New Bologna Centrale High Speed Railway Station Monitoring project- technology at the service of safety

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ABSTRACT: The Bologna Central Station, is one of the new stations on the Milan-Naples high speed railway line and it is located in the center of the city. The station has been developed mostly underground, on three levels. The excavation covered an area approximately 640 m long and 56 m wide, with an excavation depth of 23 m. The particular characteristics of the underground structure and its location, required the design of a complex geostructural monitoring system. The purpose of the monitoring network is to control the behaviour of the structural elements of the station during and after construction, to check the effect of excavation and construction works on existing urban and railway structures and to monitor compliance of the works with project forecasts. A particularly important aspect was the determination of possible effects on hydrogeological and geotechnical parameters and, consequently, the effects induced on adjacent structures.

1 INTRODUCTION

The new Bologna Centrale Railway Station, on the Milan-Naples High Speed railway line, is located in the centre of Bologna and was built mostly underground, on three levels, with reinforced concrete structures.

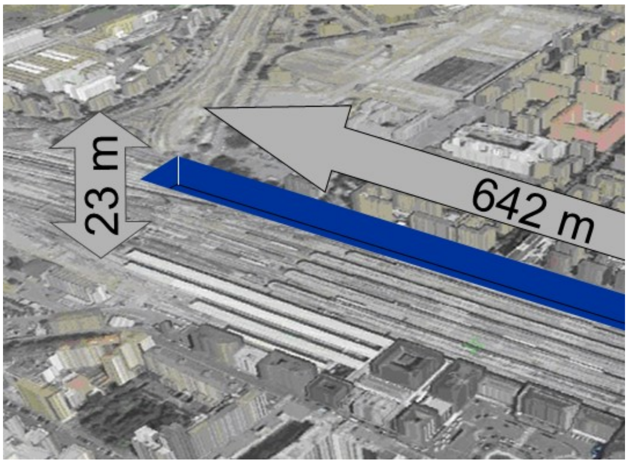

Figure 1 Dimensions of the new station

The Station was designed by Italferr S.p.A and the construction was performed by Astaldi S.p.A.

The excavation covered an area approximately 642 m long and 56 m wide, with a depth of approximately 23 m from the ground level.

The underground part consists of a reinforced concrete structure, but steel elements have also been used for the construction of temporary struts during the excavation phases and later included in the structure.

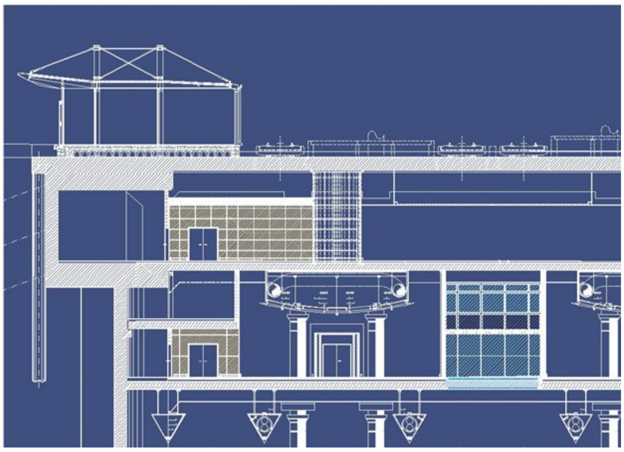

Figure 2 Cross section of the new station

The station was built in a highly urbanized area, in the heart of the city of Bologna and is bordered, on the north side, by the buildings of via De Carracci and, on the south side by track 11 of the Bologna Centrale railway station.

2 STRUCTURAL DESIGN AND EXECUTION METHODS

The initial project underwent substantial changes during the progress of the works and the execution steps can be summarized as follows:

- Jet–grouting all around the perimeter of the excavation area;
- 3 metres deepening of the work surface to be used for the execution of consolidation and deep foundation works;
- "Strut diaphragms", with variable stiffness, all along the excavation depth;
- Cutter Soil Mixing around the perimeter of each structural element;
- Diaphragm excavation using grab bucket instead of hydromill;
- Micropiles anchoring bottom slab instead of large diameter piles;
- Water-sealing bottom plug made with jet-grouting.

