# A MODERN APPROACH TO THE RAILWAY TRACKS SURVEY BY MEANS OF THE RDS AUTOMATIC SYSTEM

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## 1. HYSTORICAL OUTLINE

The history of rail transport dates back nearly 500 years, and includes systems with men or horses power and rails of wood or stone. Wagonways or tramways are thought to have developed in Germany in the 1550s to facilitate the transport of ore tubs to and from mines, utilising primitive wooden rails. The technology spread across Europe and had certainly arrived in Britain by the early 1600s. The first railway steam locomotive was built in 1804 by Richard Trevithick, an English engineer .

**A replica of the Planet, an early steam locomotive from 1830**

In 1814 George Stephenson built a steam-powered machine. Stephenson played a pivotal role in the development of the steam locomotive. His designs considerably improved on the work of the earlier pioneers. In parallel in the United States engineers and inventors, published a vision of what steam railways could become, with cities and towns linked by a network of long distance railways plied by speedy locomotives, greatly reducing the time required for personal travel and for transport of goods. Unfortunately, conditions in the infant United States did not enable his vision to take hold. Modern rail transport systems first appeared in England in the 1820s.

These systems were the first practical forms of mechanized land transport, and they remained such as the primary form for the next 100 years before the coming of motorcars. At the beginning, canals were in competition with the railroads, but the railroads quickly gained ground as steam and rail technology improved, and railroads were built in places where canals were not practical. Railways quickly became essential to the swift movement of goods that was needed for industrialization. The success encouraged the rich investors of the rapidly industrializing North West of England to embark upon a project to link the rich cotton manufacturing town of Manchester with the thriving port of Liverpool. The Liverpool and Manchester Railway was the first modern railway.
After the Second World War the large demand of transportation imposed to improve and develop the existing railway networks in order to meet the exacting demand of high comfort and fast speed. The late 20th century saw high-speed rail systems such as the TGV, the AVE and the EUROSTAR.

## 2. STANDARDS AND REGULATION

The provisions of Directives 96/48/EC and 2001/16/EC and the adoption of EC Regulation No. 881/2004 of the European Parliament establishing a European railway agency (Agency Regulation) on safety on the Community's railways (Railway Safety Directive) have established the task of a European railway area without borders and helped to revitalise the railway sector together with reinforce its essential advantages in terms of safety.
The Agency contributes to the development of a genuine European railway culture and forms an essential tool of dialogue, consultation and exchange between all the actors in the railway sector, giving importance to their individual competences necessaries for the development of common safety indicators, common safety targets and common safety methods. Development of these tools requires independent technical expertise. Promotion of innovation in the field of railway safety and interoperability are important tasks which encourages the professional approach of design and construction method includes also the realization of advanced monitoring systems.
In Italy the demand of monitoring the rail geometry became effective with the RFI (Rete Ferroviaria Italiana) standards which defines the tasks in order to assess the track geometry quality (longitudinal level and transversal alignment) of the high-speed rail systems up to 300 km/h.
The EC directive and the RFI Standards are applied to the new railway under construction, but also to the existing railways which are going to be renovated according to the modern standards.

## 3. RAILWAY DEFORMATION SYSTEM (RDS)

The RDS, Railway Deformation System, is a non-conventional monitoring system designed by Sisgeo for automatic survey of the longitudinal deformation of the rail tracks and the twisting of the sleepers. According to the RFI Standards RDS permits to monitor the rail track geometry as:

- Longitudinal level: measured in "mm" as a difference of level between two points located longitudinally at certain preset intervals;
- Transversal alignment: measured in "%" as inclination change of two sleepers located at the same intervals of longitudinal.

Compared to the traditional systems, including topographic surveys, RDS offers to the Customers either high performances and significant reduction of the operating costs. In fact when the system is correctly installed there is not field activity required by technicians at site; RDS can be managed also by a single operator onWeb site.

RDS consists of a chain of gauges directly positioned on the railway tracks. The system permits, by means of an automatic data acquisition unit, to perform real time monitoring and to transmit the measurements to a remote server for data processing and publication on the Web. The Client and/or the Authority can check and compare the data with the safety limits, taking the necessary actions if the safety of the rail track could be compromised, even stopping the traffic of the trains.

