HOW A 10-ENGINEER STARTUP

# CAN SAVE THE ITALIAN INFRASTRUCTURE

sensoworks
SENSING THE FUTURE

# SUMMARY



# 1. ACKNOWLEDGEMENTS

Sensoworks is what came out of a very happy equation between more than 20 years of expertise in the field of data and system integration and the interception of the many opportunities, challenges and solutions in the field of infrastructure monitoring.

We believe in a team of dedicated people to build a solid platform for companies that own or manage complex infrastructure and that are looking for - or should be looking for - new and innovative solutions and well: the rest is (going to make) history.

At Sensoworks, we work with the certainty that information and data are a must-have for today's companies. Indeed, being aware of what's happening across the organization's infrastructure helps teams to predict and prevent outages, to deliver better projects, to make infrastructure last longer and allows citizens to feel safer when making use of them.

Being these topics relatively recent and in constant change, we think that many of the decision makers inside companies and public institutions should be more aware of the infrastructure landscape: what are the new technologies, what they pledge to do, what are the benefits of structured monitoring solutions for all the involved stakeholders, and so on.

This is this whitepaper's goal as well. Not only this is a way for us to get to know companies that could be interested in our product. It is a way to spread knowledge, to help companies become more familiar with these concepts, with common issues and potential solutions.

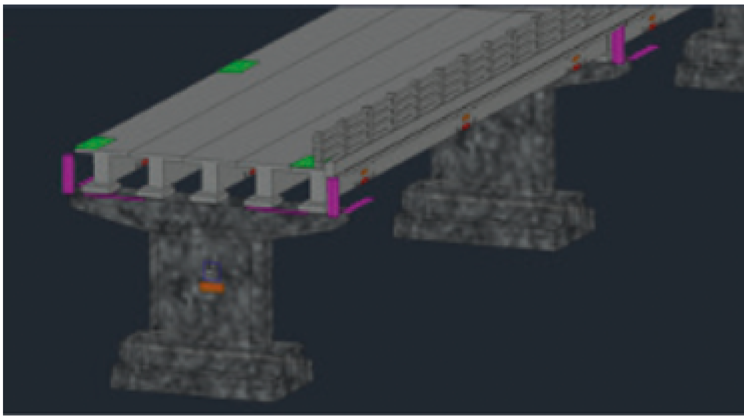
This whitepaper, thus, works in a broader company strategy and will be followed by other similar resources and activities, all of them aimed to inform our readers about infrastructure news, use cases, technological advancement, etc. In this version, a readjustment of a version published last year, developments and evolutions pertaining to the implementation of features looking at BIM and GIS and the introduction of OMA have been included.

If this work of ours helps you and your companies to better understand what your infrastructure needs and where you should direct your efforts, we will have achieved our key goal.

Hold fast,

**Niccolò De Carlo**
***CEO and co-founder of Sensoworks***

# 2. WHAT IS SENSOWORKS



**Sensoworks** is the **IoT platform** that integrates IoT devices with company systems and cloud infrastructures. It's a ready-to-use, "made in Italy" platform for the remote management and control of complex infrastructure systems.

Sensoworks gathers, monitors and interprets the data collected from sensors connected to machinery or infrastructure. It allows the customers to develop and manage their own IoT ecosystem simplifying the flow of data, communication among items, device management and, in general, enabling advanced application functionalities.

# 3. OUR VISION, METHODS AND TOOLS

One of Sensoworks's most important missions is to have things speak, with a strong focus on infrastructure management - such as bridges, tunnels, construction sites, buildings, wind turbines - simplifying all the pieces of infrastructure in need of maintenance or monitoring.

What we do is to understand - and help our customers understand - the health status of these "objects", starting from the huge amount of data they communicate. This way, we can easily prevent breakdowns or issues. For this reason, we cooperate with companies that chose a solid foundation in infrastructure monitoring, with those that manufacture advanced sensors and with experts in the field of monitored "things". The cooperation with physics, geologists, construction engineers is what makes the difference in delivering real results in these kinds of projects. We firmly believe that combining two skills yields more than just their algebraic sum. Only facing a problem from different angles and with different professional backgrounds allows us to solve whatever issue better and faster.

# 4. FROM THEORY ...

## A) INDUSTRY PROBLEMS

Infrastructure monitoring has been a hot topic in recent years: several cases reported in the news let us know that there's a clear necessity - both at the institutional and the industrial level - for a faster and more efficient solution to the main infrastructural problems.

