RITE GEOSYSTEMS

ENCARDIO RITE METASENSING FOR MEGA STRUCTURES

APPLICATION NOTE

ONLINE MONITORING OF MINES

1 INTRODUCTION

Geotechnical instruments play an important role in mining to ensure continual productivity and safety in mines, whether the mine is underground or on the surface. Mining has a significant impact on the geological formations in the area in which it is conducted and is in turn also influenced by these formations.

In the case of underground mining works, ground movement is one of the most significant threats to the safety and continued operations, as it can lead to rock falls, tunnel collapses and other catastrophic events. In the case of the open-pit, it is very important to monitor slope stability/any significant ground movement, study soil behavior and to develop means to reduce accidents and fatalities caused by ground movements or failure of surrounding structures.

Encardio-rite offers a wide variety of instruments for measuring deformations, groundwater, strain, stress, and load. The sensors have a proven track record for reliability and long-term performance under harsh conditions. If used diligently, these instruments can provide important quantitative information regarding the mining-induced behavior of the surrounding rock/ground, performance of ground support systems as well as the safety and stability of underground mining works, as the excavation progresses.

The online web-based monitoring service provided by Encardio-rite enables data at the client's desk with automatic alerts, warns the related authorities of impending ground failures or hazardous working conditions well in advance.
Encardio-rite also has expertise in advanced technologies being used today for safety monitoring and risk assessment of mining works, such as automatic 3D deformation monitoring using ATS, laser scanning and aerial survey using drones.

2 BENEFITS OF MONITORING MINES

Online monitoring and risk assessment solutions ensure the following:

- **Increase safety** - Maintaining safe operational systems and procedures to protect personnel, material, nearby structures, communities, and the environment. It provides timely alarms on potentially unstable ground.
- **Reduce costs** – Instrumentation aids in optimizing mine operations for example while increasing steepness of slopes to minimize waste removal and maximize recovery of ore it keeps a close check on the slope movements and that of the surrounding ground.
- **Operations control** - Provide pre-alerts on any expected failure zones, to develop and design appropriate remedial action plans and timely evacuations of the area, if required.
- **Verify designs** - Assessing the performance of implemented ground support systems, the stability of underground mining operations, slope design, etc.
- **Impact assessment of extraordinary natural events** - Provide details on the impact of events such as earthquakes or excessive rainfall to minimize risk.
- **Regulation compliance** - To conform to the current and future standards & regulations for safety.
- **Learnings for future** - Building up a history of information to determine different rock/soil/slope behaviors over a long period of monitoring.

3 MONITORING SOLUTIONS FOR MINES

Following solutions are available with Encardio-rite for online monitoring of mines:

- Geotechnical sensors to measure all relevant parameters required to monitor different types of dams
- Automatic monitoring of geotechnical sensors with SDI-12 digital interface using SDI-12 data logger with GSM/GPRS telemetry
- Automatic monitoring of geotechnical sensors using LoRa nodes and gateways
- Geodetic monitoring with automatic total stations (ATS) with GSM/GPRS telemetry
- Laser scanning
- Survey by UAVs (unmanned aerial vehicle) or drones
- Public cloud-based web data management service (WDMS) that provides data online (with alarms) to authorised users at different locations on their computers/mobile devices.

Advances in geotechnical instrumentation, geodetic survey and data transmission systems make it possible to monitor the performance of mining works from any remote location, conveniently and economically. The datalogger and total station automatically collect reading from the installed sensors and targets, at selected intervals. An alarm is triggered or SMS is automatically sent if any of the pre-determined trigger values are exceeded. Data is transmitted to a remote data management software, at a central server or cloud, where large quantities of collected data are processed, evaluated and presented as meaningful information. The same becomes accessible to the concerned authorities, at their desk or mobile devices through the world wide web.

4 MONITORING REQUIREMENTS OF DIFFERENT TYPES OF MINES

4.1 Open-pit mine

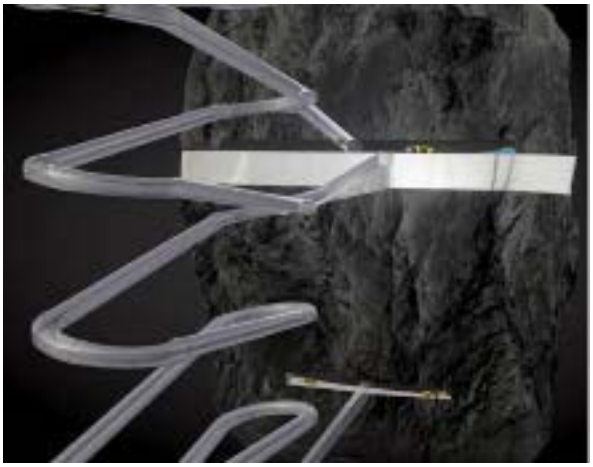
Slope monitoring forms an integral part of the risk management of open-pit mines. The monitoring data provide reliable information to detect potentially unstable ground and to identify any slope instability to evaluate the performance of slope design. With online monitoring, the risk of slope movement and the subsequent consequences can be considerably reduced. This allows for optimal mining conditions that are safe for mine personnel as well as surrounding structures.

4.2 Underground mine

Underground mining is carried out when ore deposits are located deep below the surface. The following are the major underground mining methods:

4.2.1 Cut and fill stope

Cut and fill stope mining is used in steeply dipping or irregular underground ore bodies In a cut-and-fill stoping operation, ramps or inclined tunnels are excavated to connect the surface to the underground ore body. Stoping is the process of extracting the desired ore or other minerals from an underground mine, leaving behind an open space known as a stope. Drifts are excavated to access the ore. The ore is mined in horizontal slices, bottom slices are mined first. Drilling is the first stage in removing ore using a rotary percussion jumbo drill. A secondary stage involves blasting the ore to further break it up. It is common to remove horizontal slices of ore that span the entire width and length of the ore. Once the ore has been completely mined, the stope is backfilled hydraulically. Sometimes ore waste is mixed with other materials such as sand, cement, waste rock, or dewatered mill tailings-a low-grade ore that has been rejected for processing—to make the backfill. The backfill provides a working floor for miners and equipment as the mining progresses to the top of the ore and also supports the stope walls. Mucking of ore is accomplished with a wheel loader. The ore is then hauled away in dump trucks up to the surface via the ramps.



