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GENOVA CASELLA RAILWAY (GENOVA, ITALY). AN EXAMPLE OF INTEGRATED MONITORING SYSTEM APPLIED TO RAILWAY LINE SAFETY.

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Abstract:

In order to guarantee the safety of railway traffic and safeguard the safety of passengers and line operators, AMT S.pA., the company that manages the Genoa Casella railway line, decided to implement an integrated monitoring system capable to provide information about the structure behaviour and the hydrogeological risk. The Genova Casella railway line winds for a total length of 25 km along a route characterized by steep slopes and narrow curves between Apennine ridges, cliffs and trenches as if it were a high mountain railway. Along its route, the line crosses the Bisagno, Polcevera and Scrivia valleys. The line has 13 tunnels with a length ranging from 30 m to 150 m. The structures present are completed by 8 masonry bridges with three or four arches, a concrete bridge and two with metal girders and one in concrete. The line was built starting in June 1921 and was finished in June 1928 with the first maiden voyage. The line was opened for operation in 1929. Since 2010 it has been managed by the Azienda Mobilità e Trasporti S.p.A. of Genoa. The integrated project for the Genoa Casella railway line consists of three main elements:

I. *Mapping of instability along the railway line, using InSAR. The study is divided into two phases: the first which, on the basis of satellite data from 2010 until 2023, aims to define the areas of greatest interest, the second through flight with Lidar survey to carry out a more detailed survey. The analysed and processed data have been entered into an interactive GIS database and will allow visualization in a Web environment.*
II. *Design and installation of a pilot monitoring system to study the behaviour of a viaduct called "Poggino". The system will consist of instrumentation for carrying out both static and dynamic measurements. The sensors will be installed in the main arch and connected to a data acquisition system with data transmission to a web-based HMI to view the stored measurements and be able to analyse the behaviour of the structure.*
III. *Generation of an integrated Building Information Modeling (BIM) system. Digitization of the Genoa-Casella section was developed starting from the geometric reconstruction of the line and the main artefacts and inserting it into a BIM system with the aim of is knowledge. The data generated by the two previous phases will become part of the BIM platform in such a way as to allow consultation in the same work environment.*

1. General considerations

In order to guarantee the safety of railway traffic and safeguard the safety of passengers and line operators, AMT S.pA., the company in charge of management of the Genoa Casella railway line (Figure 1: one of the bridges along the railroad(, has decided to implement an integrated monitoring system that allows through investigations and studies to be able to map the instability present along the territory crossed by the railway line, and to verify the behavior of the works of art present on the line.

The objective of the integrated monitoring system is to follow up on what is indicated in the strategic document for railway mobility of passengers and goods (DSMF 01/08/2022, Law 29 December 2021, n. 233, art. 5), and in particular, as indicated in Section III.3.2 and III.3.3 of the aforementioned document, in consideration "[...] of the fragility of the territory with sudden and destructive events that determine continuous phenomena of hydrogeological instability, which require a continuous effort to control of the infrastructure and the implementation of protection and consolidation works that increase the resilience of the infrastructure itself and the territory.(Figure 1).

Investments at European and national level relating to the broader National Recovery and Resilience Plan (PNRR) also fit into this context, in which a portion of the funding is dedicated to the monitoring of railway structures (Mission 3: Infrastructure for sustainable mobility ; M3C1 Investments in the railway network), natural risks and hydrogeological instability (Mission 2: Green Revolution and Ecological Transition; M2C4 Protection of the Territory and Water Resources), as well as the importance in the use and development of space and satellite technologies , of which Italy is an international excellence (Mission 1.2 – Digitalization, innovation and competitiveness of the production system).

Furthermore, as underlined in Annex A of the same strategic document for railway mobility of passengers and goods - MIMS (DSMF 01/08/2022, L. 29 December 2021, n. 233, art. 5), "[...] The development technology characteristic today of data detection, transmission and processing systems offers the concrete possibility of developing the development of monitoring networks of components of the railway infrastructure aimed both at improving the safety of transport operations and at better directing the preventive maintenance actions. In the implementation of these systems main aspect to be considered is to define the suitable algorithms for evaluating the detected parameters: Expected result aim at transforming data into useful information for the management of the infrastructure. In some cases, such as for bridge monitoring, this aspect can be particularly complex. […]".

A careful and timely design of the monitoring system relating to the individual structure is therefore essential.

