
APPLICATION NOTE

ONLINE MONITORING OF TUNNELS

1 INTRODUCTION

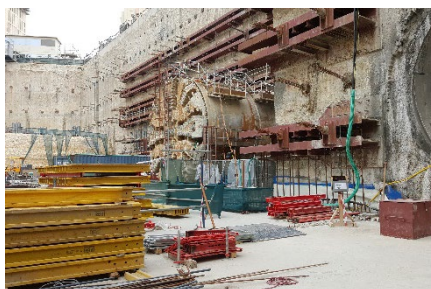
Encardio-rite offers a comprehensive web-based monitoring solution for the long-term safety monitoring of Tunnels. It manufactures a wide range of sensors which have a proven track record for reliability and long-term performance under harsh conditions.

It also offers advanced monitoring technologies such as automatic 3D deformation monitoring using ATS, laser scanning and aerial survey using drones for keeping a tab on the structural health of tunnels and appurtenant structures. Construction survey related solutions are also available.

2 BENEFITS OF INSTRUMENTATION & MONITORING

For tunnels, instrumentation and monitoring are beneficial at every stage of its lifecycle:

- During the design stage, instrumentation installed in the exploratory tunnels and boreholes done from the surface give information on the existing ground conditions, It helps in optimizing the design.
- During the construction stage, instrumentation gives information on how the design is actually performing during execution. In case certain assumptions were made during the design stage, the instrumentation data will determine if these are indeed correct. If required, changes in design could be made at an early stage saving time and money on remedial measures later. Instrumentation carried out from the surface on the alignment gives data for the surface and subsurface conditions. Instrumentation is also done on the structures on the surface which are likely to be affected by the tunnel construction.
- Long term monitoring during the operational stages of the tunnel, ensures its safety, determining the effects of any natural calamity like an earthquake on its structural integrity. It also helps in planning and optimizing he maintenance schedules.

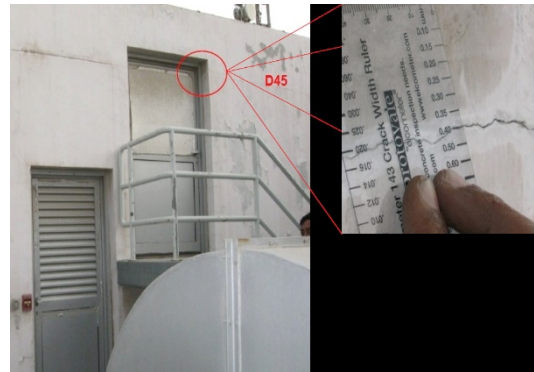


3 SOLUTIONS OFFERED FOR TUNNELS

Encardio-rite offers the following solutions for tunnels before, during and after construction:

A. **Tunnel construction surveys:** Establishing an accurate and reliable geodetic survey network is a vital step to be taken at the start of the tunnel construction as the reliability of land surveys, stakeouts, alignment control, quantity surveys, deformation monitoring surveys, as-built surveys etc. depends on it.

B. **Pre and post construction dilapidation surveys:** Pre-construction surveys are conducted using photography/videography/laser scanning (land and aerial) or a combination of the these for the existing assets such as buildings, utilities, and infrastructure located within the zone of influence of tunnel construction. It provides a baseline record of the condition of these before the start of the construction. Post survey is carried on the same assets to determine any change in the pre-existing conditions and new signs of distress.