RDS gauges are equipped with a high performance tilt sensors (solid state accelerometers MEMS technology) which are able to measure rotation with 0.015 dg accuracy managing data with polynomial factors.
Tilt sensors have been selected in order to satisfy the following criteria which are essential for qualified performance in the railways working environment:

- Reliability
- Rugged and vibration-proof
- Linear behaviour with temperature

Tilt sensors are housed in a rugged and waterproof aluminium box which is built-in an aluminium bar which guarantee a further mechanical protection. The aluminium bars are available in different lengths in order to satisfy any request of application. The bars are supplied with mounting brackets for installation on sleeper by means of expanding or chemical bolts or by using specific resin.

RDS offers different solutions for installation on wooden or concrete sleepers, or directly on the rail. It has been also designed in order to facilitate the disassembly of the sensors when the maintenance of the rail track is required.

Basically there are two types of RDS gauges:

- the longitudinal RDS gauge. It normally consists of a 3m aluminium bar equipped at the ends with special joints in order to allow their installation in chain;
- the transversal RDS gauge for direct application onto the sleeper surface. The mounting bar of the transversal sensor is available 20cm and 1m long for application on concrete and wooden sleeper respectively.

**RDS Longitudinal gauge**

**RDS Transversal gauge**

The technical features of RDS gauges are reported in the following table:

| | Longitudinal RDS | Transversal RDS |
|---|---|---|
| Instrument type | RDS L gauge | RDS T gauge |
| Instrumental class | **II – Long-term application.** Instruments available for Calibration and Maintenance after installation. | **II – Long-term application.** Instruments available for Calibration and Maintenance after installation. |
| Use | Measurements of railways longitudinal rotation (levelling) | Measurements of sleeper rotation |
| Application | On concrete or steel structures | On concrete or wooden sleepers |
| Measuring type | angular | angular |
| Measuring axis | X - Longitudinal | Y - Transversal |
| Sensor type | Accelerometer | Accelerometer |
| Measuring range | ± 10° | ± 10° |
| Calibration range | ± 10° | ± 10° |
| Accuracy (linearity-histeresys-repeatability) | ± 0.4% FS (linear factor)<br>± 0.15% FS (polynomial factors) | ± 0.4% FS (linear factor)<br>± 0.15% FS (polynomial factors) |
| Signal output | 4–20 mA (current loop) | 4–20 mA (current loop) |
| Power supply | from 12V to 24V c.c. | from 12V to 24V c.c. |
| Temp. operating range | -40°C +85°C | -40°C +85°C |
| Temperature sensor | NTC Thermistor (YSI 44005) | NTC Thermistor (YSI 44005) |
| Measuring range | -50° C +150° C | -50° C +150° C |
| Resolution | 0.1°C | 0.1°C |
| Accuracy | 0.5° C | 0.5° C |
| Electrical connection | 2-twisted pairs cable | 2 twisted pairs |
| Sensor housing | Die-cast aluminium | Die-cast aluminium |
| Protection level | IP 67 | IP 67 |
| Bar length | 1m, 2m, 3m | 200mm, 1m |
| Bar section | 40 x 60mm | 40 x 60mm |
| Bar material | Aluminium alloy | Aluminium alloy |

## 4. RDS ON MILAN-NAPLES HIGH SPEED RAILWAY

The Italian general transportation plan has defined six multi-use corridors intended to play in all of the country's domestic and international traffic. With regard to the railway network, the national Transportation plan considers the central Milan-Naples line, which connects the Northern, Central and Southern area of the country, to be the major trunk line of the Italian railways system, since this section covers less than 5% of the entire network (about 800 km) carrying about 30% of the total passenger traffic.