This need is also taken up and underlined in the Guidelines for the safe management of civil works on the railway network - ANSF, Sept. 2018, in the Guidelines for Risk Classification and Management, Safety Assessment and Monitoring of Existing Bridges, rev 2022 (in particular PART III - Surveillance and monitoring system) and specifically by the UNI/TR 11634:2016 Guidelines - Guidelines for structural monitoring.

For this purpose, a study will be carried out to map the disruptions present in the areas straddling the railway route using innovative technologies such as interferometric synthetic aperture radar A-InSAR and Lidar surveys, the design and installation of a pilot structural monitoring system for the Poggino viaduct.

The results of the studies and the data coming from the monitoring system will be integrated into a platform that uses the BIM system to have a georeferenced localization of the surveys carried out which will be integrated with all the data relating to the management of the infrastructure.

The phases envisaged in the project are in summary the following:

- Mapping of disruptions along the railway line considering a study band equal to 500 meters wide from the axis of the line, through satellite interferometry A-InSAR. The study is divided into two phases: the first which, based on satellite data from 2010 to 2023, aims to define the areas of greatest interest, the second through flight with Light Detection and Ranging (Lidar) survey to carry out a more detailed survey. The analyzed and processed data will be inserted into an interactive GIS database and will allow visualization in a Web environment.
- Design and installation of a pilot monitoring system to study the behavior of a viaduct called "Poggino". The system will consist of instrumentation to carry out static measurements (joint meters, inclinometers and temperature meters) and dynamic sensors (accelerometers). The sensors will be installed in the main arch and connected to a local data acquisition system. All the data will be transmitted to an appropriate Web platform to store and visualize acquired data in order to able to analyze the behavior of the bridge.

- Digitalization of the Genoa-Casella railway, starting from the geometric reconstruction of the line and the main structures (tunnels and bridges). All this information will be used to develop a Building Information Modeling (BIM) system.

2. Genova Casella railway

Figure 1: one of the bridges along the railroad

The Genoa Casella railway line runs for a total length of 25 km and runs along a route characterized by steep slopes and narrow curves between Apennine ridges, cliffs and trenches as if it were a high mountain railway, however remaining in the first 6 km in view towards the sea (Figure 2: Location of the area involved in the instability studies

Along its route the line crosses the Bisagno, Polcevera and Scrivia valleys.

The line is a metre-gauge single track railway. The maximum slope is 45‰.

The line begins at an altitude of 93 meters above sea level. of the Genoa Piazza Manin station, to then pass in just nine kilometers to the 370 m of Trensasco and reach the 410 meter altitude of Casella, final stop of the railway, in the upper Scrivia valley. The highest point of the route is the watershed of the hamlet of Crocetta d'Orero, at 458 meters above sea level.

The line has 13 tunnels with a length ranging from 30 m to 150 m. The works of art present are completed by 8 masonry bridges with three or four arches, one concrete bridge, two metal girder bridges and one concrete bridge.

The line was built starting in June 1921 and was finished in June 1928 with the first maiden voyage. The line opened for business in 1929. Since 2010 it has been managed by the Azienda Mobilità e Trasporti S.p.A. of Genoa, which operates there both as a railway company and as an infrastructure manager.

3. Instability along the railway line

SAR satellite technology and the Lidar are used to define a map of the instability present along a strip of territory straddling the railway line with a width of 500 meters considered significant to study the possible interactions between the instability and the railway line. The following figure shows the area under study of the instability (red line) and the route of the railway line covered by this proposal.

In more detail, the study was carrying out through the following activities:

a) In relation to the study and monitoring of disruptions, the following activities are proposed to be carried out (Genoa-Casella railway section (24 linear km, considering a buffer of 500m each side around the railway):

b) Smart Geotechnical Asset Management Service: innovative approach for the analysis of risks associated with the interaction between infrastructure works and the geotechnical context in which they are inserted, with particular regard to interference with geological hazards (geohazards);

c) Historical satellite Interoremetrical Sintetic A-DInSAR analysis starting from 2010, to estimate the surface displacements undergone by the ground and structures in the area of interest;

d) Aerial LiDAR survey + monitoring service using aerial and satellite PhotoMonitoringTM which will be performed on the most relevant portions of territory emerging from satellite processing.

e) No. 2 satellite Corner Reflectors (Figure 6:One of the Corner Reflector installed in San Olcese area.installed in an area considered representative and significant in terms of extent of the ongoing disruptions (Figure 5).

Figure 2: Location of the area involved in the instability studies

The activities carried out in the first phase of the study allowed us to obtain a picture of the critical issues present along the route characterized by a high level of detail.