These can be divided into three main categories:

- Infrastructure age-related issues;
- Overemployment-related issues;
- Unpredictable issues (extraordinary events, design issues, etc.).

In the first place, we have one of the most critical issues for our country. The majority of our infrastructure (highways, entire neighbourhoods of our largest cities, bridges, dams, etc.) were built in about 20-30 years, mainly between the '50s and the '70s.

What follows is that infrastructure, today, is almost 50 years old, sometimes even older, and presents issues related to stability. However, we should stress that the age of infrastructure is a common issue across all European countries (where they developed their infrastructure in the same years Italy did), but it is perhaps more critical in the USA.

In the United States, they started the construction of great infrastructures way before the Second World War, but they did not suffer the consequences of enemy bombings. Therefore, there was no immediate need to renovate the infrastructural system.

In the second place, we have issues related to the overemployment of infrastructure, especially for mobility purposes (i.e. roads, highways, bridges, etc.). In the years these were designed - that is from the '50s onward - no one could imagine the exponential growth in the number of vehicles travelling on our streets. Here too, we have to stress that: in this case, maybe, the issue is more critical to Italy rather than to other countries such as Germany. Their logistics are mainly based on rubber in place of iron (for instance, they prefer trucks to trains for the transfer of consumer goods).

In the third place, we find a set of lesser statistical cases regarding potential anomalies, likewise critical in their consequences. We can trace this third set of issues back to the increasingly frequent natural disasters - due to the growing anthropization of territories and, more generally, to climate changing phenomena on a global scale. The hard predictability of these phenomena puts all kinds of infrastructures at risk. To natural disasters, we also add lesser cases due to potential human mistakes in the construction, whether they are related to the infrastructure design, making or the materials' quality.

The whole of these issues (not an exhaustive list, but rather a hint of what the industry is in constant need of) should clarify the reasons why, in the last years, the research of new technological solutions is becoming increasingly hectic and relevant, in such a way to involve governments and multinational companies alike.

## B) TRADITIONAL SOLUTIONS

A traditional solution usually relies on visual/ manual periodic monitoring by human resources, remotely or on site. However, these are very expensive and inefficient operations, for several reasons.

First off, from a chronological perspective, we cannot say for sure that periodic inspections can correctly foresee potential harmful events. A periodic monitoring every few months could ignore events starting and ending within the time between the periodic checks.

Moreover, human mistakes due to distractions, wrong measurements or even the tiniest errors might take no notice of imminent danger. Speaking of effort in terms of time, then, it's clear that the cost of a resource and its deployment in a given place to carry out monitoring activities has a tangible impact on any project.

## C) NEW SOLUTIONS

The great tech developments at the IT (new software programs for data processing, incredible speed for internet data transfer) and technical levels (data storage, manufacturing of miniaturized sensors to be installed in the most peculiar contexts) allowed for the development of technological solutions we could not even imagine just 10 years ago.

To the traditional manual and visual solutions, today, we can add an innovative and completely automated solution based on, for instance, the platform we developed and named after our company, Sensoworks. In line with the industry's technological developments, Sensoworks and similar infrastructure monitoring platforms allow for the constant gathering of information from the infrastructure they are installed on.

They also allow the immediate processing of the gathered data (through advanced algorithms increasingly reliant on machine learning to train autonomously). Thanks to such a pervasive solution, even the answer can be as immediate. Not only, the platform can give us an extremely precise answer, aimed only at the exact point of the infrastructure that needs maintenance.

The speed of gathering and processing the information it's important not only to cut the maintenance costs (which are important nonetheless), but also for the safety of users (residents of a building, passersby on a road, vehicles on a highway) who can have a timely notification in case of potential issues.

## D) NEW TECHNOLOGIES

New technological solutions are based on many little innovative pieces. Base technologies, or components, unavoidable for the construction of a successful monitoring solution are:

### Sensors

Sensors are the foundation of our platform, the long antennas we gather relevant information with. Information which we then translate in real value for companies that have complex infrastructures to monitor. Accelerometers, extension gauges, clinometers, pressure sensors, and various kinds of hardware allow us an extremely precise, timely, constant and reliable monitoring. For example, we built our architecture to simplify the process of "adding" and "changing" sensors in the whole monitoring activity, whenever you want, whenever you need, with the least impact on your IT infrastructure.

### IoT

Internet of Things is not just a trendy word for us. It is also the pillar upon which all the data collection, storing and alert activities are based. New broadband technologies, mobile communications, these are all components that make information available in real time and infrastructure monitoring possible.

