RITE GEOSYSTEMS

ENCARDIO RITE
METASENSING FOR MEGA STRUCTURES

APPLICATION NOTE

ONLINE MONITORING OF DAMS

1 INTRODUCTION

Instrumentation plays a key role in safety monitoring for dam and people, providing necessary information on the performance of the dam and detect problems at an early and preventable stage. The extent and nature of instrumentation depend not only on the complexity of dam and the size of the reservoir but also on the potential for loss of life and property downstream. This information is critical for the dam's owner who is directly responsible for any consequences of its failure.

Instrumentation includes different type of sensors used for measuring pore pressure, water flow, lateral movement, deformation, stress, strain and temperature, installed in the dam and its auxiliary structures. It also includes geodetic targets measured using surveying techniques.

Advances in geotechnical instrumentation, surveying technologies and data transmission systems make it possible to monitor the dam performance 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 system, 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.

2 MONITORING INSTRUMENTATION & THE NEED FOR IT

2.1 What to monitor?

A dam can fail due to a number of reasons like design error, geological instability, poor maintenance, deterioration of construction material, etc. A good instrumentation program can prevent such failures by providing the following information:

2.1.1 Measurement during construction

- To verify the hypothesis and the assumptions of design
- To monitor safety during construction
- To measure the change in parameters during construction
- To ensure that the interface of construction with adjacent structures and foundation is sound
- To certify the performance of the new construction

2.1.2 Measurement after construction is completed

- Performance monitoring for safety during the life of the structure
- Evaluation of the effect of the operation of the reservoir on parameters like stress, strain, water, pressure, inclination, deflection and water seepage
- Comparison of observed data with design assumptions
- Monitoring of reservoir level and water discharge

2.1.3 Measurement for research

- Determination and evaluation of design parameters
- Testing of new construction materials and techniques
- Study of the laws of behaviour of soil, rock and man-made materials used in the construction of such structures.

2.2 Why monitor?

Safe operations of the dam is an important matter of economic benefit and public safety. Catastrophic dam failure can threaten life and property downstream. The primary purpose of instrumentation is to supply quantitative data on its performance to aid in evaluating the safety of structure and detecting problems at an early and preventable stage.

Tehri earth and rockfill dam, India

Tala concrete gravity dam, Bhutan

A good instrumentation program serves the following purpose:

2.2.1 Site investigation

Instruments are used to characterize and determine initial site conditions. Common parameters of interest in a site investigation are pore pressure, the permeability of the soil, slope stability etc.

2.2.2 Design verification

Instruments are used to verify design assumptions. Instrumentation data from the initial stage of a project may show the need or provide the opportunity to modify the design in later stages.
For example, data obtained from reinforcement bar strain meters installed by Encardio-rite at Teesta Barrage in the left embankment led the project authorities to revise their estimates of the requirement of steel in the right embankment.

2.2.3 Construction control

Instruments are installed to monitor the effects of construction. Instrument data helps the engineer to determine how fast construction can proceed without adverse effects on the foundation soil and construction materials used.
For example, the temperature rise in concrete due to the heat of hydration was monitored at Sardar Sarovar Dam on Narmada river with Encardio-rite's temperature meters to determine the pouring temperature of mass concrete. By mixing ice flakes, the temperature of the concrete to be poured was brought down to around 15°C. This resulted in the temperature of the setting concrete not exceeding the critical 29°C, as specified and required by the Central Water and Power Research Station (CWPRS), Pune.

2.2.4 Safety

Instruments can provide early warning of impending failure. Safety monitoring requires quick retrieval, processing, and presentation of instrument data so that analyses and decisions can be made promptly. An effective action plan for implementing corrective measures can then be prepared.

Teesta Concrete Gravity Dam, India

Chukkha Concrete Gravity Dam, Bhutan

Sardar Sarovar Concrete Gravity Dam, India

For example, Encardio-rite instrumented the side walls of the Chukha underground powerhouse located in the fault zone with borehole extensometers and anchor bolt load cells. As the excavation proceeded downwards, their data showed increasing movements and loads respectively, at a number of locations and corrective action taken by installing deeper anchor bolts. Accidents were common before the instrumentation work was undertaken. No further accidents took place after the instrumentation and the cavity was completed as per the schedule.