Cut & fill stope

Shrinkage stoping

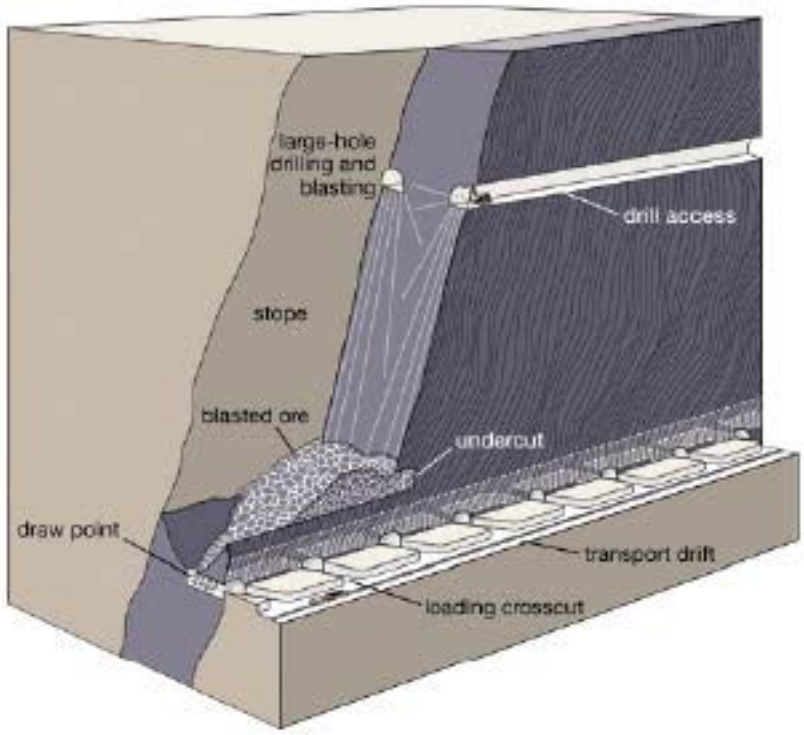
4.2.2 Shrinkage stoping

The shrinkage stoping method is similar to cut and fill method described above, however, instead of removing the ore after blasting and backfilling, the initially broken ore is left in the void to create a working platform for the next level (and to support the wall stability of the stope).

After all the planned levels have been blasted, then all of the ore is removed for processing.
This method requires many active stopes because the ore is not removed from each mining area until completion-meaning longer lead times for ore to get to the process plant compared to cut and fill operations.

4.2.3 Sublevel longhole stoping

This bulk underground mining method involves mining large amounts of material from a single stope –similar to cut and fill, this method starts at the bottom of a level and moves upward. Ore is removed from the bottom, and then more ore is blasted from a higher level which falls to the same level to be removed, with the process repeating up the orebody.
The supporting walls need to be very strong to support the large underground openings that is created by this process



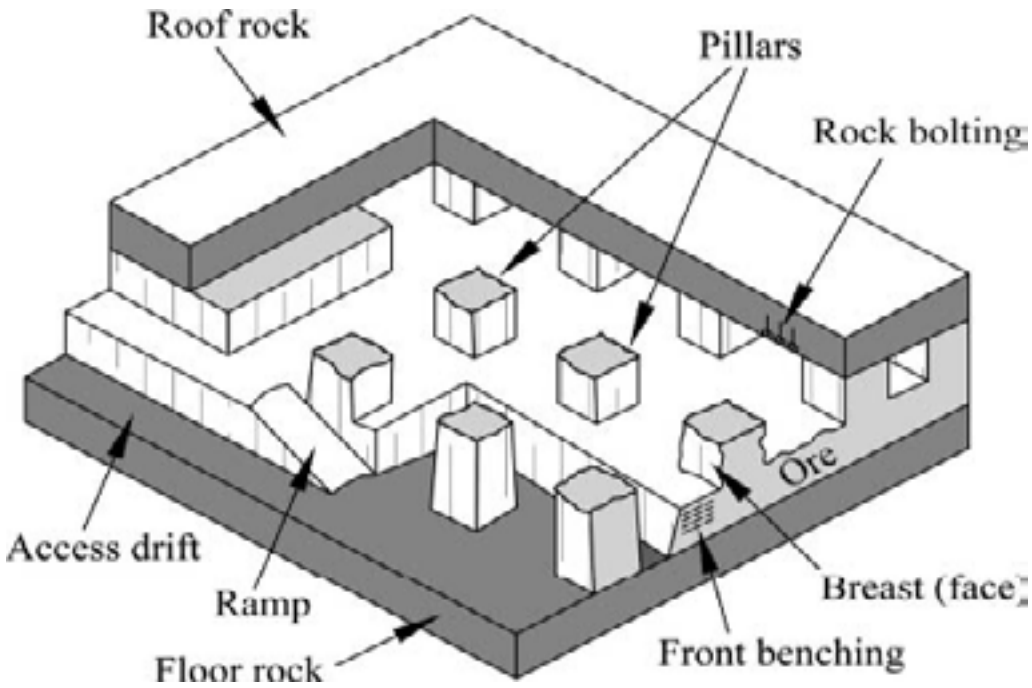
Sublevel longhole stoping

4.2.4 Room & pillar

Room-and-pillar mining is typically chosen for flat-lying (or at slightly dipping) ore bodies. Commonly used for base metal or uranium metal deposits, or bedded seams of coal/potash/salt, mining is done by creating openings (rooms) on a single level, leaving pillars of rock at regular intervals to support the weight of the material above (the roof).

In hard-rock deposits (i.e. copper, lead-zinc), drilling and blasting are required to break up the ore before being able to remove it.

After mining out levels, the pillars may be removed (to recover the remaining ore or material) and the roof is allowed to safely collapse and fill in the mined-out area.



