MONITORING SYSTEMS FOR CIVIL STRUCTURES

move
SOLUTIONS

We Love Measuring Our World

Business presentation
Move Solutions

MOVE SOLUTIONS

Business presentation

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We love Measuring our World.

INDEX

MOVE IDENTITY

1.

MOVE SOLUTIONS

Move provides innovative, complete and high quality solutions at an affordable cost.
The aim is to change the approach to monitoring by making it accessible to every construction and infrastructure.

Move Solutions started at the beginning of 2017 for the shared passion of some young Italian boys from Lucca, Tuscany. After a study on the most advanced telecommunication systems, **Move has focused on the conception, design and production of innovative electronic devices for monitoring large structures.**

Initially the young company studied and applied itself in the use of new technology communication systems, capable of transmitting through long distances with low energy consumption, very suitable for the so-called **Internet of Things (IoT)**: the extension of internet also in the physical world, sensing and connecting to the network any device that may need it. This research led to a main application for Move, **Structural Health Monitoring.**

Move first developed and patented a new technology sensor called **DECK**, part of an entire monitoring system, which then extended to the development of various other types of sensors, building a complete, all-round solution applicable in many situations.

AWARDS

**Award of the “Premio Italia Giovane 2019 - VI Edizione” in the StartUp category as one of the best Italian initiatives in the sector.
Ceremony at the Luiss Business School in Rome.**

Ferdinando Frediani, a young businessman from Lucca and COO of his start-up Move Solutions is listed among the 17 winners of the sixth edition of the “Premio Italia Giovane”, a prestigious recognition that was awarded in Rome directly by Franco Frattini (president of Sioi - Italian Society for the International Organization).


Il personaggio

GIOVEDÌ — 7 NOVEMBRE 2019 — LA NAZIONE

5..

Lucca

Ferdinando vince con Move, start up anti crolli

Il 25enne Frediani si aggiudica il premio nazionale Italia Giovane. Il dispositivo di punta è deck, sensori low cost per monitorare la stabilità

LUCCA

Venticinque anni. Laurea in ingegneria in pugno, un'attività – Move Solutions – fondata in proprio, avviata da due anni con soci cofondatori, e un brevetto che sta facendo il giro d'Europa. Difficile dubitare che non sia per meritocrazia il premio nazionale conquistato da Ferdinando Frediani, lucchese doc.

Emozionato?

«Tantissimo. Una grande soddisfazione, in effetti, essere tra le 17 aziende vincitrici del Premio Italia Giovane, destinato alle giocellenze e presieduto da Frattini – risponde Ferdi- . La mia Move Solutions nel campo delle startup a delle più innovative imnergenti. Il premio va ai soci che lavorano dua tutti i giorni. Senza di lo- ci sarebbe niente di tutto

ha creato con Move srl?

dotto principale è deck. Si

Ferdinando Frediani, ingegnere laureato all'università Pisa, ha creato l'azienda con un team di finanziatori

tratta di sensori a costo molto basso, circa mille euro l'uno, che possono essere applicati a 'guardia' H24 sulle strutture civili, di cui rilevano oscillazioni prevenendo e prevedendo rischio di cedimenti».

L'uovo di Colombo?

«In un certo senso. I risultati sono incoraggianti. Ora mi trovo a Bolzano, sono stato in Vipiteno, in Austria, a Ferrara, Firenze, in Puglia. I miei sensori sono già applicati sui ponti autostradali di diverse località?».

Cerca finanziatori?

«In realtà no. Quando fondai la società entrarono alcuni soci fi-

SUI PONTI AUTOSTRADALI

Il sistema wireless è già stato adottato ed è richiesto anche all'estero

nanziatori che vorrei ringraziare: Ansano Cecchini, Mario Monzo, Luca Fini e Olivia Bernacchi. Successivamente sono entrati in società anche Marco Colzi, Gabriele Corsi e Gilberto Braglia. Questi ultimi sono giovani come me, altri sono imprenditori navigati, e di successo che hanno creduto nel progetto».

Come funziona?

«Si tratta di un sistema wireless, completo di una piattaforma online che permette di misurare l'ampiezza delle oscillazioni 24 su 24 da qualunque dispositivo e svolgere analisi avanzate sulla salute della struttura mediante algoritmi di intelligenza artificiale».

Che margine di errore ha?

«Infinitesimale. Siamo sull'ordine di 0.01 millimetri».

Ritiene che questo dispositivo sarebbe necessario per la sicurezza dei ponti lucchesi?

«Eccome. Infatti presto vorrei incontrare il sindaco Tambellini. La spesa è veramente minima, il risultato, in termini di sicurezza, importante».

Laura Sartini

**Rai 1 - Linea Verde - 2nd of February
Marcello Masi interviews COO Ferdinando Frediani of Move Solutions.**

Marcello Masi interviewed the COO Ferdinando Frediani about the innovative sensors for monitoring civil structures, interventions and Move Solutions products. The interview was TRANSMITTED on the "Green Line" program on Rai 1, the first Italian national TV channel.


Imprese

INNOVAZIONE

VII

TUTTO SOTTO CONTROLLO L'UOMO DEL PONTE DICE SÌ

Si chiama Move Solutions, è nata a Lucca e attraverso sensori elettronici su assetti verifica la tenuta di ponti, dighe, gallerie. Attirando clienti come Autostrade e Reach

di Marzio Fatucchi

Rumori

55%

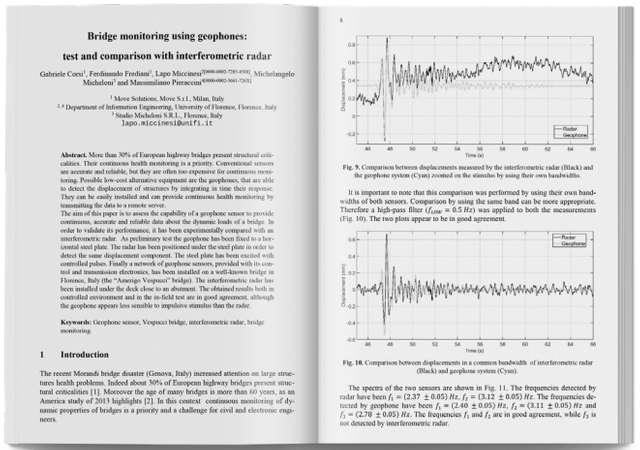
soli 8 mesi)

PUBLICATIONS

DAMAS 2019

Paper:
**Bridge monitoring using geophones:
test and comparison with interferometric radar.**

Published at:
**DAMAS2019 (Damage Assessment of Structures)
Porto, Portugal.**



Bridge monitoring using geophones:
test and comparison with interferometric radar

Gabriele Corsi[1], Ferdinando Frediani[1], Lapo Miccinesi[2][0000-0002-7285-4593], Michelangelo Micheloni[3] and Massimiliano Pieraccini[4][0000-0002-3681-7203]

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Abstract. More than 30% of European highway bridges present structural criticalities. Their continuous health monitoring is a priority. Conventional sensors are accurate and reliable, but they are often too expensive for continuous monitoring. Possible low-cost alternative equipment are the geophones, that are able to detect the displacement of structures by integrating in time their response. They can be easily installed and can provide continuous health monitoring by transmitting the data to a remote server.
The aim of this paper is to assess the capability of a geophone sensor to provide continuous, accurate and reliable data about the dynamic loads of a bridge. In order to validate its performance, it has been experimentally compared with an interferometric radar . As preliminary test the geophone has been fixed to a horizontal steel plate. The radar has been positioned under the steel plate in order to detect the same displacement component. The steel plate has been excited with controlled pulses. Finally a network of geophone sensors, provided with its control and transmission electronics, has been installed on a well-known bridge in Florence, Italy (the "Amerigo Vespucci" bridge). The interferometric radar has been installed under the deck close to an abutment. The obtained results both in controlled environment and in the in-field test are in good agreement, although the geophone appears less sensible to impulsive stimulus than the radar.