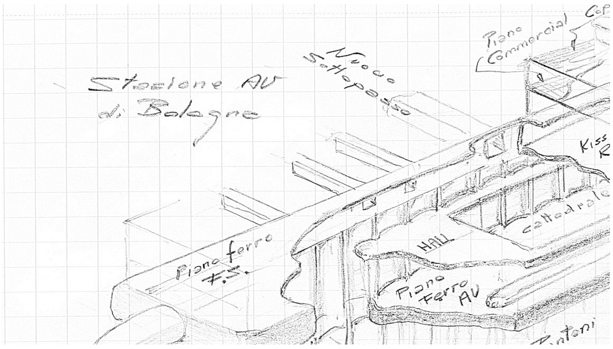

Figure 3 Sketch of the new station

The main structural elements used for containment and construction of the work consist of:

- Spurs
- Vaults
- Metal struts.

3 MONITORING PLAN

The peculiar characteristics of the station, located in an intensely developed context and featuring highly innovative reinforced concrete and steel structures, has implied a monitoring plan designed to:

- Control the behaviour of the new civil works during and after construction;
- Control the effects of the works on existing urban and railway structures;
- Check compliance of works with project forecasts.

A particularly important aspect was the assessment of possible effects on local hydrogeological and geotechnical parameters and, consequently, the effects induced on structures adjacent to the new station.

Therefore, the system used for monitoring the stages of construction of the new Bologna High Speed railway station has been designed to include:

- Surface and in-ground geotechnical monitoring in the area of influence of the station excavation;
- Structural monitoring of both temporary and permanent elements of the new station;
- Structural monitoring of the buildings located along the perimeter of the station;
- Structural monitoring of existing railway tracks adjacent to the excavation area.

The type of instruments and measurement methods used are listed in Table 1 below.

Table 1.Instruments and data acquisition method.

Description	Instrument	Measure
Geotechnical Monitoring	Casagrande piezometer with electrical pressure transducer	Automatic
	Multirod Extensometer with electrical displacement transducer	Automatic
	Inclinometer casing with IPI chain	Automatic
	Levelling pin	Manual
	BRS/INCREX extensometer	Manual
Structural Monitoring	Anchor load cell	Automatic
	Welded and embedded strain gauge	Automatic
	Inclinometer casing with IPI chain	Automatic
	Inclinometer casing	Manual

Additional structural monitoring during the final excavation stages	Optical prism	Partially automatic
	Electrolevel	Automatic
	Strain-gage	Automatic
	IPI chain	Automatic
Structural monitoring of railway tracks	Electrolevel	Automatic
Structural monitoring of buildings	Optical prism	Automatic
	Levelling pin	Manual

The distribution and position of the measurement instruments was determined by means of monitoring sections, laid out orthogonally with respect to the main axis of the station (Ordinary and Special Measurement Sections) as well as a dense network of control points distributed evenly inside and around the excavation and the newly built structures.

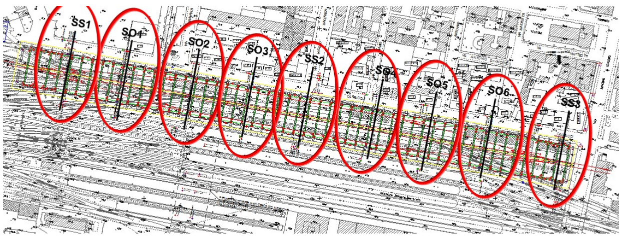

Figure 4 Monitoring sections

The highly complex architecture, with over 2.000 measurement points, and the need to have immediate access to monitoring data, required an exceptional effort, from both a technological and organizational point of view.

The main elements and objectives of the monitoring system, in its final configuration, can be summarized as follows:

- Maximum automation and remote control of instruments and measurements;
- Development of a highly-interactive Web-based software platform for displaying and managing data, with the possibility of increasing the reading frequency of the instruments according to the nature of the events observed, from either on-site or remote users;
- Integration of the automated and remote monitoring system with complementary measurement activity, partially automated or fully manual (e.g. topographical levelling), with results always uploaded into the software platform.
- Possibility of extending access to the monitoring system to persons outside the works construction chain, with the aim of improving and facilitating the exchange of information with Local Organizations wishing to check the effects of the works in progress on surrounding city areas. This possibility contributed to the creation of a climate of transparency and trust.

3.1 *Geotechnical monitoring in the area of influence of the station excavation*

The effects produced by the excavation in the volume of soil involved and on the surface were monitored along the main axis of the excavation through 9 Monitoring Sections, divided into Ordinary Sections (no.6) and Special Sections (no.3).

