AN INNOVATIVE DYNAMIC MONITORING SYSTEM

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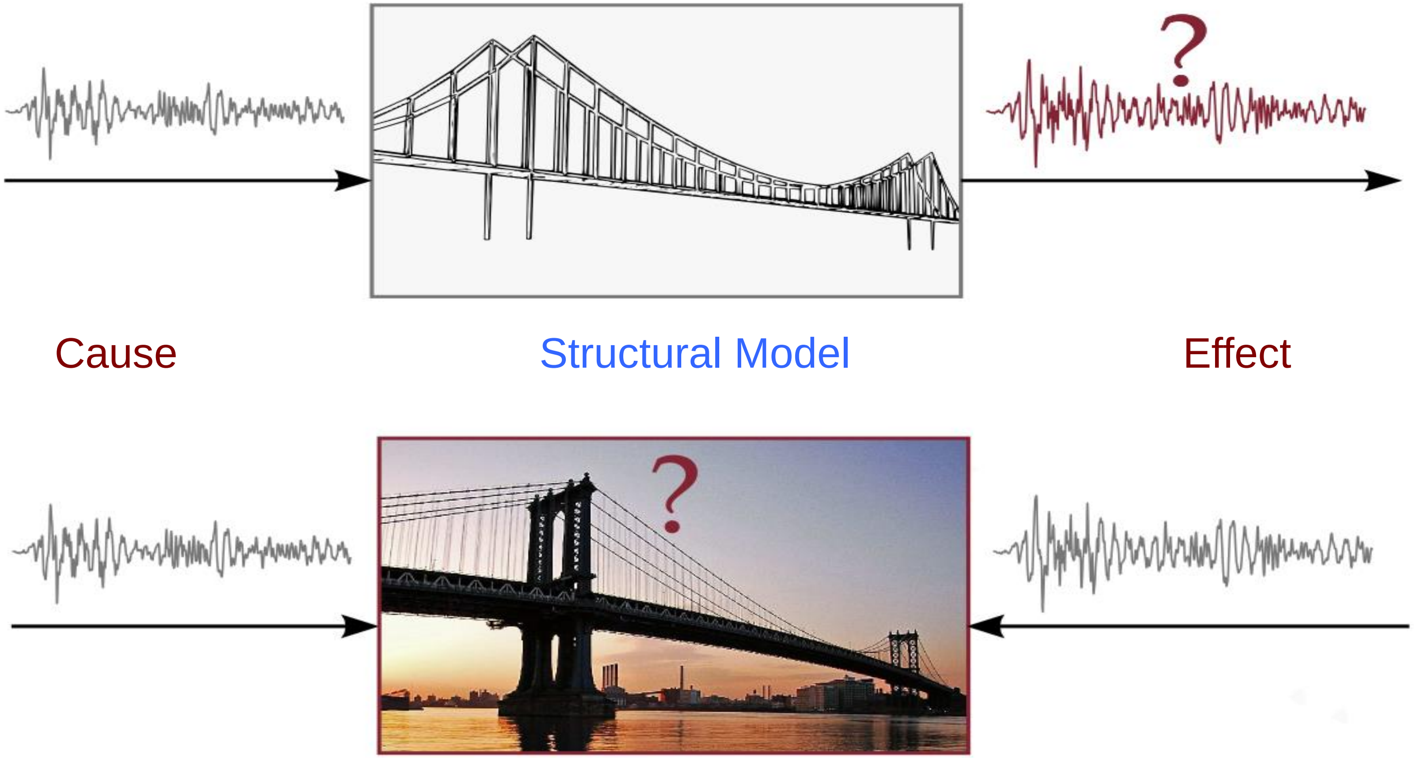
Dynamic identification of structures

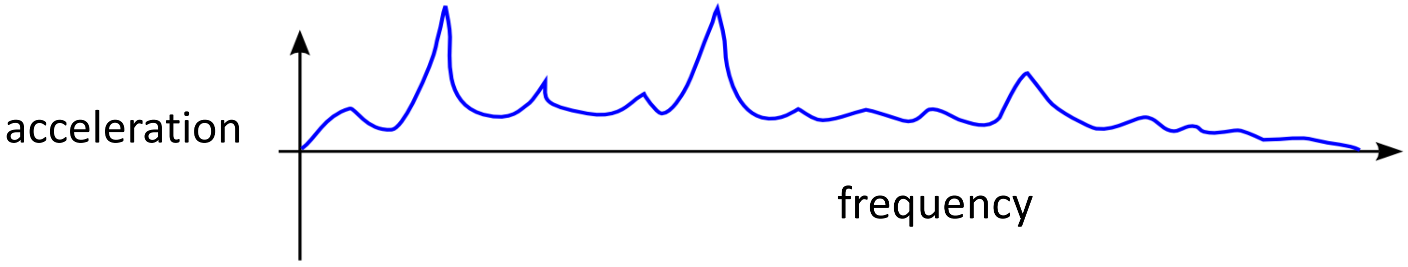
For an existing bridge, **numerical forecasts** must be substantiated by **experimental data**.



Having measured in situ the real dynamic response of the structure, the **dynamic identification techniques** consist of a procedure to determine the **modal model** (natural frequencies, vibration modes, dampings).

The proposed system

A dynamic identification way based on the measure of accelerations in the frequency domain using environmental resources of energy



Result of a research conducted in the last two PIARC cycles in the TC D.3 National with the collaboration of two spin-offs of the University of Rome "La Sapienza" (DIAMONDS - prof Ciambella, Eng. Ricci)) and the University of Perugia (WISEPOWER - Dr. H. Vocca)).