Room & pillar mining

4.2.5 Block Caving

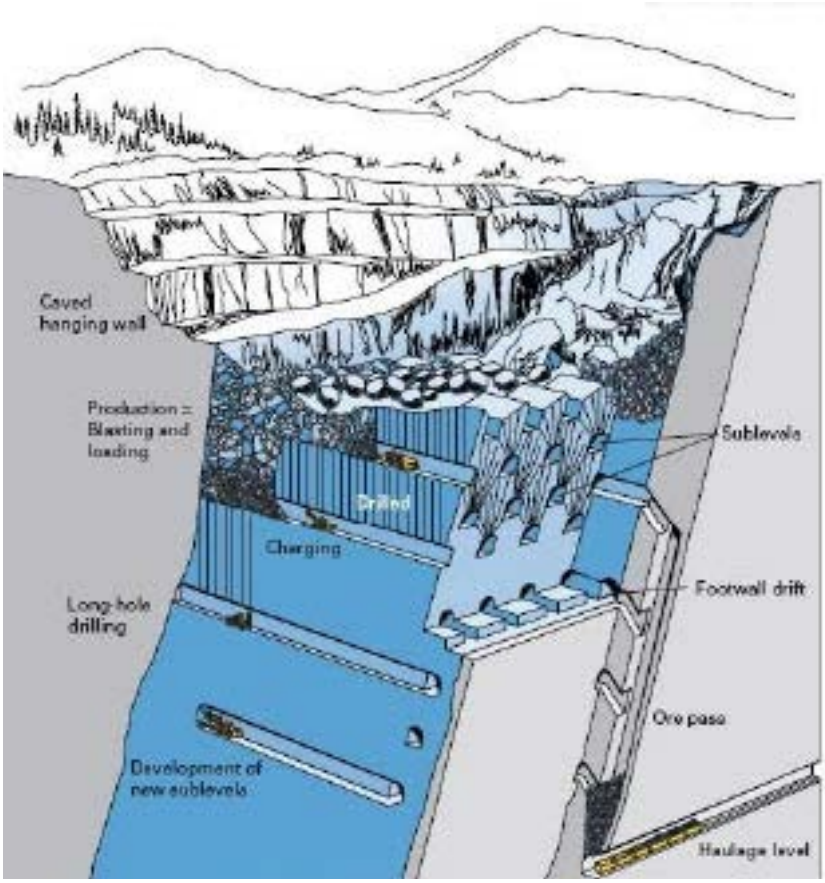
Block caving is essentially the underground version of open-pit mining. It is the only underground mining method that can reach similar production rates to surface mining operations, up to around 100,000 tonnes per day.

The method involves undermining an orebody, then allowing it to collapse under its weight. The orebody is drilled and blasted and the collapsed ore is removed through haulage access, and as more material is removed the orebody caves in.

The choice of the above-described method depends on the concentration of the ore, strength of the surrounding rock and various risks involved.

Mponeng gold mine, located south-west of Johannesburg in South Africa, is the deepest mine in the world. The operating depth at Mponeng mine ranged from 3.16 km to 3.84 km below the surface.

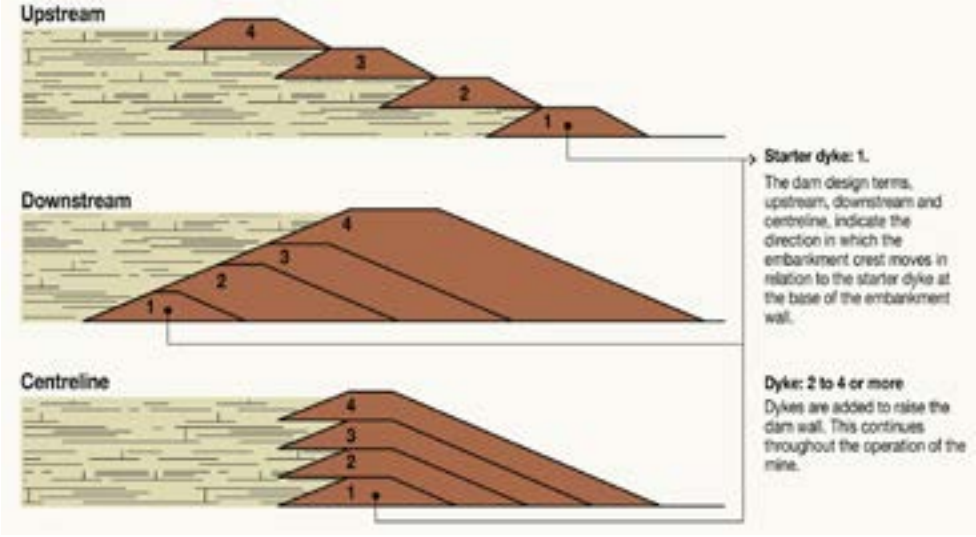
Construction of underground mine caverns and tunnels have great challenges to address. The main challenges include the variable stress field in underground mines, the proximity to other large excavations such as open pits. Monitoring deformation, the stability of excavation (caverns and shafts), tunnel convergence and surrounding ground movements become critical. Early warnings allow mine owners to have timely contingency plans to prevent any failures.



Block caving mining

4.3 Tailings dams

A tailings dam is typically an earth-fill embankment dam used to store byproducts of mining operations after separating the ore from the gangue. To save land and to store more tailings at a particular area, the height-raising of tailings ponds are being adopted. There are various methods of height-raising of ash ponds such as upstream raising, downstream raising & central line raising. The upstream method of raising is often adopted as it is economical, results in better stability, viable to construct in a comparatively small land area and short construction time.



Types of sequentially raised tailings dams

Tailings can be liquid, solid or a slurry of fine particles and are usually highly toxic and potentially radioactive. Failure of a tailings dam is thus a hazard source of debris flow with high potential energy leading to environmental disaster.

The real-time monitoring system with pre-alerts is vital to monitor the stability of the tailings dam to ensure the safety of human lives, properties, and environment, as well as for sustainable mining.

5 GEOTECHNICAL SENSORS

Instruments available with Encardio-rite for surface and sub-surface online monitoring of mines are as follows:

Parameter	Instrument	Application area
Sub-surface		
Sub-surface lateral movement (automatic)	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	Open-pit mines-around excavation, in slopes Tailings dam, in the fill area (manual inclinometer can be installed with magnetic settlement points to monitor lateral as well as vertical movements)
Sub-surface lateral movement (manual)	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	
Sub-surface movements uni-directional	Model EDS-70V vibrating wire type multiple point borehole extensometer for monitoring sub-surface movements at different depths	Open-pit mine: near-horizontal installation at the face of the excavation Underground mine: Vertically upwards and near-horizontal installations inside the mine
	Yield-point's d-EXTO Mk II multipoint borehole extensometer with up to six (6) Linear Variable Induction Transducers (LVIT). All rods are housed within a single fiberglass tube. The maximum diameter of the MPBX is 25 mm including the head assembly.	

