

APPLICATION NOTE



ONLINE MONITORING OF TUNNELS

1 INTRODUCTION

Encardio-Rite offers a comprehensive real-time monitoring solution for the long-term safety monitoring of tunnels. From our in-house developed online web based database software, to reliable sensors, dataloggers and advanced systems like AMTS (automatic motorised total station), accelerometers and laser scanning, we offer end-to-end monitoring solution for any type of tunnel, whether it is TBM, NATM, cut & cover tunnel or Micro tunnelling. Construction survey related solutions are also available.

During tunnel construction, monitoring instruments are of utmost importance. They help in verifying the stability and strength of the tunnel, certifying the design, assessing the intensity and sequence of the operations involved during construction. Instrumentation data also helps in studying the behaviour of tunnel over time, especially with respect to the rheological behaviour of the rock mass and obvious changes in the fault zones, walled sections, inflow, etc.

Encardio-Rite specialises in providing online monitoring data at customer's desk; where we integrate data from different types of sensors installed in tunnel, surrounding ground as well as on structures within zone of influence, into a single database system at central server. Data can be co-related with TBM movement, excavated material in the same database. This helps in evaluating the data faster and better to understand any warning, resulting in prompt action preventing any failure or disaster.



Encardio-Rite has executed thousands of kilometers of tunnel providing not only instrumentation, but working as partners for construction companies providing them optimised solutions, along with installation, monitoring and engineering services. Our knowledge has evolved with the industry giving us the experience that is exponential. This puts us in an unmatched position in the sector.

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 the maintenance schedules.

3 PARAMETERS MONITORED

Encardio-Rite offers instrumentation to measure following parameters

- Deformation, settlement
- Lateral movement, ground movements
- Tilt, inclination
- Displacement
- Stress, strain, pressure
- Load/force

4 ENCARDIO-RITE'S SCOPE

Encardio-Rite offers following solutions:

- Pre-post construction building condition survey (dilapidation survey)
- Geotechnical sensors and geodetic targets for sub-surface and surface monitoring of parameters like water level, pore water pressure, lateral deformation, settlement, convergence, stress, strain, load, temperature, crack and tilt.
- Automatic data collection using GSM/GPRS dataloggers or RF nodes and gateways
- Tunnel construction survey with robotic total stations (ATS) and our in-house developed TCB control box with mini PC and software for remote access and controlling ATS.
- Public cloud-based web data management service (WDMS) to provide online data with instant alarms
- Laser scanning with our in-house developed OPSIS software
- Aerial-survey by UAVs (unmanned aerial vehicle) or drones

Our scope of works includes:

- Supply of geotechnical and geodetic instruments
- Installation of sensors, integration programming and commissioning of data acquisition systems
- Calibration & maintenance
- Manual + automatic monitoring and surveying
- Real-time integrated data monitoring service
- Daily, weekly, monthly report



5 REAL-TIME DATA MONITORING SOLUTION

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

5.1 Sensors

5.1.1 Monitor deep excavation works (station box/shafts)

Sensor	Purpose	Encardio-Rite model
Piezometer	to monitor pore pressure and ground water levels within and outside the excavation zone	Model EPP-30V
In-place inclinometer	to monitor sub-surface lateral movements outside the excavation zone	Model EAN-52M
Multipoint borehole extensometers	to determine relative sub-surface settlement at different depths outside the excavation zone	Model EDS-70V
In-place inclinometer with settlement	to monitor sub-surface lateral movements as well as settlement (in single borehole) outside the excavation zone	Model EAN-61
In-place inclinometer	to monitor retaining wall inclination	Model EAN-52M
Anchor load cells	to monitor tension in anchors and rock bolts, stresses in the retaining structures	Model ELC-30S and ELC-30S-H (high capacity)
Strain gage	to monitor strut load	Model EDS-20V-E (embedment) and EDS-20V-AW (arc weldable)
Compression load cells	to monitor strut load	Model ELC-210S and ELC-150S-H (high capacity)
Surface settlement targets	to monitor ground settlement	Model ESMP-10 (soil) and EPS-12 (pavement)