Each Ordinary Section consisted of the following instruments:

- No.1 deep inclinometer casing (approx. 40 m long), equipped with in-place inclinometer chains (no.6 probes each);
- No.1 multi-rod extensometer (with 5 measurement point);
- No.2 Casagrande piezometers, equipped with electric pressure transducer, for control of surface and intermediate stratum;
- Surveying marking plates on the surface.

The Special Sections featured the following instruments:

- No.6 anchor load cells;
- No.3 inclinometer casings (max. depth approx. 40 m), equipped with in-place inclinometer chains (no.6 probes each);
- No.1 multi-rod extensometer (with 5 measurement point);
- No.3-5 Casagrande piezometers, equipped with electric pressure transducer, for control of surface, intermediate and deep stratum;
- Surveying marking points (levelling pins) on the surface.

In addition to the above sections, the installation included BRS magnetic extensometer or INCREX incremental extensometer, positioned inside deep vertical drills, in the centre of the excavation area, by each equipped section.

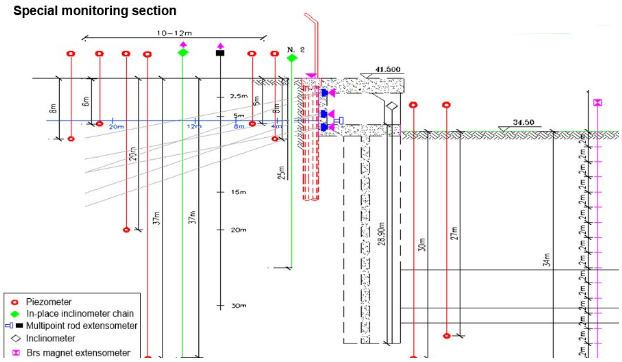

Figure 5 Special Sections instruments

These instruments, characterized by higher precision and resolving power, gave the opportunity to control deep soil movements below the excavation surface as well as the behaviour of the Jet grouting bottom plug.

Figure 6 Pictures of automatic instruments

All the instruments installed in the Ordinary and Special Sections, except for the levelling pins and the above mentioned BRS and INCREX extensometers, are connected to a data logger for data acquisition and communication to the data management information platform.

3.2 *Structural monitoring of the elements of the new station*

Tensile and deformation monitoring of the structural elements of the station was achieved by means of no.9 instrument sections, located in the same positions as the Ordinary or Special Sections.

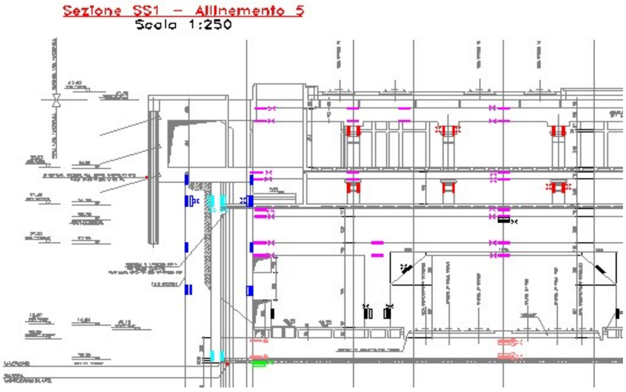

Figure 7 Strain gauges installation cross section

Each instrument section was equipped with vibrating wire strain gauges (in reinforced concrete structures and in metal structural elements) and inclinometer casings (inside the

spurs and in the key section of the vaults).

A total of 1.068 vibrating wire strain gauges and 266 inclinometer casings were installed.

3.3 *Structural monitoring of buildings*

The objective of the topographic structural monitoring was to provide all the information needed to ensure that the excavation operations did not cause any damage to buildings located in area adjacent to the site.

Figure 8 Structural monitoring instruments

The use of over 100 optical prisms, installed on buildings adjacent to the excavation area, and their control through three Robotic Total Stations, featuring continuous acquisition and remote management, guaranteed the safety of residents and enabled constant control over the effects induced by the excavation (Near Real-Time Monitoring).

Figure 8 Robotic total station

In addition to the automated planimetric and altimetric monitoring, systematic topographic levelling campaigns were carried out on level pins/sockets installed at the bottom of buildings facades, for the entire duration of the works.

3.4 *Monitoring of existing railway tracks adjacent to the excavation area*

In order to guarantee real time control of the stability of the tracks located close to the excavation area, track twist and settlement parameters were monitored.

Monitoring was carried out by means of 120 single-axis electro-levels, partly mounted on lengthwise bars, set on sleepers along the track alignment, partly positioned directly on the sleepers, with rotation axis orthogonal to the tracks.