Keywords: Geophone sensor, Vespucci bridge, interferometric radar, bridge monitoring.

1 Introduction

The recent Morandi bridge disaster (Genova, Italy) increased attention on large structures health problems. Indeed about 30% of European highway bridges present structural criticalities [1]. Moreover the age of many bridges is more than 60 years, as an America study of 2013 highlights [2]. In this context continuous monitoring of dynamic properties of bridges is a priority and a challenge for civil and electronic engineers.

Fig. 9. Comparison between displacements measured by the interferometric radar (Black) and the geophone system (Cyan) zoomed on the stimulus by using their own bandwidths.

It is important to note that this comparison was performed by using their own bandwidths of both sensors. Comparison by using the same band can be more appropriate. Therefore a high-pass filter ($f_{cutoff} = 0.5\ Hz$) was applied to both the measurements (Fig. 10). The two plots appear to be in good agreement.

Fig. 10. Comparison between displacements in a common bandwidth of interferometric radar (Black) and geophone system (Cyan).

The spectra of the two sensors are shown in Fig. 11. The frequencies detected by radar have been $f_1 = (2.37 \pm 0.05)\ Hz$, $f_2 = (3.12 \pm 0.05)\ Hz$. The frequencies detected by geophone have been $f_1 = (2.40 \pm 0.05)\ Hz$, $f_2 = (3.11 \pm 0.05)\ Hz$ and $f_3 = (2.70 \pm 0.05)\ Hz$. The frequencies f_1 and f_2 are in good agreement, while f_3 is not detected by interferometric radar.

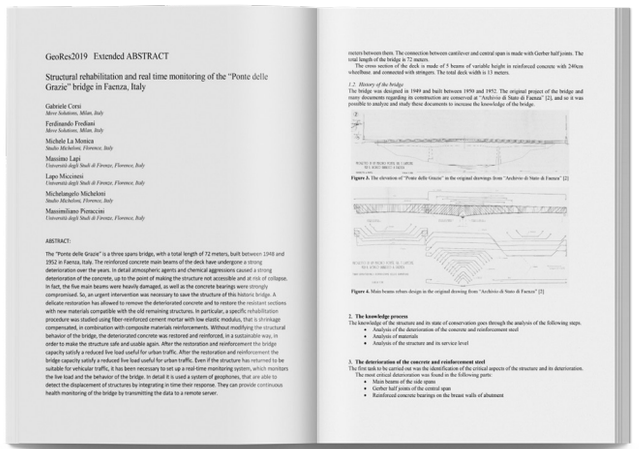
During 2018, experiments were carried out for the comparison between the patented system on which DECK is based and the interferometric radar, an instrument with very high precision and reliability.

The experiments were made in collaboration with Professor Massimiliano Pieraccini of the University of Florence, who is the interferometer inventor. The surprising results of the experiment are collected in the paper Bridge monitoring using geo-phones: test and comparison with interferometric radar which has been published at DAMAS2019 (Damage Assessment of Structures) in Porto, Portugal.

GEORES 2019

Paper:
**Structural rehabilitation and real time monitoring of the
“Ponte delle Grazie” bridge in Faenza, Italy.**

Published at:
**GeoRes2019 (2nd international conference of geomatics and restoration)
Politecnico di Milano, Italia.**



GeoRes2019 Extended ABSTRACT

Structural rehabilitation and real time monitoring of the “Ponte delle Grazie” bridge in Faenza, Italy

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ABSTRACT:

The “Ponte delle Grazie” is a three spans bridge, with a total length of 72 meters, built between 1948 and 1952 in Faenza, Italy. The reinforced concrete main beams of the deck have undergone a strong deterioration over the years. In detail atmospheric agents and chemical aggressions caused a strong deterioration of the concrete, up to the point of making the structure not accessible and at risk of collapse. In fact, the five main beams were heavily damaged, as well as the concrete bearings were strongly compromised. So, an urgent intervention was necessary to save the structure of this historic bridge. A delicate restoration has allowed to remove the deteriorated concrete and to restore the resistant sections with new materials compatible with the old remaining structures. In particular, a specific rehabilitation procedure was studied using fiber-reinforced cement mortar with low elastic modulus, that is shrinkage compensated, in combination with composite materials reinforcements. Without modifying the structural behavior of the bridge, the deteriorated concrete was restored and reinforced, in a sustainable way, in order to make the structure safe and usable again. After the restoration and reinforcement the bridge capacity satisfy a reduced live load useful for urban traffic. After the restoration and reinforcement the bridge capacity satisfy a reduced live load useful for urban traffic. Even if the structure has returned to be suitable for vehicular traffic, it has been necessary to set up a real-time monitoring system, which monitors the live load and the behavior of the bridge. In detail it is used a system of geophones, that are able to detect the displacement of structures by integrating in time their response. They can provide continuous health monitoring of the bridge by transmitting the data to a remote server.

meters between them. The connection between cantilever and central span is made with Gerber half joints. The total length of the bridge is 72 meters.
The cross section of the deck is made of 5 beams of variable height in reinforced concrete with 240cm wheelbase and connected with stringers. The total deck width is 13 meters.

1.2. History of the bridge
The bridge was designed in 1949 and built between 1950 and 1952. The original project of the bridge and many documents regarding its construction are conserved at “Archivio di Stato di Faenza” [2], and so it was possible to analyze and study these documents to increase the knowledge of the bridge.

Figure 1. The elevation of “Ponte delle Grazie” in the original drawings from “Archivio di Stato di Faenza” [2]

Figure 2. Main beams rebars design in the original drawing from “Archivio di Stato di Faenza” [2]

2. The knowledge process
The knowledge of the structure and its state of conservation goes through the analysis of the following steps.
- Analysis of the deterioration of the concrete and reinforcement steel
- Analysis of materials
- Analysis of the structure and its service level

3. The deterioration of the concrete and reinforcement steel
The first task to be carried out was the identification of the critical aspects of the structure and its deterioration.
The most critical deterioration was found in the following parts:
- Main beams of the side spans
- Gerber half joints of the central span
- Reinforced concrete bearings on the breast walls of abutment

A research paper, *Structural rehabilitation and real time monitoring of the “Ponte delle Grazie” bridge in Faenza, Italy*, describing the real-time monitoring of the first case study of application of this system, is published at GeoRes2019 (2nd international conference of geomatics and restoration) at the Politecnico di Milano, Italy.

SCENARIO IN ITALY

2.

MONITORING LAW

Currently the law requires a systematic control of the structures - having spans longer than 10m - with annual inspections made by specialized engineers and technicians.

There are many decrees, laws and similars on the methodology for building structures but, from a legislative point of view, there is nothing about how to monitor them. Only after the events of Genoa of August 14, 2018, through the law decree of September 28, 2018, Italy started talking about dynamic monitoring.

Certainly this decree lays a first milestone on both the legislative and the market points of view. **Finally, even the Italian state feels the need to monitor structures with modern and reliable techniques to guarantee citizens safety.** This aspect highlights how the market is growing and how in the following years most of the structures will have to be controlled by one of these systems.

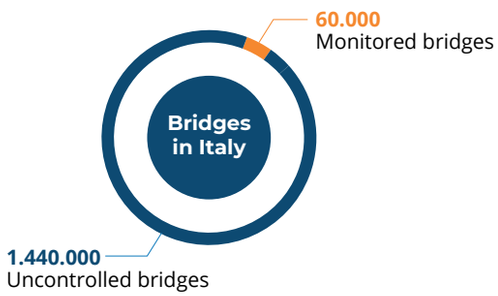
Law Decree 28/09/2018, n. 109

It was believed necessary and urgent to carry out dynamic monitoring of those road and motorway infrastructures that present critical conditions, through the use of equipment for the constant instrumental control of safety conditions, as well as to dictate specific provisions regarding the safety of road infrastructures and the competences of the Transport regulatory authority.