### Cloud/On-Premise

Every company is different, with different needs and specific, internal safety guidelines, sometimes with different national or international laws to follow according to the installation location.

A new monitoring solution must foresee what kind of technology will be necessary to integrate the customer digital infrastructure while maintaining the right flexibility to choose where and how to install and use our whole product, besides the degree of dependency on external servers.

New platforms such as Sensoworks are usually as flexible as it gets to allow their customers to modify their infrastructure according to the evolving market needs.

# 5. ... TO PRACTICE: A REAL MONITORING PROJECT

## A) ESSENTIAL ELEMENTS OF A MONITORING PROJECT

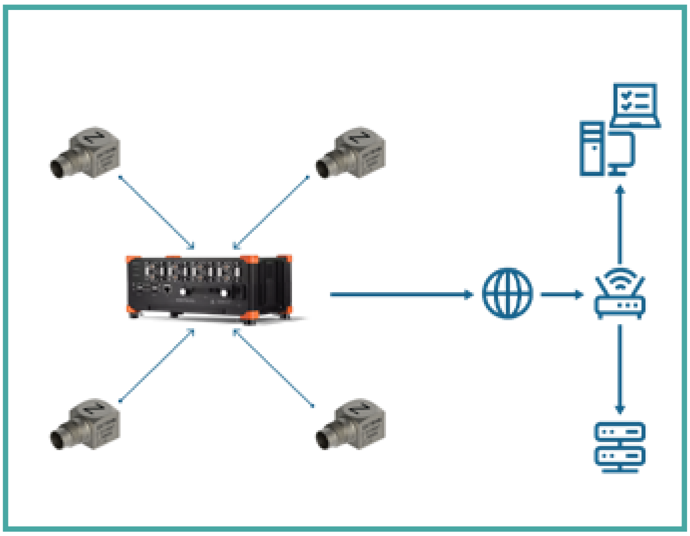
Here are the fundamental elements to monitor a Sensoworks project. As we'll see, the monitoring platform is only a piece of a larger puzzle, although a fundamental one to prepare and then implement an efficient solution:

- An initial brief with the customer to verify their monitoring requests and consequent delivery of the monitoring activity.
- Collection of the specifications for the item to monitor.
- Structural analysis of the item and involvement of technical consultants for each aspect of the analysis.
- Design of the hardware monitoring system and set up of the necessary software to implement it on Sensoworks's platform.
- Installation of a web of sensors and specific tech devices for the monitoring activity.
- Provision of Sensoworks's platform, set up together with the customer.
- Continuous monitoring service with alerts and checks arranged with the customer.

**The proposed monitoring system (as for the case study we'll see later) integrates different measurement kinds and technologies:**

**Static Monitoring:** for pillars and supports, beams through joint gauges, clinometers, extension gauges. It allows for the evaluation of the static behavior of critical components of works to monitor their conditions while operating and highlighting the consequences of decay and/or deterioration.

**Dynamic Monitoring:** through accelerometers, allows for the evaluation of the dynamic behavior of structures throughout their operation cycle via the verification of design hypotheses and to evaluate structural performance losses even following extraordinary phenomena such as earthquakes, floods, etc.



**Visual Control Component:** for critical supports and elements via directionable IP cameras. It allows for the direct visual evaluation of critical segments and/or elements to optimize the surveillance, inspection and maintenance activity of the team according to the maintenance plan.

The system aims at allowing the infrastructure manager to acquire relevant data to evaluate the infrastructure's behavior while operating, so as to define its conditions and predict potential issues due to decay and/or anomalies.


Moreover, we also proposed to use the equipment for the evaluation of the infrastructure's history. Data which will be consequently gathered to follow the evolution of the work's behavior (static and dynamic) and conditions in time, through:

- Identification of sudden or progressive damage of structures/materials while operating or due to extraordinary events, such as earthquakes;
- Evaluation of critical variations in the typical parameters of the structure (static and dynamic parameters), starting from a nominal condition (baseline);
- Survey of potential anomalies in time, allowing for more efficient maintenance interventions and reparations, with minimum intervention effort by the maintenance team and a consequent reduction of operation costs.

Our proposed system is based on a solid architecture certified by its implementation in numerous similar projects. It allows for the optimization of the management and maintenance of the system, it minimizes the risks related to data loss and it creates a web of external connection to transmit all the necessary information in whatever format and for whatever requirement. We deliver a full monitoring project to structures and users concerned with the phenomena affecting the piece of infrastructure and the information gathered in close and constant contact with the management team.