Sub-surface movements (x, y & z)	Model EAN-61MS 3D in-place inclinometer for measuring 3D (X-Y-Z) profile of gage well/ borehole	Open-pit mines-around excavation, in slopes Tailings dam, in the fill area
Pore pressure	Model EPP-30V vibrating wire piezometer for monitoring pore pressure variations during fill or excavation The above piezometers are suitable for multilevel installations in a single borehole using the fully grouted method. The grout effectively limits the intake zone for the piezometer, preventing migration of water upwards or downwards through the borehole. VW piezometers can also be installed in the same boreholes used for inclinometers	Tailing dam, infill, and foundation (titanium option available for harsh applications)Open-pit,around excavation in slope for slope stability investigations The underground mine, in rock mass around the excavation.
Water level	Model AWLR 101 automatic water level recording system	In the observation wells within the body and around the tailing dam, to monitor the water level For measuring the level in the reservoir of a tailings dam, it is recommended to use a non-contact type sensor such as a radar type. This because of the highly corrosive nature of the tailings stored in the reservoir
Surface instruments		
Tilt	ModelESDL-30MTorEAN-95MWtiltmeters to record changes in slope inclination near cracks and areas of maximum anticipated rotational movement Can be coupled to a local light & sound alarm system to alert the mining crew immediately	Open-pit, on a slope for slope stability monitoring For monitoring nearby structures and assets such as transmission towers
Displacement	Model EDJ-40V crack and joint meters for monitoring displacement/opening of cracks in the rock mass	Open-pit, to monitor any crack opening

Anchor load	Model ELC-30S/ELC-30SH resistive strain gage type center hole load cell for monitoring tension in anchors and rock bolts used for stabilizing the slope or tunnel lining.	Open-pit, on anchors placed in slopes The underground mine, on anchors placed in rock mass around the excavation area
Convergence	Model ERT-20P2 mini prism target to monitor 3D deformations using an automated total station (ATS) with control box	The underground mine, around the excavation, to monitor convergence and deformation of the rock mass Open-pit, around excavation in slope to monitor slope stabilization/deformation
Stress	Model ESC-30V vibrating wire shotcrete pressure cell or model EPS-30V-C vibrating wire concrete pressure cell for monitoring radial and tangential stress in shotcrete lining	The underground mine, the stress of rock mass around excavation, hoop and radial stresses in concrete tunnel linings/shotcrete (if a permanent tunnel is being constructed)
Parameter	Instrument	Application area
	Model EPS-30V-S soil pressure cell to monitor stress on plane surfaces	Open-pit, in raft foundation Tailings dam, fill and foundation to monitor total and differential pressure
	Model EPS-62V borehole stress meter to measure stress changes in rock	In the boreholes holes drilled into the walls of stopes/underground mines, the slope of an open mine
Strain	Model EDS-20V-E embedment or EDS-20V-AW arc weldable strain gage	Underground mine – tunnel lining, if the permanent tunnel is being constructed Long-distance pipelines conveying concentrates out from the mine to the processing plant
Seepage	Model EGS-30V seepage monitoring device	Tailings dam, seepage channels

Notes regarding implementation:

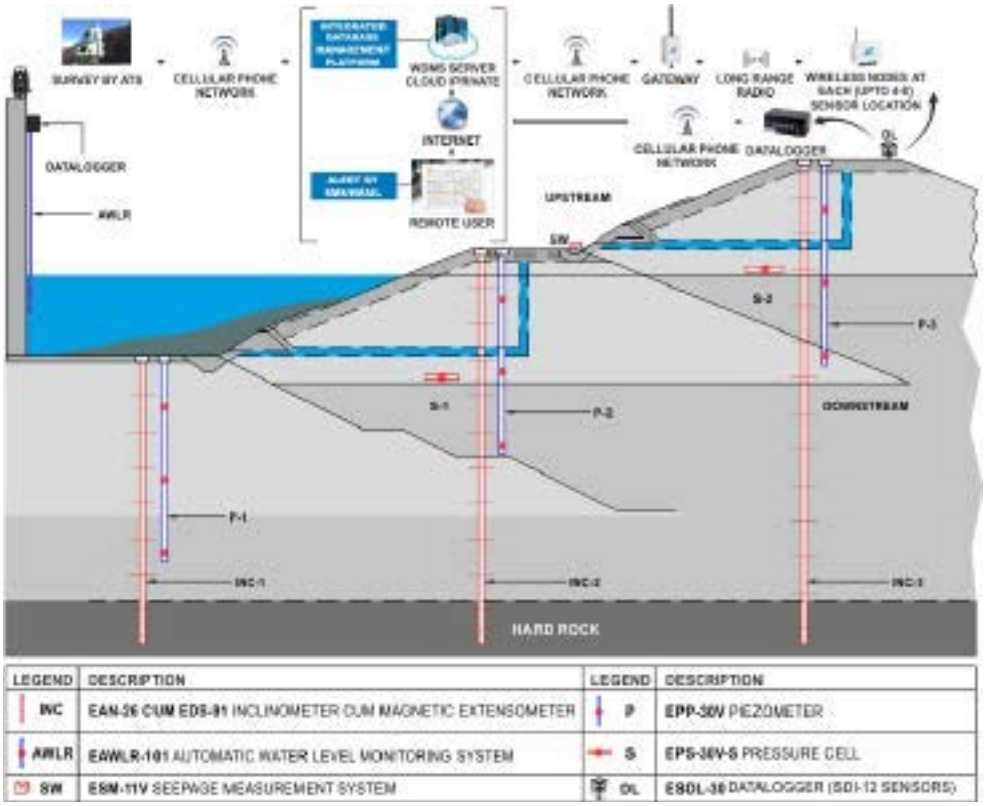
- Encardio rite provides a range of shielded armored/non-armored cables from 2 to 40 cores for connecting the above sensors to the readout devices/dataloggers. Necessary splicing kits, junction boxes, switch boxes, protective enclosures, and covers, lockable manhole covers are readily available to execute simple to complex instrumentation schemes. It also provides several solutions to reduce cable lengths by using multiplexers, SDI-12 interface and wireless transmission using the allowable RF band.

- Grouting is one of the most important factors influencing the quality of the readings post-installation. There is no remedy towards improper grouting, therefore experts should be involved in the grouting of the borehole instruments.

- Lightning Protection: Field instruments are vulnerable to lightning damage in the areas with a high rate of lightning strikes. The risk increases as the cable length increases. Although a tripolar plasma surge arrestor is inbuilt into most Encardio-rite sensors to protect these against voltage spikes across the input leads, an additional lightning protection system is recommended. It is preferable to engage a local agency specializing in earthing and lightning protection systems to implement the same.