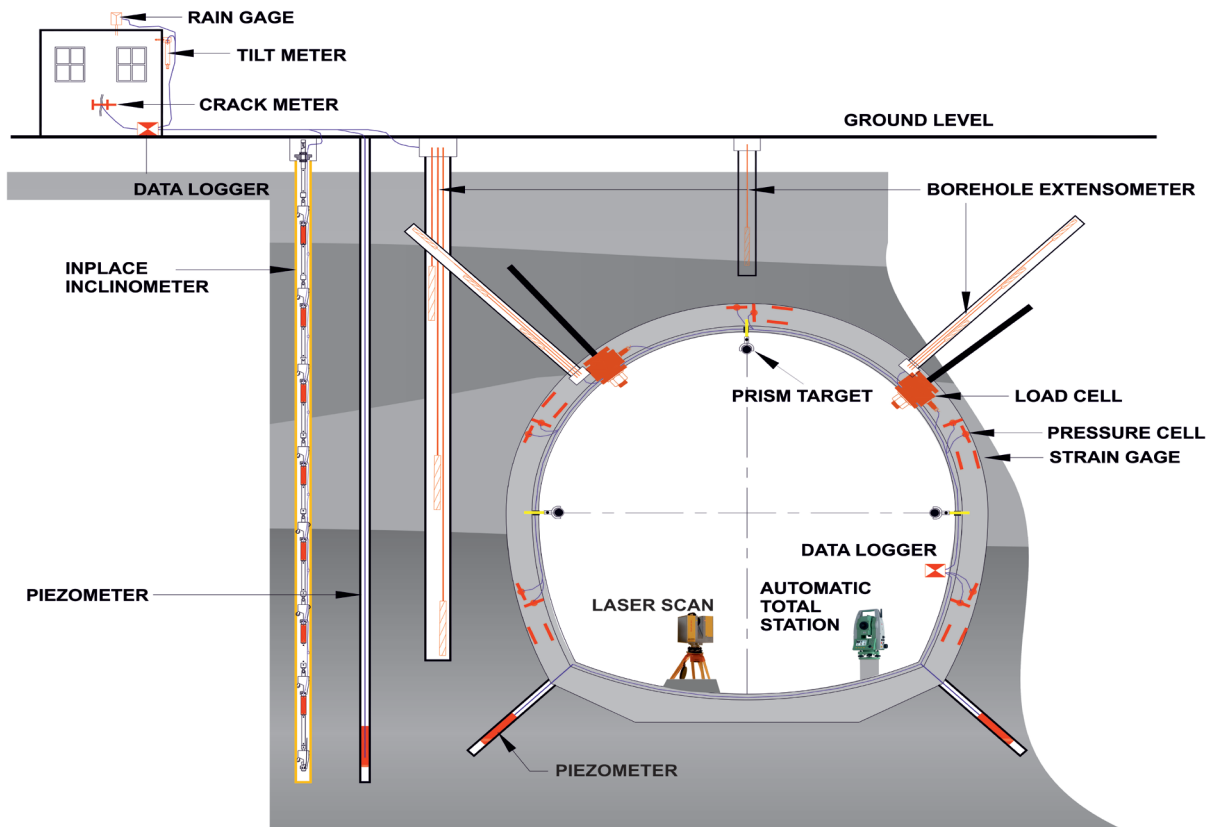
5.1.2 Monitor tunnelling (arrays)

Sensor	Purpose	Encardio-Rite model
Piezometer	to monitor pore pressure and ground water levels	Model EPP-30V
In-place inclinometer	to monitor sub-surface lateral movements	Model EAN-52M
Multipoint borehole extensometers	to determine relative sub-surface settlement at different depths	Model EDS-70V
In-place inclinometer with settlement	to monitor sub-surface lateral movements as well as settlement (in single borehole) outside the excavation zone	Model EAN-61
Surface settlement targets	to monitor settlement of ground above the tunnel alignment	Model ESMP-10 (soil) and EPS-12 (pavement)
Strain gage	to monitor strains in tunnel linings and concrete pre-cast segments	Model EDS-20V-E (embedment) and EDS-20V-AW (arc weldable)
Shotcrete pressure cell	to monitor radial and tangential stress in shotcrete lining	Model ESC-30S
Concrete pressure cell	to monitor radial and tangential stress in concrete pre-cast segments	Model EPS-30V-C
Prism target	to monitor convergence inside tunnel	Model ERT-20P2
Liquid level settlement monitoring system	to monitor settlement profile	Model ESM-40S