Figure 9 Tracks Monitoring

The instruments were configured to automatic acquisition and communication mode.

The tracks were periodically measured with precision levelling.

3.5 *Additional monitoring during the final excavation stages*

During the final excavation stages, up to the laying of the bottom slab, additional monitoring was introduced to control the convergence of the large chamber walls and the tensional state of the temporary metal struts.

This monitoring system required the temporary installation of no.6 optical prisms positioned on all the spurs located close to the area involved in the excavation.

The prisms, installed at different levels, on both sides of the excavation, were measured twice a day by a mobile Total Station.

The data acquired were immediately processed and sent to the Designer, to the Engineer/Supervisor and to the Contractor.

In addition to surveying measurements, the following instruments were installed:

- in-place inclinometer chains and surface electro-levels, for control of spur deformation;
- vibrating wire strain gauges (on KR and VAV planes), for control of the tension developed on the struts.

Figure 10 Surface electro-levels monitoring

Data acquisition was performed by means of small, easy-to-carry dataloggers, connected via cable to the geotechnical instruments and via radio to the local server, for immediate processing and uploading of the data on the web platform.

A comparison between the values measured and the alert/alarm threshold values, set by the Designer, enabled excavation operations to be carried out under maximum control of deformation, ensuring timely intervention for interruption of works and implementation of additional safety measures.

4 ARCHITECTURE OF THE DATA MANAGEMENT SYSTEM

The over 40 million data acquired during the execution of the works, required the design and development of a complex system for data management and security.

The use of the best technology for data acquisition and transmission is the basis for the creation of an high-performance and near real-time infrastructure, suited to the specific needs of the project.

The main components of monitoring system, developed for this project, consist of:

- Sensor/instrument;
- Datalogger;
- Data Communication System between Datalogger and Local Server;
- Local Server
- Web Server located in a suitable Data Center

The huge amount of instruments, and their distribution over a large area, required the integration of different data transmission systems, connecting dataloggers to the Local Server:

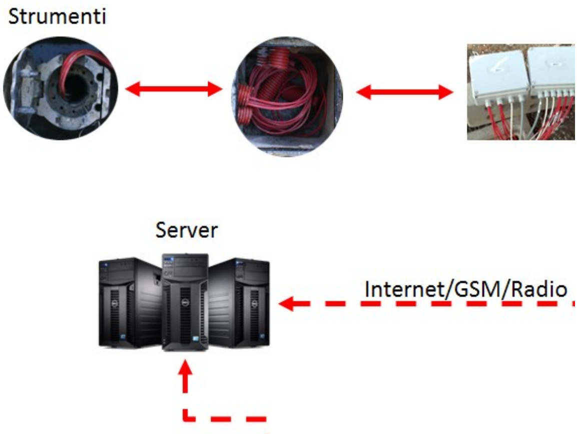

Figure 12 Architecture of data management System

- GPRS in "always-on" mode: the Dataloggers, always connected to the internet, allow data to be sent to the Local Server (via FTP protocol) and enable two-way communication with authorized users, through their IP address.
- RADIO in "on demand" mode: the Dataloggers and Robotic Total Stations send data to the Local Server immediately after data acquisition, using directional radio aerials.

Structured storage of data in the Local Server installed in the worksite offices was managed, in real time, inside a single large SQL relational database.

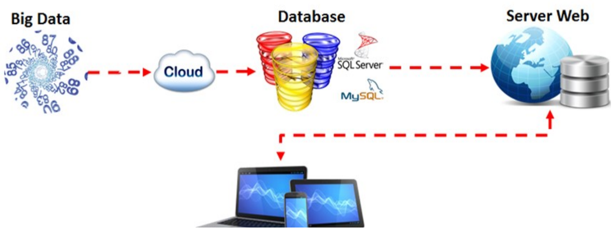

Figure 11 Scheme of data process

By using customized data analysis software, specialized technicians constantly monitored the tensile and deformation parameters during construction.

Information sharing, by all the technical staff involved in the works, was made possible by an innovative highly-interactive web platform, which guaranteed accessibility of information to authorized users through a standard web browser (e.g. Internet Explorer). The monitoring data registered by the dataloggers and by the Robotic Total Stations, were made available in two graphic and numeric modes:

- Not Validated data, in real time, without any verification of the technical staff in charge of control;
- Validated data, following the data analysis and control phase, complete with notes and reports of any incongruous measures.