2.2.5 Performance

Instruments are used to monitor the in-service performance of a structure. In the case of dams, monitoring leakage, pore water pressure and deformation can provide an indication of their in-service performance

3 HOW TO MONITOR? SOLUTIONS AVAILABLE FOR DAM MONITORING

Encardio-rite offers a simple to use, comprehensive and cost-effective solutions to the user for online monitoring of different types of dams and its auxiliary structures. This includes supply, installation, calibration, maintenance, data collection and web-based data monitoring service that provides information in the most suitable forms for easy interpretation of the monitoring data.

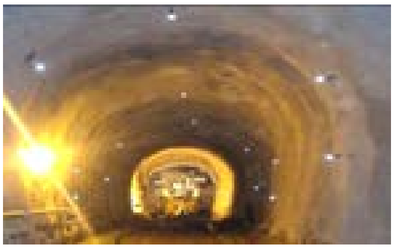
Following solutions are available with Encardio-rite for online monitoring:

- 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 datalogger 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.

Work in progress at Middle Marsyangdi Dam, Nepal

Work in progress at Middle Marsyangdi Dam, Nepal

Work in progress at Salma Dam, Afghanistan



Prism targets in HRT at Dagachhu HEP, Bhutan

Load cell & BHE in powerhouse at Koprubasi HEP, Turkey

4 TYPICAL MONITORING INSTRUMENTATION SCHEMES

Each dam is a unique situation and requires an individual solution for its instrumentation requirements. There are no simple rules for determining the appropriate level of instrumentation and monitoring because it depends on the size and hazard potential classification of the dam, the complexity of the dam and foundation, known problems and concerns and the degree of conservatism in the design criteria. Based on our vast experience in instrumenting over 200 dams, few typical instrumentation schemes for online monitoring of different type of dams are given below:

4.1 Concrete dam

Figure 1 gives the instrumentation scheme of a typical block in a concrete gravity with Encardio-rite instruments.

The table below gives an insight into the purpose of the different instruments, along with their locations. Typically three or more different blocks are instrumented in a concrete dam. The instrumentation scheme of the blocks may differ from each other, depending upon design considerations and other factors.

Purpose	Instrument	Location
Monitor pore pressure or seepage of water through the cross-section of the dam	Pore pressure meter	Dam blocks at different elevations
Monitor stresses in the concrete of the dam body	Stress meter	Near foundation where the height of the dam is maximum (can be just below the gallery)