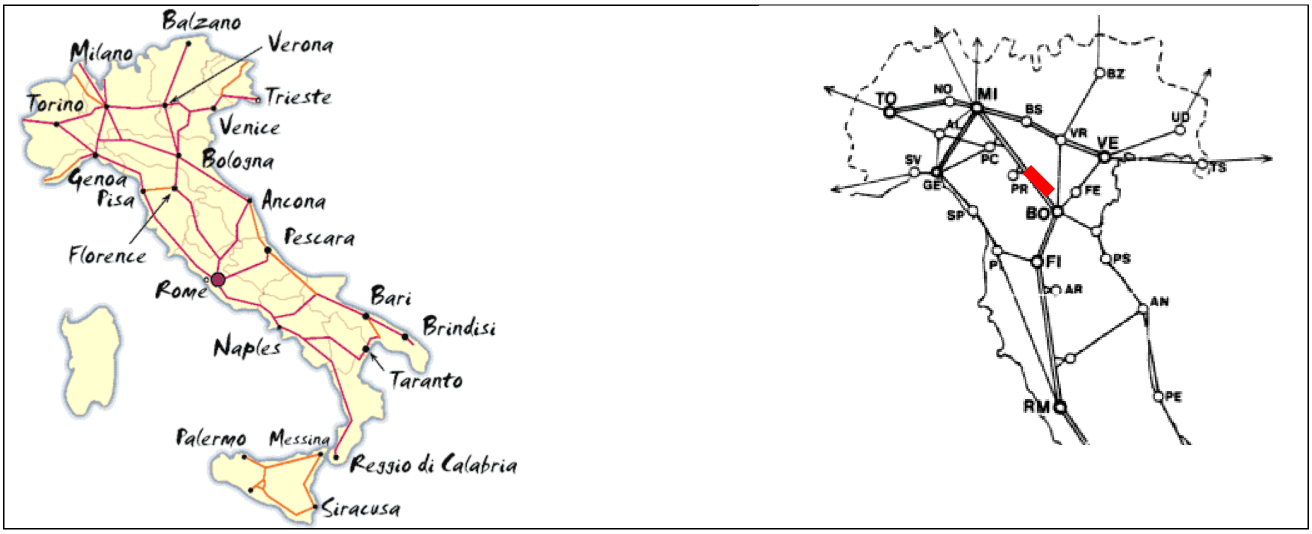



**Fig. ….. Italian railways system**

The construction of this line started early this century and recently was introduced the high-speed rail service between Bologna and Milan. Italy's train service is called "Freccia Rossa", named in favour of the gorgeous new red trains.

**Fig. ….. Freccia Rossa and ETR 500 on operation**

Since 2004, in a short section of this line between Parma (PR) and Bologna (BO) where the high speed railway runs close to the A1 motorway, the topographic survey shows significant soil settlements in the range from 5 cm to 25 cm.