Main functions of the software available to operators are listed below:

- Display of instrument position on a GIS plan;
- Data structure according to a layout, previously set out by the Contractor and the Engineer;
- Fast data processing in an engineering unit;

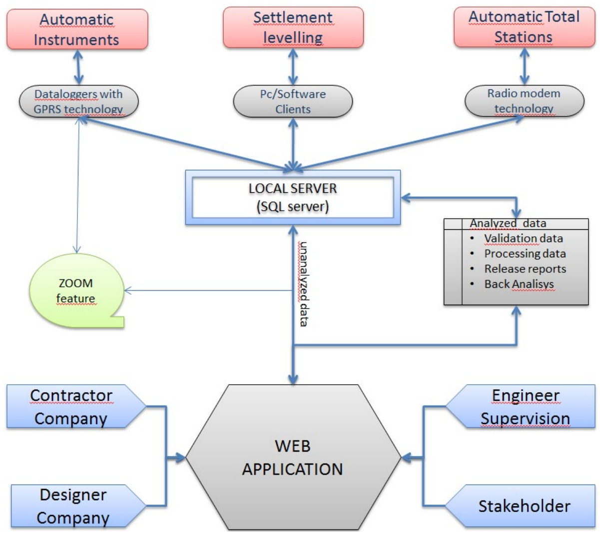

Figure 13 Flowchart of data process

- Data analysis, with numeric and graphic display, to detect movement as it occurs;
- Printing of graphic and numeric reports, in excel or pdf format;
- Data validation and action in case of system failure.

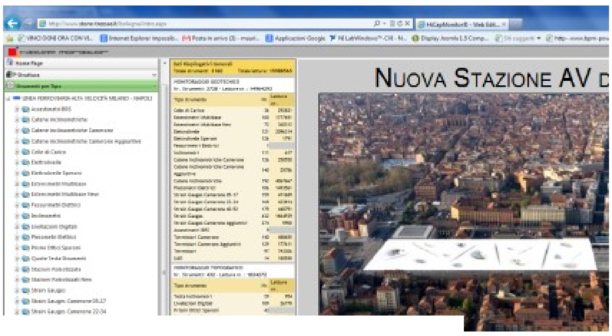

Figure 14 Local Data management software

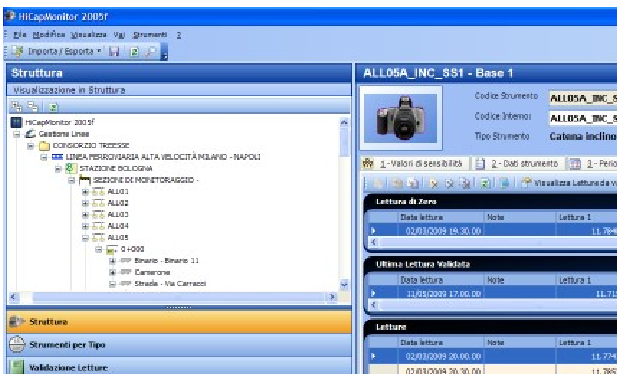

Figure 15 Web Data Manager

The management and processing of large quantities of data required the implementation of IT tools for summarizing and recalculating historical data, in order to avoid slowdowns or blocks of the software. For this purpose, the application of a statistical analysis algorithm based on the median calculation, applied after the step of data validation, has been a successful tool that has allowed to reduce the amount of "historical" data to be managed in the monitoring data analysis and interpretation process.

The basic advantage of the median in describing data compared to the mean (often defined as the "average") is that it is not much affected by extremely large or small values.

The median represents a "robust" measure, as the effect of anomalous data on it is very limited.

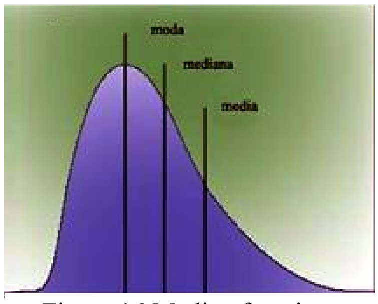

Figure 16 Median function

These corrective operations have proved to be very useful and have made historical data more accessible, facilitating the analysis of events and their evolution over time.

This experience has led to the creation of more complex downsampling algorithms with important benefits in the automatic validation processing.