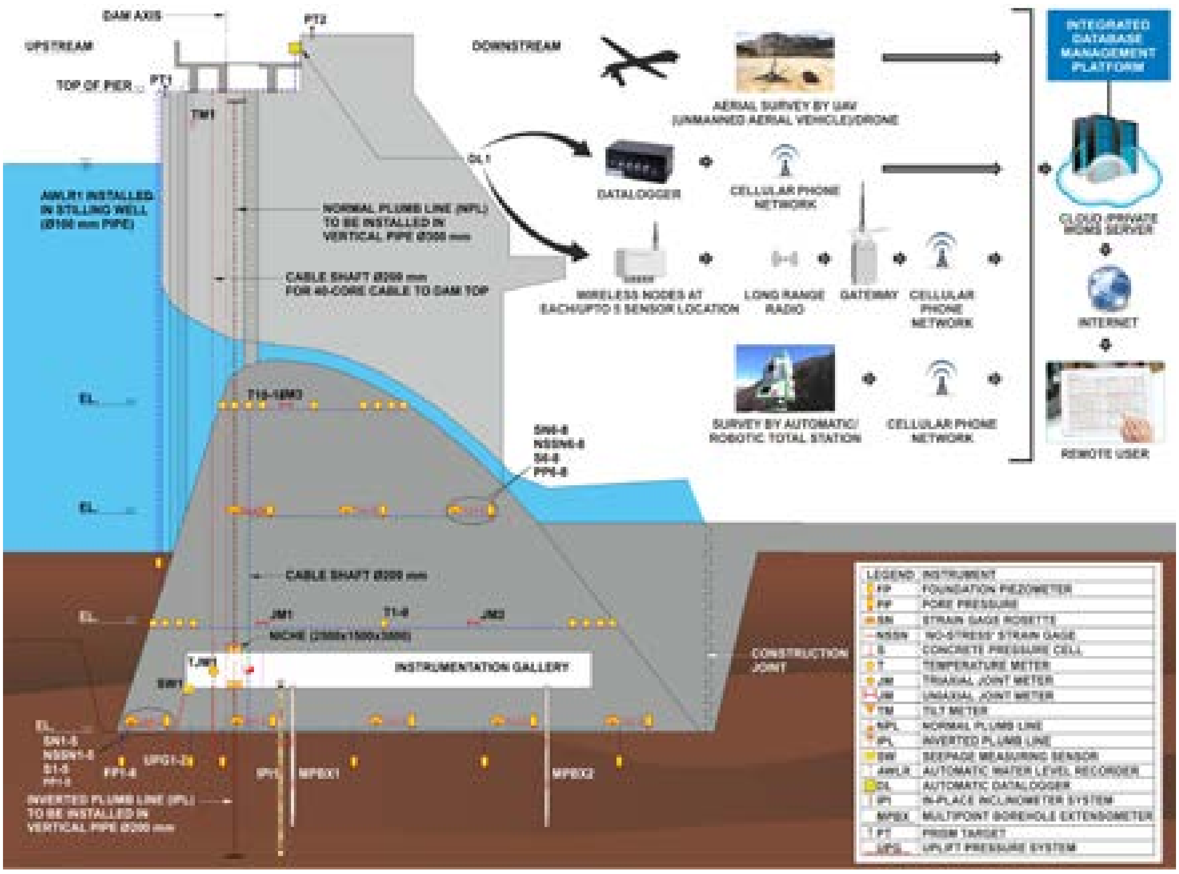


Figure 1: Typical instrumentation scheme of a block of concrete gravity dam

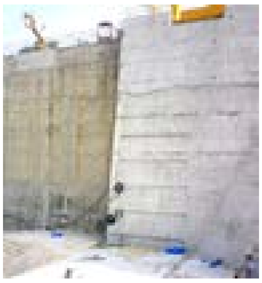
Purpose	Instrument	Location
Monitor pore pressure to adjust it from stress meter readings to get true stress	Pore pressure meter	Near stress meters
Monitor joint opening between the blocks	Joint meter – uniaxial, triaxial	Between the concrete blocks
Monitor tilt of the dam	Tiltmeter	Dam block, at the top
Monitor deformation due to all causes - including those due to stress	Strain meter rosette	In dam body - in a group of five four strain gages at angles of 0°, 45°,90°, 135° in one plane and one strain gage at right angles to this plane
Monitor deformation due to changes in temperature, moisture or autogenous growth in the mass concrete of the structure. Adjusting this from strain meter readings gives strain due to stresses in the dams	No-stress strain meter	Near strain meter rosette - inside the no stress container
Monitor water level in the reservoir	Automatic water level recorder	The upstream side of the dam
Monitor temperature of concrete during the casting of the concrete blocks to prevent undesirable micro-cracks. Temperature variation is also one of a major factor causing stress on the surface of the dam that results in material fatigue	Temperature meter	Dam blocks and spillway
Monitor water pressure on the base of the dam caused due to water seepage from the reservoir to the foundation. This pressure exerts a vertical upward force on the base of the dam and tries to lift it up	Uplift pressure meter	In the dam Gallery - downwards - with a stop valve on the uplift pressure pipes, which is opened to release the water and reduce pressure on the base of the dam.
Monitor amount of seepage through, around and under embankments	Seepage measurement	The downstream side of the dam