FOCUS ON BRIDGES

Currently in Italy there are many thousands of bridges and structures with high risk of collapse.

Only a small part is constantly monitored.

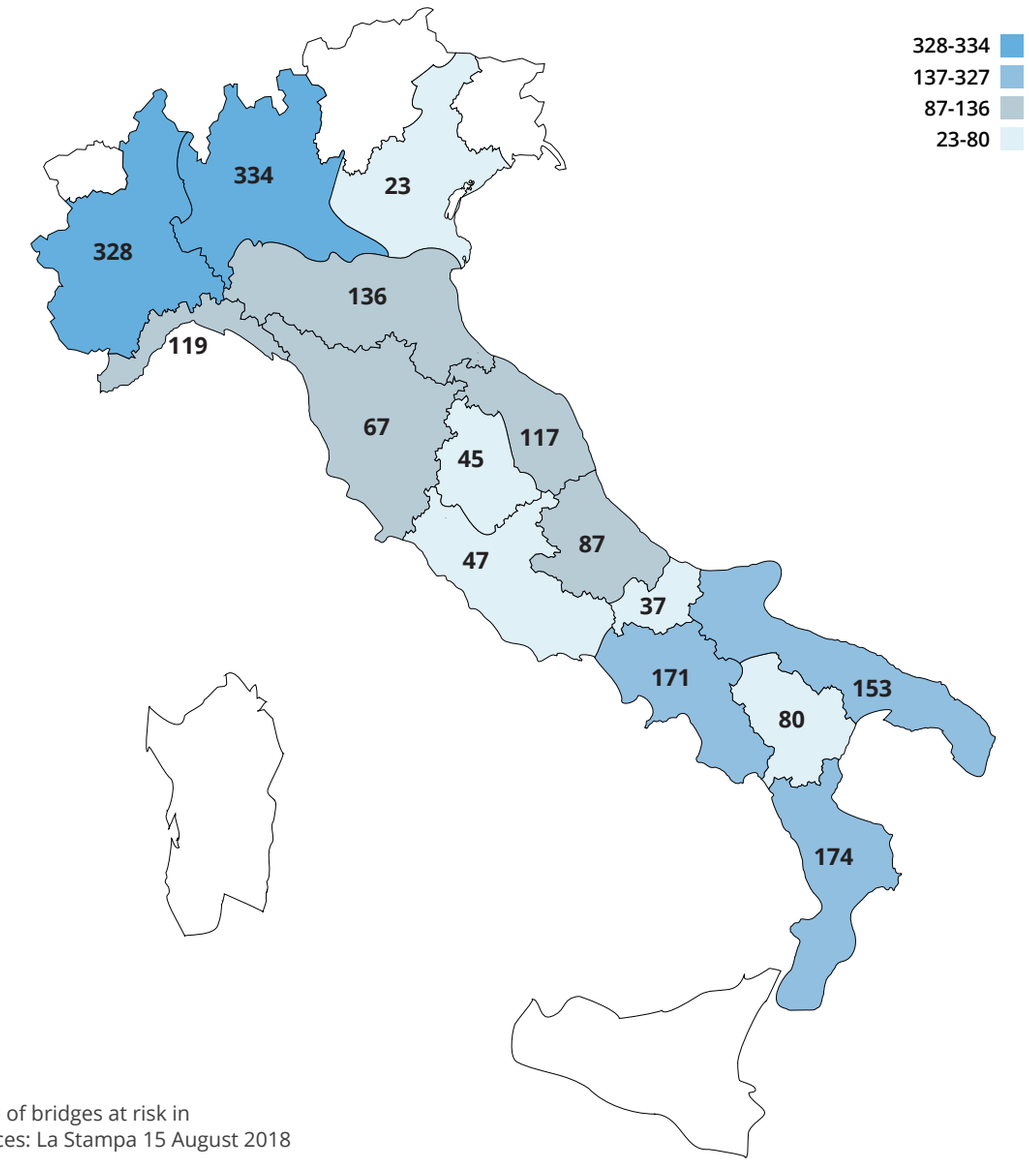


In Italy there are more than 1.5 million bridges (data from 4EMME). Only 60.000 of them (0.04%) are monitored, while all the others are not. These bridges are the responsibility of state bodies or private companies. Many of these structures were built between the 1950s and 1980s, when concrete was believed to be much more resistant than it actually is. These bridges today have a very high risk of collapse and for this they must be secured and continuously monitored.

According to the CNR (National Research Center), there are many thousands of bridges at imminent risk that must be immediately monitored. Autostrade per l'Italia (a big national highway company) estimates that the average cost of building a bridge in Italy is around 2000 €/ m^2. These numbers reveal that it would take at least 10 billion Euros to rebuild only the critical bridges if they were very small.

1918 Bridges and viaducts at risk of fail in Italy

Data from 2018, **large metropolitan cities are excluded**. These structures, specifically bridges and provincial viaducts require urgent maintenance and structural improvement.



/ The map of bridges at risk in Italy Sources: La Stampa 15 August 2018

€ 10.000.000.000

To rebuild only the critical bridges, assuming these are small sized.

Even if tens of billions of euros were made available for the reconstruction of critical works, and even if it were possible to build a thousand bridges a year, it would take at least **20/30 years for the total reconstruction of the bridges in question.**

50%
are over
40 years old

25%
are over
50 years old

Observing this practical and economic impossibility of rebuilding now all the critical bridges, **the strong need to monitor structures by public bodies and companies becomes evident.** Certainly the critical bridges are the structures that most need the monitoring system and therefore those who manage them could be strongly interested in the installation of the devices. As mentioned above, even non-critical buildings require a monitoring system to check the progress of the structure.

But still only 0,04% of bridges in Italy are monitored.

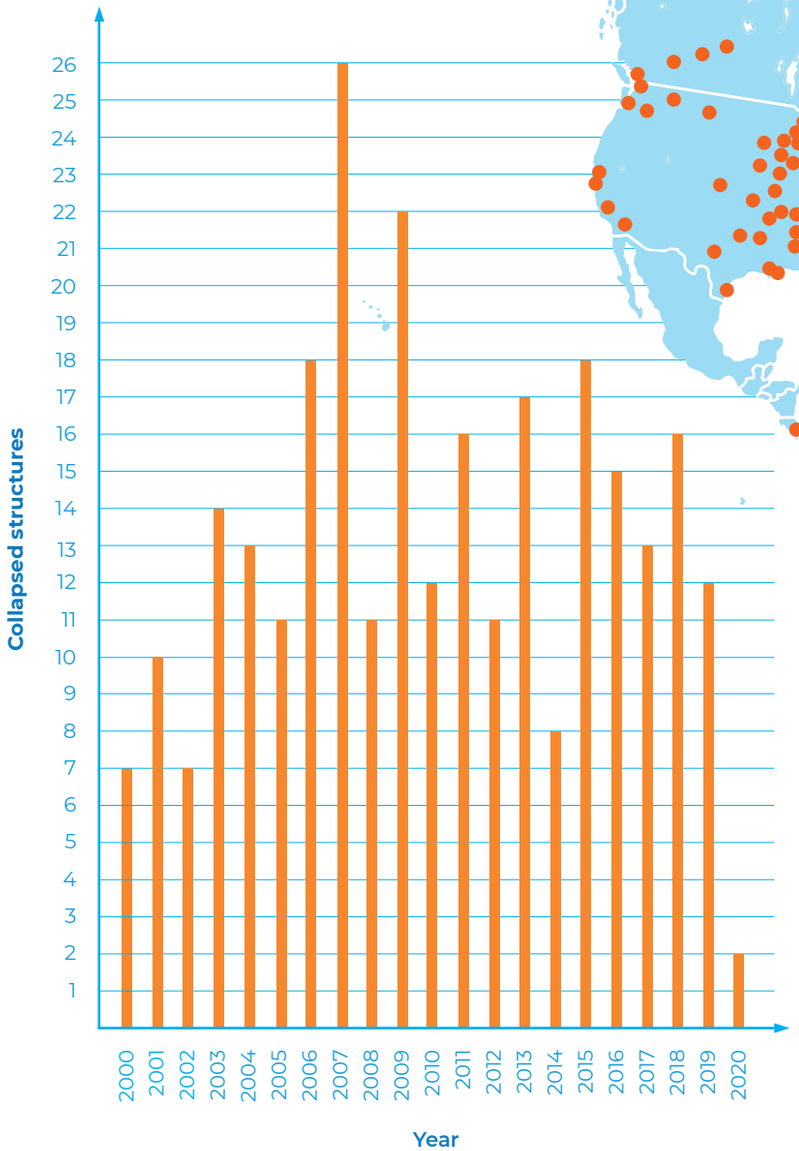
Bridges and viaducts under special surveillance and with critical issues