The SGAM (Smart Geotechnical Asset Management Service) service, through the consultation of national and international catalogues such as IFFI, Inventory of Italian Landslide Phenomena (APAT, 2007), PAI, Hydrogeological Structure Plan (ISPRA, 2021) and ELSUS (European Landslide Susceptibility Map version 2, 2018), highlighted how the area is located in a context full of already known gravitational instability. In particular, 42 known landslide phenomena involving the railway section already reported in IFFI were identified, mostly classified as landslides, roto-translational and complex slides. The danger relating to landslide phenomena is also highlighted by the PAI (Idrogeological Plan) data, on the basis of which the area is categorized with risk values between moderate and high, and by the ELSUS (European Landslide Susceptibility Map

) data, which classify the entire European territory based on susceptibility spatial to the landslide, providing in this case values from high to extremely high, with an average value of 4.5 on a scale from 1 (extremely low) to 5 (extremely high). This information was fundamental during the post-processing and interpretation phases of the data obtained from satellite interferometric analyses.

Thanks to the advanced differential satellite SAR (A-DInSAR) interferometry analyses, a total of 320 satellite images of the COSMO-SkyMed (the first Earth observation mission of the Italian Space Agency) constellation were processed, of which 118 in ascending orbital geometry and 202 in descending orbital geometry, and 707 of Sentinel -1 (ESA – European Space Agency), 312 ascending and 395 descending. From this set of images, a total of approximately 304,000 Measurement Points (PM) were extracted for COSMO-SkyMed, and 52,000 for Sentinel-1 (figure 2). These points, corresponding to natural and anthropic elements present in the area and with high stability to the reflection of radar waves over time, provide information on the displacement recorded over time in the form of displacement time series. From these it is possible to obtain various information such as the average annual speeds of movement of the PMs along the sensor-target direction.

Thanks to the previous analyses carried out on the entire area, it was possible to carry out a study on the satellite coverage of the bridges along the route and identify the areas subjected to the greatest criticality according to the IA-DInSAR data (Figure 3: Example of dataset obtained from A-DInSAR analyses, carried out from COSMO-SkyMed images. At the top, there is the dataset obtained from the ascending orbital geometry, at the bottom from the descending one. Some areas were therefore selected and subjected to in-depth analysis on a larger scale, areas corresponding to areas in which the combination of historical data obtained from the SGAM analysis with satellite data highlighted the presence of critical issues. These areas concerned the Poggino, Olcese and Molinetti bridges and the areas near the stations of San Pantaleo, Sant'Olcese Chiesa and Canova-Crocetta (figure 4). These areas showed the highest deformation rates, with the greatest criticality expressed by the rates above 10 mm/year identified in the Sant'Olcese area. In other cases, the average annual deformation rates recorded reached values up to 10 mm/year.

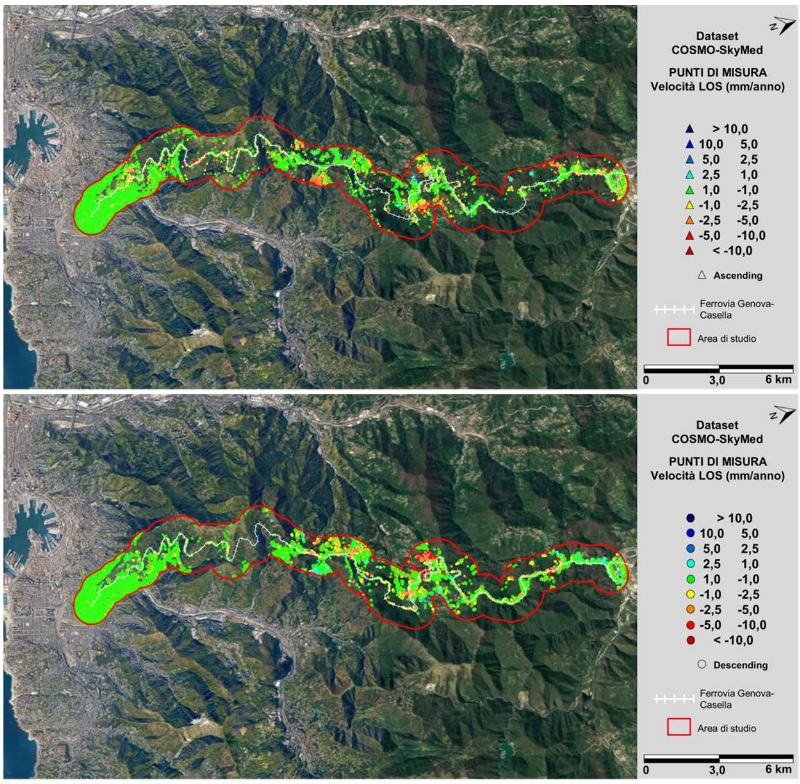

Figure 3: Example of dataset obtained from A-DInSAR analyses, carried out from COSMO-SkyMed images. At the top, there is the dataset obtained from the ascending orbital geometry, at the bottom from the descending one