Parbati Concrete Dam, India

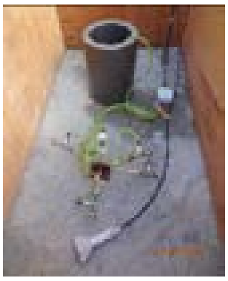
Ghatgar RCC Dam, India

Karchham Concrete Dam, India

Triaxial jointmeter installed at Teesta III Dam, India



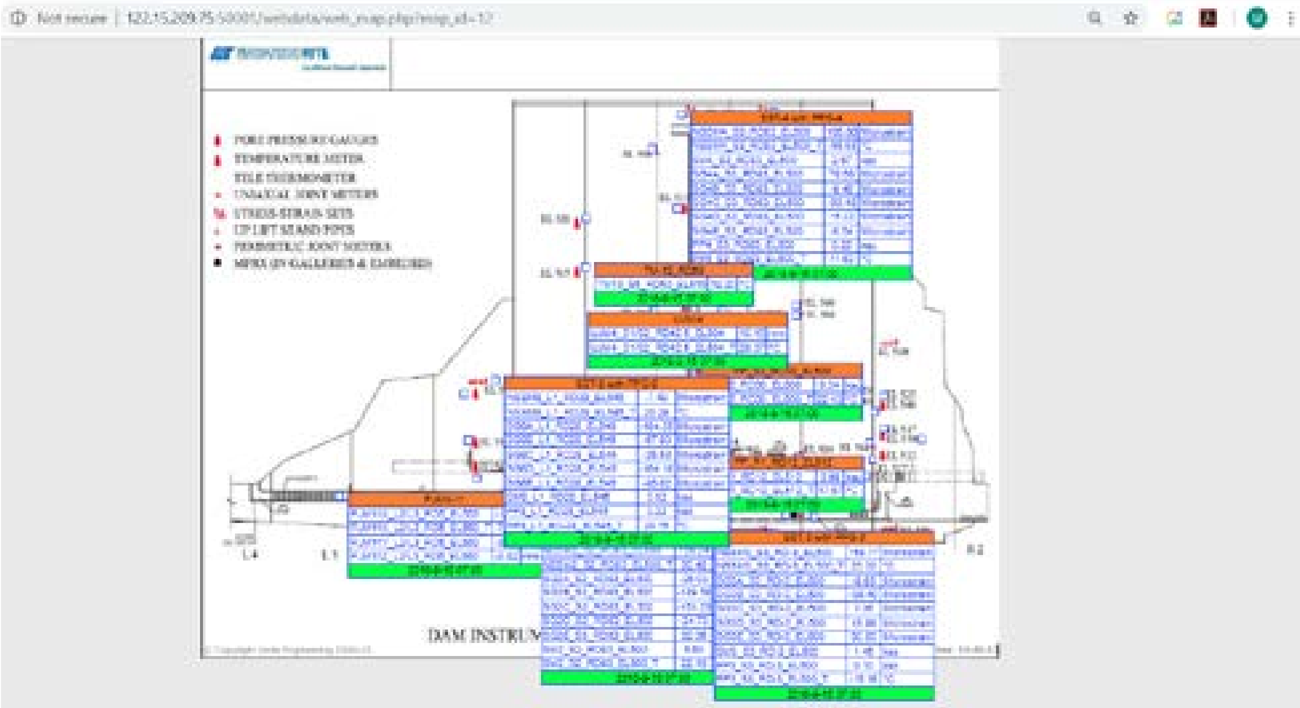
Sensors being installed at Middle Marsyangdi Dam, Nepal



Strain gage rosette and piezometer being installed at Nam Pha Dam, Laos

Concrete pressure cell being installed in Ghatgar Dam, India

Purpose	Instrument	Location
Monitor tilt of dam - caused by thrust applied by water pressure on the dam	Normal plumbline (telecoordinometer)	Blocks
Monitor relative displacement between the dam bottom and the foundation base rock	Inverted plumbline (telecoordinometer)	In the same block as that of the Normal plumbline
Monitor lateral movement of the foundation	Digital inclinometer, in-place inclinometer	Dam foundation with top in cross or transverse gallery
Monitor vertical displacement of the dam bottom in respect to the foundation base rock	Borehole extensometer	Dam foundation with the top assembly in cross or transverse gallery
Monitor 3D movements or deformations	Optical targets and robotic total stations with control box	Dam surface
Monitoring of construction progress; Monitoring and inspection of dams for maintenance	UAV equipped with a high-performance camera	Aerial