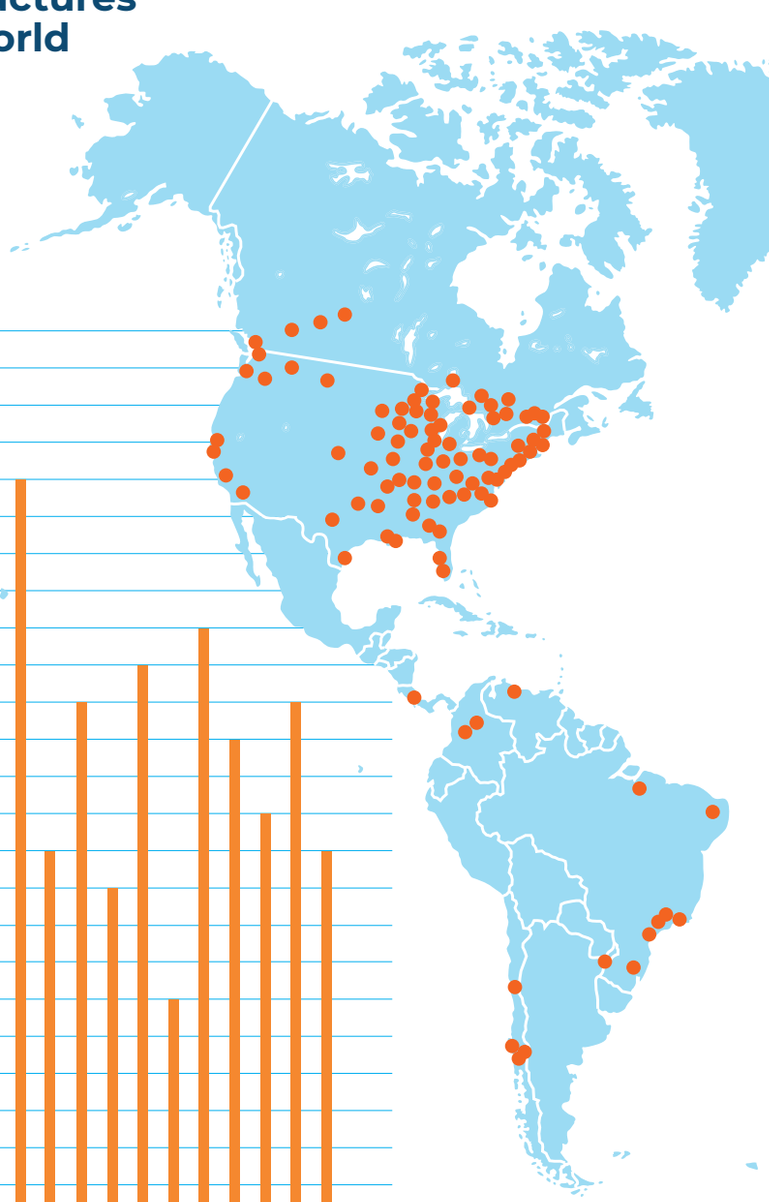
30.000
bridges managed by the provinces

12.000
bridges managed by Anas

1.628
bridges on the Aiscat network

Collapsed structures around the world





The graph on the left shows the total number of collapses of the most important and serious civil works worldwide per year. Unfortunately, this problem, linked to the critical nature of civil works, affects any structure with the passage of time, all over the world. The resulting situation is not very far from the Italian one, since the inevitable degradation affects all those structures that were built about 50 years ago.

THE DECK INNOVATION

DECK is an electronic system that measures the amplitude of the displacement, with an accuracy of one hundredth of a millimeter, of any structure on which is applied.

It adapts perfectly to vertical structures such as towers, skyscrapers, as well as to structures under stress such as bridges or dams, and constructions of any type.

The device is wireless and communicates through very wide areas thanks to a new telecommunication technology called LoRaWAN. Thanks to it, it's possible to communicate between devices that are scattered in very large areas, optimizing energy consumption in the best way and making the batteries last for years.

Using the LoRaWAN protocol it's possible to easily send and collect data from sensors located on any point of one or more structures.

deck
dynamic · electronic · control · kernel

Value for money

All Move devices are very competitive on the market, thanks to their good price and high quality. The DECK device has no competitor: being designed and patented by Move as a new technology, in the commercial area of monitoring, it has not comparative products. Regarding the type of measurement, the only other instrument comparable to DECK is the **Interferometric Radar**, which has a cost that exceeds one hundred thousand euros, without considering the overall dimensions, energy requirement, operator and much other. **DECK costs 100 times lower and is designed to be mounted on a structure and to be left to measure and transmit for long periods of time.**

Wireless

One of the great advantages of all Move devices is the entire wireless operation linked with the battery as power source. The radio transmission protocol has been chosen among the most advanced technologies, selecting **LoRaWAN for its long-range transmission (hundreds, thousands of meters) and its low power consumption.** This low consumption al- lows the devices to work for years only with on-board batteries. Replacing the batteries is fast and easy, they are commercial type batteries that are easy to find and replace.

Installation

Thanks to this full wireless feature, the installation operation is very easy. Considering the wireless communication and the battery power, the devices are closed boxes with no incoming or outgoing wires, on whose back there is an installation plate.
So, the device can be installed with four simple screws and wall plugs in the desired surface. There are also other installation solutions, for example with metal bands for poles. The devices and the receiving Gateway are delivered already set and configured and already switched on. After installation, the Gateway must be turned on to immediately have the monitoring system online, displayed on the Move Web Platform.

General features

High precision
Hundredth of millimeter accuracy

Low cost
Measurements comparable to devices costing € 100,000.

Small size
Minimum visual impact on infrastructure and buildings

Easy installation
Quick and non-invasive installation, simple even in uncomfortable places

Wireless
No need for wiring. Internal battery supply.

Advanced statistical analysis
Long-term analysis on the health of the structure with predictive algorithms.

Artificial intelligence
Real-time analysis of huge amounts of data.

Management interface
Data visualization and management thanks to the Cloud platform, working on any device.

MONITORING SYSTEM

The Move Solutions monitoring system is composed of multiple types of sensor and communication devices, capable of measuring dynamic oscillations and vibrations, static deformations, the state of opening of cracks and much more. In all its devices Move maintains the core of wireless transmission with LoRaWAN protocol.

After installation, the sensors can also be of great help during and/or after emergency situations for **Civil Protection** support:

- **Earthquakes;**
- **Collapse;**
- **Floods;**
- **Avalanches;**
- **Eruptions;**
- **Landslides.**

DECK sensors

The only patented wireless sensor on the market capable of measuring uniaxial structure oscillations and providing displacement values. Detection accuracy is equal to that of interferometric radar, 0.01mm. It samples continuously and remotely at 100 Hz. It can also detect temperature and vibration frequency.