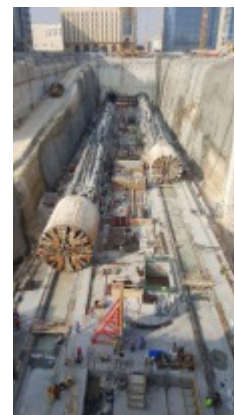


5.1.3 Monitor structures within zone of influence

Sensor	Purpose	Encardio-Rite model
Tilt meter	to monitor tilt or inclination structure	Model EAN-56MW (wireless RF) Model ESDL-30MT (wireless GSM/GPRS) Model EAN-92 (SS cylindrical)
Crack meter	to monitor displacement/opening of existing crack in structure	Model EDJ-40V
Prism target	to monitor 3D movements of structure	Model ERT-20P2
Vibration monitoring device	to ensure whether vibration caused due to construction activities are within limit	Model EDA-103



Typical Instrumentation scheme for tunnel





5.2 Data collection

Rite Geosystems provides advanced dataloggers for automatic collection of data from installed sensors. We offer different types of dataloggers with multiple communication module options to suit different site requirements.

Dataloggers with GSM/GPRS modem

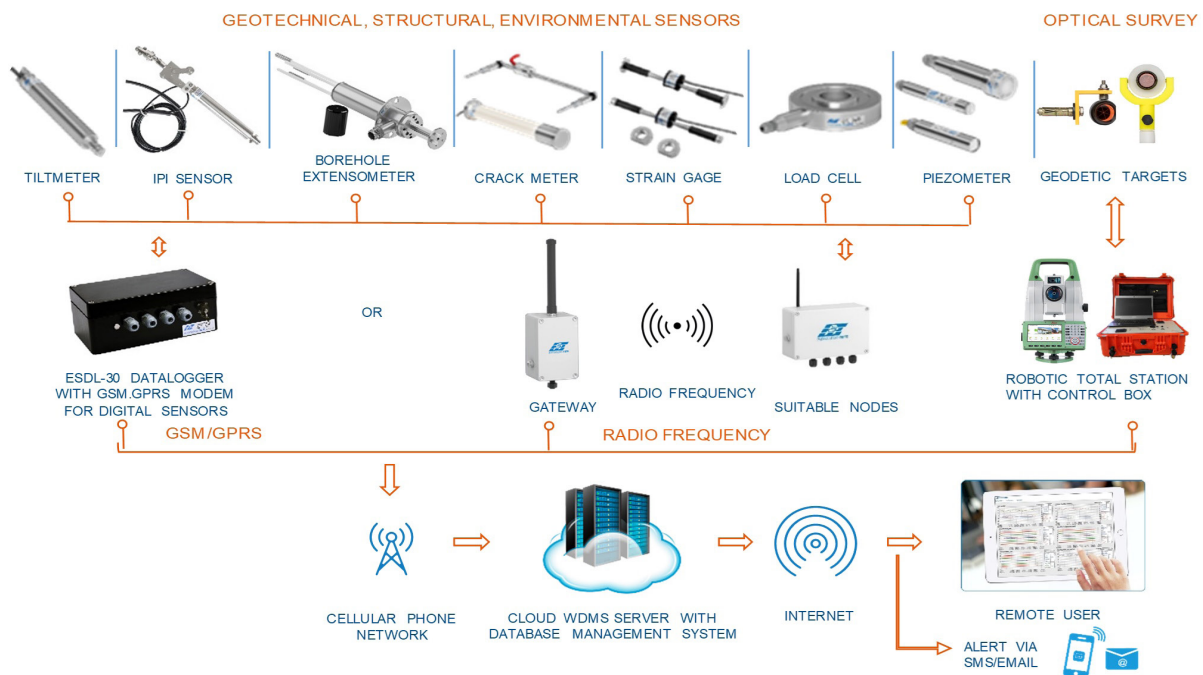
Encardio-rite model ESDL-30 is a compact datalogger suitable for digital sensors with SDI-12 serial interface or Modbus (RS-485) output. A single datalogger can connect several digital sensors; it has 3 channels and can connect upto 160 sensors. One of the advantage of the datalogger is that only a single 3-core (6-core for longer distances) cable is required to interconnect all the sensors and the datalogger in a serial bus. EDAS-101 is suitable for a wide variety of sensors having different outputs. Different types of control modules are available to suit various site requirements. For both the dataloggers, a cellular network is required to transfer the data from the datalogger location to a remote server.