Innovative features:

- Self-supply (environmental energy recovery and reuse at km 0)
- No wiring for both power supply and data transmission

Advantages:

- Wireless sensor Network (**WSN**)
- Reliability
- Easy installation
- Low maintenance
- Data can be consulted on-line quickly and securely through a dedicated APP
- Automatic data processing and continuous dynamic identification

1- Preliminary phase of the research

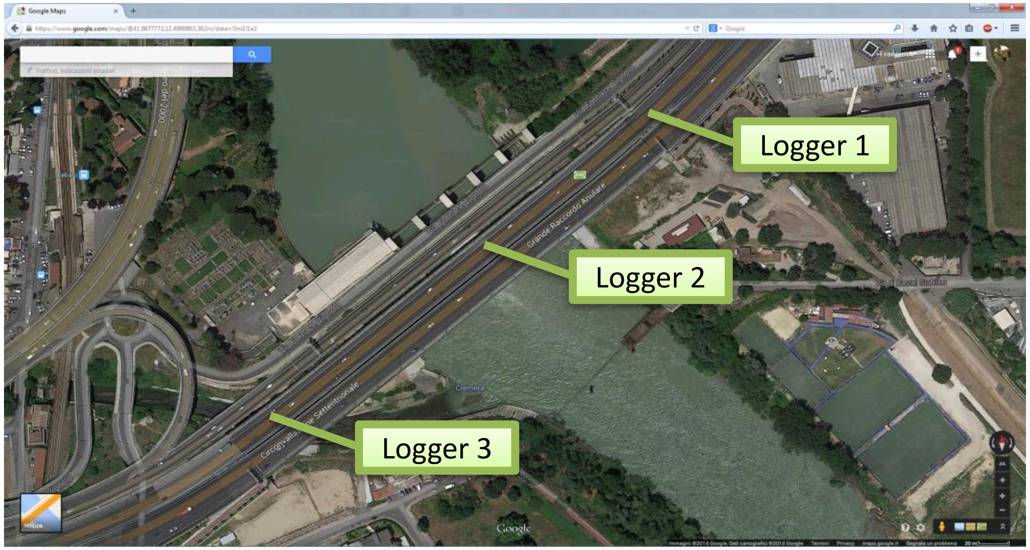
Vibration measurements on some sample structures (bridges)

- evaluation of the frequency spectrum in which vibrations are most concentrated
- choise of the harvester tipology (linear or non-linear, piezoelectric or electromagnetic)

to design

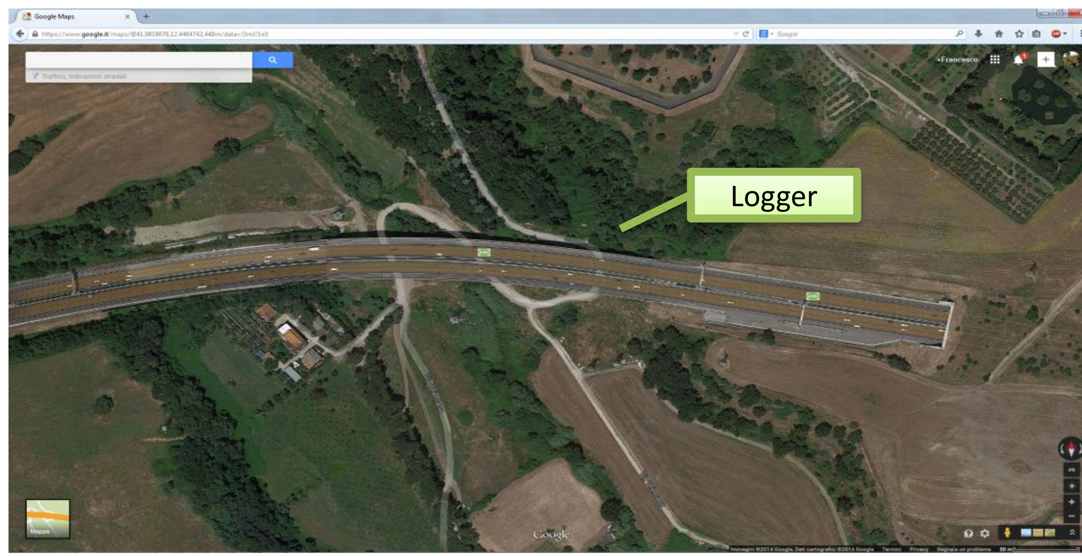
- a generator responding well to the stresses imposed and therefore efficient in converting energy, robust enough to withstand the dynamic stresses imposed by the accelerations
- and the best meccano / electric transducer for the conversion of energy needed to power the sensors