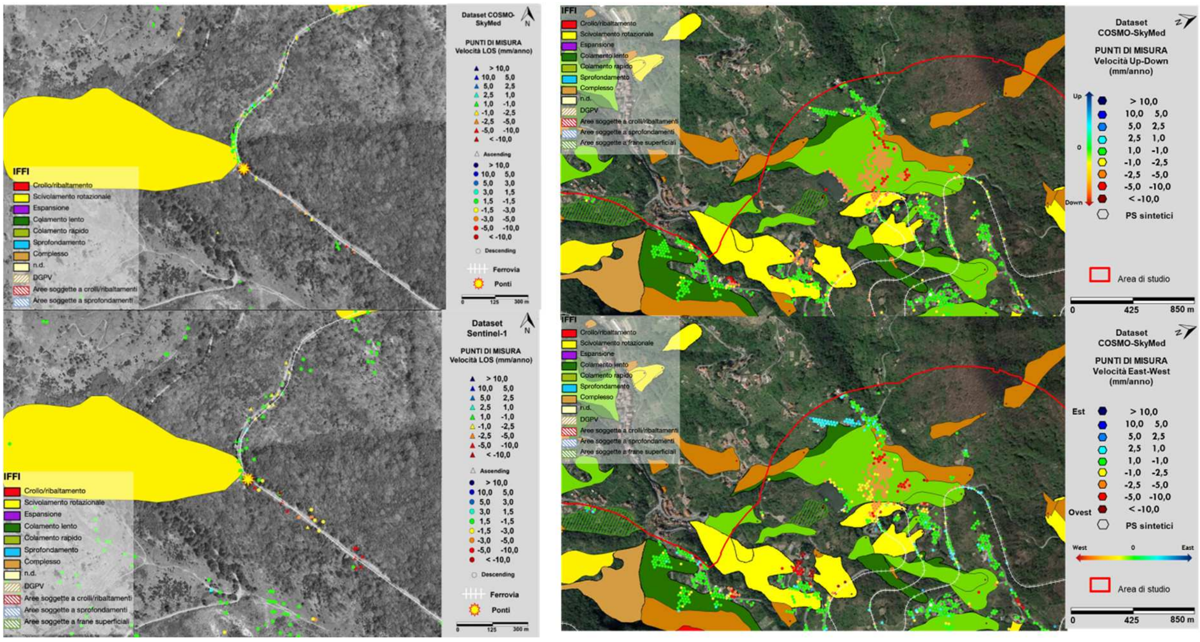

Figure 4: On the left, the PMs of COSMO-SkyMed (top) and Sentinel-1 (bottom) near the Poggino bridge, which was poorly covered by satellite data. On the right, the PMS which express the speeds broken down along the vertical (Up-Down) and horizontal (East-West) directions of the movement in the Sant'Olcese area. Both maps also show the contents of the IFFI inventory.

Next figures show the installation of the n.2 Corner Reflector in the San Olcese area

Figure 5: Position of the two Corner Reflector installed in San Olcese area.

Figure 6:One of the Corner Reflector installed in San Olcese area.

4. Poggino bridge monitoring system

The objective of the monitoring system is to know the evolution over time of the state variables, as directly measurable parameters to characterize the static and dynamic behavior of the work of art.

The Poggino bridge is a masonry viaduct located along the Genoa-Casella railway between pole 365 and pole 369, more precisely from chainage 6,947.60 to 7,000.00m (Figure 8).

The bridge is located in the municipal territory of Genoa in the "urban Val Bisagno" section of the line; the purpose of the bridge is to cross the Briscata torrent and it has an uphill trend, proceeding from Genoa towards Casella, equal to 4.2% for a length of approximately 50m and a curve of approximately 60°.

The bridge is composed of three spans, with a round arch with a radius of 5.00m; the central pile is 10.50m high, while those on the sides decrease in height following the trend of the slope. The deck has an overall width of approximately 4.00m. Abutments, piers and gable walls are made of freestone masonry. The round arches are made of concrete masonry.