Tiltmeters

The triaxial Tiltmeter is able to measure the variation of the static angular inclination of the structure with respect to the horizontal plane, perpendicular to the gravitational axis. By installing an entire system it's possible to reconstruct the static deformation of the DECK. The Tiltmeter can also measure temperature.

Accelerometers

The Triaxial Accelerometer is able to measure the acceleration of the point where it's installed, which is fundamental for measuring vibration frequencies and for carrying out a modal study of the structure. With the use of Accelerometer devices it's possible to highlight any seismic vibrations and monitor their risk.

Gateway

The Gateway device is a data receiving and sending unit that uses the LoRaWAN wide-area communication protocol and Cellular communication. With the use of this device, it's possible to receive data from dozens of sensors and send it to Cloud servers without the use of any cabling.

Analog Node - Digital Node

The Communication Node is a wireless device to which multiple wired sensors or probes can be connected. All connected devices can communicate via the LoRaWAN protocol with the installed Gateways.

Sensors DECK

Characterisation of the dynamic oscillation modes of the structure. DECK is a complex tool to monitoring all the dynamic behaviour of the structure such as oscillations and vibrations.

It can monitor the traffic on a bridge, the gusts of wind on a sky-scraper, the vibrations of a production plant, the currents of water on a dam and in general all the most energetic movements.

Each measure is related to the temperature, detected by another on-board sensor. The transmission to the Gateway is done via LoRaWAN protocol and the device is battery powered.

Gateway

The Gateway allows the connection of the data detected and transmitted by the devices with internet and has a dual connectivity: LoRaWAN and Cellular: it receives via LoRa all the data transmitted at low power from the devices around the monitoring site via LoRa, and forwards it to the cloud with Cellular connection.

In each monitoring setup, at least one Gateway is required to ensure that the data is loaded on the visualization and analysis Platform. Each Gateway can manage hundreds of
devices over wide areas.

Move's Gateway is IP67, out-door, and it accesses to internet via a mobile sim and it's poweerd with an external common 220v plug. Having been custom designed, it has the maximum performance when matched with Move devices, having also complete compatibility with any LoRa device.

Tiltmeters

Move's tiltmeters are high-end devices used to measure the inclination of the point where they are installed taking the gravitational axis as a reference. The measurement carried out is static, for the slowest, least energetic movements. By positioning several units along a structure, it's possible to find the static deformation even if it's a very slow movement. For example: it's possible to detect the inclination of a viaduct under a heavy stationary load, or detect the tendency of a building to tilt forward or backward. Tiltmeters also have a temperature sensor on board. As DECK, the heart of the transmission is LoRaWAN and battery powered.

Accelerometers

Accelerometers are highly recognized and used sensors in the field of monitoring. Accelerometers from Move can measure acceleration in the three axes with high resolution and measurement reliability. It's possible to correlate the measurements to the temperatures detected by the on-board thermometer. LoRaWAN transmission, battery powered.

Analog-Digital Node

Multiple sensors of different types can be connected to a single Communication Node. This device is capable of converting the data communication medium of any associated sensor.
Wired devices can then receive and send data to the Gateway via LoRaWAN wireless communication. The Digital Communication Node is compatible with all geotechnical sensors that use the Modbus RTU communication protocol.
The Analogue Communication Node is compatible with most analogue interfaces of geotechnical sensors.

MOVE APPLICATIONS

4.

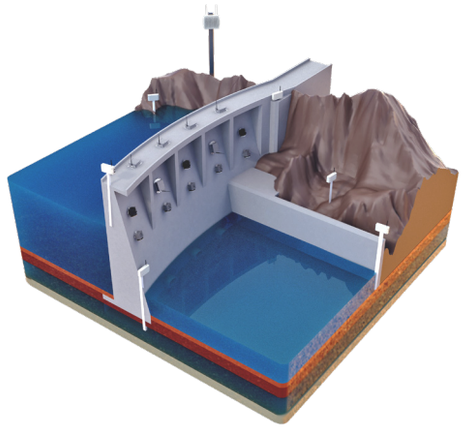
APPLICATIONS

The aim of Move Solutions' structural health monitoring is to constantly check the state of the structure and to be able to intervene well in advance in the event of compromise, so that it can continue to perform its function in complete safety.

The applications of the Move Solutions monitoring system are several, covering many solutions. By having different sensor types, suitable for both dynamic and static moni- toring, it's possible to apply the system on any structure that may be affected in some way by aging or structural degradation, especially if subject to stress. **On all bridges, overpasses and viaducts,** Move devices have of their main applica- tions. It's possible to monitor the reaction to ordinary traffic and notice the passing of something heavier, observe aging and structural deformation, understand any deterioration by detecting frequency changes and much more. Static measurement can monitor **roads and tunnels**, and combined with dynamic measurement it can be applied on **vertical buildings** subject to gusts of wind, such as dams under the pressure of the watercourse which causes rapid vibrations and slow deformations. Static measurement can monitor **roads and tunnels**, and combined with dynamic measurement it can be applied on **vertical buildings** subject to gusts of wind, such as dams under the pressure of the watercourse which causes rapid vibrations and slow deformations.

Construction or working sites with temporary structures or in partial construction, subject to great stress, such as **industrial production plants**, are situations of great interest for the Move monitoring system.

Dams monitoring:



With the Move monitoring system it's possible to measure the deformation of the structure over time due to continuous water pressure, as well as vibrations due to rapid currents.

- Movement
- Inclination
- Crack
- Deformation
- Inclination
- Temperature
- Settlement of the dam
- Structural loads

The use of multiple Tiltmeters is essential to determine if (and how) the constant water pressure is deforming the structure. Monitoring can be extended by adding DECK devices and/or Accelerometers to understand any vibrations and stresses. The results are a modal analysis of the structure, static monitoring of system inclination and water pressure.

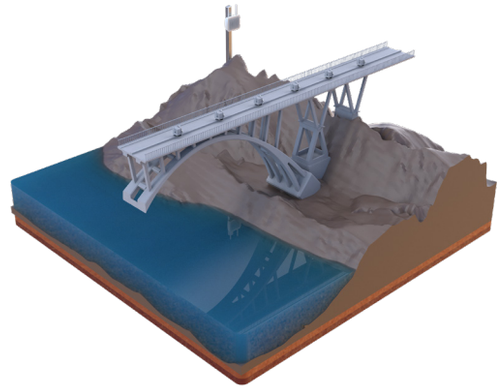
Buildings monitoring:

With the Move monitoring system it's possible to monitor the ageing of a building, the change over time caused by a specific event (earthquakes or floods) or everyday stress.

- Movement
- Inclination
- Crack
- Deformation
- Structural loads
- Temperature

For this case study, a static monitoring approach based on Tiltmeters is recommended to highlight the slow and low energy movement of the structure. Accelerometers for dynamic monitoring and DECK devices for displacement detection and modal analysis can also be used. The results are monitoring the change after an event (earthquake or flood),
daily stresses and the ageing of the structure.

Bridges monitoring:

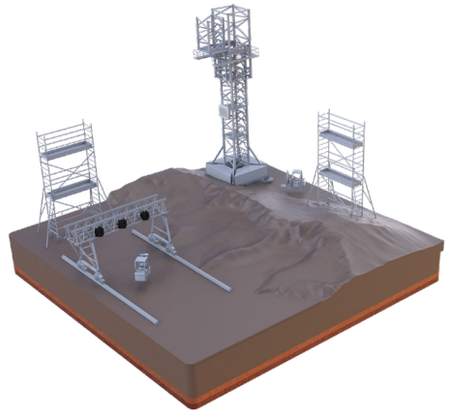


Bridges and flyovers are among the highest risk structures. With the Move monitoring system it's possible to monitor the intensity of the dynamic and static response of the structure over time.