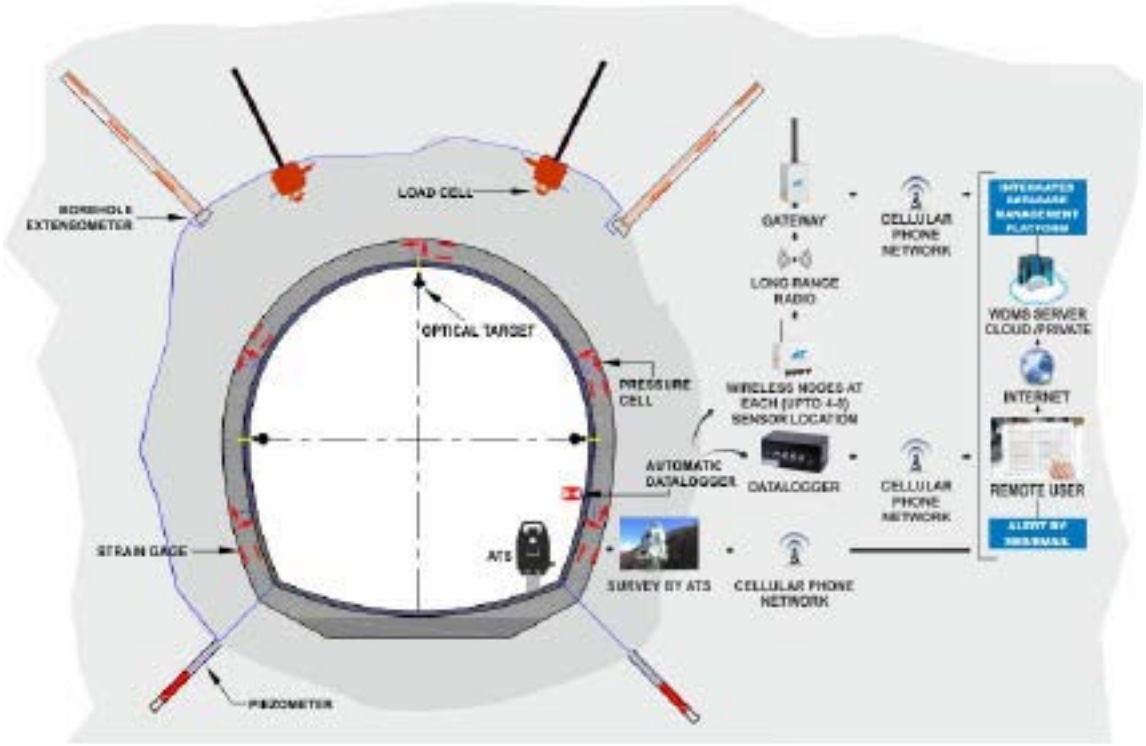
- In some sites, the field instrumentation is required to be connected to the client's existing local network based on fiber optic cables. In such cases, Encardio-rite can provide an ethernet interface NL201. However, the ethernet to fiberoptic media converter shall be arranged by the client.

Typical monitoring schemes

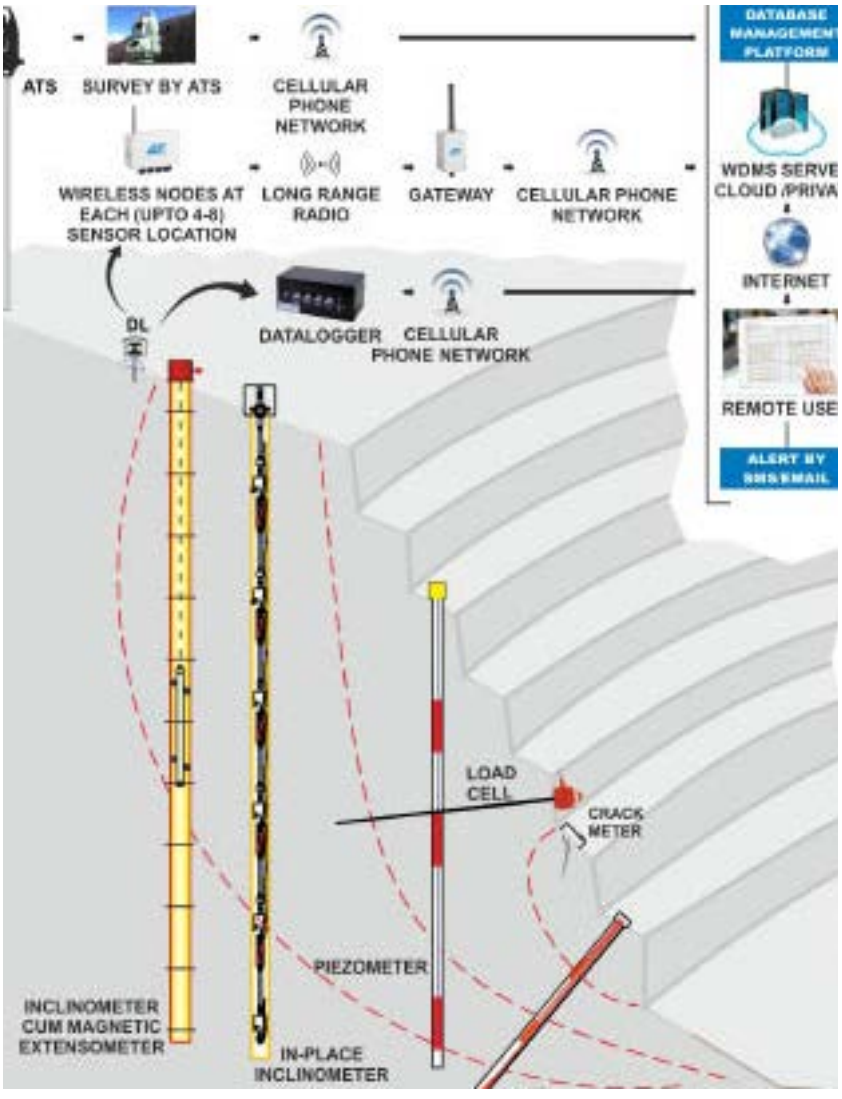


LEGEND	DESCRIPTION	LEGEND	DESCRIPTION
INC	EAN-36 CUM EDS-01 INCLINOMETER CUM MAGNETIC EXTENSOMETER	P	EPP-36V PIEZOMETER
AWLR	EAWLR-101 AUTOMATIC WATER LEVEL MONITORING SYSTEM	S	EPS-36V-S PRESSURE CELL
SW	ESM-11V SEEPAGE MEASUREMENT SYSTEM	DL	ESDL-36 DATALOGGER (SDI-12 SENSORS)

Typical monitoring plan for tailings dam



Typical monitoring plan for underground mine/cavern



Typical monitoring plan for Open-pit mines

7 AUTOMATIC WIRED SENSORS MONITORING SYSTEM

Encardio-rite offers advanced automatic dataloggers with an in-built GSM/GPRS modem for data collection of geotechnical instruments with SDI-12 digital interface and transmission to a remote server. The dataloggers can be programmed to measure once every 5 seconds to once every 168 hours.