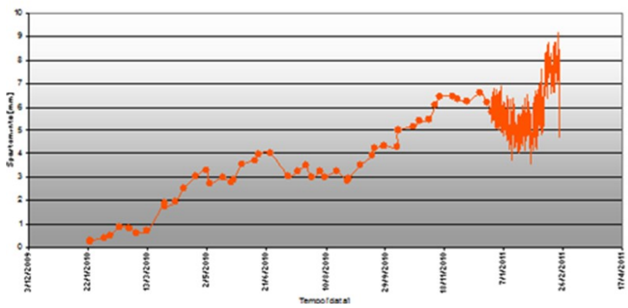

Figure 17 Application of the median function

Another important aspect concerns user/sensor interactivity, obtained with the creation of a new application, designed for direct access to dataloggers via web, to perform forced data acquisition, based on current needs, and to display the measurements obtained in real time.

All authorized users were able to employ this very powerful instrument named ZOOM.

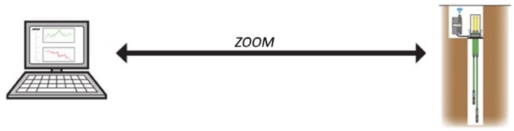

Figure 18 Zoom function

The possibility of personalizing data acquisition on specific sensors, in addition to the normal data acquisition cycle, was an effective aid for punctual analysis of sensitive areas.
In a few seconds, users were able to have control over the data acquisition unit and "force" continuous acquisition from up to a maximum of 3 sensors, displaying the data recorded in graphic or table form.

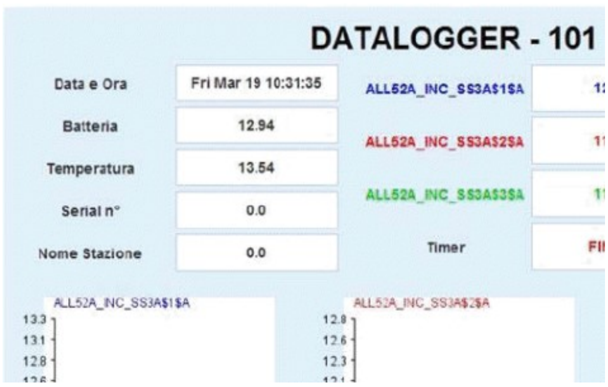

Figure 19 Recorded data in zoom function

5 PROBLEMS AND TROUBLESHOOTING

The installation of several Datalogger (UAD) in a location affected by high electrical noise, caused mainly by the presence of high-voltage lines, by strong absorptions of electrical current due to the passage of trains and to the presence of electrical power delivery systems, created some interferences on the data collection.

Through systematic measurement of the electrical voltage distribution it was possible to identify the main reasons of the problems due mainly to the combination of the following factors:

- Electrical disturbance due to earthing of the UAD;
- Electrical disturbance on the UAD metallic casing;
- Instability of the power supply network, both in common and differential mode;
- Presence of radiated noise on signal cables.

The elimination of the earthing and the galvanic insulation of UAD casing solved the first two issues.

Moreover, an intervention on the Power system, by changing from a switching type power supply to a linear one, has allowed to eliminate the network instability.

These interventions have permitted to significantly reduce the acquisition anomalies, without further interventions on the signal cables.

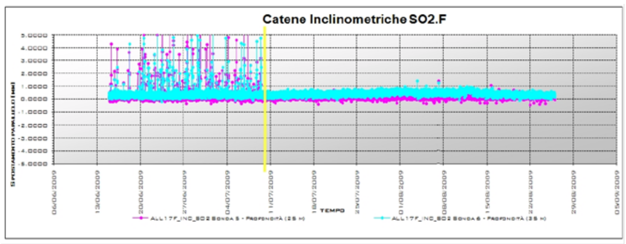

Figure 20 Elimination of noise on inlinometric chain measurements

6 CONCLUSIONS

Monitoring of the new Bologna Centrale High Speed Railway Station was a strongly innovative project, in terms of the resources deployed as well as of its technological content.
The key element of the monitoring system was the maximum automation of data acquisition processes and of data verification/analysis processes.
The huge amount of instruments, mainly in automatic acquisition mode, and the very high frequency of sampling, made it possible to carry out the work in a highly controlled environment.
An indispensable element for making the best use of the information acquired was the innovative, fully web-based data management platform, which allowed worksite personnel to access data with extreme rapidity.
In addition, the huge quantity of data acquired called for effective query tools and for specialized technicians who could evaluate their quality.
Equally important was to assign staff members, from both the Engineer organization and the Designer's organization, to supervise all monitoring activities and to be constantly present at the worksite.

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