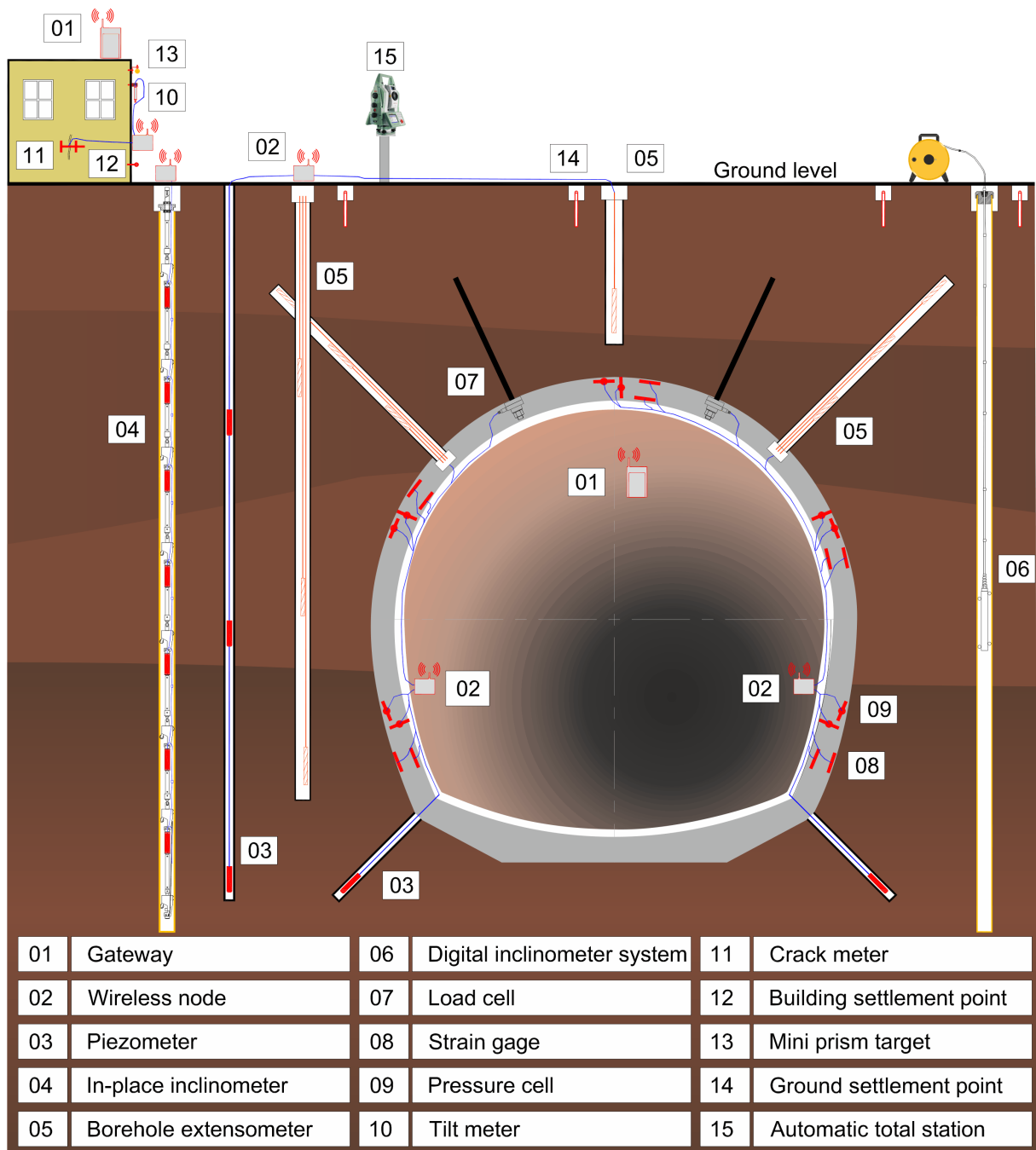
Dilapidation survey

C. **Web-based data monitoring solution** for any type of tunnel construction such as NATM, TBM tunneling, cut & cover, micro-TBM/pipe jacking, etc. essentially comprising of the following:

1. Encardio-rite model EAN-52M vertical **in-place inclinometer** system with several biaxial probes with SDI-12 output mounted vertically in a borehole. These are connected in a daisy chain manner with a single output cable for continuously monitoring sub-surface lateral movements.
2. Encardio-rite model EPP-30V vibrating wire **piezometer** with model ESVI-01-01 or ESVI-10VB SDI-12 interface box for monitoring pore pressure variations.
3. Encardio-rite model EDS-70V vibrating wire type **multiple point borehole extensometer** (with ESVI-01-04 SDI-12 interface box) for monitoring sub-surface settlement and lateral movement at specified depths.
4. Encardio-rite model EAN-92M-B or EAN-93M-B **biaxial tilt meter** with SDI-12 output mounted at one or more locations on the structures within the zone of influence to record changes in tilt.
5. Encardio-rite model EDJ-40V vibrating wire **crack meter** (with ESVI-01-01 SDI-12 interface box) for monitoring displacement/opening of existing cracks in structures within the zone of influence.
6. Encardio-rite model ELC-30S/ELC-30SH resistive strain gage type **center hole load cell** (with ESBI-10 SDI-12 interface box) for monitoring tension in anchors and rock bolts. Model ELC-210S/ELC-150SH resistive strain gage type **strut load cell** for monitoring loads on struts.
7. Encardio-rite model ESC-30V vibrating wire **shotcrete pressure cell** or model EPS-30V vibrating wire **concrete pressure cell** (with ESVI-01-01 SDI-12 interface box) for monitoring radial and tangential stress in shotcrete lining or concrete pre-cast segments.
8. Encardio-rite model EDS-20V-E/EDS-20V-AW vibrating wire **strain gages** (with ESVI-01-01 SDI-12 interface box) for monitoring strains in tunnel linings and concrete pre-cast segments.
9. Encardio-rite model EBS-16 **building settlement points** for monitoring settlement of structures using a digital level.
10. Encardio-rite model ESMP-10C2 or EPS-12-60 **surface settlement points** for monitoring settlement of ground above the tunnel.