- Movement
- Inclination
- Crack
- Deformation
- Loads
- Temperature
- Settlement of the bridges
- Structural loads

The Move monitoring system allows to obtain a complete dynamic characterisation of the structure under a profile of maximum oscillations, accelerations and main modal frequencies. Also the static part of the monitoring is guaranteed through the use of Tiltmeters that allow, if used in series, to obtain the deformation and how it's varying over time.

Worksite monitoring:



Construction sites are environments where strong vibrations and oscillations of various kinds are encountered. With the Move monitoring system you can create a safe and controlled environment.

- Slippage/Movement
- Regulation
- Groundwater level
- Piezometric pressures
- Pressures on earth
- Structural loads
- Deformation

On almost all construction sites there are machines in action that develop great energy and consequent vibrations. In a progressive work situation supported by scaffolding and temporary structures, it's therefore very important in this situation to monitor the integrity of the structures and the response to vibration. DECK devices are perfect for measuring dynamic displacement due to vibration, possibly combined with the use of Accelerometers.

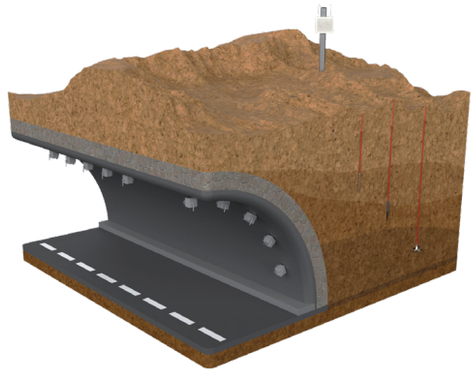
Radio tower monitoring:

Move provides the tools to monitor communication towers by measuring quantities of interest such as oscillations and static deformations.

- Angular variation
- CLS voltage status
- Triaxial accelerations
- Modal Analysis
- Temperature
- Structural degradation

For this type of structure, static monitoring is recommended by means of a series of Tiltmeters that allow reconstruction of the deformation and movement of the tower as a whole. Dynamic characterisation of the tower by measuring the acceleration on 3 axes and analysing the modal frequencies. The results are a monitoring of the state of deterioration, its trend and immediate intervention in case of abnormal variation of the parameters.

Tunnel monitoring:

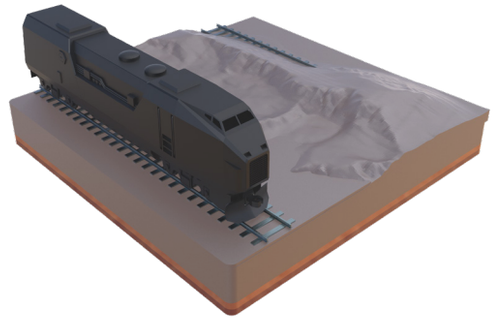


Move provides the tools to perform static monitoring of tunnels and underground sites, to understand the deformation of excavations under pressure over time.

- Angular variation
- Tunnel deformation
- Soil pressure
- Piezometric pressure
- Subsidence caused by excavations

The deformation of these structures is monitored through the installation of a series of Tiltmeters on the same section to assess convergence and/or divergence and thus evaluate its integrity. In addition to structural monitoring, we can also investigate, through the use of probes, the surrounding terrain and how it's changing to assess possible negative effects.

Railways monitoring:

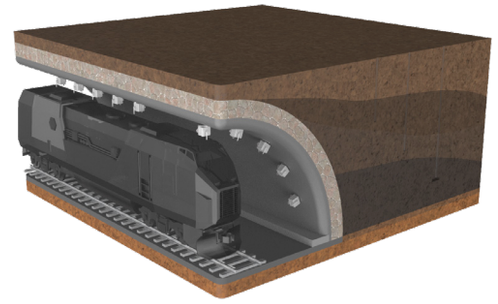


Move provides the tools to monitor railway lines to understand the state of vibrations suffered by the tracks due to natural ground subsidence or work near the line.

- Angular variation
- Longitudinal deformation
- Transverse deformation
- Rail misalignment
- Temperature

A system consisting of a series of Tilt-Beam and Tiltmeters is used to monitor the movement and deformation of railway tracks. This system allows the angle of rotation between two directly connected sleepers to be measured and the longitudinal and transverse deformation to be obtained. Some of the main reasons for continuous monitoring of the overall geometry are: works or excavations in the vicinity of the tracks, natural ground movements or replacement of elements in the track.

Subways monitoring:



Move provides the tools to monitor underground railway stations in order to understand the constant pressure in the ground that can lead to deformations and safety risks for people.

- Angular variations
- Tunnel deformation
- Ground pressure
- Piezometric pressure
- Subsidence caused by excavations
- Longitudinal deformation
- Transverse deformation
- Rail misalignment

To monitor the movement and deformation of railway tracks, a system of Tiltmeters and tilt calculation systems is used to detect the angle of rotation of the sleeper and the longitudinal angle of rotation. For the static monitoring of tunnels, a series of Tiltmeters is used and the angles acquired are calculated to obtain the deflection shape of the structure.

MONITORING SYSTEM

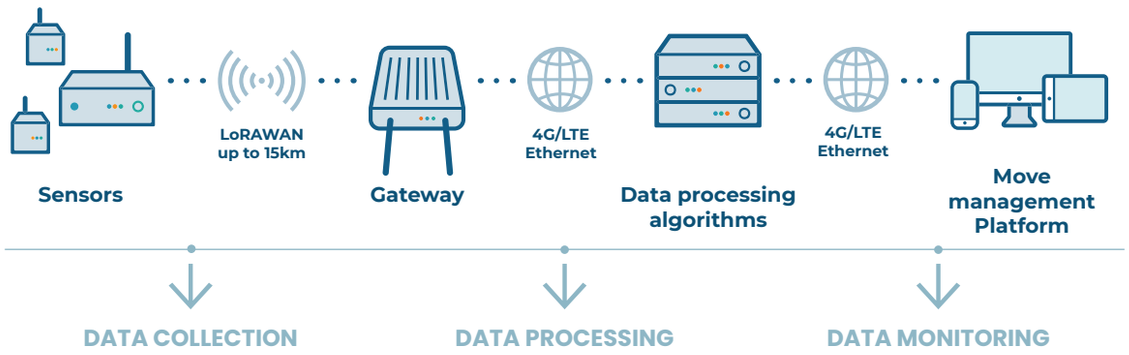
5.

THE SYSTEM: HOW IT WORKS

All the data detected by the sensors are transmitted via the LoRaWAN protocol to the receiving Gateway: it's a control unit that has the purpose to collect all the data transmitted by the sensor network and forwarding it to the online servers, through cellular connection.

At this point the information can be viewed on the Move Web Platform, useful to constantly check the health status of the structure and to create a history of data that can be consulted at any time.

Several sensors detect any type of stress and any structural change in the structure, and then make them accessible and viewable via the Web Platform.



Multiple sensors constantly monitor any structural changes, mapping of morphological and kinematic variations and identifying the most critical areas.

The system receives and stores the data transmitted via LoRaWAN. LoRa communication technology allows bi-directional communication between each device and the gateway itself.