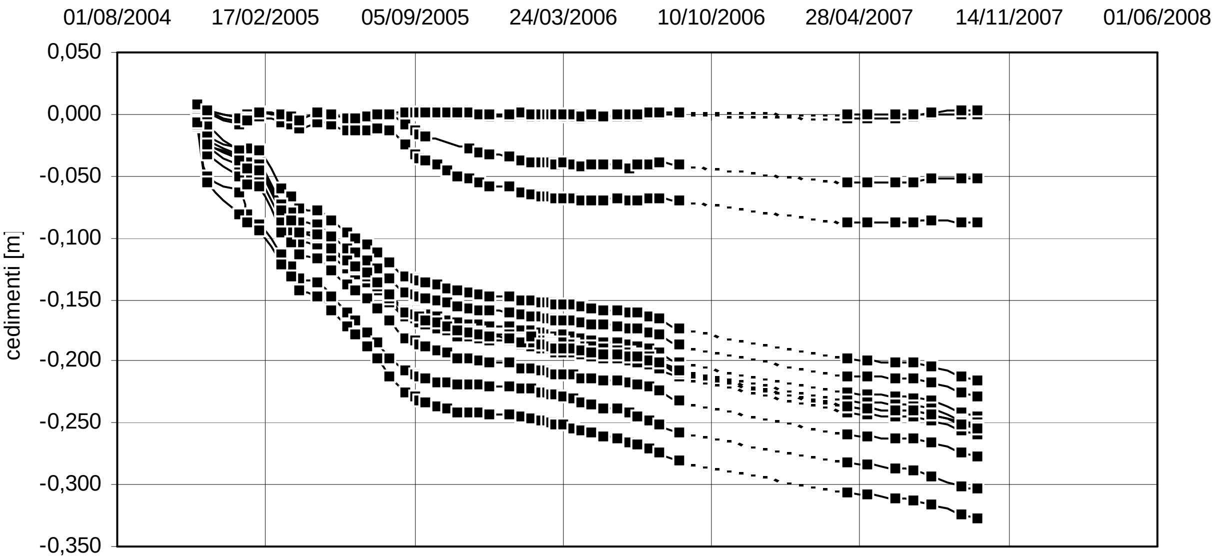



**Fig. ….. Trend of soil settlements from Aug 2004 to Nov. 2007**

In this section the railway track runs over embankment which is confined inside a “U shaped” containing wall insisting on direct foundation. The length of the wall is approximately 80m with average height of 5m. The poor mechanical characteristics of the surrounding soil beneath the embankment and the large soil settlement occurred have obliged the General Contractor to provide with soil improvement in order to guarantee the stability of the structure and the safety of the railway.

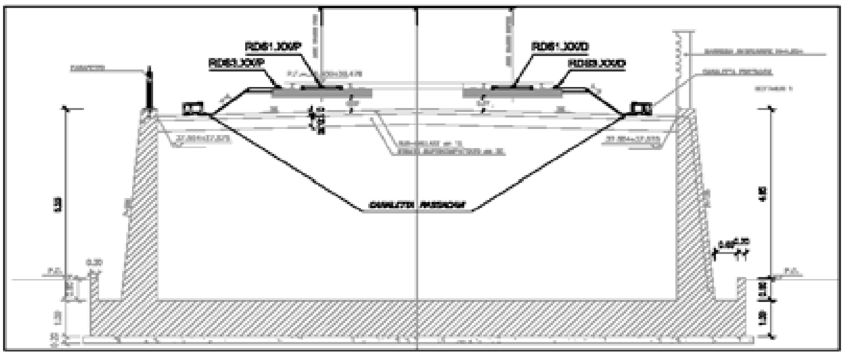


**Fig. ….. Railway track and containing wall section**

Before the beginning of the rail service the Owner, RFI (Rete Ferroviaria Italiana), has required the installation of a monitoring system which is able to control the behaviour of the structure monitoring the deformation of the railway track. RDS was offered as a possible solution and it was approved in compliance with the standards. RDS has offered a qualified solution in order to guarantee the safety of the railway during operation. The system was installed on November 2008 covering 70m of railway line (double track) and it will remain active during the 2009.

**Fig. ….. Panoramic view of the monitored section**

The system installed consists of:

- n. 25 RDS longitudinal gauges with 3m bars installed in chain on the right rail track,
- n. 25 RDS longitudinal gauges with 3m bars installed in chain on the left rail track,
- n. 18 RDS transversal RDS gauge mounted onto the concrete sleepers,
- n. 10 junction boxes and cable,
- a field monitoring station equipped with a solar powered ADK-100 data acquisition system and GSM/GPRS modem for remote communication,
- a remote control centre with dedicated server.

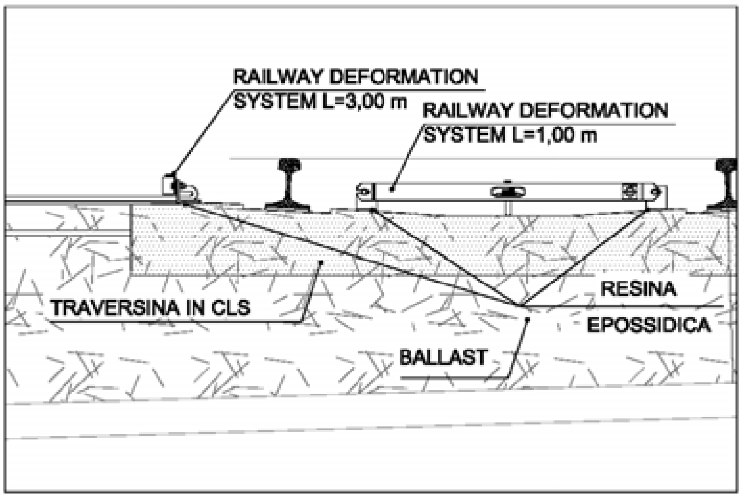



**Fig. ….. Railway track instrumented cross section**

The installation of RDS gauges on the rail tracks was performed almost after interruption of the main power of the line and according to the rail traffic. Thus the time available for installation was quite restricted and in many cases it has been performed during the night. RDS has been designed to be simple and quick to be installed: after the locations have been defined, the supports were positioned fixing them by means of epoxy resin. Afterward the bars were fixed and set.