The realization of the monitoring system will be structured and developed through the execution of the following activities:

a) General design of the monitoring system (layout);
b) Executive design of the monitoring system (electrical diagrams, sensor installation layout, etc.);
c) Supply and installation of everything necessary for the realization of the system in a workmanlike manner;
d) Supply and configuration of software for the management of the collected data (data acquisition and consultation).

The monitoring system is divided into two subsystems (Figure 7):

- Static system: inclinometers, deformometers, sensors for temperature measurement
- Dynamic system: mono- and tri-axial accelerometers

Such a system is equipped with a minimum redundancy to ensure that, in the event of a malfunction of a key sensor, there are others that provide comparable information and whose measurements serve to avoid false alarms.

Based on the structural typology of the selected artefact, it is believed that the pilot monitoring system for the 3-span masonry Poggino bridge of similar geometry and homogeneous material characteristics should include the following instrumentation:

- 2 biaxial inclinometers at the top of the piles (Figure 9;
- 1 triaxial accelerometer at the top of a stack;
- 3 uniaxial accelerometers (for measuring vertical acceleration) corresponding to the key section of a selected span;
- 3 displacement transducers corresponding to the key section of the same span;
- 1 sensor for temperature measurement.

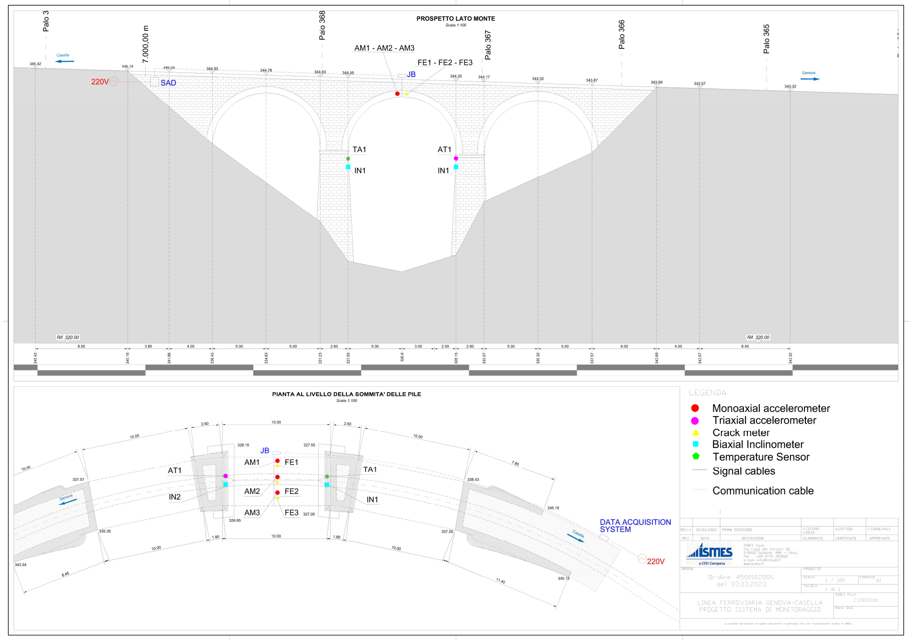

Figure 7: Poggino bridge monitoring system lay-out

With the above sensors it will be possible to monitor the following quantities:

• Accelerations and movements of the points of the span monitored due to the effect of traffic and environmental loads, in particular when the variable load (train) passes, using dedicated accelerometers;

• Accelerations and movements of the pile head points due to traffic and environmental loads, using dedicated accelerometers;

• Rotations of the vertical elements (piles) due to the effects of traffic and environmental loads, such as for example temperature, wind, foundation settlements/imposed displacements due to landslides, mudslides, global slope instability phenomena, etc.

• State variables (directly measurable), such as temperature using dedicated sensors;

The properties of the sensors adopted for monitoring purposes will have the characteristics shown in the following table.

Le grandezze di interesse del monitoraggio sono:

- Grandezze meccaniche caratteristiche della risposta strutturale (accelerazioni, deformazioni, spostamenti);
- Grandezze termodinamiche (temperature);

Figure 8: Poggino bridge

Table 1. Instruments main technical specifications

Accelerometers	
Working principle	MEMS (Micro Electronics Mechanical system)
Measuring Range	0 – 400 Hz
Dynamic range	< 100 dB
Full-range	± 4g
IP protection degree	IP69
Inclinometers	
Working principle	MEMS (Micro Electronics Mechanical system)
Measuring range	± 30 °
Resolution	0.005°
IP protection degree	IP67
Crackmeters	
Working principle	Resistive
Measuring range	1 ÷ 250 mm
Resolution	0.1% F.S.
IP protection degree	IP65/67

The continuous recording and transmission of accelerometer noise can be guaranteed through continuous acquisition in SEEDLINK mode. The procedure also includes the recording of trigger events.

