
APPLICATION NOTE

ONLINE MONITORING OF LANDSLIDES/SLOPE STABILIZATION

1 INTRODUCTION

A good prediction and forewarning system, when implemented with effective efforts to control and mitigate landslides, can drastically reduce destruction caused by landslides. Unstable slopes require monitoring systems that can be accessed remotely and provide an immediate warning in case of failure. Advances in geotechnical instrumentation, surveying technologies and data transmission systems now make it possible to monitor these slopes conveniently and economically.

Remote (near real-time) monitoring of slope movement and other parameters potentially affecting it can be a correct approach for risk mitigation in unstable or potentially unstable slopes. Pore water pressure can be observed using vibrating wire piezometers. Lateral movements and deformations can be determined with in-place inclinometers, tilt meters, extensometers, crack meters and automatic survey systems.

All of these instruments are connected to a datalogger that automatically collects reading at selected intervals and trigger an alarm or sends an SMS if pre-determined values are exceeded. Data can be transferred using SDI-12 bus, cellular network or radio frequency technologies, depending on site conditions. Collected data can be evaluated by an engineering geologist and consultant to take corrective measures and prevent landslide problems, present or expected in future.



Borehole extensometers and in-place inclinometers installed for online slope monitoring at Al Mirani Fort, Oman



In-place inclinometers and piezometers installed for online slope monitoring at Cabo Fort, India

2 MONITORING INSTRUMENTATION & THE NEED FOR IT

In general, following steps can be adopted in landslide-prone areas:

- Monitor slope to detect any sign of instability. Remedial measures can then be instituted before alarm conditions are generated.
- Stabilize slopes that need corrective action using appropriate slope stabilization technique(s).
- Devise an online (near real-time) monitoring program to verify that stability of the slope is achieved.

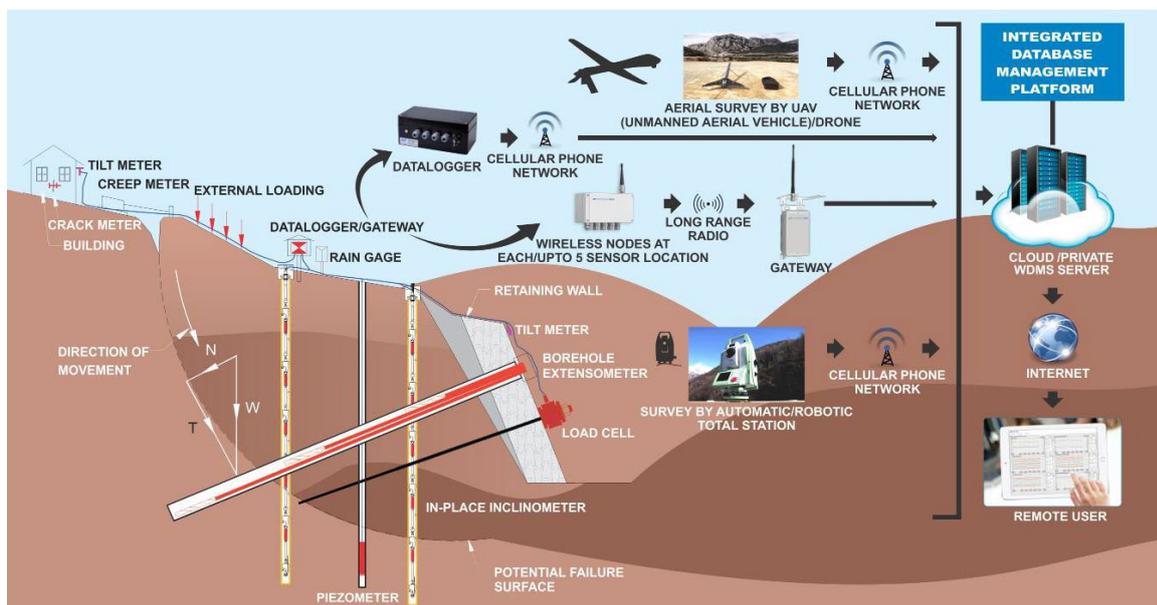
By implementing a good prediction and forewarning system, coupled with effective efforts to control and mitigate landslides, the destruction caused by these can be drastically reduced. Any worthwhile plan for corrective and preventive measures in a landslide or an area susceptible to landslides must be based on a detailed integrated geological and geotechnical investigation and monitoring.