The opportunity to set up the thresholds, as well as to define the logic behind the analyses of the historical trends, allows the customer to understand what is going on and to intervene in time if necessary.

To evaluate the changes in the materials and to react before the emergence of serious harms, it is fundamental to implement a specific monitoring system made up of:

- A web of sensors, disposed along the structure;
- Systems for the acquisition of data and terminals to store and analyze the measurements;
- Systems to transmit the data with remote processing terminals and software procedures for the analysis and interpretation of data;
- Alarm systems;
- A platform to visualize historical or near real time data.

## B) CASE STUDY - PROPOSAL FOR THE STATIC AND DYNAMIC MONITORING OF A BRIDGE

The following case study is that of an ANAS infrastructure, specifically a bridge with the following characteristics:

- 1 roadway
- 2 aisles
- 3 double-T, steel beams supporting each aisle.

The solution we proposed - based on Sensoworks's integrated system - is characterized by the opportunity to optimize and maximize the value of data and information, allowing for a more reliable and less subject to external factors behavioral analysis

We consider the system's components as a whole rather than individual, disjointed elements. We valorize the global condition of the infrastructure through the union of its components' potential.

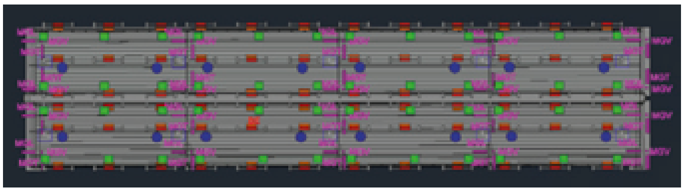
# 6. SENSOWORKS'S WAY

### Sensor Monitoring

Our platform connects to all the installed sensors to allow you to set up your infrastructure and to customize it straight on the platform. Once set up, all the sensors are immediately monitored in real-time. All the data are gathered, registered and structured to be analysed by our powerful predictive algorithms.

For the case study presented, the installation of the following sensors was provided:

- 72 thermometers;
- 144 strain gauges;
- 48 triaxial accelerometers;
- 60 joint meters;
- 20 uniaxial clinometers;
- 16 video surveillance systems;
- 8 dynamic monitoring data loggers;
- 110 static monitoring data loggers.



Sensoworks can be easily programmed to set up utterly automatic actions, based on stored information and configured algorithms and according to the customer's specifications. The customer is free to choose what action triggers when something specific happens, for instance, when values exceed a threshold or an alarm has ceased. In case it occurs, Sensoworks will alert who is in charge via SMS or email, according to the customer's preference.

### Customized Reports

Sensoworks provides customized reports to have its customers always up to date with the state of the art of their infrastructure. Our customers can choose between already existing templates we designed or they can log in the Report section to set up engaging and simple reports. On average, we deliver our reports monthly or weekly, but a more ad-hoc installation allows for limitless options.

### Predictive Maintenance

Sensoworks accurately chooses the companies it works with to develop the right algorithms and to efficiently and constantly monitor the health status of your machinery, buildings or infrastructure. Thousands of monitoring hours gave us the right expertise to understand what is going on and to notify our customers immediately, with a straight connection to their company's departments.

### Certified on Blockchain

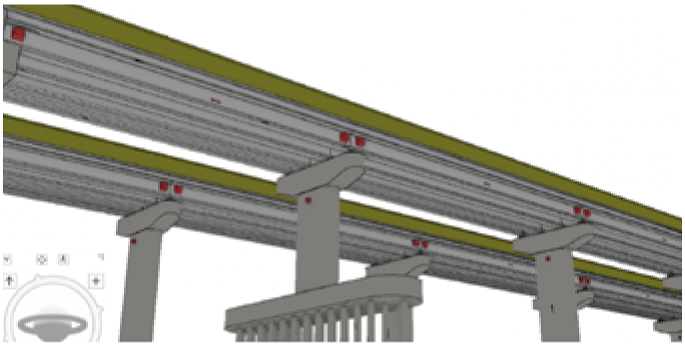
A main focus of Sensoworks is the security of stored information. All the data we gather, share and analyze are not only protected but also certified through blockchain technology, for an extra layer of security, information and precision.

### BIM and GIS Integration

The integration of BIM and GIS will transform the future of the construction sector, thanks to the countless advantages that the combined use of these two working methods can lead to the construction of infrastructural works.

The GIS (Geographical Information System) or geographic information system, is a tool that allows you to analyze the territory by collecting large amounts of data of different nature.