RF datalogger with Gateway

In this end-to-end wireless monitoring system, the sensors (vibrating wire, analog or digital) are interfaced with the long-range, low-power wireless network through RF dataloggers that send recorded data to the gateway with utmost reliability. The gateway needs to be in line of sight of the RF datalogger. Gateway transmits the collected sensor data to the central/cloud server through cellular communication network.

We offer a choice of both the wireless technologies. Depending on site requirement, either any of the two, or a combination of the two technologies can be used. The dataloggers have the facility to collect and store recorded data and transfer it to a central remote server at desired intervals over a wired or cellular telemetry link. The dataloggers can be programmed to take a measurement from once every 5 seconds to once every 168 hours. The measured data is stored, together with the current date, time and battery voltage, as a data record in the internal non-volatile memory of the datalogger. The datalogger is housed in weather proof housing.

The dataloggers have different options for power supply like batteries, mains and solar power supply. Gateway has mains and solar power supply options. Depending on the project requirement, choice of datalogger, communication network and power supply can be made.



Online monitoring sys with wireless data transfer option to central/cloud server



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.

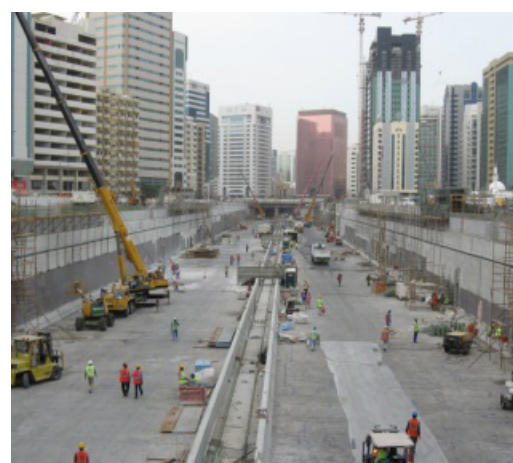
The above deformation monitoring system consists of a high accuracy automated motorized total stations (AMTS) that have the ability of auto target recognition (without any human interference). Each AMTS has a dedicated control box that includes a computer running special software. This control box manages 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.

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.



Automated motorized total station (AMTS) for tunnel 3D deformation monitoring



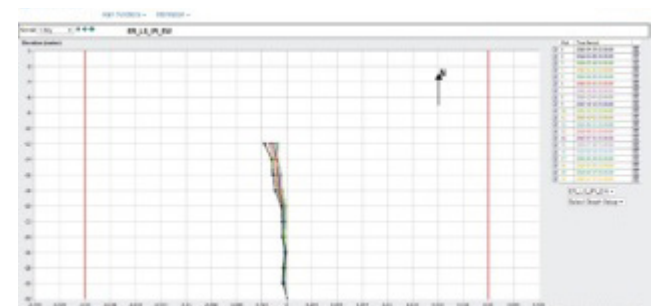
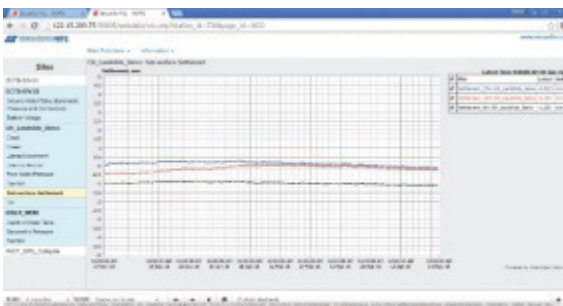
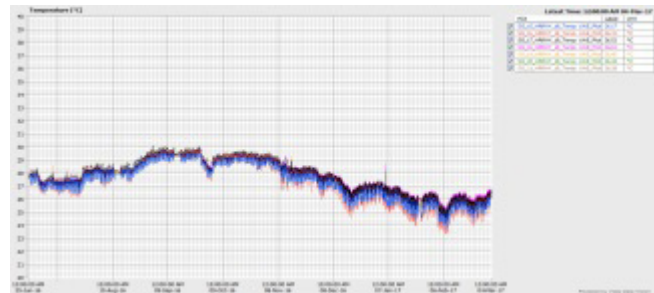
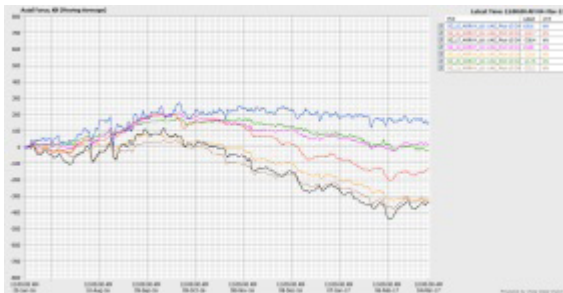