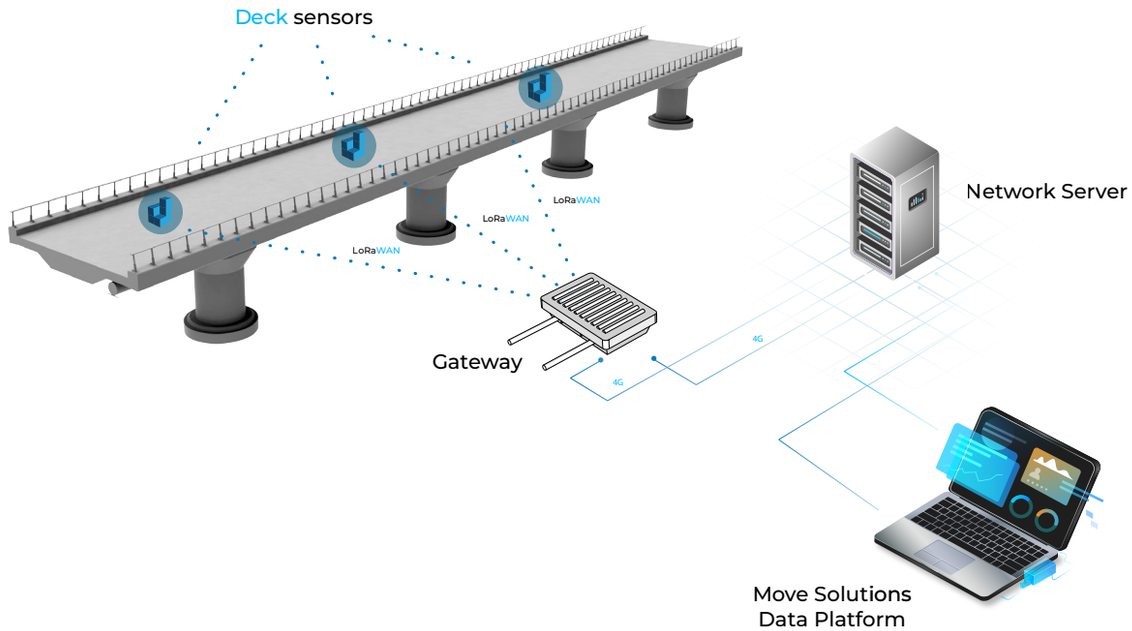
The data are processed through statistical analysis algorithms generating objective reports and creating a history of uneditable data. This database is available at any time for checks or revisions.

Data management and visualization through graphs and analysis on the online platform. Once received from the gateway, the data is forwarded on the Move web platform, a fundamental tool for civil engineers to actually have the structure under control.

Scheduled maintenance interventions at the right time. Having daily structural monitoring data, it is always possible to have a clear view of the structure and to act at the right time, without urgencies and high costs.

LORAWAN COMMUNICATION

LoRaWAN is an innovative communication protocol born a few years ago, part of the LPWAN (Low Power Wide Area Network) family. **Using LoRa it's possible to transmit data through large areas (over 10 km in optimal situations) with low transmission power and low energy consumption.** It's perfect for transmitting light data with devices that do not have large energy supplies, in fact Move devices are usually battery powered. LoRa uses free sub-gigahertz radio frequency bands such as 433 MHz, 868 MHz (Europe) and 915 MHz (North America).



Thanks to these characteristics LoRaWAN is perfect for the **Internet of Things**, where many devices are spread in large areas, often without electricity grid, and their function is usually to transmit very light data for long periods, as in the case of structure health monitoring. Several types of sensors can be installed in the same area: if the transmission takes place via LoRaWAN, all data can be collected by a single LoRa Gateway, which will then forward them to the cloud.

MOVE DATA PLATFORM

It's possible to understand the ageing of the structure and estimate the intensity of stress, optimising preventive and predictive maintenance interventions through multiple tools and graphics. Free access to and management of all operating parameters of each installed sensor. A complete historical database can be developed and accessed to quickly retrieve all desired data by selecting any time interval to be displayed, at any time.

Move Solutions has developed multiple visualisation and analysis tools, data processing algorithms and statistics to help make sense of complex data.

To monitor and check safely, remotely and constantly any structure, receiving information in real time.

Analyze

Monitor 24/24h displaying, comparing and downloading all the data and trends you want.

Manage

Set the alarm threshold, the sampling frequency and many other parameters for any device.

Understand

By viewing the trends and statistics you get a complete sensitivity on the health and behavior of the structure.

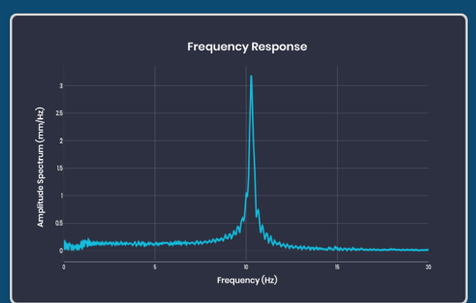
DATA PROCESSING ALGORITHMS

Our Advanced Analysis Algorithms facilitate the understanding and analysis of very complex data. Using machine learning technologies, these tools can automatically process large amounts of data from installed sensors over long periods of time.
This makes continuous structural monitoring of a structure much simpler, more intuitive and more efficient for any user. By monitoring the progression over time and comparing data, trends and processing algorithms, it's possible to identify and understand the fundamental modes and structural trends of the structure in question.

- **Advanced analysis algorithms**
  Advanced analysis tools are available to ease deep understanding and data processing.
- **Data cleaning**
  Receive only clean and validated data. Unwanted noise and interference are automatically blocked and removed.
- **Access to all historical data**
  You can quickly access and recover all your data by selecting any time interval to view whenever you want.
- **Customize all sensors**
  Simply manage each sensor by setting the alarm and activation thresholds, the sampling frequency and the resolution.
- **Technical support**
  We guarantee reliable and constant end-to-end support.
  Custom development available.

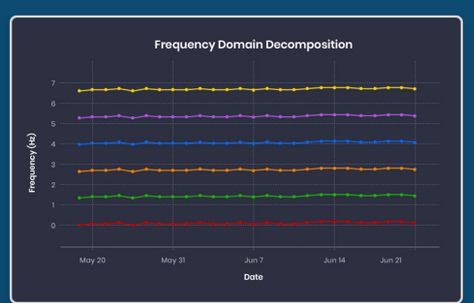
FFT (Frequency Response)

Algorithm for the fast and optimized calculation of the DFT (Discrete Fourier Transform) which allows to highlight the spectral contents of the signals coming from the sensors. It provides the frequency response of the oscillations thanks to which it's possible to obtain characteristics and information of the signal, not perceptible in the time domain.



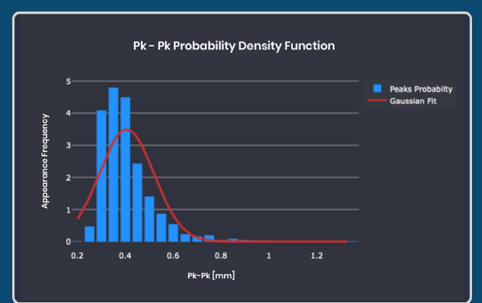
FDD - Frequency Domain Decomposition

Algorithm that performs a statistical processing, in a time interval, starting from all the oscillations coming from the sensors used for monitoring. It's used to estimate the frequency response of the system, through which it's possible to extrapolate useful modal information. It allows you to make an active and prolonged monitoring of even a very complex structure.



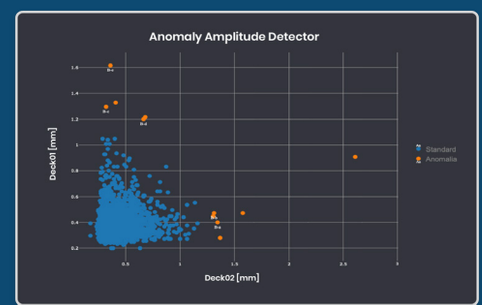
Maximum excursion probabilities

Estimate of the probability density of the peaks of the oscillations (maximum excursions) starting from the histograms of the probabilities. The statistical behavior of the peaks is analyzed in order to characterize their trend over time.