**Installation of RDS longitudinal support by means of epoxy resins**

**Installation of longitudinal RDS chain**

In order to reduce the wiring operation, the signal cables of the longitudinal RDS gauges have been preassembled at laboratory with specific lengths and then connected to the junction boxes. RDS transversal gauges are provided with a standard length of 1 m cable terminated with a connector to fit the cable running to the junction box.

Cables are laid onto the rail bed to the beginning of the ballast; then protected by a non metallic cable tray -to reduce electromagnetic interference – to the junction boxes. Junction boxes have two main purposes:

1. collect the signal cables from RDS gauges and connect them to the multicore cables in order to reduce the number of cables to the data acquisition unit;
2. contain surge arrestors for the protection of RDS gauges from overvoltage effects.

**Cable wiring inside Junction Box**

**Removal of RDS longitudinal bars**

From the junction boxes, the multicore cables run generally outside the rail track area to the data acquisition unit where they are connected to the multiplexer boards.

As said, the RDS system has been developed to be removed when maintenance activities have to be performed on the railway tracks. RDS gauges can be easily removed:

- the bars which contain RDS longitudinal gauges can be unscrewed from the supports and get aside from the track area;
- the RDS gauges can be easily disconnected due to the presence of connector.

Only the steel supports cannot be removed, but they don't create any problem to the incoming activities. When activities are terminated, the bars are easily positioned and fixed to the supports.

The installation of the data acquisition unit has been performed without any restriction – in time and safety - since it is far from the railway restricted area. ADK-100 is a multitasking programmable data acquisition unit which is able to manage:

- n. 50 RDS longitudinal gauges,
- n. 18 RDS transversal gauges,
- n. 68 NTC thermistors built-in the RDS gauges,
- n.3 electrical joint-meters,
- n. 1 RTD air temperature sensor.


**ADK-100 Data Acquisition Unit**

ADK-100 is the core of the system since it provides power to the RDS gauges, collects their signals, store them into the internal memory and it also manages warning and alarm signals.

ADK-100 is wall mounted and solar powered by means of 60W solar cell. It consists of a waterproof stainless steel box containing:

- n. 1 control module CR-1000 with 4 MB SRAM memory,
- n. 6 multiplexer boards, rack-mounted with surge arrestors protecting each single channel,
- n. 1 controller board for Multiplexer control, rack mounted,
- n. 1 serial interface, connected to CR-1000 module and to GSM/GPRS modem,
- n. 1 GSM/GPRS modem for remote data communication.