Experimental preliminary phase: measurement stations

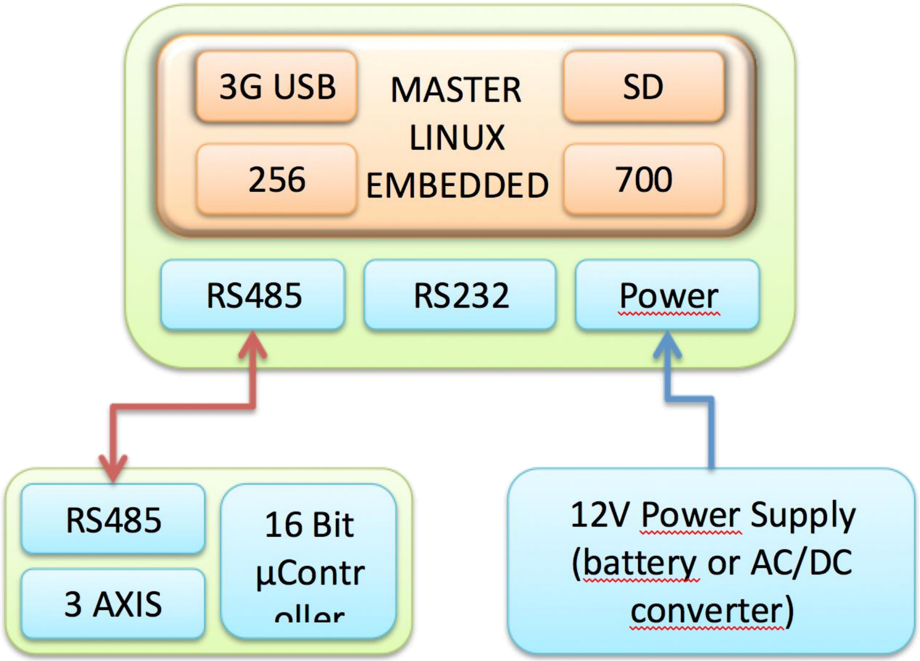


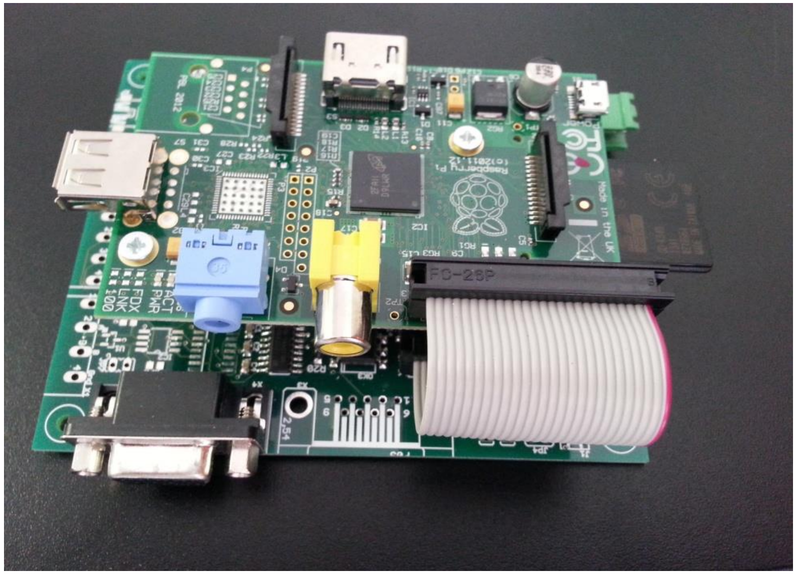
Installations on the “Tiber bridge” close to Castel Giubileo, Rome, internal roadway.

Installation on a bridge along the GRA close the exit for via Cassia: external roadway



Experimental preliminary phase: development of a stand alone acquisition system



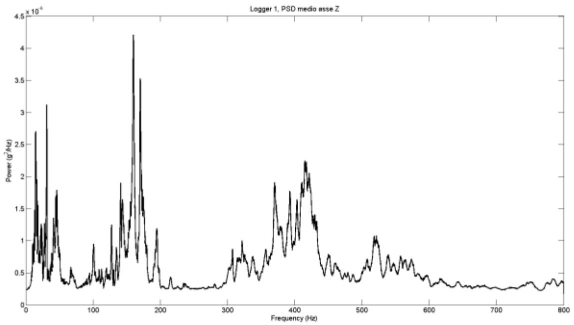


Working mode:

- sampling of vibrations at 1600 Hz on three axes for one minute;
- creation of a binary file and compression in gzip;
- file sent via email.

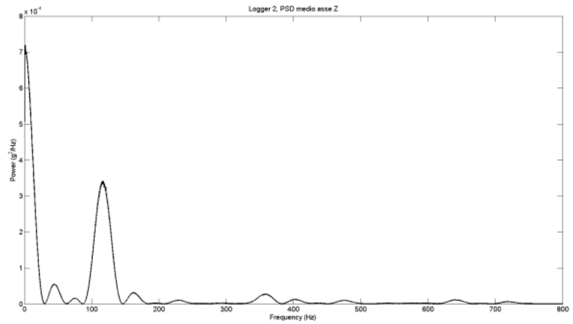
Measurements are acquired every 5 minutes, 24 hours a day.

Experimental preliminary phase: acquisition result



Logger 1, installed at the exit of "Tiber bridge" close to Castel Giubileo.

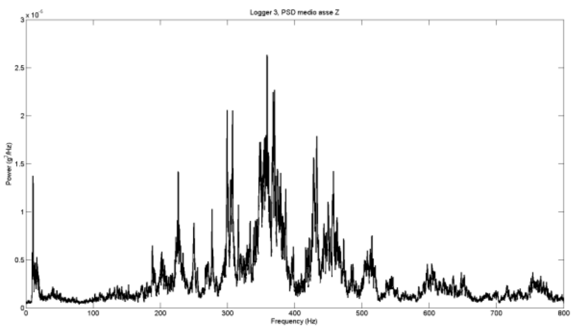
Most stressed axis is the vertical one with respect to the motion direction (Z axis), with a peak intensity of about $5x10^{-5}$ g^2/Hz at 150 Hz.



Logger 2, installed in the center of "Tiber bridge" close to Castel Giubileo.

Observing the spectra, it is easy to understand that the central part of the bridge oscillates only around a frequency equal to about 120 Hz.

On 3 axes' peak intensity is between$3x10^{-4}$ g^2/Hz and $5x10^{-4}$ g^2/Hz



Logger 3, installed at the entrance of the "Tiber bridge" close to Castel Giubileo.

In this third point the oscillations are due to the tires impact on the bridge: the technical joint is present, a small step is formed.

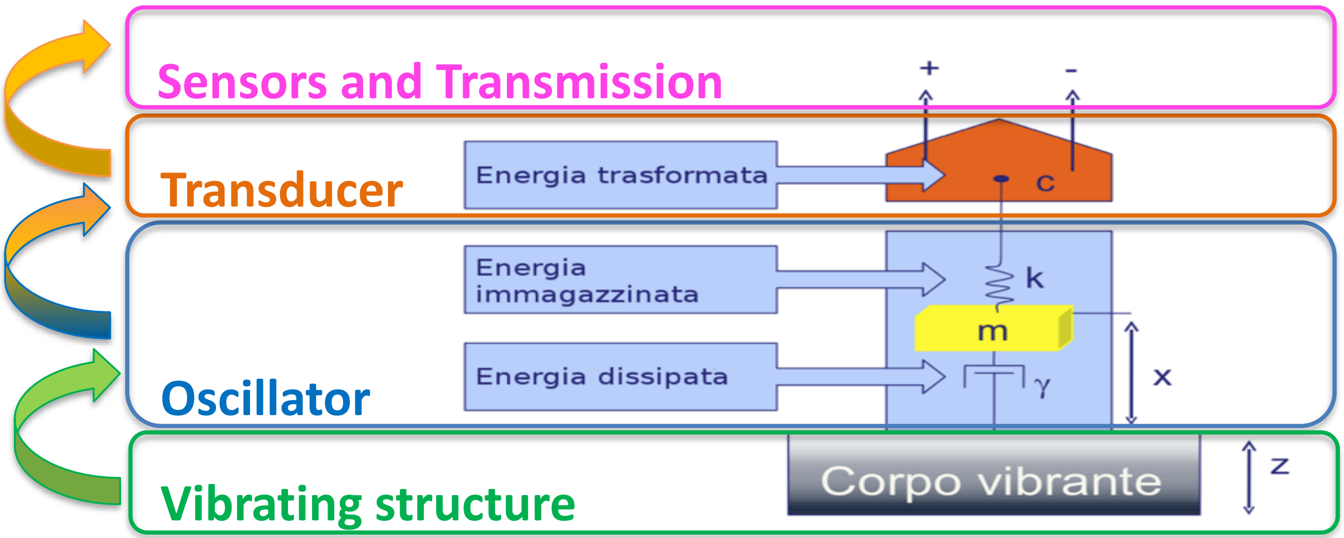
On the vertical axis, respect to motion direction, the energy is dispersed up to about 500 Hz, with peak intensity of about3×10^{-5} g^2/Hz