Landslide problems, present or expected in future, require an engineering geologist to exactly evaluate the type of landslide and take corrective measures based on collected data and experience gained to tackle similar problems. The solution should be based on a well thought of working hypothesis taking into consideration cost involved and effectiveness of the efforts put in.

3 SOLUTIONS AVAILABLE FOR LANDSLIDE/SLOPE MONITORING

Encardio-rite offers a simple to use, comprehensive and cost-effective solution to the user for online monitoring of landslide-prone areas. This includes supply, installation, calibration, maintenance, data collection and web-based data monitoring service that provides information in most suitable forms for easy interpretation of the monitoring data. Following solutions are available with Encardio-rite for on-line landslide monitoring:

- Geotechnical sensors to measure all relevant parameters required to monitor landslide/slope
- Automatic monitoring of geotechnical sensors using SDI-12 digital interface datalogger with GSM/GPRS telemetry
- Automatic monitoring of geotechnical sensors using LoRa nodes and a gateway
- Geodetic monitoring with automatic total stations with GSM/ GPRS telemetry
- 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.





3.1 Monitoring instrumentation

Instruments available with Encardio-rite for surface and subsurface online monitoring are as follows:

Subsurface instruments

1. In-place inclinometers for monitoring sub-surface lateral movements
2. Piezometer for monitoring pore pressure variations throughout the landslide area
3. Borehole extensometers for monitoring sub-surface settlements at specified points

Surface instruments

4. Tilt meters mounted at one or more locations on the retaining wall/buildings in the zone of influence to record changes in slope inclination near cracks and areas of maximum anticipated rotational movement
5. Crack and joint meters for monitoring displacement/opening of cracks in rock mass or buildings/structures
6. Creep meter with invar wire for monitoring displacement/opening of faults in the ground
7. Center hole load cell for monitoring tension in anchors used for stabilizing the slope
8. Rain gage for monitoring rainfall

Datalogging, data transfer and online monitoring

9. Dataloggers for the above-mentioned sensors, with integral GSM/GPRS modem for transmitting data to a central server
10. Web based data management systems with suitable softwares

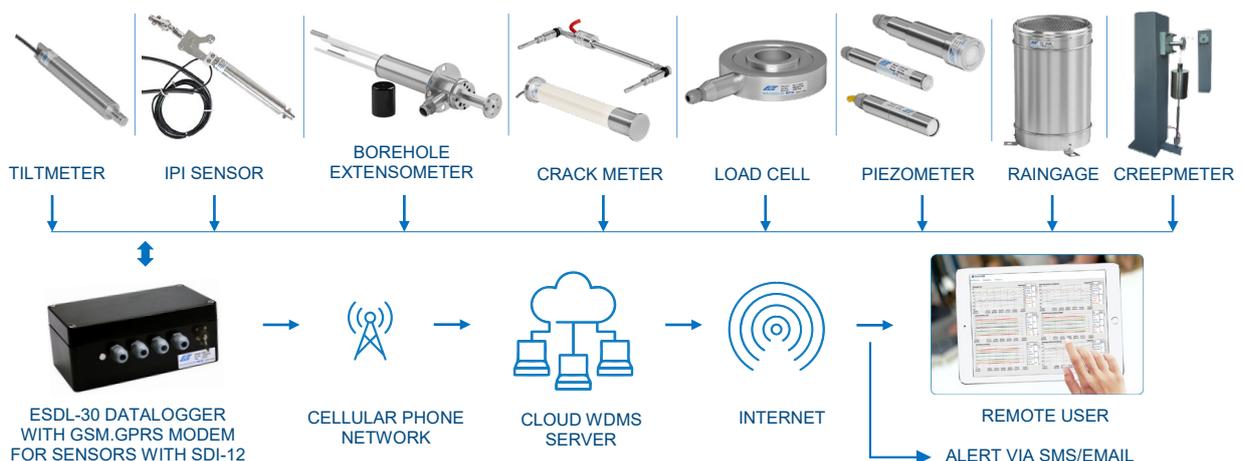
Surveying

11. Automatic total stations and control box with integral GSM/GPRS modem for transmitting data to a central server

3.2 Data transmission options

3.2.1 SDI-12 interface real-time monitoring

Encardio-rite offers advanced automatic dataloggers with GSM/GPRS for data collection of geotechnical instruments with SDI-12 digital interface and transmission to a remote server. Refer to the block diagram below.