11. Encardio-rite model EAN-26-MV manual inclinometer system comprising of a bi-axial digital inclinometer probe, operating cable on a reel with Bluetooth transceiver and a smartphone datalogger with inclinometer application.
12. **RF wireless nodes** for collecting, storing and transmitting data from analog and digital sensors. These could be single & multichannel. **RF Gateways** with integrated GSM/GPRS modem for enabling cable-free wireless transmission of data. Refer to the figure below showing installed sensors in a typical tunnel section with RF data transmission.
13. Encardio-rite model ESDL-30 **data logger** for the SDI-12 output sensors, with integral GSM/GPRS for wireless data transmission.
14. Encardio-rite Online **Web Data Monitoring Service (WDMS)** that provides data access (with alarms) to authorized users at different geographical locations, on their computer/laptops. More details are given in section 4.



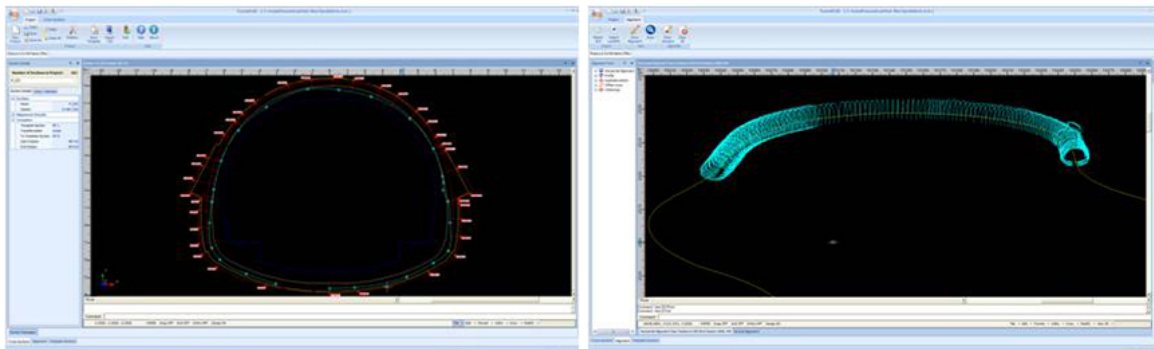
Tunnel instrumentation with RF enabled wireless data transmission



NOTE: Data retrieval from datalogger is also possible by directly downloading it on a laptop. Results of manual monitoring like precise leveling surveys for settlement monitoring, manual inclinometer, crack, groundwater monitoring etc. could also be inputted to the on-line monitoring database.

D. **Geometry control:** Encardio-rite offers TunnelCAD PC and TunnelCE field software. Together these provide a complete solution for graphical and numerical comparison of design vs/measured cross sections of tunnels. The following results could be obtained using a variety of inputs such as project data, import from DWG/DXF, direct communication from tunnel CE etc.