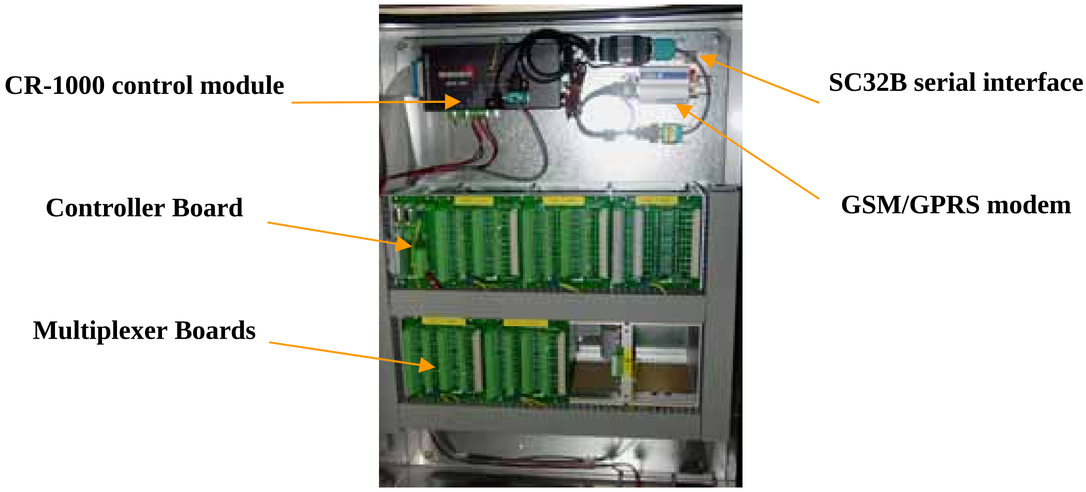



**Fig. 4.5 ADK-100 inside view**

As requested from the Owner, the system installed provides automatic data collection at preset intervals and storage. ADK-100 is programmed to transfer data by means of the GPS/GPRS modem to the remote control centre, where a dedicated server is installed. Data are automatically managed and validated in order to eliminate picks or erroneous values. Afterward they are converted into physical units: angles of rotation. When requested, rotations are converted into displacements [mm] by introducing the geometry of the RDS bars.

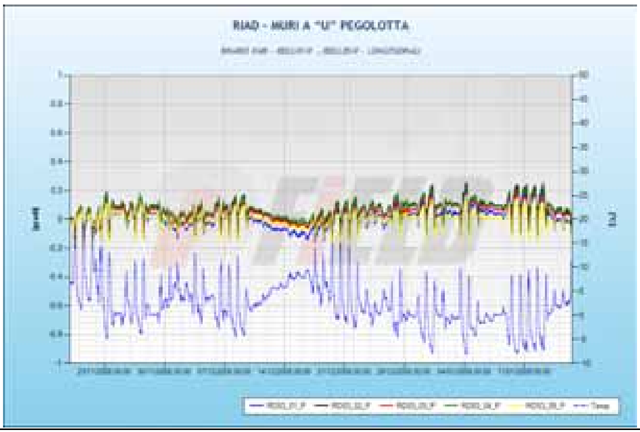
ADK-100 is also set to transmit alarm signals (by means of SMS messages) when a threshold value is overcome. This is useful when the system is intended to control the tracks deformation due to activities undergoing in the area (for example during excavation below the tracks level). The alarm message can be used to check the situation and to activate consequent safety procedures.
It has to be remarked that the system has to be intended as a support to those who have the responsibility of the safety of the work, it must not be intended as the unique control system. A dedicated software package provides for thermal correction of the measurements.

The Owner has access to data by means of dedicated web pages protected by Username and Password. The page shows the chronological plot of data as well as provides for information regarding works progress, special events, anomalies and so on. Moreover inside the page it is possible to find general information on the system such as pictures, electrical schemes, instruments data sheets and calibration sheets.

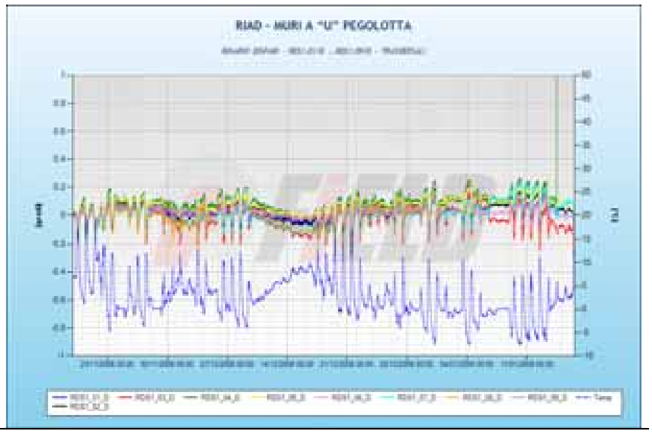
## 5. DATA REPORT

RDS system is managed by a specific software which permits a statistical processing of the historical data stored in the ADK-100 memory. This software also permits the comparison of the measures between different values (i.e. temperature, thermal gradients, electrical picks, etc.) which can influence the valuable data. The ADK-100 has been programmed to read all the instruments (RDS gauges, temperature sensors, joint-meters) every hour. Obviously the reading scan intervals can be modified at simple request.