2.- Energy Harvesting

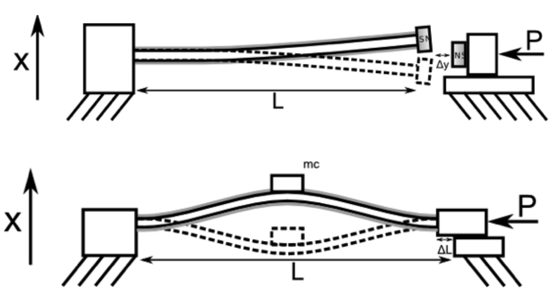
Two sources of sustainable energy

- vibrations
- solar

2.1- The vibration harvester

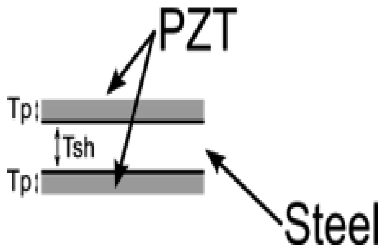


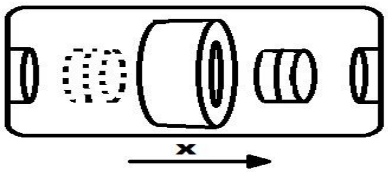
Possible oscillator stategies:



Piezo non-linear cantilever beam

Piezo nonlinear clamped-clamped beam





Electromagnetic non-linear oscillator

Depending on the installation site and on its vibration frequency and amplitude content, either the non-linear piezoelectric or the electromagnetic systems are used.

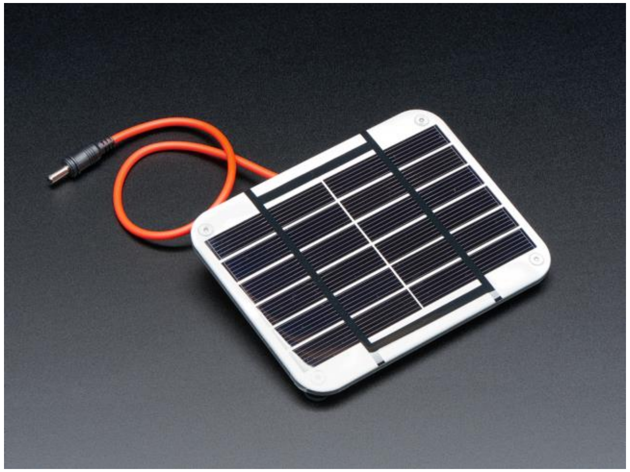
- the former amplifies the stress on the material, allowing increased efficiencies in respect to linear methods, at higher frequencies (>10Hz)
- the latter amplifies the response of the oscillator, increasing efficiency at lower frequencies (≤10Hz)

on the basis of the results obtained in the preliminary phase the piezo cantilever was chosen
assuming that the dynamics of the vibrating body remain unchanged in the oscillator because the presence of the last one is negligible compared to the environment (small size, large mechanical impedance)

The reliability tests of the generator have been carried out with
field and laboratory tests (with shakers and vibratory tables to reproduce the stresses recorded on site)

2.2.-The solar harvester

Small photovoltaic cells were installed in the device to work as a supplementary energy harvesting system, to ensure stable powering in every environmental condition.



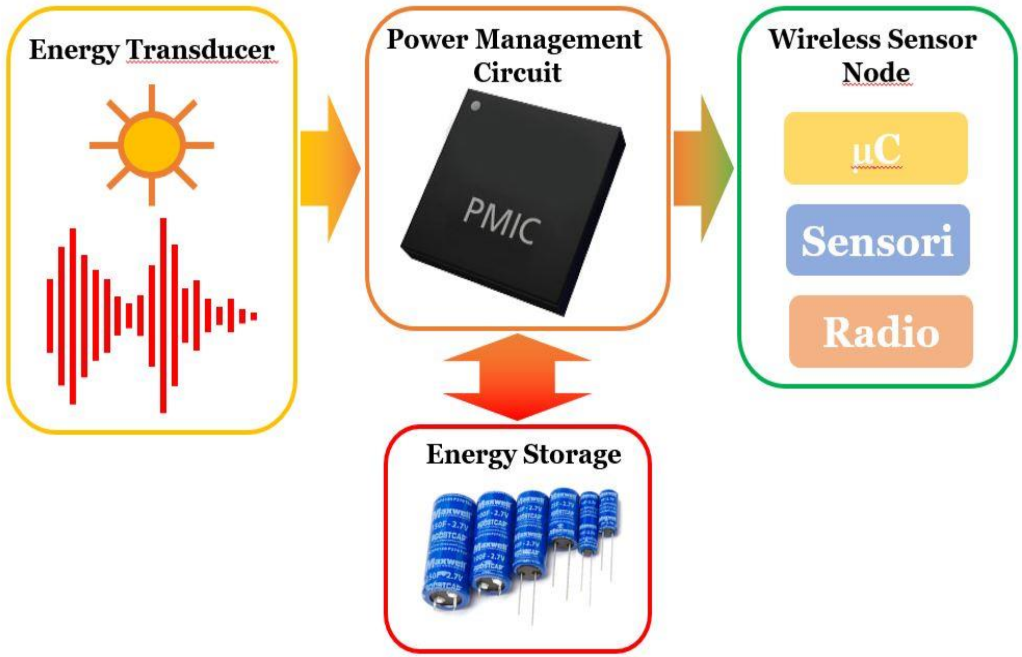
- Open Circuit Voltage: 7.7
- Peak Voltage: 6.5V
- Peak Current: 180mA
- Peak Power: 1.2W
- Power Tolerance: +/-10%
- 3.5" x 4.4" x 0.2" (89mm x 113mm x 5mm)
- 2.4 oz / 67g

When in excess, the sunlight energy is used to recharge a Li-Ion rechargable battery, that serves as energy reservoir.