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

The dataloggers can be programmed to take a measurement from 5 seconds to 168 hours. For better battery life, it is recommended to transfer the logged data 2~4 time/day. 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.

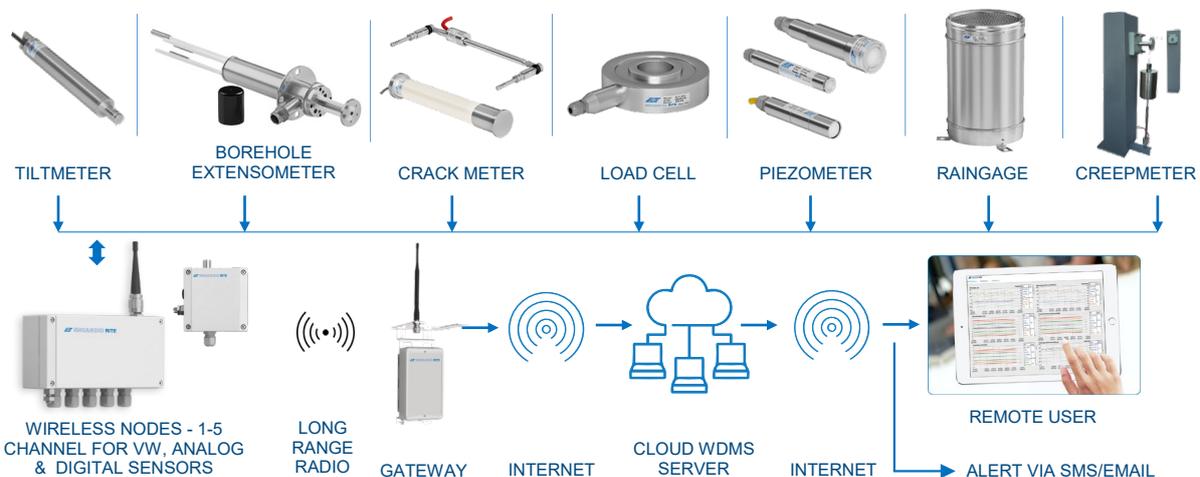
3.2.2 Wireless real-time monitoring using RF

Encardio-rite offers state-of-the-art wireless monitoring solution comprising of wireless dataloggers compatible with a wide array of geotechnical and environmental sensors and gateways.

The radio-communication devices are battery powered and are based on **LoRa** technology and provide 'Long Range' communications on a wide area network (WAN) using very low power levels.

Data collected from the remote field sensors can be viewed in near real-time by the authorized users from any part of the globe by logging on to Encardio-rite's WDMS. Refer to block diagram given below.

The system features long communication on an ISM frequency range of up to 10 km in open field conditions. The low power consumption of datalogger results in batteries lasting for up to 5 years.



The wireless dataloggers, functioning as nodes of the wireless network, are available in single and multichannel configurations suitable for receiving digital inputs from vibrating wire and analog devices to automatically collect, store and transmit data from the connected sensors. The gateway is the aggregator of all data collected by the nodes. It has an integrated 3G modem and transmits the data over the internet to the WDMS.

The system offer benefits such as cost & time savings, remote monitoring of hard to access locations, easy expansion of the system, if required in future and easy maintenance.

4 AUTOMATIC SURVEYING SYSTEM

Encardio-rite offers an automatic three-dimensional deformation monitoring system with highest accuracies achievable in the industry presently. Displacement data is measured from the prism targets by a high end robotic total station and control box with an inbuilt GSM/GPRS modem. Structural deformation data is available online through WDMS in near real time.