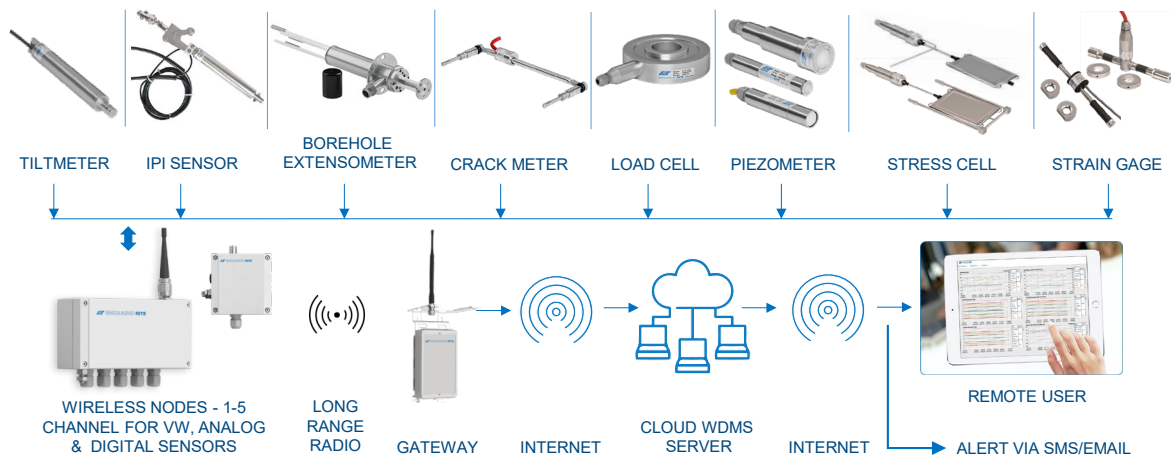
- Profile evaluation with graphical and/or numerical data analysis.
- Volume computations between theoretical and measured lines.
- Layer thickness analysis.
- Under and overbreak.
- Automatic creation of 3D visualization from any measured line.
- As built documentation.



TunnelCAD Software

4 PUBLIC CLOUD-BASED WEB DATA MONITORING SERVICE (WDMS)

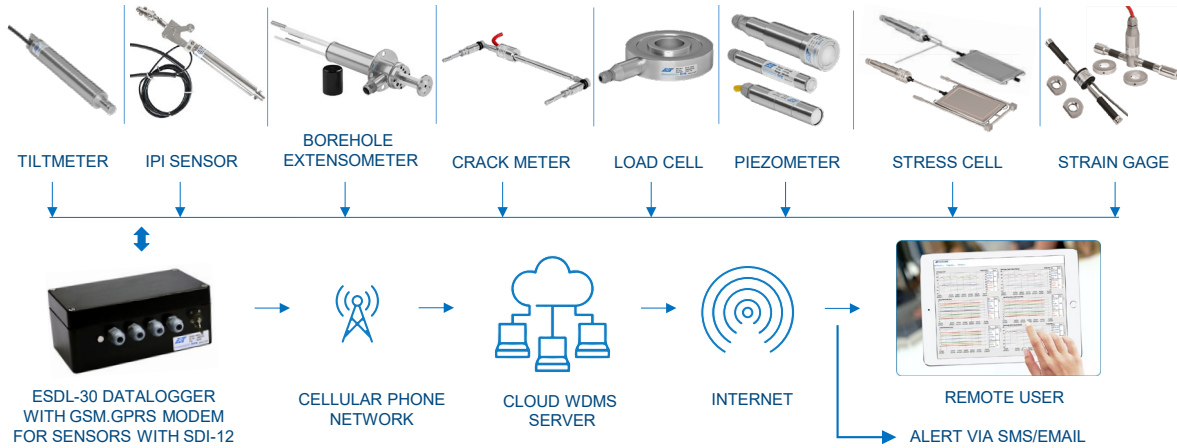
The heart of the online tunnel monitoring system is a Public Cloud-Based Web Data Monitoring Service(WDMS) offered by Encardio-rite for retrieving data from the wireless Gateway/ESDL-30 SDI-12 data logger, archiving the data in a SQL database, processing the data and presenting the processed data in tabular and most suitable graphical forms for easy interpretation of the logged data. The tables and graphs related to any site or sites can be accessed by authorized personnel who can log in to their site using the supplied login ID and access password from anywhere in the world over the internet.