5.4 Real-time Data Monitoring Software

Encardio-rite provides a highly flexible WEB based or local access data management solution. Our database software can combine data from structural, geotechnical, geodetic and environmental sensors.

Some of the features of this software are:

- Single platform for comprehensive project data allows rapid evaluation, interpretation and decision-making
- Single portal to manage multiple projects
- Variety of visualization and analysis tools to identify potential failure scenarios.
- Support to have a live visual feed from the project site
- Offers an interactive user interface, taking care of all database interactions automatically
- User defined multiple graphs on single screen provide visual insight for analysis
- Real time multiple alarm setting ensures no critical information is missed.
- All key information can be viewed at a glance on customized screen options
- Virtual variable calculations available for corrections (temperature effect etc.) and re-calibration of sensor
- Instant automatic alerts sent via SMS or email for data variations, missed data or sensor malfunction
- User can generate comprehensive report or a customized report quickly



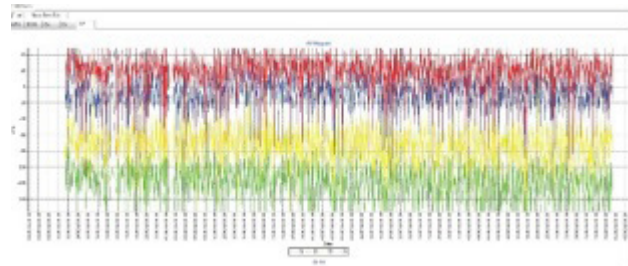
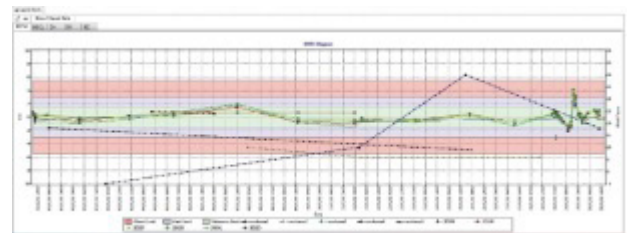
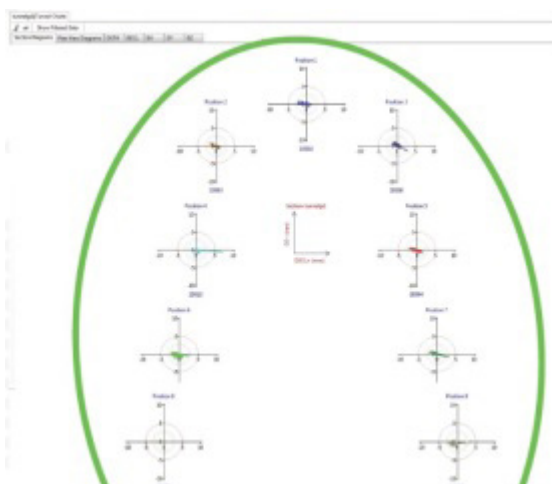
Typical online data