3.- The sensor node

WiseSensing device
(10cm x10cm x5cm)

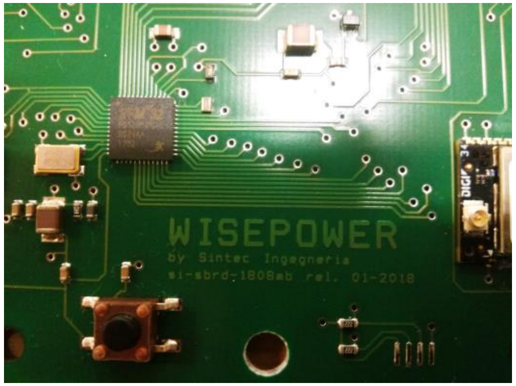
(6cm x 6cm x 2cm) ??



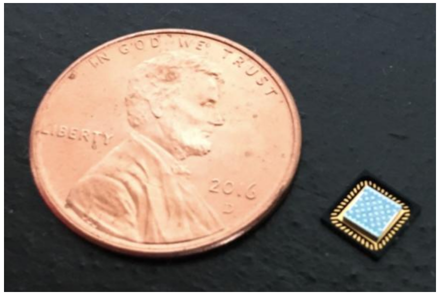
Each node is composed of :

- Two energy harvesting systems (solar + vibrational), in a hybrid configuration.
- A power management circuit, which regulates the output to mantain a constant powering
- A rechargable Li-Ion battery, or an equivalent energy storaging system
- Sensors and communication modules, managed by a microcontroller unit
- An integrated memory, for data storage and elaboration

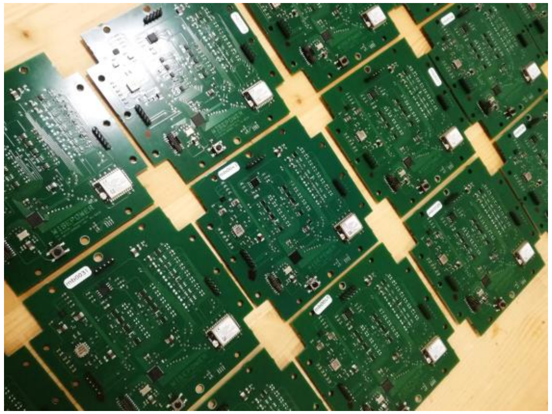
3.1-The sensors’ Board



- A new generation low power triaxial accelerometer (MEMS) with 2g-4g-8g scale:
  - 3.9-15.6 µg/LSB sensitivity
  - 25µg/√Hz noise over the three axes.
  - 0.02° sensitivity on inclination.
- A second accelerometer to detect shocks, with custom thresholds 1g-8g.
- A temperature sensor (-40°C - +125°C) with 1°C precision and 0.3°C sensitivity.
- A RFID tag for easy identification of nodes during installation.



<u>**The following characteristics can be changed from remote:**</u>

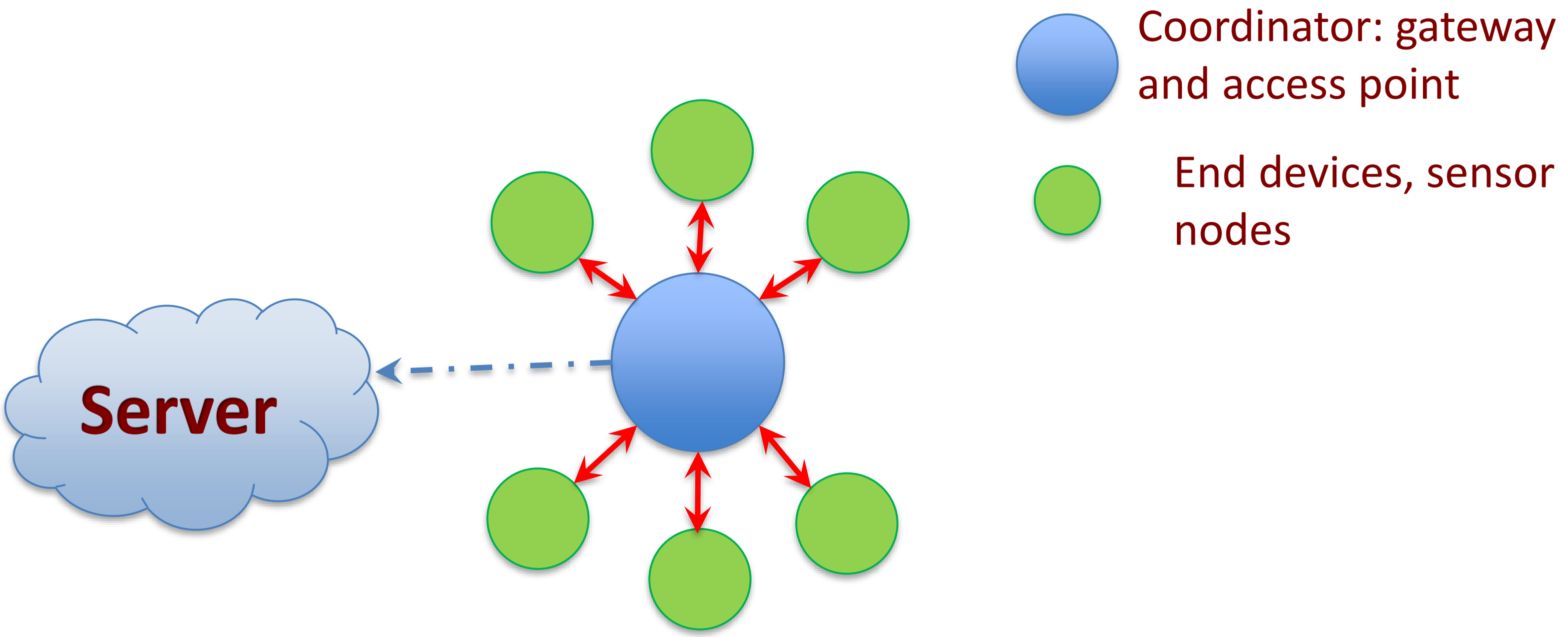


- Acquisition frequency from 32.25Hz up to 500Hz (default 125).
- Acquisition of from 2048 up to 32768 samples (default 16384)
- Choice of receiving 1,2 or 3 axes data (default 1 axis [Z])
- Choice of frequency of the acquisition during the day every 2,4,6 or 8 hours (default every 2h)