Online monitoring system wireless nodes and gateways

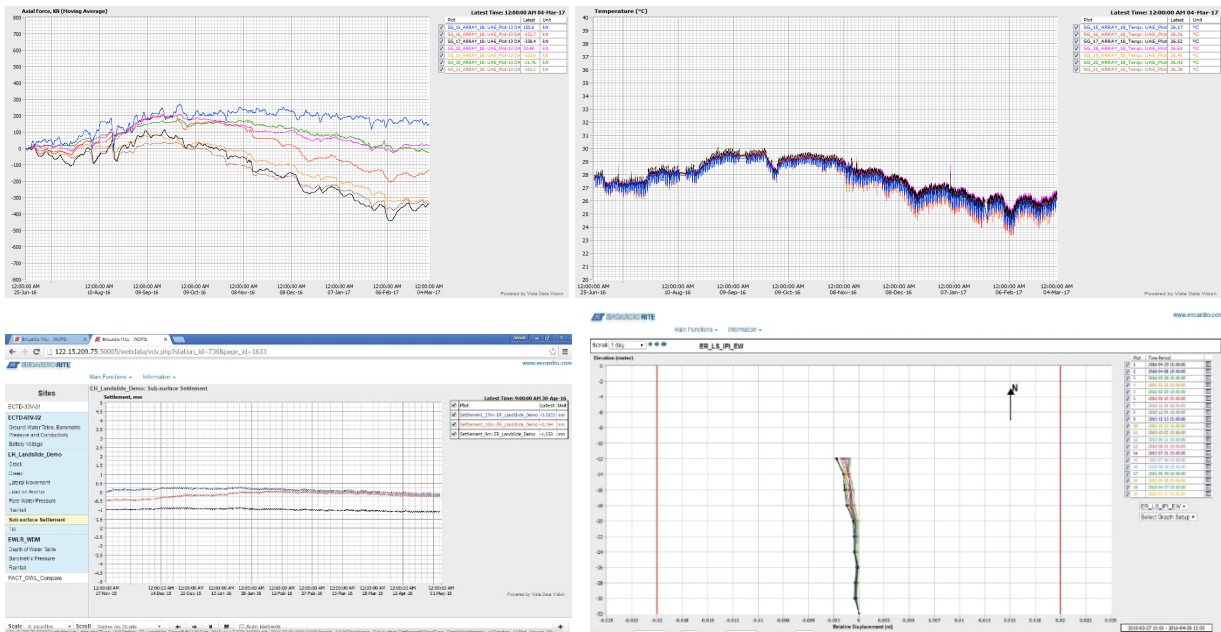


Data from Encardio-rite cloud-based web monitoring service can be accessed from just about any type of device that supports a standard web browser like a desktop or laptop PC, Tablet, smartphone or most other mobile computing devices. No special software is needed for accessing the user sites as the information can be viewed using most standard and popular web browsers like Microsoft Internet Explorer, Mozilla Firefox, Google Chrome etc.



On-line monitoring system with SDI-12 digital interface sensors and dataloggers

A graphic like a map, ground plan or a photograph of the tunnel section being monitored can be put on the opening screen marked with the position of installed sensor/sensors with a square dot or hotspot near its symbol. As soon as the mouse pointer is brought over the hot spot location the corresponding sensor details like sensor identification tag, last recorded sensor reading, and the values of the programmed alert levels pop up in a box. If any one of the alarm levels is exceeded the sensor location turns to a red dot. Clicking the pop-up table with the mouse brings up an associated data window where the sensor data can be seen either as a table or as a graph.