Figure 9: installation of the monitoring system. Biaxial iinclinometer

The management of the proposed monitoring system will be guaranteed through the HMI developed by ISMES, which is called ComMon Suite.

The monitoring suite allows the integrated management and analysis of data acquired from different monitoring systems (Figure 10 and Figure 11). The main characteristics are the following:

- Multi-platform web interface, with access via intranet and internet using standard and recent technologies. The system runs on a server which operators access through their client browsers. The web interface will be able to adapt as much as possible to different resolutions and be prepared for subsequent porting to other devices.
- Interaction with highly scalable NoSQL databases
- Components for dynamic graphics and cartographic rendering.

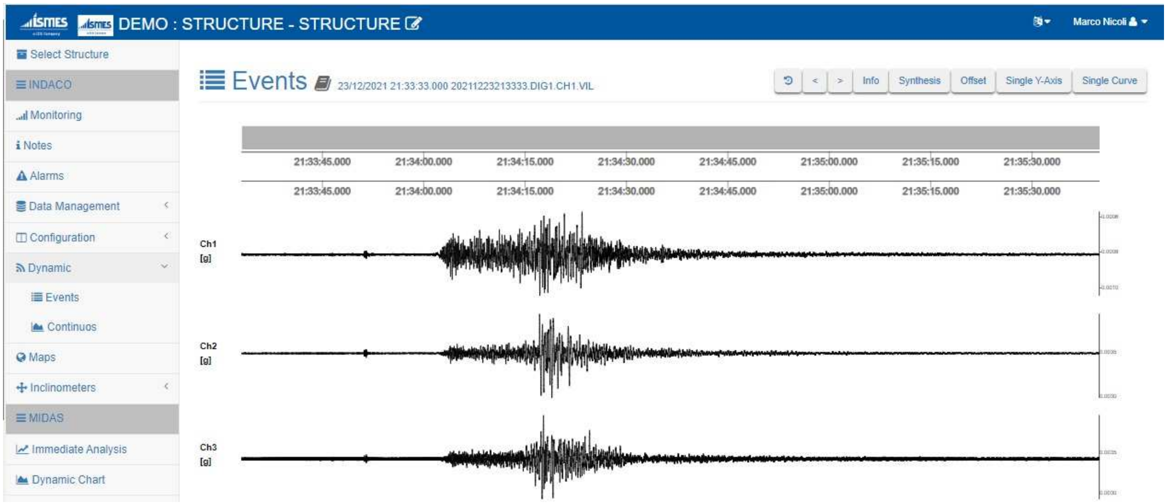

Figure 10: Web interface used to the visualization of dynamic data.

- Map-based visualization of the measurement points of the monitoring system with the possibility of consulting real-time data;
- Configuration and management of alarms and anomaly reports (instrumental alarms; structural alarms are not the subject of this offer).

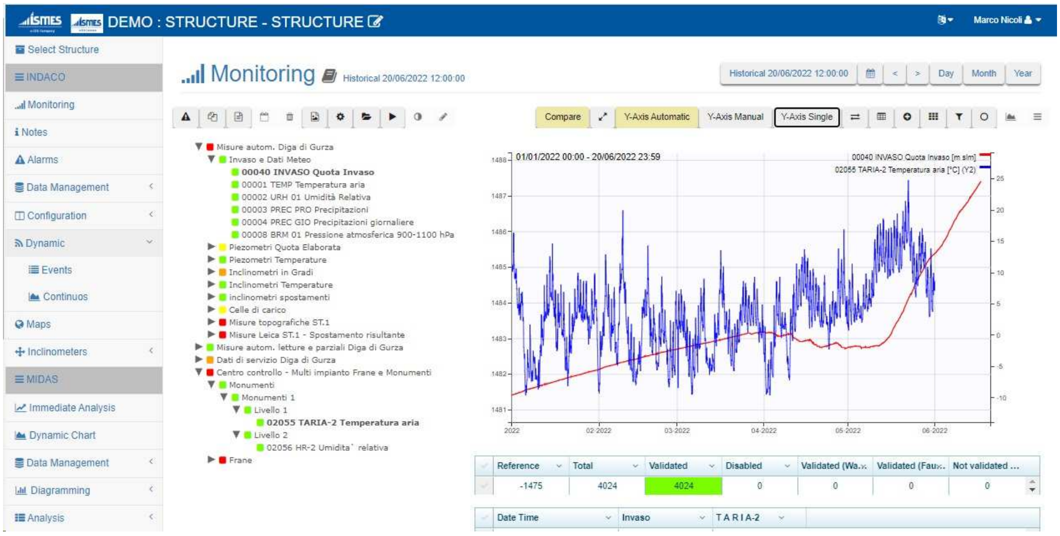

Figure 11: Web interface used or the static monitoring system data

5. Building Information Modeling (BIM) system

The introduction of the BIM regulation has opened up new opportunities in both the design and management fields. The advantages lie in being able to integrate the available data with the new data.