GIS are IT tools designed for land management and planning. Geographical systems make it possible to carry out analyzes and representations of space and the events that occur in it; in geographic software, the common operations that can be carried out on databases (such as searches, statistical analyzes, graphs etc.) are added the features of a GIS, such as the storage of territorial data, their treatment and above all their representation in the form of cartograms or tables cut out on more or less extended portions of territory.



In this way, users have a tool that allows them to view and analyze information to explain events, plan strategies or design territorial infrastructures.

In recent years, the geographic information systems sector has also been affected by the evolution that the world of design is experiencing with the transition from 2D to Building Information Modeling (BIM) in 3D.

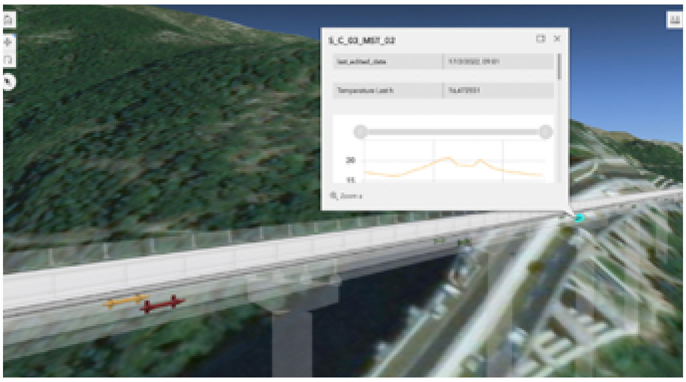
GIS and BIM have long remained two separate realities, although both are part of the process of digitizing planning and design data.

BIM is intended as a digital container of three-dimensional information relating to a building or infrastructure while GIS is the geographic information system that shows the events that

occur in a given territory.

With the integration between BIM and GIS it is possible to enhance the information data as a central element of the entire process: despite having different needs, the two parties need to query the data within a single database.

The information provided by GIS systems make it possible to design buildings and infrastructures within a much more realistic context. Designers can avoid many errors, especially in the preliminary and feasibility plan phase, by integrating the BIM project with the topographic and cartographic DB,



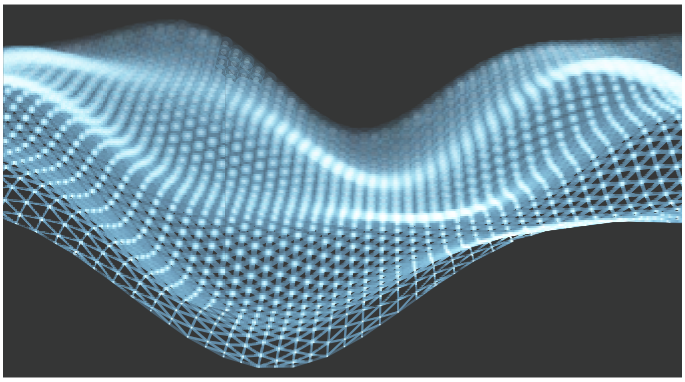
and by framing the project in a coordinate system. On the other hand, the project information, and especially the information on the actual construction of the work (the so-called “as built”), are of fundamental importance for updating the GIS systems, which in this way can be updated very much accurate.

The benefits of this interaction can also be found in other areas besides design, for example in architecture and in all fields in which the territorial component is taken into consideration in the decision-making or maintenance phase.

## Operational modal analysis

Operational Modal Analysis (OMA) is a technique used to identify the modal parameters (natural frequencies, damping, and mode shapes) of a structure or object during operation. By measuring and understanding the modal parameters, engineers, architects and designers can help create structures, machines and devices that perform better, last longer, and are more comfortable for their users or occupants.

As the name suggests, OMA focuses on investigating the structural dynamics of a system while it is inoperation. While other techniques are typically performed in a laboratory, on a shaker table, or with highly controlled boundary conditions, OMA is performed in-situ under real-world load conditions. This ensures that the forces acting upon the structure are realistic with respect to level, location/direction of application, as well as frequency/order content.



**There are three main benefits/reasons to perform a modal analysis during operation:**

- Real world operational conditions differ significantly from laboratory conditions
- Practical / Size limitations
- Ongoing health monitoring / damage detection

Real world conditions: Some structures exhibit a high degree of non-linearity when they are tested in a laboratory environment compared to their real-world usage. An example of this phenomena is an automotive suspension. The shock absorbers in the suspension have a high level of static friction when the vehicle is at rest that isn't present when the vehicle is in motion on the road. This friction not only artificially raises the stiffness of the local structure but can also exhibit non-linear behavior when the friction is overcome, and the suspension begins to articulate. Non-linear behavior can wreak havoc when attempting to accurately measure and analyze structural dynamics data on vehicles in the lab.