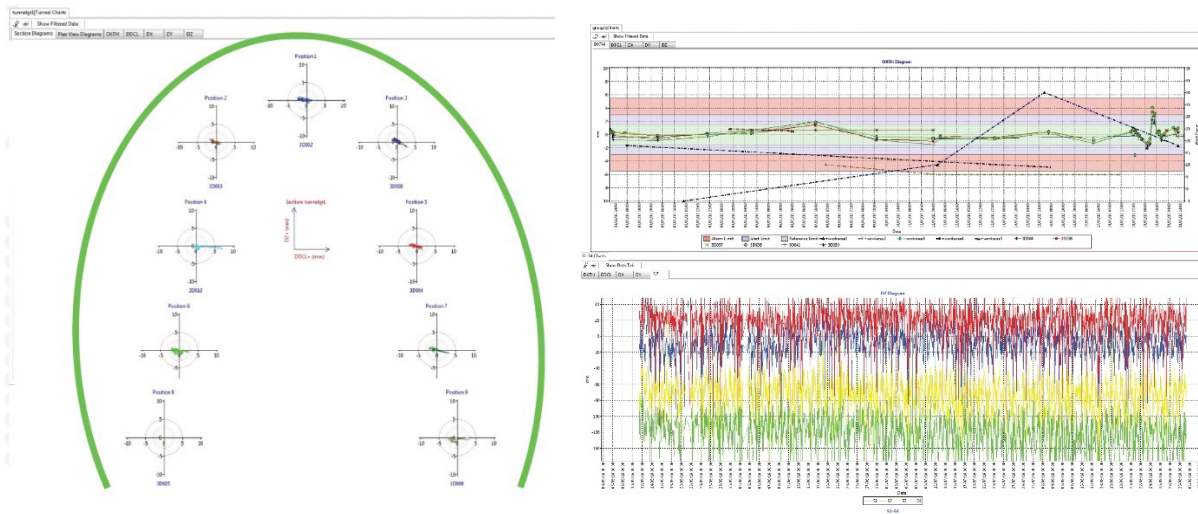


Typical online data

Site administrators can set two alarm limits which are generally considered as “alert level” and “evacuate level”. Other users can only view the data and alarm status but cannot make any changes. It is also possible to show AutoCAD based site layout plans with instrumentation locations.

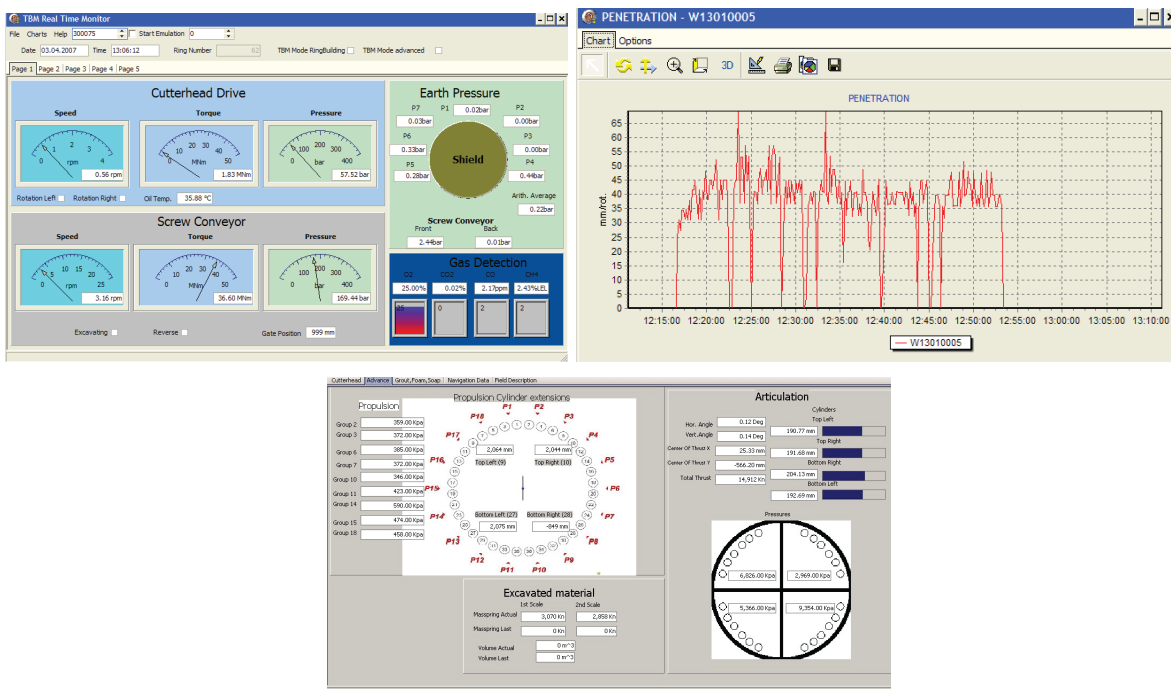


The WDMS can also be programmed to send SMS alert messages or e-mail to selected users as soon as any sensor data crosses its predefined alarm levels, either while going above or going below the alarm level. It can also be programmed to send the health status of the system to selected users.



Graphical representation of 3D points data on WDMS

It is also possible to integrate live TBM data with the monitoring data on the WDMS. Diagrams from key TBM parameters are updated in real time. It is possible to create diagrams from any combination of parameters and time period.



Tunnel parameters on WDMS

The web browser interface is very simple to use and intuitive. Any user who is only interested in viewing the data and reports will take just a few minutes to get familiar with the operation of the system.

Representation of settlement contours and those for the groundwater table is possible along with access to dilapidation survey reports and geotechnical profiles in the WDMS.