Anomaly Amplitude Detector

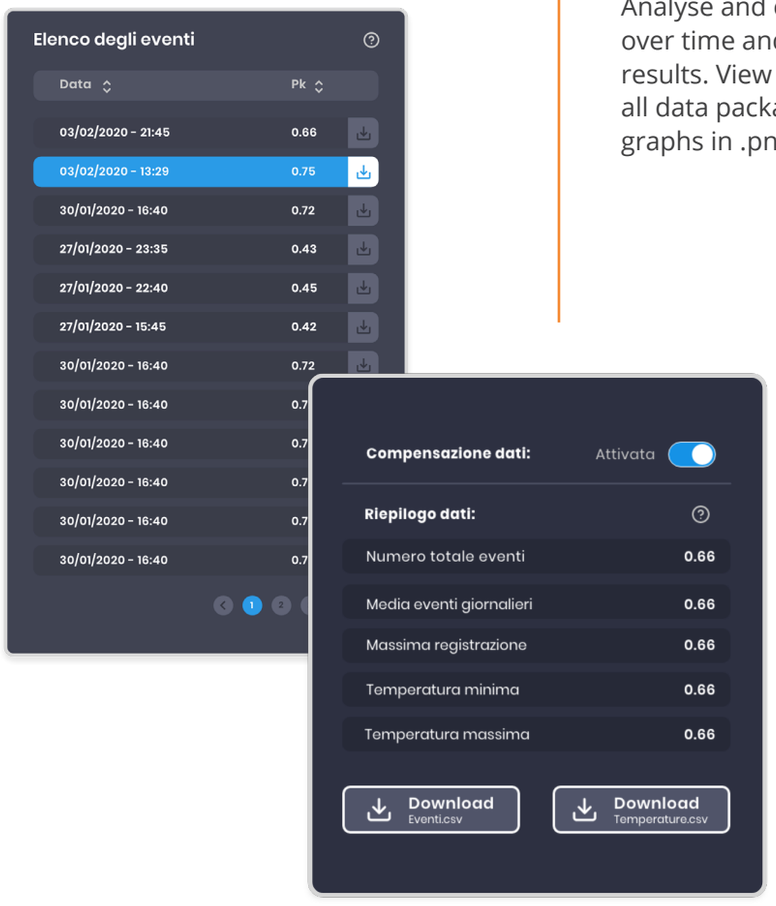
Based on the statistical analysis of the peaks, it's used to highlight the amplitude anomalies relating to oscillations that have excessively large peak values compared to their average behavior.



Check and manage your sensors easily thanks to our Web Platform.

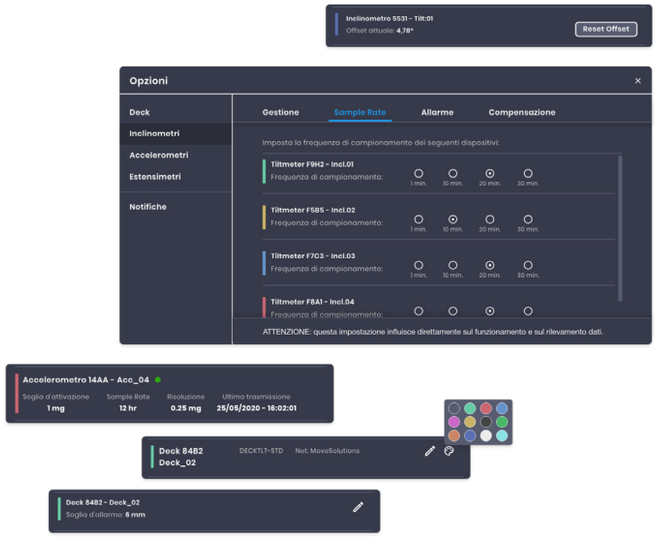
Get free access to an unlimited database.

Analyse and compare all data collected over time and convert it into usable results. View in detail and download all data packages in .csv format, or all graphs in .png.



Intelligently set up devices.

Modify the operating and display parameters of any sensor.
Set the alarm and activation thresholds, the resolution, the sampling frequency and much more.



Receive an alarm in case of anomalous events.

Alarm functions ensure that all your data is closely monitored and that you receive an e-mail alert whenever sensor readings exceed set thresholds.

CASE STUDIES

7.

PROJECT EXAMPLES

Via Aldo Ferraresi Overpass

Subject: Elevated overpass over the city
Structure: 18 spans supported by pylons
Location: Ferrara, Italy
Start of monitoring: October 2018
Installation: 6 DECK devices; 12 crushing devices; 1 Gateway

This long viaduct with 18 spans located on the west side of Ferrara showed some signs of subsidence. Thanks to the dynamic monitoring, performed with DECK devices, it was possible to detect the high precision dynamic displacement due to traffic and carry out the mapping of the same. In addition, in some specific and very critical points, 12 crushing sensors have been installed, devices that are activated by sending an alarm in the event of significant failures.

Vespucci Bridge - Engr. Morandi

Subject: Bridge over the Arno river, built in 1957 Structure: 3 spans, 2 stacks
Location: Florence, Italy
Start of monitoring: November 2018
Installation: 6 DECK devices; 6 Accelerometers; 1 Gateway

Vespucci bridge is a bridge in central Florence that crosses the Arno river. It was designed by Engr. Morandi, built between 1955 and 1957, and has deteriorated over time, especially in the stacks that support it, for the underwater part. The basic approach was the classic one: two DECK devices on each span, one per lane, for a total of 6 units, to monitor drop and twisting of each span as traffic passes.
Furthermore, having to prepare maintenance interventions on the damaged and submerged part of the support piles, there were installed six Accelerometers in six chosen points of the piles, with the aim of monitoring the structural reaction to the restoration interventions.

During the monitoring period, a comparative measurement test was done with the interferometric radar, with Prof. Pieraccini of University of Florence, after which the paper *"Bridge monitoring using geophones: test and comparison with interferometric radar"* was published at DAMAS2019 (Damage Assessment of Structures) in Porto, Portugal.

Paolillo bridge

Subject: Highway bridge over a stream
Structure: 1 span
Location: Cerignola (Foggia), Italy
Start of monitoring: August 2019
Installation: 4 DECK devices; 1 Gateway

Paolillo Bridge is a short bridge with a single span passing over the Paolillo stream along the highway near Cerignola.
After an inquiry for structural report counterfeit, a structure monitoring activity was requested. Four DECK devices were then mounted in the center of the span, on some specific beams indicated by the structural engineers. After the setup, a comparative test was performed with the interferometer to check the quality of the measurements of the DECK devices, which was confirmed.

Temporary bridge for a construction site in San Lorenzo di Sebato

Subject: Modular metal bridge over a river
Structure: 1 span
Location: San Lorenzo di Sebato, Bolzano, Italy
Start of monitoring: June 2019 (Single test)
Installation: 2 DECK devices; 1 Gateway

This temporary metal bridge was installed at the end of June 2019 in San Lorenzo di Sebato, Trentino Alto Adige, to allow the passage of operating vehicles necessary for the development of a construction site, and it will remain operational for a few years. After the first installation, a static deformation test was done by loading in the center of the bridge some trucks, waiting for the lowering of the structure. Then two central DECK sensors were mounted (one on each side) and dynamic oscillation tests were done with the passage of the trucks.

Public Health Department Building

Subject: Elevated overpass over the city
Structure: 18 spans supported by pylons
Location: Ferrara, Italy
Start of monitoring: October 2018
Installation: 6 DECK devices; 12 crushing devices; 1 Gateway

More historic and older buildings, such as the Department of Public Health, can slowly undergo deformation and structural changes. These changes must be monitored in a static regime, through the use of inclinometers. This building in question presented some critical issues that led to the emergence of a large crack pattern. Thanks to the continuous monitoring with crack meters and inclinometers, it has allowed the understanding of the causes and the consequent immediate intervention for the safety of the building.

Load Test of Bridge

Subject: Bridge and Overpass
Structure: New or critical structures to be tested
Location: Every structures to be monitored
Installation: Tiltmeters in series, DECK, Accelerometers, Gateway

Very often, load tests are carried out on bridges and viaducts for static testing of the structure. Move Solutions guarantees the reconstruction of the deformation of the structure and the maximum deflection in the middle of each monitored span, using a series of Tiltmeters. The Move Deformation has the same accuracy as the Total Station. During these load tests, DECK devices can also be used to measure the maximum dynamic deflection.

move
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