Data processing includes the mathematical conversion from electrical values to engineering values (angles, displacements), compensation of the temperature effects, comparison with historical measures and data validation. As a result of the data processing on the Web pages, the following plots are published.

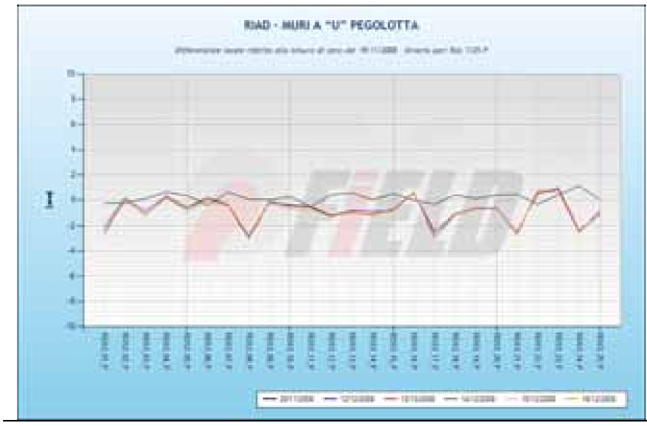



**RDS longitudinal level vs. time**

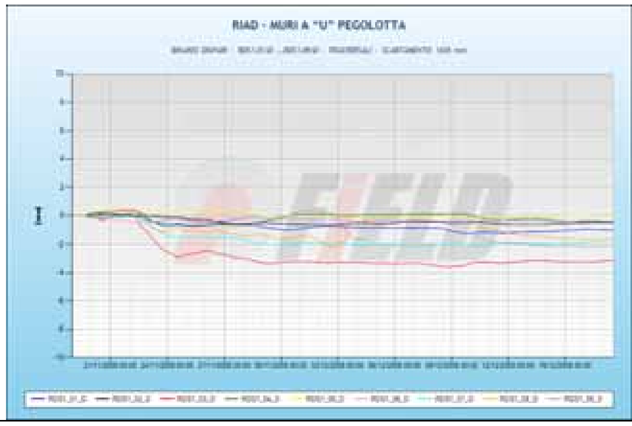



**RDS transverse level vs time**

Left side plot shows an example of the behaviour of RDS longitudinal gauge vs. time, together with temperature plot. The right plot shows the same RDS gauges after the signal value has been treated by means of a temperature compensation process.




**Data processing with integration of local displacements.**




**Transversal gauges vs. time plot**

According to the RFI  Quality System for this applications, the Owner is required to issue a specific "Warning Procedure" in order to manage correctly any safety actions which can be activated as a consequence of the alarm occurred. Three different levels of alarm can be activated by ADK-100.

The Warning Procedure determines:

| Level | Safety Action | Responsible for actions |
|---|---|---|
| **1** | Shorting of the reading scan interval until the standard situation will be restored | System Manager |
| **2** | Modification of the rail traffic (reducing train speed, two rounds traffic, etc.) | Treni Italia (Italian Rail Authority) |
| **3** | Stop the rail traffic, routine maintenance in support and restoration of the rail geometry | Treni Italia,<br>Rail Maintenance Service |

Since nowadays the system has been working continuously without the activation of safety actions. The rail traffic is regularly on operation since December 15$^{th}$, when the High Speed train service started.

## 6. CONCLUSIONS

As described, RDS can be validly used where a continuous monitoring of the rail tracks is requested. It is simple, rugged, reliable and easy to install. Longitudinal and transverse levels are crucial for tracks control when settlements are expected or may occur due to nearby activities.
If correctly designed, installed and managed, the application of RDS can offer a great contribute for railway monitoring. Compared to the traditional systems RDS offers to the Customers a significant decrease of the operating costs reducing the presence of technicians at site.
At present RDS is successfully installed on the Milan-Bologna High Speed Line where a section of 70 m of double railway track is monitored offering to the Owner a valid support in order to guarantee the safety of the rail traffic during operation.

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