Remote real-time monitoring system with SDI-12 digital interface sensors and dataloggers

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. An alarm is triggered or SMS is automatically sent if any of the pre-determined trigger values are exceeded.

The advantage of the system is that only a single 3 conductor cable is required to interconnect all the sensors in a daisy chain configuration and eventually to the datalogger. SDI-12 is a multi-drop interface that can communicate with multi-parameter sensors.

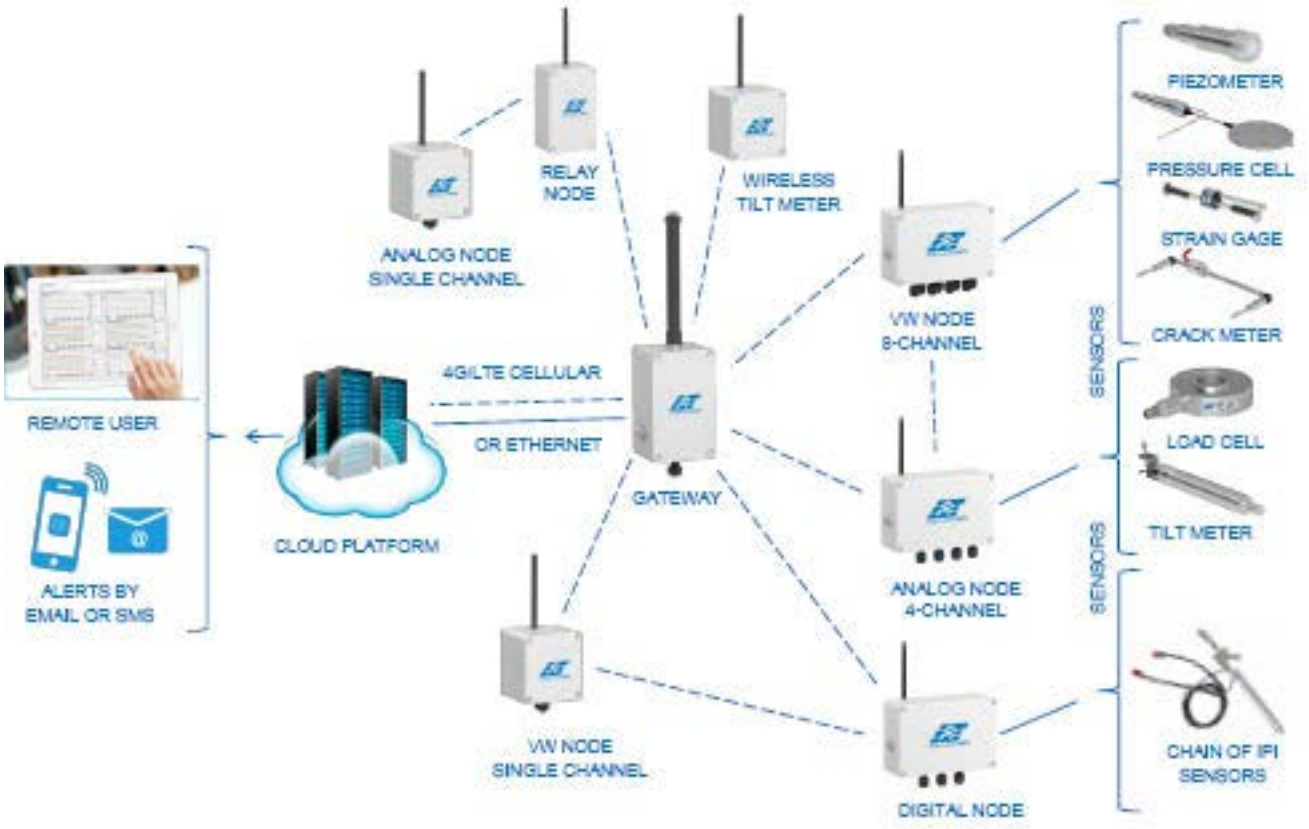
7 AUTOMATIC WIRELESS SENSORS MONITORING SYSTEM (RF)

Encardio-rite offers a state-of-the-art multi-hop wireless mesh network solution that allows real-time monitoring of geotechnical sensors in challenging projects, with reliable data transfer over long distances without any delay.

The system comprises sensors interfaced with the long-range, low power mesh network through nodes that send recorded data to the gateway with over 99 % reliability. The gateway uploads the collected sensor data to the central/cloud server.

The unique feature of our innovative mesh network is that even if a node cannot reach the gateway directly, it can send its data to the gateway via other nodes in the network. The mesh network allows all nodes to talk to each other, thus allowing them to relay data from other nodes to the Gateway. This ensures that data from all nodes are transferred to gateway (and hence cloud server) without any delay.

The wireless system eliminates the need for running lengthy cables, thus offering benefits such as convenient installations, cost & time savings, remote monitoring of hard to access locations and easy maintenance.



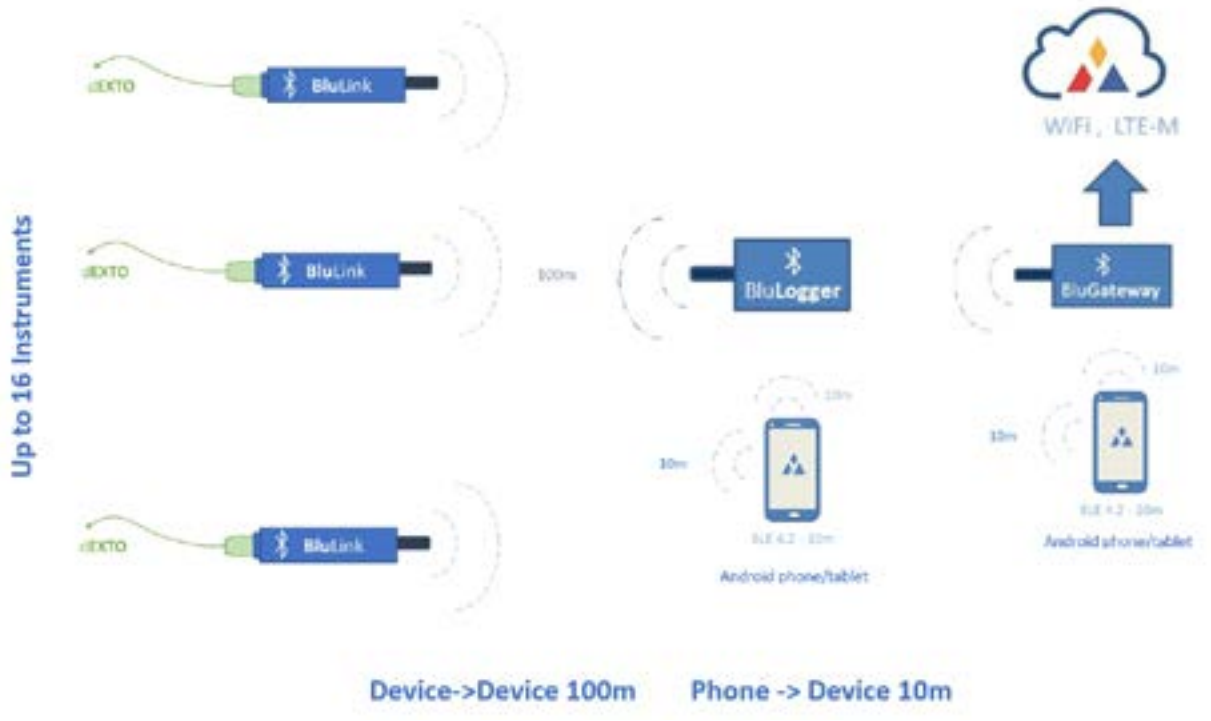
Remote real-time monitoring system with wireless (RF) nodes and gateways