The first point to address the virtualization of an infrastructure or a building is the knowledge, in order to fill the gaps in the historical archives where information often exists, but it is not known where it is stored.

The digitalisation of the Genoa-Casella route was developed starting from the geometric reconstruction of the line and the main structures.

The development phases of a BIM system involved the execution of the following activities.

- Execution of georeferenced TPS survey (Figure 12)
- Survey execution using Laser Scanner of the railway line and its main structure (Figure 13)
- Creation of a management digital model

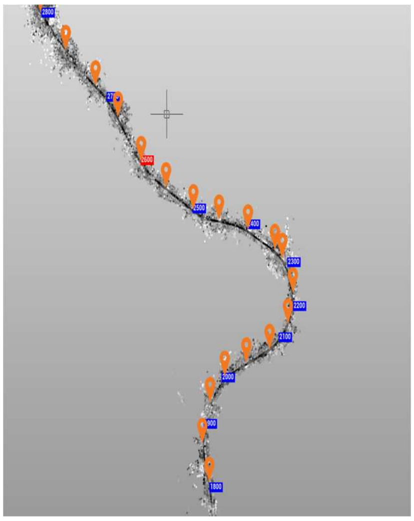

Figure 12: Digitalization of the railway line using laser scanner.

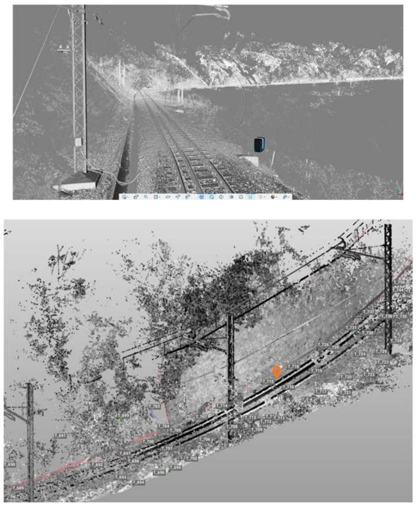

Figure 13: laser scanner survey

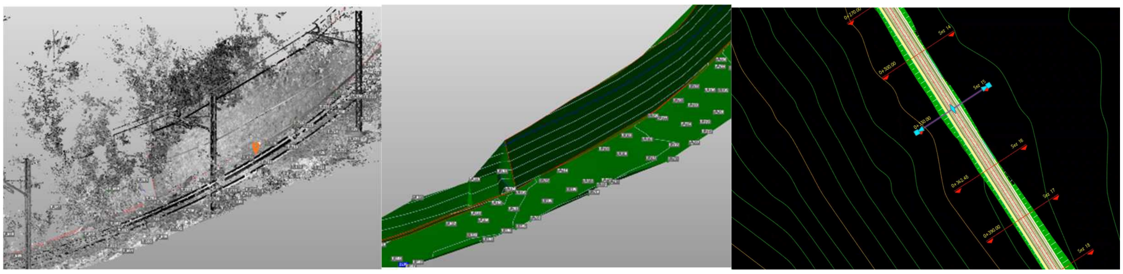

Figure 14 From Laser Scanner survey to BIM model

Within the scope of the project, configured BIM system will allow the integration of the geometric information of the railway (Figure 14), including its characteristics with the data coming from the surveys of the instability carried out by applying the InSAR technology and data acquired from the static and dynamic measurement sensors which they will be installed on the Poggino bridge.

In this way, in a single georeferenced platform it will be possible to have information about the structure behaviour and the evolution of the hydro-geological instability (Figure 15 and Figure 16).