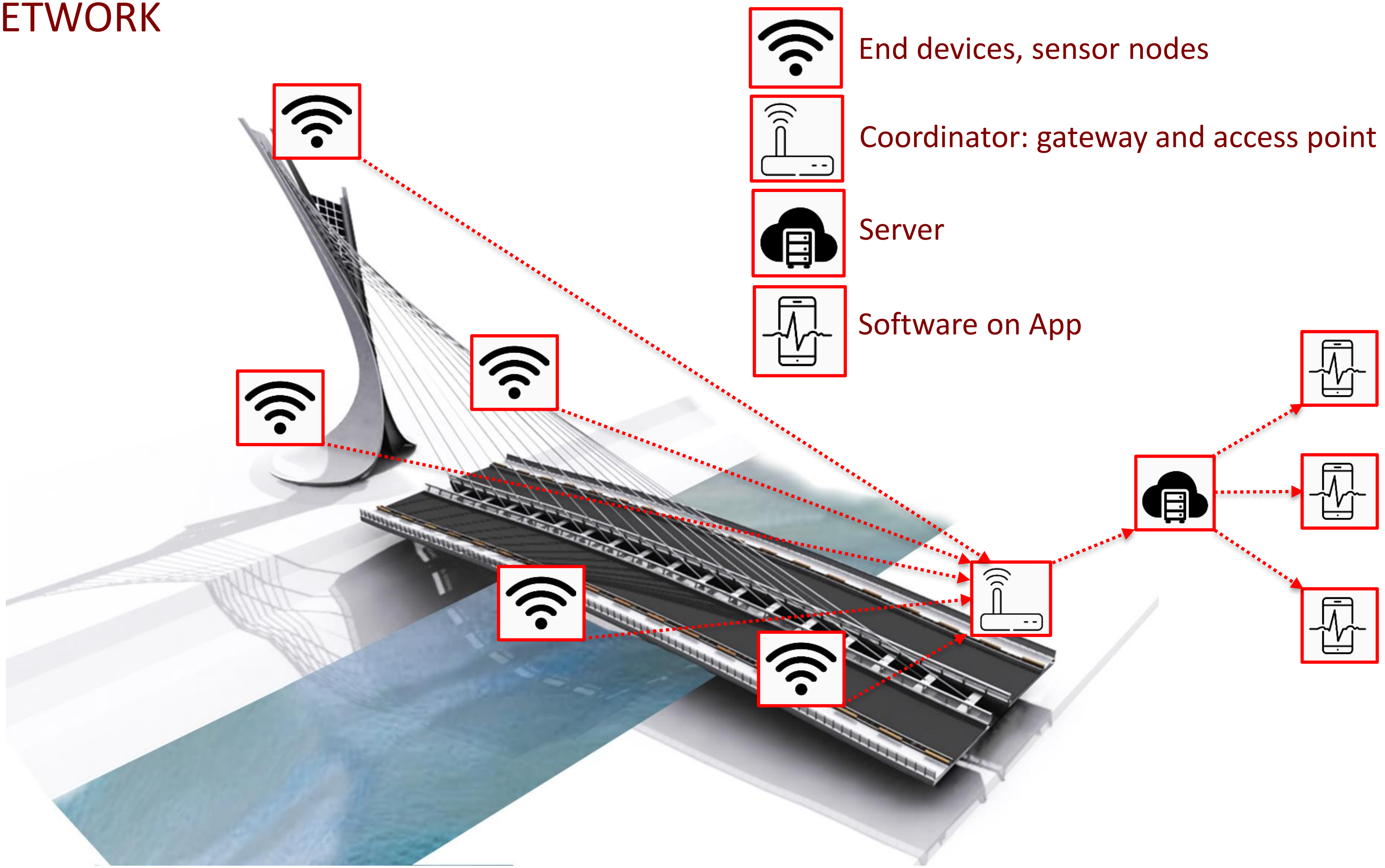
3.2.- data acquisition and transmission

The sensors store the measured data and send them via wireless technology (WSN) to a central unit connected to the network that collects the data and transmits it to remote locations

- Network formed on a star model: each node talks to the master, which regulates the network joining. It collects the data and send them to a remote server.
- The master sends the starting signal for the acquisition, ensuring 1ms synchronisation
- 2.4GHz band, max 300m range in line-of-sight.
- Remote reconfiguration of the nodes is possible through the gateway, which is connected to the network through GPRS.
- Zigbee protocol exploited.



NETWORK



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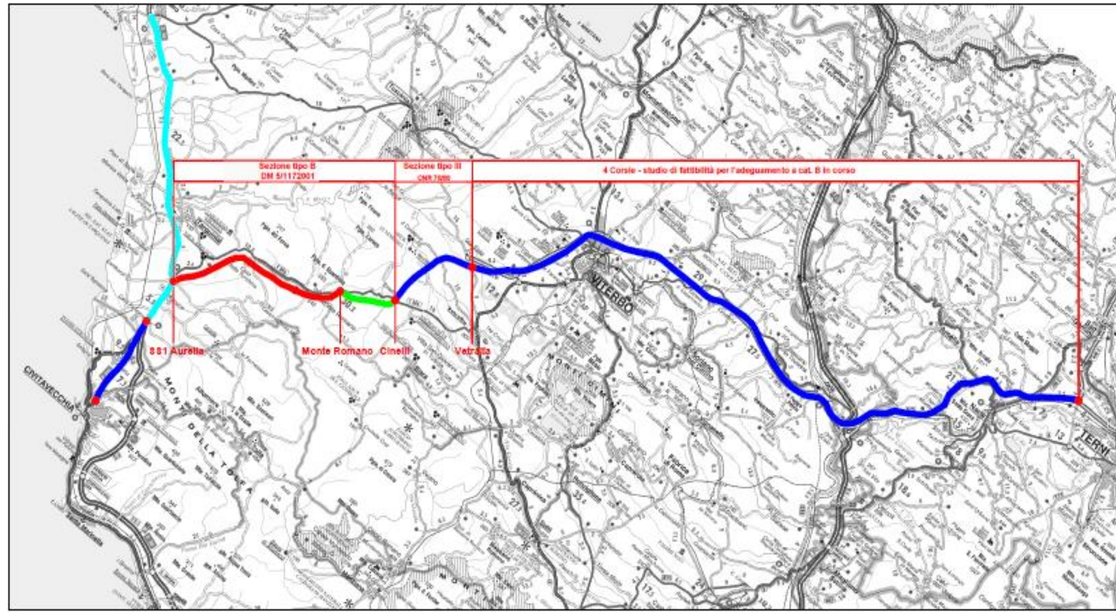
4.- Applications in progress