There may also be environmental influences on the structure that cannot be easily replicated in the laboratory. Aero-elastic interactions like wind and air flow over a structure is a common example. This aero-elastic interaction is critical for understanding phenomena like flutter seen in aircraft and cannot easily be recreated in a lab. Scale models can be tested inside a wind tunnel in this case, but the aero-elastic inputs still go unmeasured.

Practical/Size limitations: Some large structures simply cannot be tested in a laboratory environment. Structures like bridges, buildings, wind turbines, etc. are too large to be tested in a lab, and often it is impossible to properly excite the structures using traditional input methods. In these cases, the natural loads found in-situ (traffic loading, natural/wind excitation, pedestrian traffic, etc.) are more realistic and better suited to properly excite the structure. OMA is often the only option for these structures.

**Health monitoring & damage detection:** Changing modal parameters (such as natural frequency) can be an early sign of increased wear or impending failure of a machine or structure. By monitoring a structure using OMA engineers can assess the health of the structure without removing it from service or interrupting operations. This is especially useful for very large civil structures such as bridges and buildings, particularly after exposure to potentially damaging events like earthquakes.

There are several techniques to perform oma, some operating in the time domain, others in the frequency domain. Sensoworks platform implements the FDD technique.

Because of its simplicity and robustness, the Frequency Domain Decomposition (FDD) identification technique have become very popular in the operational modal analysis community. The basic idea behind this technique consists of computing the singular value decomposition of the power spectral densities estimated with the periodogram (also known as "Welch's" periodogram) approach to identify the natural frequencies and mode shape vectors. In this paper, the benefits of the application of the FDD technique to half spectral densities - the power spectral densities estimated from the positive part of the correlation functions - are investigated. In order to illustrate such benefits from a practical perspective, the FDD identification results obtained from the half spectral densities, of both simulated and real structures, are compared to those from the classical periodogram-driven FDD.

The decomposition is performed simply by decomposing each of the estimated spectral density matrices. In the above reference it is shown that the singular values are estimates of the auto spectral density of the SDOF systems in modal coordinates, and in the vicinity of the resonance peak the singular vectors are estimates of the mode shapes of the mode.

**The FDD technique involves the main steps listed below:**

- Estimate spectral density matrices from the raw time series data.
- Perform singular value decomposition of the spectral density matrices.
- If multiple test setups are available, then average the first singular value of all test setups and average the second etc.
- Peak pick on the average singular values. For well-separated modes always pick on the first singular value. In case of close or repeated modes, pick on the second singular value, the third singular value etc. as well.
- Optionally, if multiple test setups are available, inspect the singular values of each test setup and edit the peak picking position if necessary.

# 7. SHM (STRUCTURE HEALTH MONITORING): STATIC AND DYNAMIC MONITORING

Structural Health Monitoring (SHM) has rapidly become one of the main interests in the civil, mechanical, and aerospace engineering field. Every structure is subject to various internal and external factors, which can cause damage due to usage or malfunction.

The triggering causes can be, for example, deterioration, a non-carried out construction process or lack of quality controls in extreme situations, such as accidents or environmental stress. SHM consists not only in identifying sudden or progressive damage but also in monitoring structural performance during operating conditions or exceptional events, i.e. in the case of an earthquake. Hence, structural monitoring involves a large number of applications in civil engineering, such as design, damage assessment, maintenance and structural control.

In order to evaluate these changes - and to react correctly before serious damage occurs - it is essential to implement a specific monitoring system. Monitoring structural behavior can detect anomalies in time, allowing for more efficient maintenance and repair interventions, with a consequent reduction in the operating costs. Even for already-built structures, especially of monumental and historical nature, SHM can help in the acquisition of fundamental data.

SHM is carried out using a sensor net appropriately arranged on the structure, data acquisition systems, units for storage and analysis of measurements, data transmission systems to remote processing units and software procedures for analysis and data interpretation.

**The state of the structures can be checked through the execution of:**

- Static measurements that require the application of tools to measure absolute or relative displacements of structural elements such as piers, supports and beams, to allow the evaluation of the static behavior of critical elements.
- Dynamic measurements based on the analysis of signals coming from natural or induced vibrations and allow, in addition to the verification of the design hypotheses, the evaluation of the dynamic behavior of the structures during their operating life cycle, through the analysis of the variation of the parameters' modal frequencies (natural frequencies of vibration, modal deformations, damping, etc.).