Encardio-rite cloud services work on a rental model. The user has to pay a small setup fee for the first time and then a monthly rental has to be paid for accessing the data over the cloud as long as required.

5 ADVANCED SURVEY & MONITORING SOLUTIONS

Encardio-rite offers the following advanced technologies which in combination with the conventional ones described above provides a complete solution for tunnel survey & monitoring.

5.1 Laser scanning

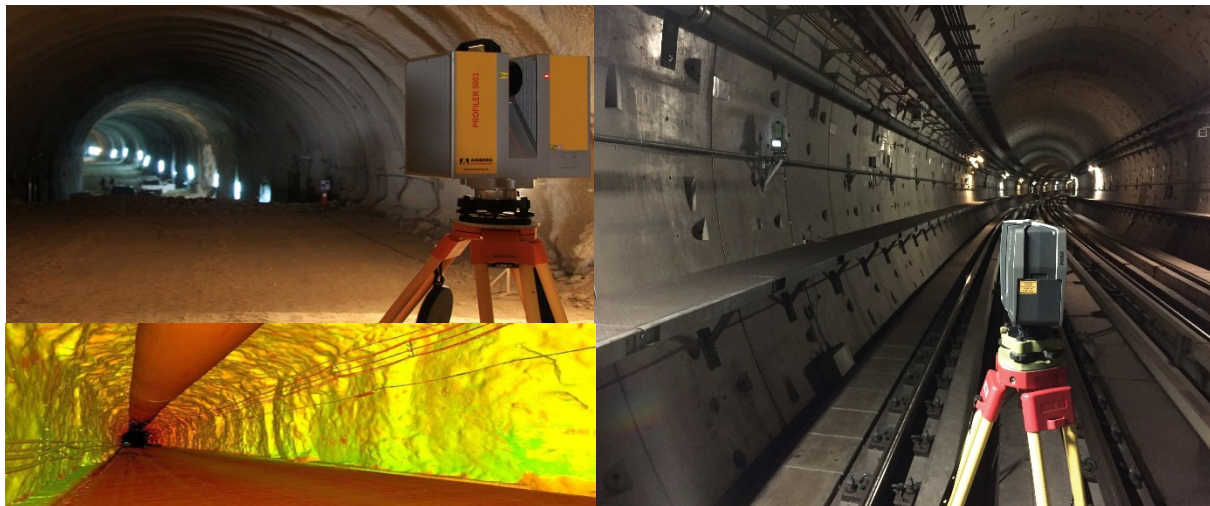
Laser scanning is an advanced method of surveying and conducting geometric documentation of buildings, architectural and archaeological monuments, engineering projects or other construction works and objects which require a high degree of analysis, are difficult to reach or gain access to, or are not to be touched.

Recent developments, especially in the software, have made it a very convenient and cost-effective tool to accurately monitor structural deformations in 3D. An accuracy of up to 2-3 mm is possible using the method. Due to the lighter nature of the new software, it takes significantly lesser time to process the results and make the same available online, almost in real time.

It is based on exceptionally dense mapping of 3D coordinates of the points on the surface that is to be surveyed, taken at speeds ranging from a few thousand up to a million points per second. Depending on the object (size, shape, desired accuracy), laser scanning may be airborne or terrestrial, static or mobile, autonomous or in combination with other standard topographic methods.

Completion of the fieldwork results in a geo-referenced point cloud which, due to its great density and its ability to bear information on the reflectivity and/or the color of each point, comes close to the term, “**virtual reality**”.

Depending on the case and on the user’s needs, horizontal, vertical or diagonal sections, aspects, images, videos, orthophotographs, surface expansions, interval curves, 3D models, determination of distortion as well as a number of other analysis derived from the scanner’s operations in the non-visible spectrum, can be produced.