TYPICAL INSTRUMENT LAYOUT SCHEME WITH CURRENT ONLINE DATA FROM A CONCRETE GRAVITY DAM

TYPICAL LONG-TERM ONLINE (8 YEARS) PIEZOMETER DATA FROM A CONCRETE GRAVITY DAM

4.2 EARTH AND ROCKFILL DAM AND CONCRETE FACED ROCKFILL DAM (CFRD)

Figure 2 gives instrumentation scheme of a typical section in an earth and rock fill dam while Figure 3 gives instrumentation scheme of a typical section in a concrete faced rock fill dam (CFRD). The table below gives an insight into the purpose of the different instruments, along with their locations:

Purpose	Instrument	Location
Monitor pore pressure or seepage of water through the cross-section of the dam	Pore pressure meter	Dam body at different elevations. Also in the dam foundation by drilling holes
Monitor compressive forces and stress	Soil pressure meter	Dam body at different elevation- near foundation where height of dam is maximum (can be just below gallery)
Monitor pore pressure to adjust it from stress meter readings to get true stress	Pore pressure meter	Near soil pressure meters
Monitor lateral movement of the foundation	Digital inclinometer, in-place inclinometer	Across dam body; from the base of the dam to the top
Monitor amount of settlement that occurs when a soil is loaded or dewatered	Settlement cell and magnetic extensometer	Across dam body; from the base of the dam to the top
Monitor water level in the reservoir	Automatic water level recorder	The upstream side of the dam
Monitor lateral movement along with the settlement	Inclinometer-cum-magnetic extensometer	Dam body, towards the downstream side, with top inaccessible area to take manual readings
Monitor soil or rock movement, lateral strains and settlement	Soil extensometer	Dam body from upstream side to downstream side
Monitor amount of seepage through, around and under embankments	Seepage measurement	The downstream side of the dam
Monitor strain in the concrete face	Strain gages	The concrete face of CFRD

Some monitoring method mentioned in the previous table for concrete dams e.g. 3D deformation monitoring using robotic total stations and UAV survey can also be used for monitoring earth & rockfill and CFRD dams.

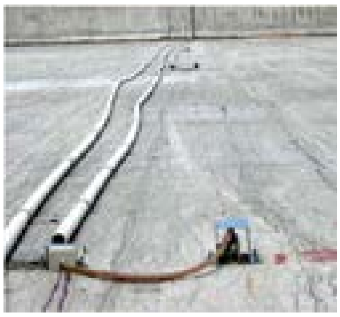
PURULIA EARTH DAM, INDIA

DHAULIGANGA CFRD, INDIA

SETTLEMENT CELL BEING INSTALLED AT GHISS DAM, MOROCCO

INCLINOMETER BEING INSTALLED IN EL PLATANAL ROCKFILL DAM, PERU

SOIL EXTENSOMETER BEING INSTALLED IN AN EARTH AND ROCKFILL DAM



TILT METER INSTALLED AT CONCRETE FACE OF DHAULIGANGA CFRD,INDIA

5 MONITORING OF EXISTING DAMS

Dams age and deteriorate with time posing a potential threat to life, health, property and environment. Safe functioning of dams is important. Changes in the behavioural characteristics may be indicative of an impending failure of a dam. Continuous monitoring of dams is essential to detect such changes at early stages and to enhance response time to prevent disasters. This calls for online monitoring systems that are commissioned for near real-time monitoring of the installed instrumentation.

The instrumentation plan will depend on the type and health status of the dam and on the existing working instruments installed in the dam. Replacement of existing faulty instruments to the extent necessary and practicable and adding state of the art new instrumentation systems depending on the feasibility and health of dam should be taken up to ensure an effective monitoring system.

6 AUTOMATIC WIRED SENSORS MONITORING SYSTEM

Encardio-rite offers advanced automatic dataloggers with 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 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.