# 8. PROJECT TIMELINE & THE IMPORTANCE OF CONSTANT MONITORING

**The implementation of a monitoring system is generally fulfilled by carrying out the following steps:**

- Structural **analysis** and monitoring system **design**: during this phase, which we carry out together with the customer, we analyze the characteristics and features of the structure, identifying the structural elements that need to be checked the most. Then, we proceed to choose the different types of sensors to install and their position on the structure according to the different variables to measure;
- **Equipment supply**: supplying time depends on various parameters such as the type of sensors and data logger to use, the quantities needed, the supplying capacity of the selected manufacturer, etc.;
- **Equipment installation**: the installation time depends on the type of equipment to be installed and the accessibility to the installation points on the structure. In the specific case of a bridge, it is often necessary to use aerial platforms to reach the measurement points;
- **Software development/integration**: the software development/integration phase involves the implementation of APIs for the integration of the acquisition systems. Sensoworks's IoT platform allows for the customization of the interface and data visualization;
- **Testing** and launch of the monitoring system: the last step before the final delivery involves the execution of in-depth verification tests of the data acquisition and measurement equipment and the correct operation of the software.

Once the tuning operations for the monitoring system are complete, the system is delivered to the customer or to the infrastructure manager.

The duration of the monitoring activity may be limited in time if the goal is to check the structure during the execution of particular processes in correspondence with adjacent areas or extended to the entire life of the structures.

## A) TYPICAL PROJECT COSTS

The monitoring systems consist of structural monitoring, geomatic monitoring and geotechnical monitoring systems, with different instrumentation.

Monitoring systems are to be installed in advance (well before the beginning of the works) in order to acquire the necessary reference basis with regard to the variations produced by seasonal and daily thermal cycles and to keep under control the damage already present and possible unfavorable evolutions of activated or to-be-activated mechanisms.

Due to the duration of the construction of the infrastructure and, consequently, the duration of the monitoring systems, we calculated that we could adapt the initial choices to technological developments and to the availability of new instruments introduced by the Manufacturers.

Moreover, we made use of the experience gained during the construction to improve the system reliability with more appropriate components/ tools.

### Type of Instrumentation

The monitoring instrumentation can be divided in two main families:

- Instrumentation for Buildings & Monuments Structural monitoring
- Instrumentation for Soil/Geotechnical Monitoring

Monuments monitoring includes both static and dynamic systems with automatic data acquisition and transmission systems to measure the following parameters:

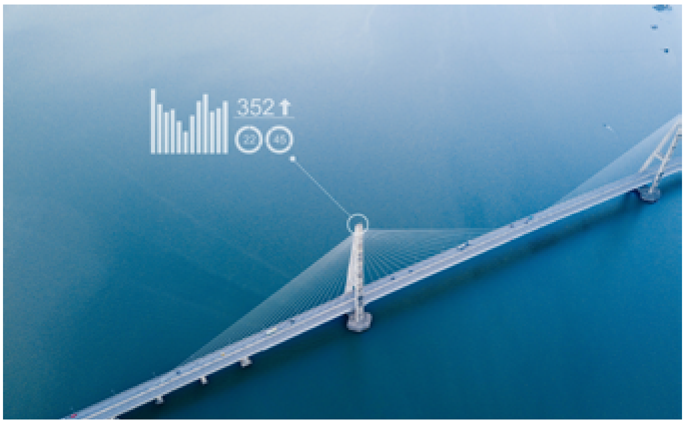
- Overall movements (by means of Automatic

Total Stations –ATS -with geodetic prisms) and manual leveling devices with leveling pins;

- Local movements / deformations (by means of joint meters, crackmeters, pendulums, tiltmeters, el-beams,)
- Loads / Forces (by means of Load Cells and Strain Gauges)-Environmental conditions (by means of temperature gauges, wind gauges, rain gauges, humidity sensors)
- Dynamic / Seismic actions (by means of Seismometers, accelerometers) Soil monitoring included both manual measurements and automatic data acquisition and transmission systems to measure the following parameters:
- Vertical movements (a.k.a. Settlement, by means of Rod Extensometers, Incremental Extensometers, ATS)
- Horizontal movements (by means of Manual Inclinometers, In Place Inclinometers, Estenso Inclinometers)
- Pore pressure and Water Levels (by means of Electric Piezometers, Casagrande Piezometers, Pressure Transducers

## B) MEASURING PRINCIPLES

We selected this type monitoring instrumentation in order to provide high reliability and robustness to reduce the maintenance activity which could be very critical in urban areas, especially for historical buildings where access is limited and controlled by archaeological authority - which has to release a special permission for each intervention.