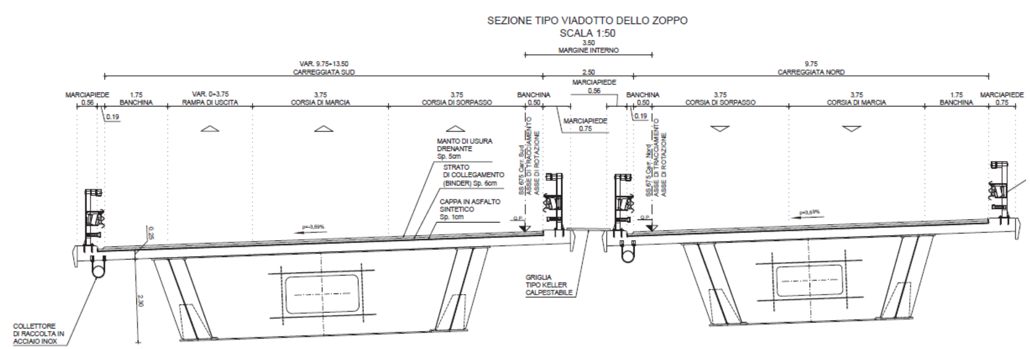
The system has been approved by ANAS (Italian Road Administration) and it is currently being installed on 3 viaducts (Crognolo, dello Zoppo, Bledano) along the SS 675 national road, not very far from Rome.



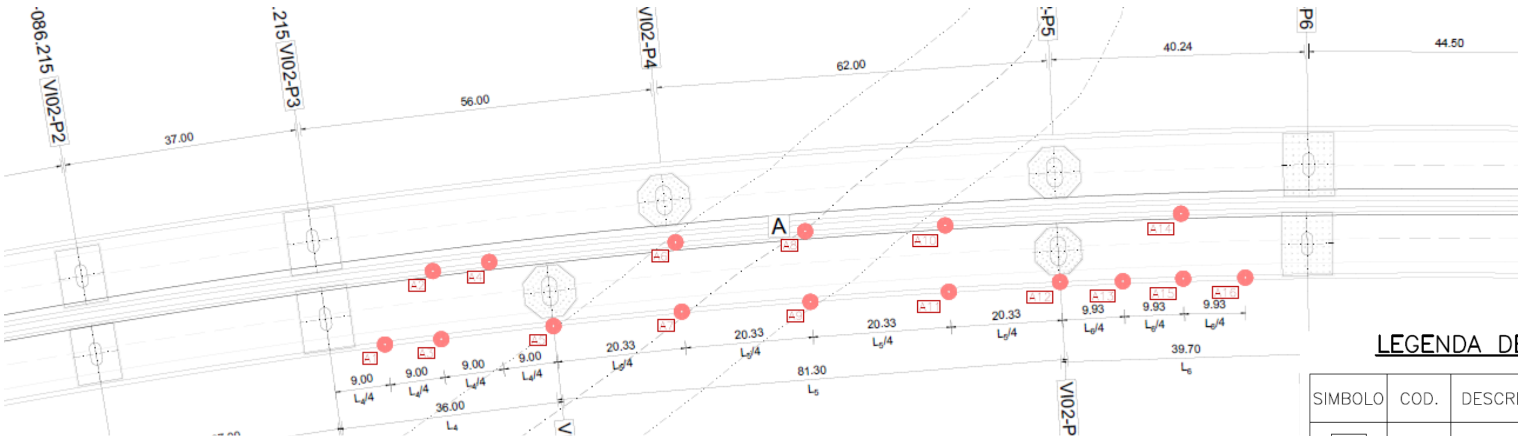
The 3 viaducts consist of 2 separate roadtracks, each with:

- static scheme of continuous beam with multiple spans,
- steel-concrete decks,
- reinforced concrete substructures,
- bonding system with elastomeric insulators.

transversal section of the viaducts



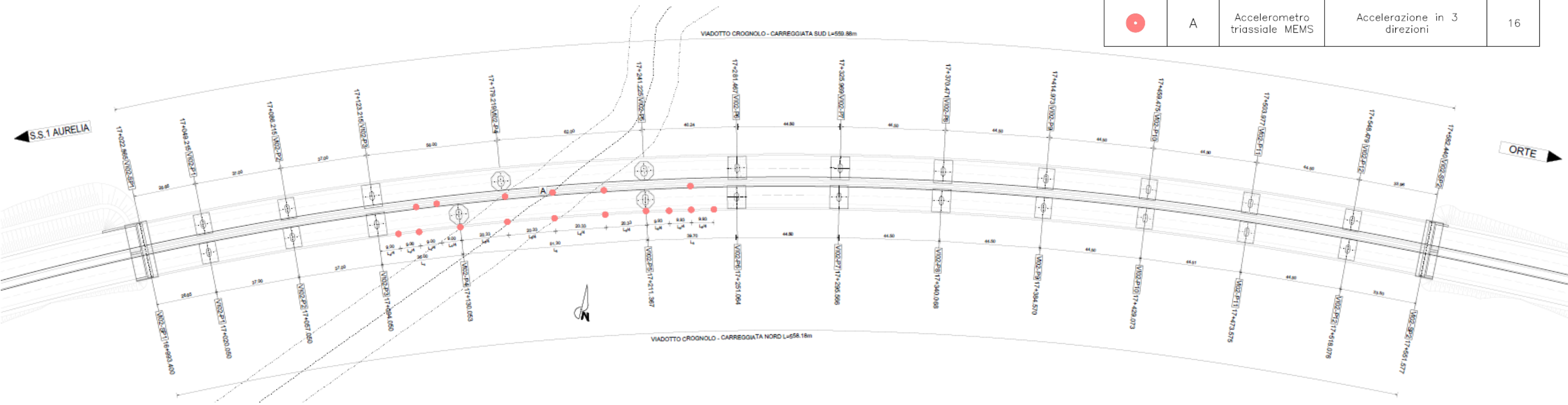
Monitoring plan of the “Crognolo” viaduct