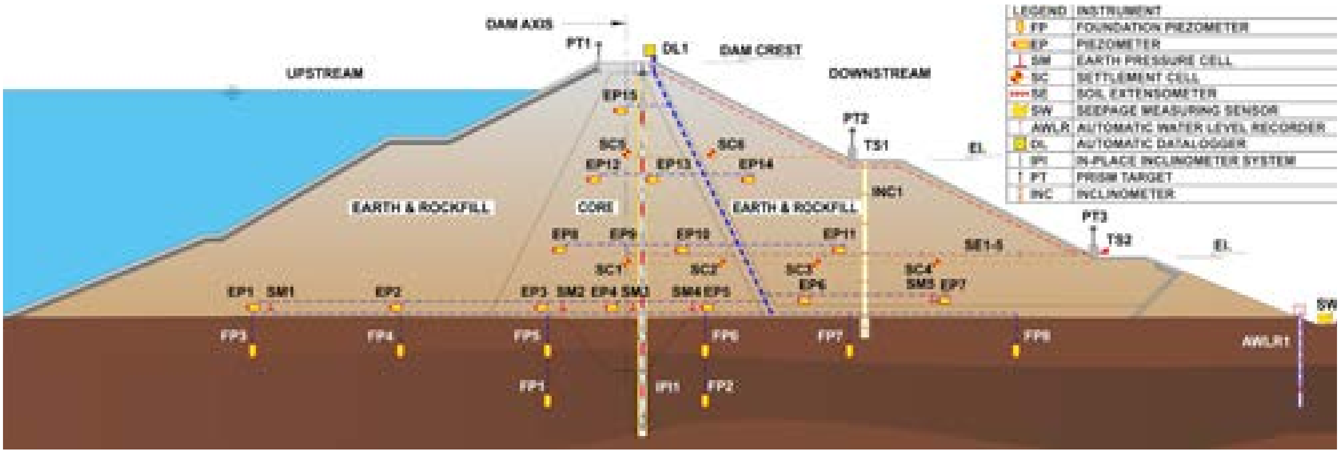


FIGURE 2: TYPICAL INSTRUMENTATION SCHEME IN AN EARTH AND