According to these assumptions, we opted for the following measuring principles:

- Joint Meters
- Potentiometer
- Crackmeters
- Vibrating WireStrain
- Clinometers/Tilt
- Extensometers
- Piezometers

Some costs are relatively simple to quantify and can be measured on the basis of the data available on the market or on site.

Others are not so easily measurable, (eg.. final labor costs associated with inspections and data processing time). For these, an in-depth analysis of the specific case is indispensable to estimate the market costs of the necessary technologies. A final cost database is, thus, strictly depending on the specific project and the data about hypothetical costs in the field, enquiries with the suppliers and further research.

In general, the elements weighing on the potential, final cost can be listed as follows:

- Supply of measurement tools and data logger (HW for data acquisition);
- On-site installation of the tools;
- Acquisition software development and integration;
- Operating expenses (design/engineering costs);
- Third-party expenses (Cloud storage/HW connectivity).

## CONCLUSIONS

The pressure to improve the economic performance of the infrastructural Italian environment, and the safety of citizens and operators, has sparked the necessity of data driven projects and stimulated the creation of new and advanced infrastructure Management Systems (i.e. Sensoworks's IoT platform).

These necessities, together with technological progress, are leading to improved structure management actions (i.e. preventive or predictive maintenance, preservation, rehabilitation, replacement decisions). The use of remote sensing technologies presents a potential alternative to improve current practices by providing both qualitative and quantitative measures.

The benefits and costs of deployed remote sensing technologies and procedures largely depend on specific locations, types and number of infrastructural complexes, density of traffic and other aspects. While the cost effectiveness of remote sensing technologies is highly dependent on the success of the integration with existing inspections and with the standardization of data collection techniques, on the simplification of data processing steps, and on the development of reporting procedures to increase the overall benefits of structure monitoring and to diminish the impact of potentially high initial fixed costs.

# 9. GLOSSARY

**ACCELEROMETERS** (sensor), used for dynamic monitoring and usually provided by internal algorithms, they are a key component in modern electronic equipment. Available with analogue and digital outputs.

**BEAMS** are the simplest structural forms for bridge spans supported by an abutment or pier at each end. No moments are transferred throughout the support, hence their structural type is known as simply supported.

**CLINOMETERS** (sensor), an instrument used for measuring angles of slope (or tilt), elevation, or depression of an object with respect to gravity's direction. It is also known as a tilt indicator, tilt sensor, tiltmeter, slope alert, slope gauge, gradient meter, gradiometer, level gauge, level meter, declinometer, and pitch & roll indicator. Clinometers measure both inclines (positive slopes, as seen by an observer looking upwards) and declines (negative slopes, as seen by an observer looking downward) using three different units of measure: degrees, percent, and topo (see Grade (slope) for details)

**STRAIN GAUGES** (sensor) measures the length of flexible electrical cord, the larger the diameter of the conductors need be to minimise voltage drop (wire gauge numbers are smaller for larger diameter wire).

**INFRASTRUCTURE MONITORING** is defined as the deployment of a built-in knowledge base to automatically diagnose performance and availability problems across the technology stack before productivity compromised

**IOT DEVICES** piece of hardware with a sensor that transmits data from one place to another over the Internet. Types of IoT devices include wireless sensors, software, actuators, and computer devices. They can be embedded into mobile devices, industrial equipment, environmental sensors, medical devices, and more.

**MONITORING (static and dynamic)** infrastructure behaviour can be recorded dynamically (changing his status in the space) or statically (maintaining fixed the space data). Usually this data is recorded incrementally at fixed time steps. This does not give a complete picture of the actual performance of the structure since there may be a significant structural response between fixed time steps which would be missed by other technology. Sensoworks records both dynamic and static structure behaviour at the same time continuously, at a frequency of 100 hertz (100 times per second).

**PRESSURE (sensor)** is a device for pressure measurement of gases or liquids. Pressure is an expression of the force required to stop a fluid from expanding, and is usually stated in terms of force per unit area. A pressure sensor usually acts as a transducer; it generates a signal as a function of the pressure imposed (i.e. electrical signal).

**REMOTE MANAGEMENT** Remote management ensures that your IoT devices are connected, and monitors that connection 24/7 to enable reliable, secure and cost-efficient delivery of your IoT services anywhere in the world.

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