6. Conclusions

The project is based on a monitoring system, which integrates a traditional measurement system, an automatic system to measure static and dynamic parameters to allow structural behaviour, together with innovative technologies for the study of large-scale hydrogeological instability. The project integrates a developed BIM system which, by displaying the data in an advanced graphic environment, allows the engineers to have the needed information in order to support management of the Genova Casella railway,

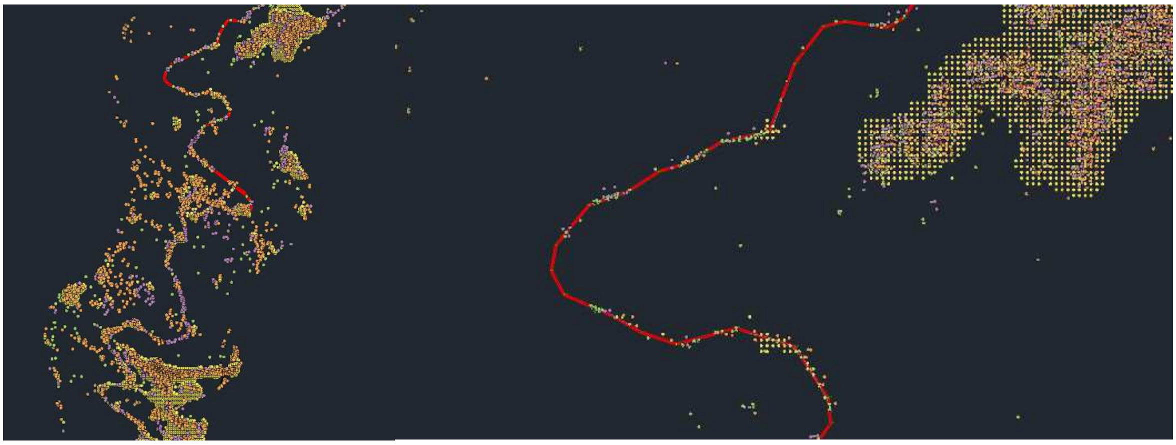

Figure 15: Example of data interpolation using the BIM platform

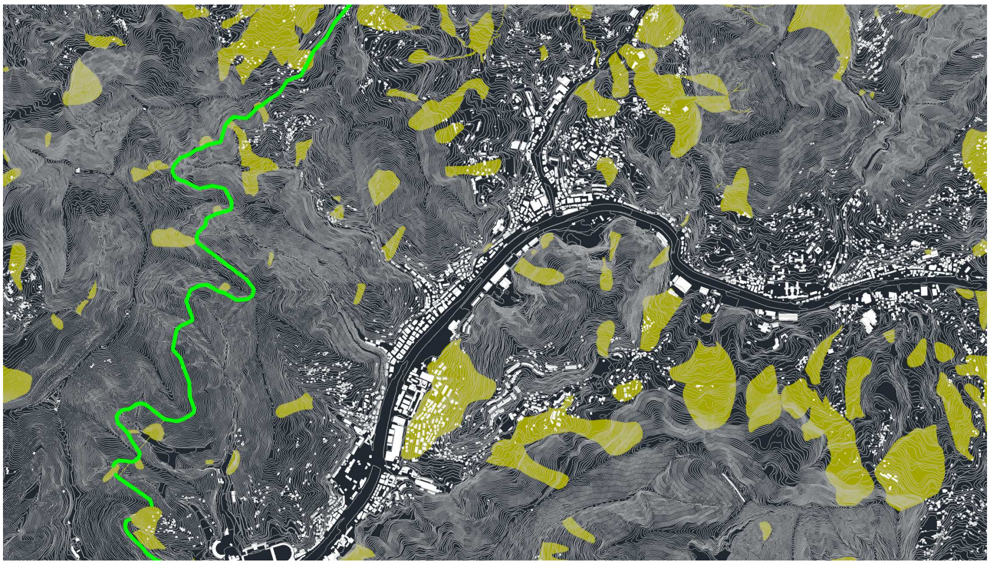

Figure 16: map of the landslide in the BIM platform

7. References

UNI/TR 11634 (2016) Guidelines - Guidelines for structural monitoring

ANSFISA (Agenzia Nazionale per la Sicurezza delle Ferrovie e delle Infrastrutture Stradali e Autostradali) (2022) “criteri per la valutazione dei piani di monitoraggio dinamico per il controllo da remoto di ponti viadotti e gallerie previsti dal piano nazionale complementare al PNRR "Criteria for the evaluation of dynamic monitoring plans for the remote control of bridges, viaducts and tunnels envisaged by the complementary national plan National Recovery and Resilience Plan)

Ministero italiano delle Infrastrutture e dei Trasporti (2022) “Linee guida per la classificazione e gestione del rischio, la valutazione della sicurezza ed il monitoraggio dei ponti esistenti (“Guidelines for risk classification and management, safety assessment and monitoring of existing bridges”)