ROCKFILL DAM SECTION

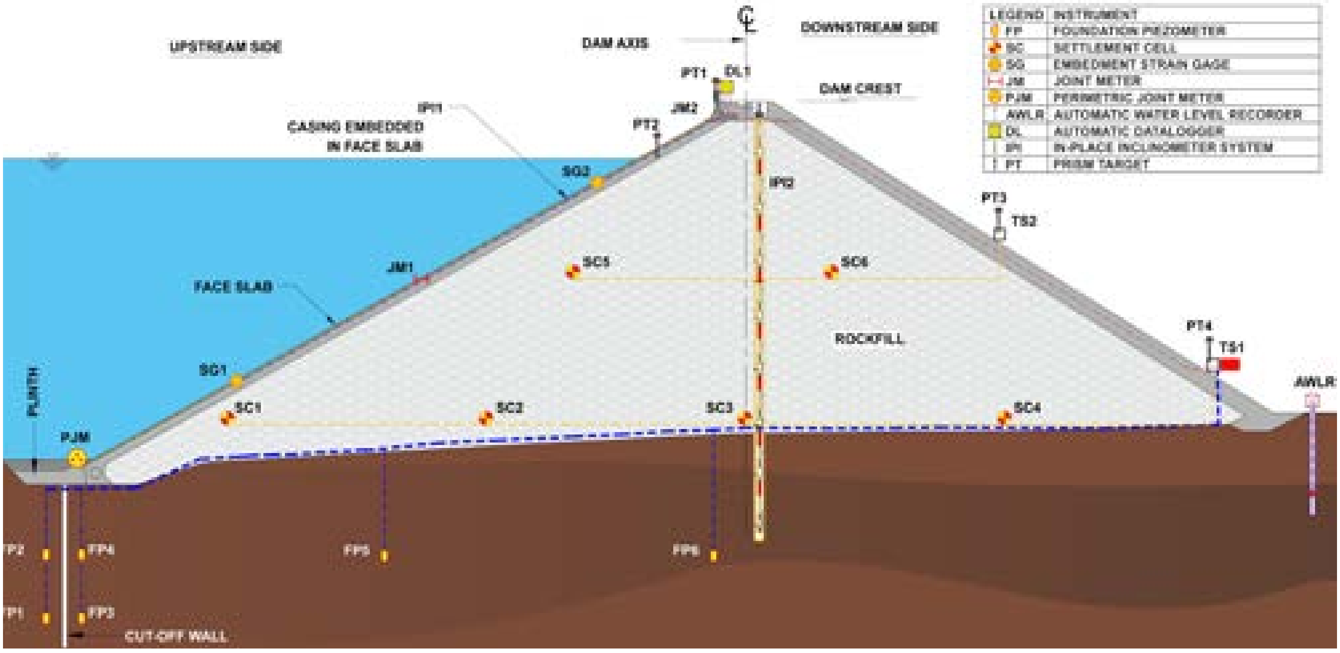
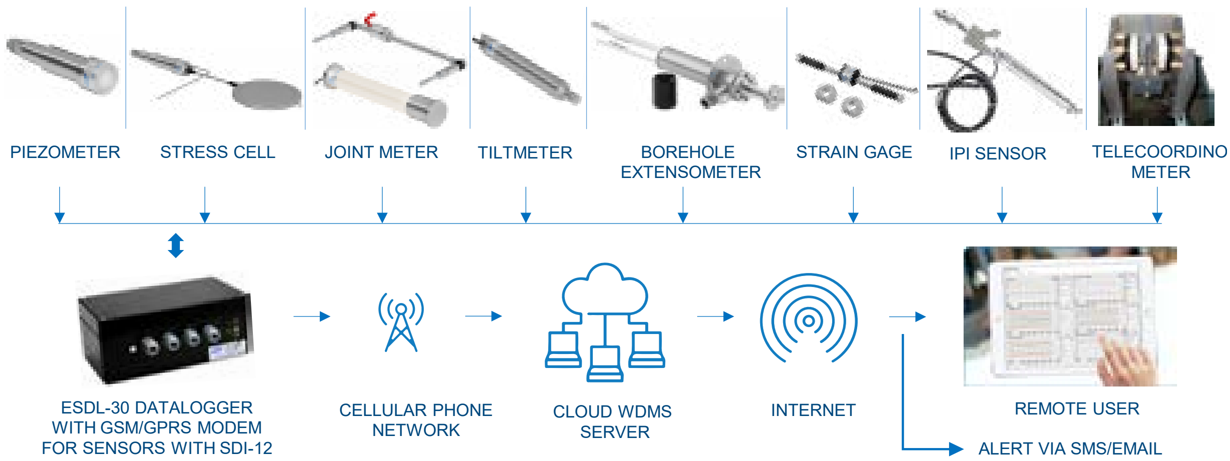