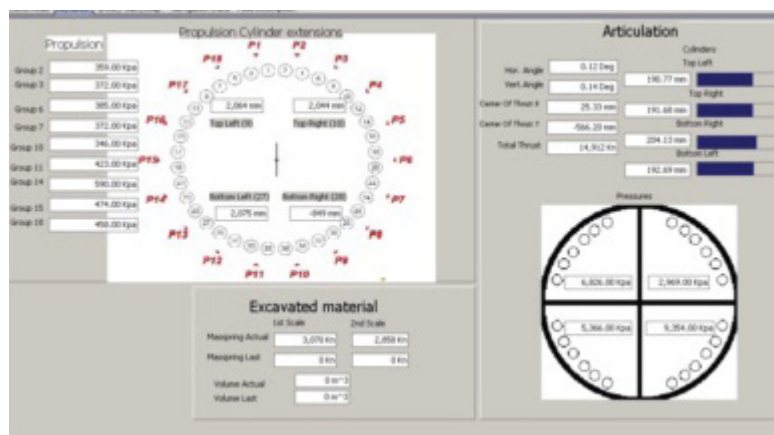
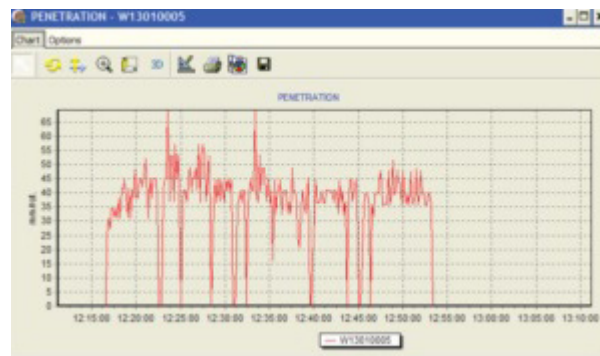
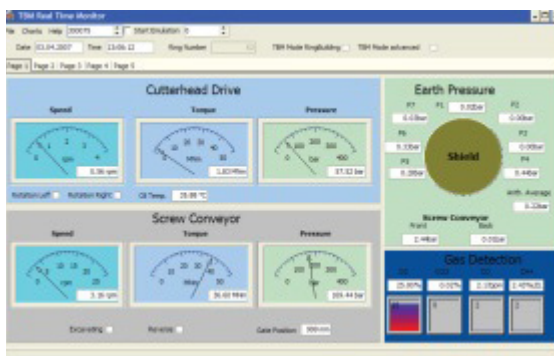
It is also possible to integrate live TBM data with the monitoring data on the WDMS. Charts from key TBM parameters are updated in real time. It is possible to create charts from any combination of parameters and time period.

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

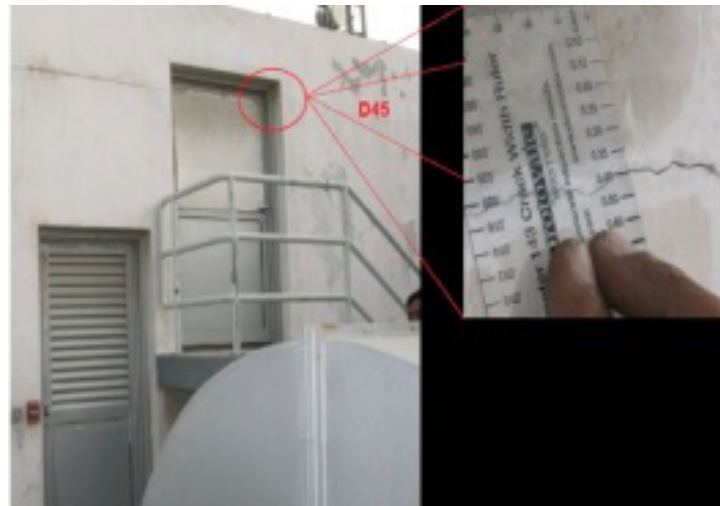


Tunnel parameters on WDMS



6 PRE AND POST CONSTRUCTION DILAPIDATION SURVEYS

Pre-construction surveys are conducted using photography/videography/laser scanning (land and aerial) or a combination of 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

7 ADVANCED SURVEY 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.

7.1 Tunnel construction survey

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.

