*save*)

In order understand how to use the in-built functions in MATLAB, you can always refer to the Help by clicking on the proper icon (question mark) or by typing on the MATLAB Command Window:

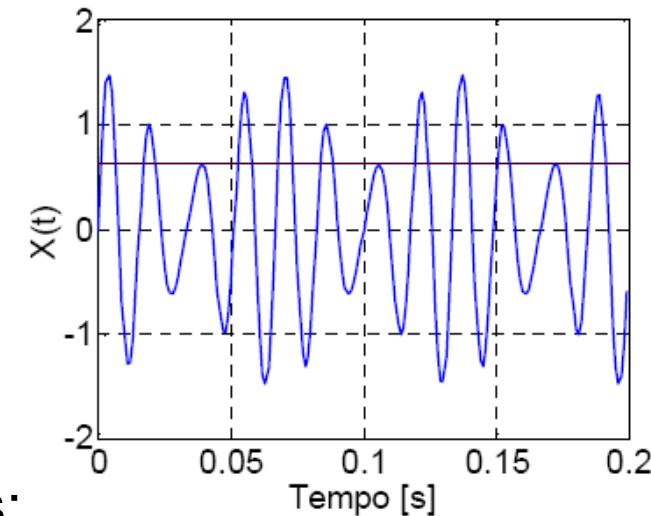
«help *function_name*» (e.g., «help min»)

Laboratory 1: to do list

RMS:

It is an index that can be calculated on time signals of a recorded physical quantity (record) and it is related to the mean power of the signal.

Definition:
$$rms = \sqrt{\frac{1}{T} \int_0^T x^2(t) dt}$$



It can be demonstrated that the RMS value can be expressed also as:

$$rms = \sqrt{\mu^2 + \sigma^2}$$

Laboratory 1: to do list

RMS value calculation:

Commands: mean, std, sqrt

$$rms = \sqrt{\mu^2 + \sigma^2}$$

Commands: **sum**, Pay attention! We have a discrete signal

$$rms = \sqrt{\frac{1}{T} \int_0^T x^2(t) dt}$$

Maximum calculation:

The maximum value of the signal can be calculated by using the in-built function **max** and with a recursive loop (**for**) that compares each value of the signal with the following one and save the maximum of the two in a temporary variable.

Compare the maximum value obtained with the two methods and display on the screen a message saying if the two values coincide or not (**if**, **disp**).

Variables available in the file «Data_Lab_1»:

- Data
- channels
- fsamp
- sens

How to access to MATLAB

<https://virtualdesktop.polimi.it/vpn/index.html>

1. Enable the *virtual desktop* service on your own notebook following the guidelines available on the website: <https://www.ict.polimi.it/software/virtual-desktop-software-for-study-and-teaching/?lang=en>

2. Install the software on your personal computer.

The university provides students with an annual software license that allows:

- to install MATLAB basic package and all optional modules on owned PC (home PC or notebook), with a maximum of 4 installations
- the distribution of updates

You can download the software and activate your personal copy by following the instructions on the website:

<https://www.software.polimi.it/mathworks-matlab/>

Signal Processing Toolbox

If you use the personal copy, please download the Signal Processing Toolbox

The screenshot shows the MATLAB R2023b desktop environment. The 'HOME' tab is active, and the 'APPS' section is highlighted with a red box and the number 1. Below the 'APPS' section, the 'Get More Apps' button is highlighted with a red box and the number 2. The 'Add-On Explorer' window is open, showing the 'Signal Processing Toolbox' by MathWorks. The 'Install' button is highlighted with a red box and the number 4. A red arrow points to the search bar in the 'Add-On Explorer' window, with the text '3 search for signal processing toolbox' next to it.