8 BLUETOOTH 5 BASED WIRELESS SENSOR NETWORK

YieldPoint's d-EXTO digital MPBX can be wirelessly networked in a star topology for data retrieval and transmission using an extremely low energy data transfer technology, based on Bluetooth 5. It features the same low power features like Bluetooth Low Energy (BLE) but with 4 times its range (100 m).

The Bluetooth devices of the wireless network include BluPoint which enables Bluetooth connectivity to the digital MPBX, BluLoggers, and BluGateways. The above bluetooth device also allows the site personnel to take the latest readings with an Android phone or tablet installed with BluPoint App. From a distance of around 10 m.

BluGateways can autonomously collect data from BluLink or Bluelogger and transmit it via a WiFi or LTE-M network to a central server. BluLoggers can also be fitted to vehicles to wirelessly collect readings from sensors with BlueLink during a drive-by. The above Bluetooth devices run on lithium or alkaline batteries. With 1 reading/hr the alkaline batteries will last 2-3 years, and lithium batteries over 4 years.



Bluetooth 5 wireless de-EXTO network

9 AUTOMATIC TOTAL STATIONS (ATS)

Encardio-rite offers an automatic three-dimensional deformation monitoring system with the highest accuracy achievable in the industry presently. Displacement data is measured from the prism targets by a high precision and accuracy robotic total station with a dedicated control box that includes a computer running special software.

The 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 the site. The on-site system transmits the collected raw data to a remote server/computer via GPRS/GPS. 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 deformation data is available online through WDMS in near real-time.

10 LASER SCANNING

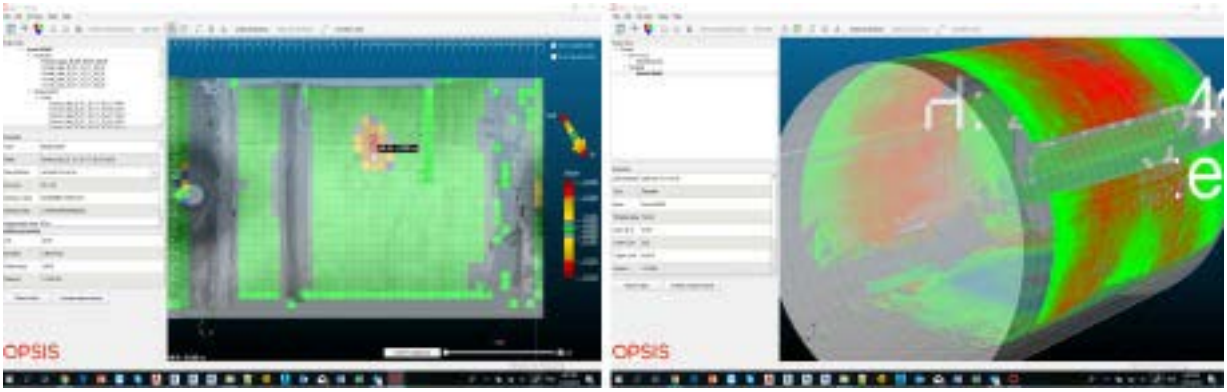
Laser scanning is an advanced method of surveying and conducting geometric profiling of mining works that require the highest degree of analysis, are difficult to reach or gain access to, or are not to be touched. Recent developments, especially in the software, have made it one of the fastest, convenient, cost-effective, accurate and efficient tools to accurately monitor underground excavations/caverns in three-dimensions. The advantage of laser scanning is that the measurements are not limited only to specific prism spots, but covers all the exposed surfaces. Particularly useful to monitor the remaining columns supporting the overburden. 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”.

OPSIS is a software tool developed to overcome the impediment caused by the vast amounts of data LiDAR. The idea within its core is to perform operations over the raw data from the LiDAR to obtain a significantly smaller data set to carry out the analysis. The task of monitoring the deformations or displacements of the scanned objects to perceive possible changes using OPSIS comes down to processing the subsequent point clouds obtained in different epochs using the same projection surface and grid obtained as the best fit for the initial point cloud. If significant changes in the object’s geometrical form were to occur, variations of the cell’s mean values will make them easily detectable.

What makes this approach unique and better than other commonly used existing software is the feature that it not only gives a point cloud pair comparison but it also provides a linear diagram visualization of the deformation history of each grid cell. 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.

To summarize, the results of laser scanning gives us:

- Surveying of current state and of «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



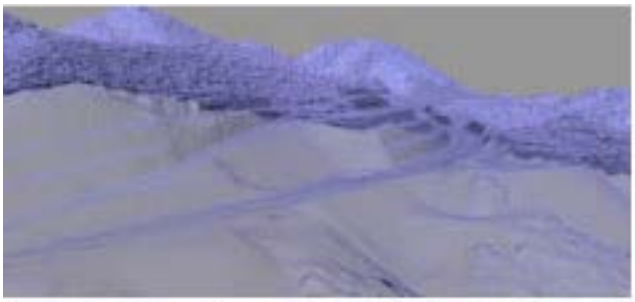
11 AERIAL MAPPING USING UNMANNED AERIAL VEHICLES (UAV/DRONE)

Inspection of huge and complex excavation works like mining requires 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.