7.2 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.

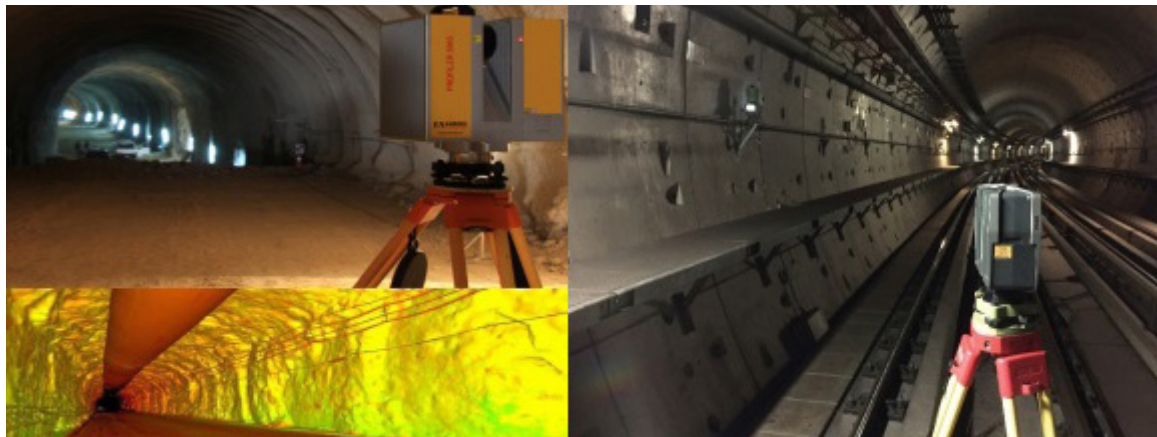


Completion of the fieldwork results in a geo-referenced point cloud which, due to its great density and its ability to bear information on the reflectivity and/or the color of each point, comes close to the term, “virtual reality”.

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.

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



Laser scanning in tunnels



Aerial mapping by UAV/Drones



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

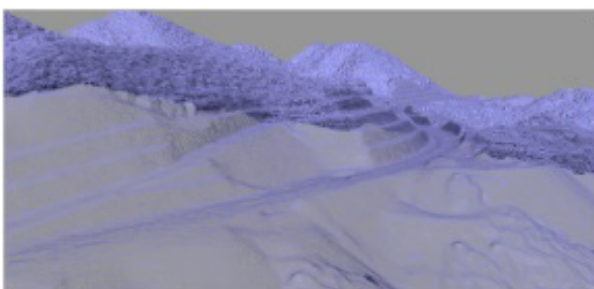
Inspection of huge and complex structures like tunnel construction sites requires a high degree of analysis but at times are difficult to reach or gain access to. Use of Unmanned Aerial Vehicles (UAV)/Drones is best suited for such applications. UAVs/Drones are unmanned and remotely-piloted aircraft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

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.

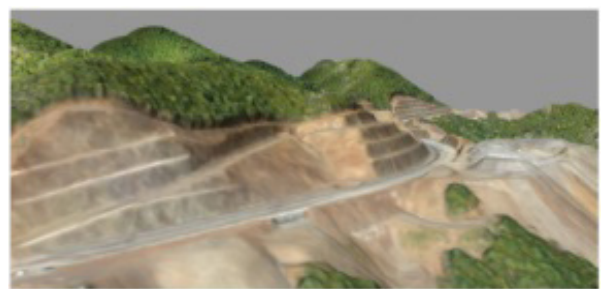
Results from UAV/drone are in the following forms:

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

Mesh 3D modelling



Texture 3D Modelling



Texture 3D Modelling



Video

Aerial mapping



8 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.

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TUNNELS



HYDROELECTRIC



CONSTRUCTION



STRUCTURAL



METRO & RAIL



BRIDGES



MINING

Encardio-Rite Group - India | Bhutan | Bahrain | Qatar | Saudi Arabia | UAE | Greece | Spain | UK | USA

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