1

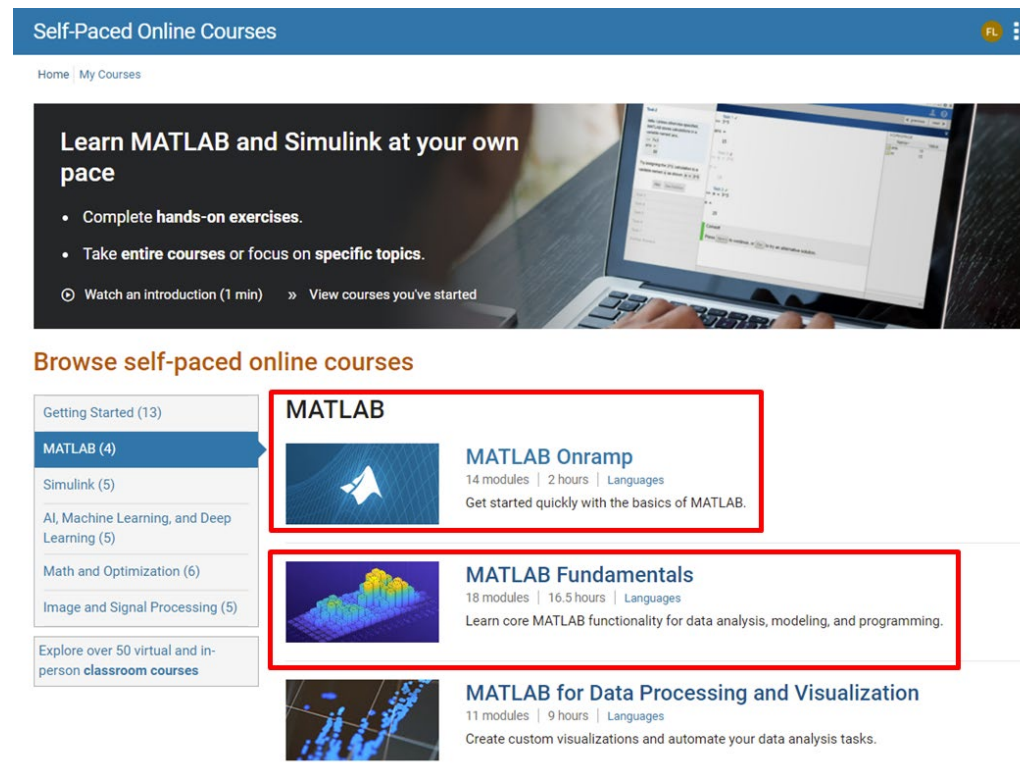
2

3 search for signal processing toolbox

4

Here you can find a basic course for MATLAB (Log in with your POLIMI account):

<https://matlabacademy.mathworks.com/>



The screenshot displays the MATLAB Academy website interface. At the top, a blue header reads "Self-Paced Online Courses" with a user profile icon and a grid icon. Below the header, a navigation bar shows "Home" and "My Courses". The main content area features a large banner with the text "Learn MATLAB and Simulink at your own pace" and two bullet points: "Complete hands-on exercises." and "Take entire courses or focus on specific topics." Below the banner, there are links to "Watch an introduction (1 min)" and "View courses you've started".

Below the banner, the section "Browse self-paced online courses" is visible. On the left, a sidebar lists course categories: "Getting Started (13)", "MATLAB (4)", "Simulink (5)", "AI, Machine Learning, and Deep Learning (5)", "Math and Optimization (6)", "Image and Signal Processing (5)", and "Explore over 50 virtual and in-person classroom courses".

The main content area lists three courses, each with a thumbnail image, title, duration, and description:

- MATLAB**
Thumbnail: MATLAB logo
Title: **MATLAB Onramp**
14 modules | 2 hours | Languages
Get started quickly with the basics of MATLAB.
- MATLAB Fundamentals**
Thumbnail: 3D surface plot
18 modules | 16.5 hours | Languages
Learn core MATLAB functionality for data analysis, modeling, and programming.
- MATLAB for Data Processing and Visualization**
Thumbnail: Scatter plot
11 modules | 9 hours | Languages
Create custom visualizations and automate your data analysis tasks.