The system ensures near real-time monitoring of displacement, providing high measurement density, simultaneous wireless transmission and availability of data online in easy to understand movement vectors in graphical and tabular formats. The system can be accessed and controlled remotely from anywhere by the users.

5 AERIAL SURVEY WITH DRONES/UAV

This is a rapid and safe way of collecting data from large-scale landslide areas and mountains where frequent geospatial and/or imaging information is needed in order to monitor the slopes.

In an aerial survey by drones, unmanned and remotely piloted aircraft follow a preprogrammed 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. The data, in form of point clouds, meshes and 3D models, is compared between sequel flights during monitoring campaign.

6 WEB BASED DATA MANAGEMENT SYSTEM (WDMS)

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

Web data monitoring service consists of **Drishti** or **Terramove** data management software. Drishti is used for providing services where only geotechnical instruments are used. Terramove is used where data is collected/correlated with both geotechnical instruments and automatic total stations.



Gateway installed for wireless monitoring



Automatic surveying system (ATS)

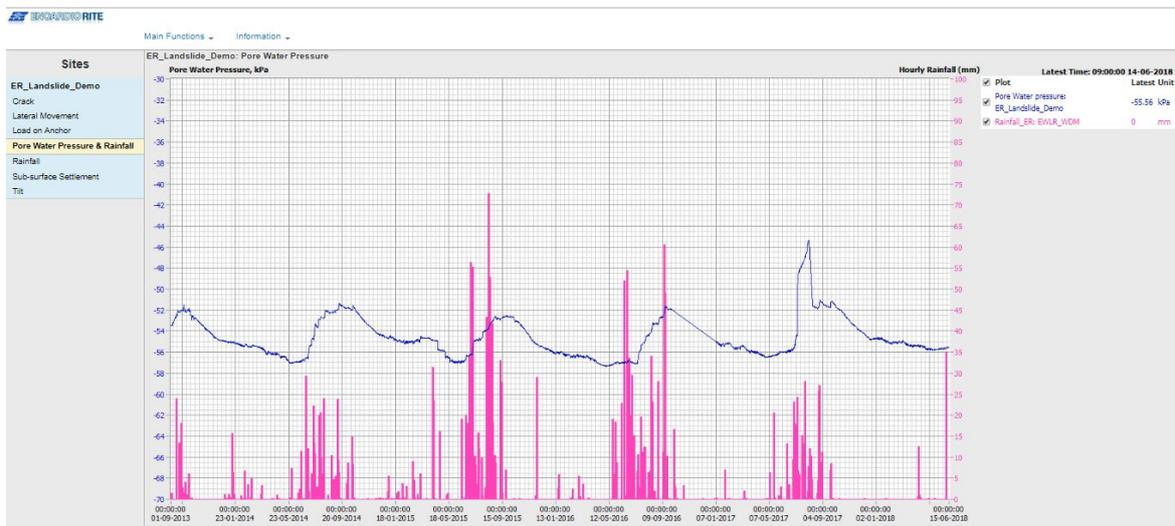


Aerial survey using drones/UAV



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 also, if required. Features of the monitoring database management software can be summarized as follows:

- Data from multiple sensor types are converted into meaningful information in graphical as well as numerical format
- Layout plan can be incorporated with locations of each monitoring sensor. From this layout plan, the user can get data in the graphical form of any sensor with few mouse clicks
- Access to all sensors in one platform
- Instant automatic alerts via SMS or email to authorized personnel
- Generate combined charts of related parameters
- Create graphs from any combination of parameters and time period
- Variety of visualization and analysis tools to identify potential failure scenarios
- 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 smartphone



Online 5 years data from demo Landslide monitoring site

7 CONCLUSION

A solution for monitoring landslide movements is not expensive. The cost is a small fraction of what is spent later on in rescue operations, removing debris and rehabilitation. By monitoring slope movement, corrective action may become possible earlier than the occurrence of the landslide. By implementing proper drainage for groundwater, using anchor bolts and cable anchors at the right places, pressure grouting and building retaining walls etc., it is possible to contain the landslide to a large extent. In cases where it is not possible to prevent a landslide, the data collected may give sufficient time for evacuation.