KEY PLAN

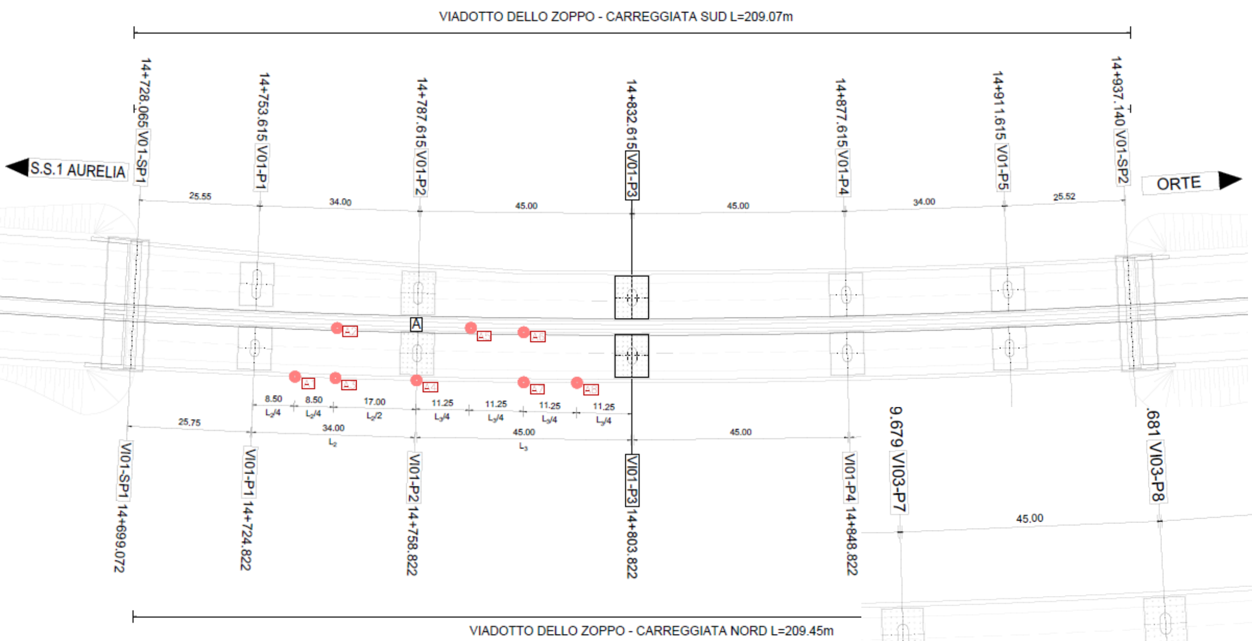
LEGENDA DEI SIMBOLI E QUANTITÀ

SIMBOLO	COD.	DESCRIZIONE	GRANDEZZA MISURATA	Q.TÀ
A	CA	Centralina di Acquisizione	–	1
●	A	Accelerometro triassiale MEMS	Accelerazione in 3 direzioni	16



The sensor network has been defined so as to grasp with sufficient accuracy the behaviour of some significant spans of each viaduct, characterizing the modal parameters of the first modes of vibration.

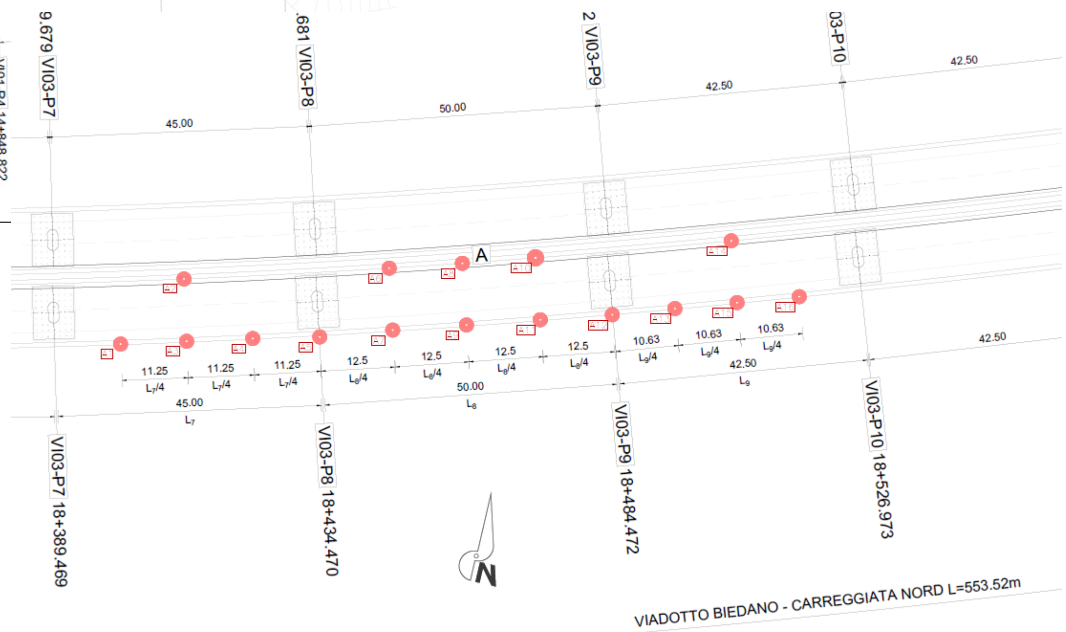
Viaduct “dello zoppo” monitoring



LEGENDA DEI SIMBOLI E QUANTITÀ

SIMBOLO	COD.	DESCRIZIONE	GRANDEZZA MISURATA	Q.TÀ
A	CA	Centralina di Acquisizione	–	1
●	A	Accelerometro triassiale MEMS	Accelerazione in 3 direzioni	8

Viaduct “Biedano”



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A	CA	Centralina di Acquisizione	–	1
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Thank you for your kind attention