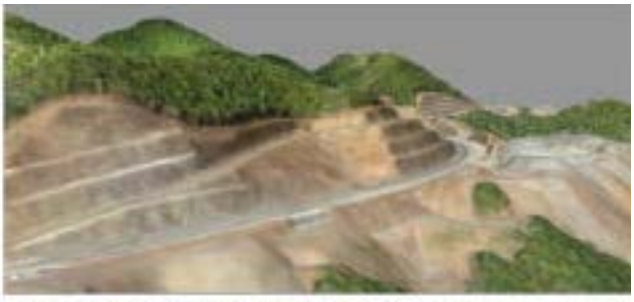
UAVs/Drones are unmanned and remotely-piloted aircraft that follow a pre-programmed path for takeoff, flight, and landing. These aircraft are equipped with HD/IR/Thermal cameras that compute aerial images and videos over a defined area at the specified height. Using UAVs/drones to video, model and scan for cracks, erosion, corrosion and defects in areas, that would otherwise require the inspector to use a rope/harness or erect access scaffolding, is safer, faster and smarter choice. Results from UAV/drone are in the following forms:

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

Mesh 3D modelling



Texture 3D Modelling



Texture 3D Modelling

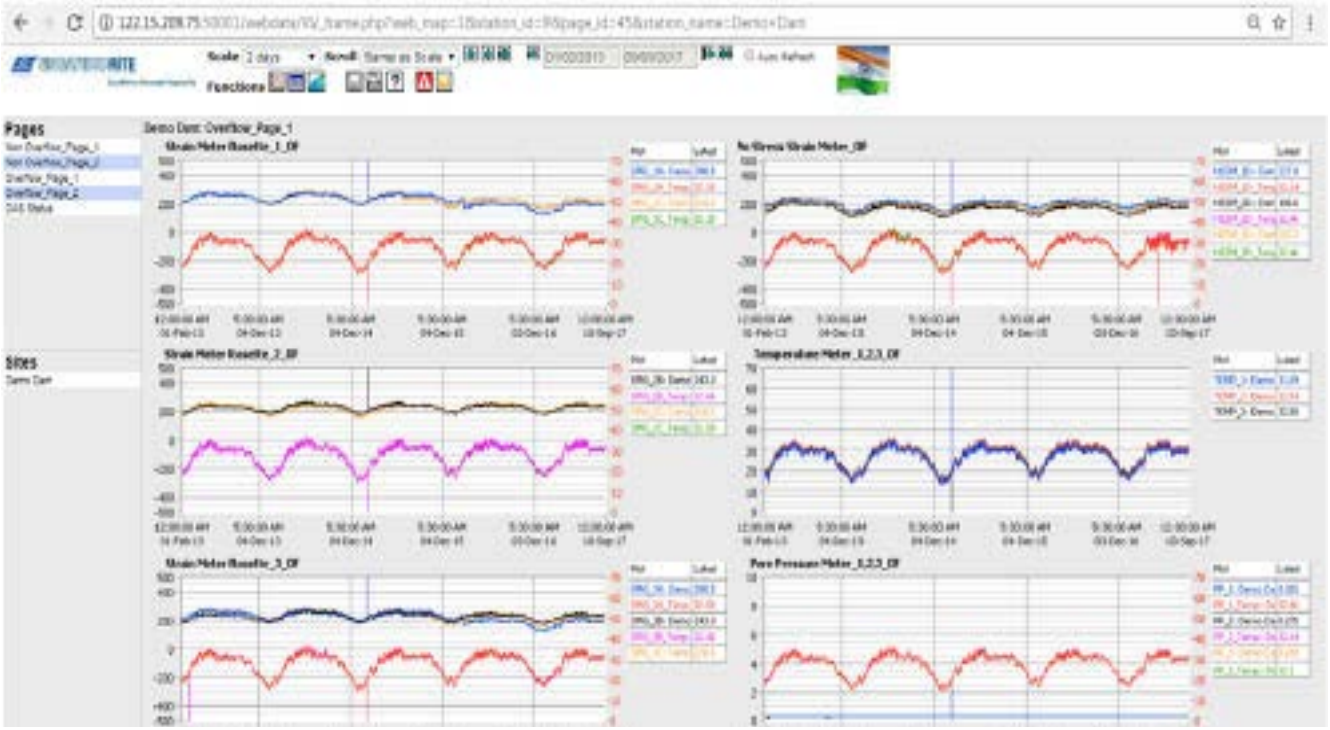
Video

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

Encardio-rite offers complete cloud-based web or local access data monitoring service to its customers for retrieving data from the dataloggers/gateways, archiving retrieved data in a SQL database, processing data and presenting the processed data in tabular and most suitable graphical forms for easy interpretation. Heart of the system is Drishti data management software. This is a highly flexible data management platform that can combine data from geotechnical, geodetic and environmental sensors.

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. Alternatively, it can be installed on the client's server, if required. Features of the monitoring data management software can be summarized as follows:

- Data from multiple sensor types are converted into meaningful information in graphical as well as the numerical format
- A layout plan or Google Maps can be incorporated with the locations of each monitoring sensor. From this view, the user can get data in the graphical form of any sensor with few mouse clicks
- The web browser interface is very simple to use and intuitive
- Access to all sensors in one platform
- Generate combined charts of related parameters
- Create graphs from any combination of parameters and period
- Instant automatic alerts via SMS or email to authorized personnel as soon as any sensor data crosses its predefined alarm levels, while either going above or going below the alarm level
- Can send the health status of the system to selected users
- No special software required for accessing the user sites as information can be viewed using most standard and popular web browsers
- Can be accessed using tablets and smartphones



Typical long-term online data

13 CONCLUSION

An online monitoring solution for mining works is not expensive compared to the losses incurred in case of any failure. By monitoring mines, corrective action may become possible earlier than the occurrence of any failure. The data observed from the installed sensors as described above plays a vital role in safeguarding the mining progress, human lives, environment, and nearby properties, providing timely warnings to take corrective measures.

To obtain the best results, the instruments need to be of superior quality and must be installed carefully and precisely under expert supervision; since once embedded, the instrument cannot be taken out. Encardio-rite designs manufacture and supply world-class sensors having long term reliability to almost 55 countries around the globe.

The collection and analysis of large quantities of data from the huge area require centralized and automated database systems as data monitored must be made available to the user promptly as meaningful information. The data collected must be reduced to a convenient form. Automated database solutions offered by Encardio-rite do the processing and analysis of the collected raw data and provide accurate data, rapidly, enabling efficient alarm systems.

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