Laser scanning in tunnels

To summarize, the results of laser scanning gives us:

- Surveying of current state or ‘as constructed’ state
- Virtual reality creations; Virtual tour videos
- Geometric documentation of the structure
- Quantitative calculation
- Inspection of free passage space – determination of bottlenecks

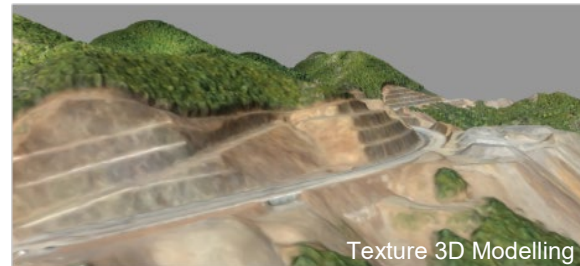
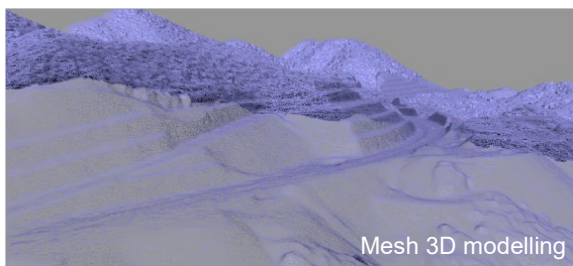


- Creation of 2D & 3D products (sections, facets, 3D models, etc.)
- Identification of deformations – discrepancies

5.2 Aerial Mapping using Unmanned Aerial Vehicles (UAV/Drone)

Inspection of huge and complex structures like tunnel construction sites requires a high degree of analysis but at times are difficult to reach or gain access to. Use of Unmanned Aerial Vehicles (UAV)/Drones is best suited for such applications.

UAVs/Drones are unmanned and remotely-piloted aircraft that follow a pre-programmed path for takeoff, flight and landing. These aircraft are equipped with HD/IR/Thermal cameras that compute aerial images and videos over a defined area at a specified height. Using UAVs/drones to video, model and scan for cracks, erosion, corrosion and defects in areas, that would otherwise require the inspector to use a rope/harness or erect access scaffolding, is obviously a safer, faster and smarter choice. Large sites with complex structures necessitate aerial photogrammetry avoiding expensive ground-based surveys.



Aerial mapping



This technology is useful during the construction process also- as the development occurs, managers have difficulty maintaining a true picture of the site. With UAV-based mapping at regular intervals, this information gap can be closed. Results from UAV/drone are in the following forms:

- Photos & Orthophotos
- Mesh 3D Models & Texture 3D Models
- Drawings
- Videos - Presentations
- Contour maps
- Slope maps
- Area - Volumetric calculations

5.3 Automatic 3D deformation monitoring system

The real-time 3D deformation monitoring system is a systematic tracking of any alteration that may take place in the shape or dimension of the tunnel as a result of stress, load, aging etc. or of any structure located within the zone of influence of the tunnel construction.

The above deformation monitoring system consists of a high accuracy automated total stations (ATS) that have the ability of auto target recognition (without any human interference). Each ATS has a dedicated control box that includes a computer running special software. This control box manages the total station and schedules the frequency of the measurements, the addition or subtraction of monitor benchmarks, the filters of acceptance or repetition of each measurement, the atmospheric corrections in distance measurements, the calculation and repositioning of the total station etc.

The whole system can be controlled/re-configured remotely after installation at site. The on-site system transmits the collected raw data to a remote server/computer via GSM/GPRS. Raw data is processed into meaningful results and presented in the WDMS. The system has the facility of alert notifications through SMS and (or) e-mail to the authorized team for any result exceeding present alarm and critical levels.



Automatic total station for tunnel 3D deformation monitoring

The system provides an accurate, continuous, real-time data, eliminating any human error/delay in manual data. The raw data is processed, analyzed and the result is majorly used for predictive maintenance, alarming for safety.



6 CONCLUSION

The data observed from the geotechnical instrumentation and survey techniques described above plays a vital role in providing verification of design assumptions, manage the construction in a safe and controlled manner, monitoring long term behavior of tunnels. It also safeguards existing adjacent buildings and nearby communities and environment at large, providing timely warnings to take corrective measures.

During the early design stages, specific instrumentation requirements are generally assessed and incorporated into the design. Specific ground and groundwater conditions, construction methodology and the location and sensitivity of adjacent existing structures have to be given due consideration in selecting a suitable instrumentation and monitoring system. The programme for the implementation of instrumentation requires advance planning. The procurement, installation and initialization of instrumentation require sufficient time to enable base readings to be taken, in most cases, before any construction activity commences within the zone of influence.

There is no substitute or shortcuts for getting reliable and meaningful data from the instruments, so both the instruments and the manpower deployed for installation, monitoring and maintenance of instruments have to be top quality and reliable. Encardio-rite Group of Companies with experience in manufacturing and monitoring of almost half a century, are one of the best manufacturer and service provider in the field.