FIGURE 3: TYPICAL INSTRUMENTATION SCHEME IN A CONCRETE FACE ROCKFILL DAM SECTION



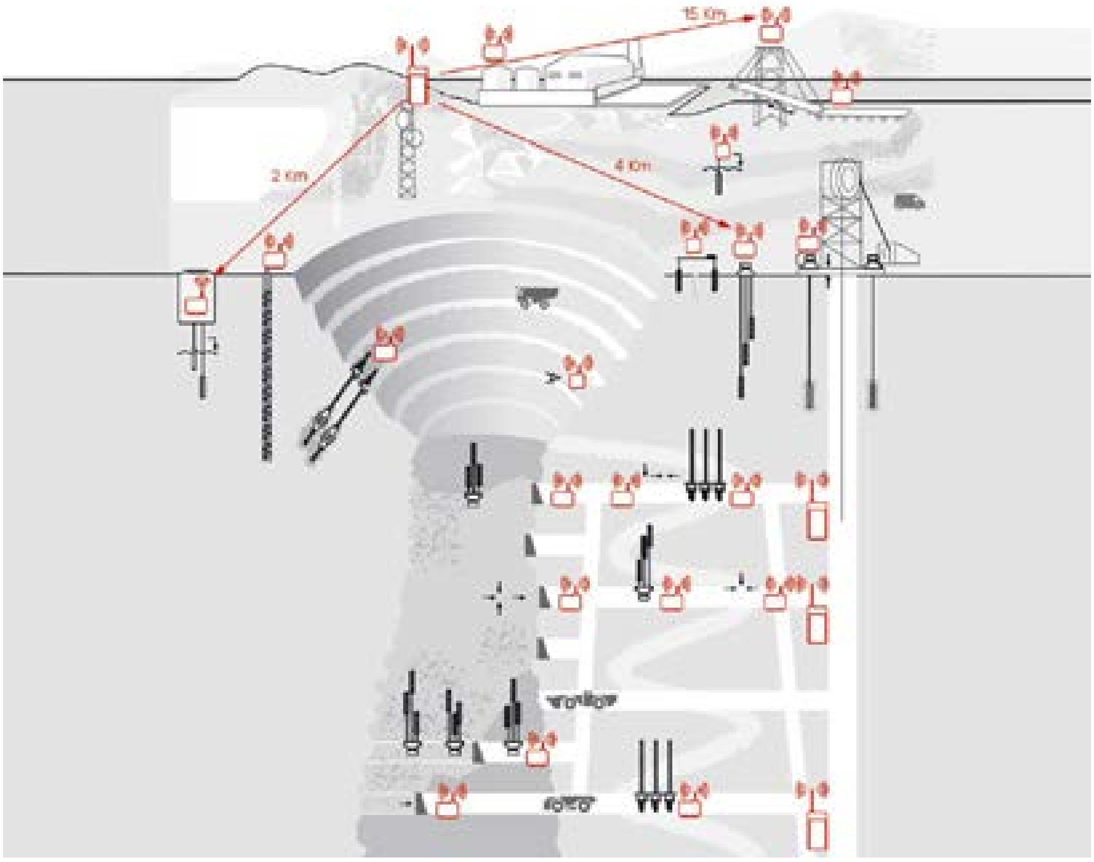
REMOTE REAL TIME MONITORING SYSTEM WITH SDI-12 DIGITAL INTERFACE SENSORS AND DATALOGGERS

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

Encardio-rite offers state-of-the-art wireless monitoring solution comprising of wireless RF 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.



TYPICAL SCHEME OF WIRELESS SENSOR NETWORK

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 on the next page.

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 inputs from vibrating wire and analog devices to automatically collect, store and transmit data. 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.

8 AUTOMATIC 3D DEFORMATION MONITORING SYSTEM

Encardio-rite offers an automatic three-dimensional deformation monitoring system with the highest accuracies achievable in the industry presently. Displacement data is measured from the prism targets by a high precision and accuracy 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 user.

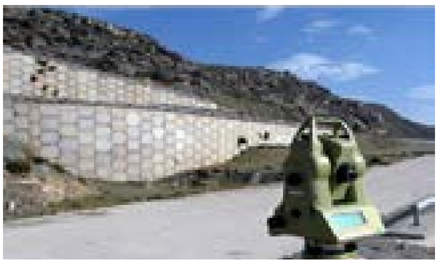
9 LASER SCANNING

Laser scanning is a new method of surveying and conducting geometric documentation of buildings, megastructures and engineering projects (such as tunnels, bridges, dams, etc) or other construction works and objects which require a high degree of analysis, are difficult to reach or gain access to. It is based on exceptionally dense mapping of three-dimensional coordinates of the points on the surface of the structure that is to be surveyed, taken at speeds ranging from a few thousand up to a million points per second. From the point where cloud is produced, the exported section profiles can be used to monitor deformations or displacements.

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

In the geodetic survey, high accuracy measurement of displacements is possible, but of a small number of points when compared to the size of the dam. The number of monitored points is even smaller in the automatic measurement system with robotic total stations. On the other hand, laser scanners are capable to acquire a very huge number of points, so that the control could be extended to the whole structure instead of being limited to a few points.

GATEWAY INSTALLED FOR WIRELESS MONITORING

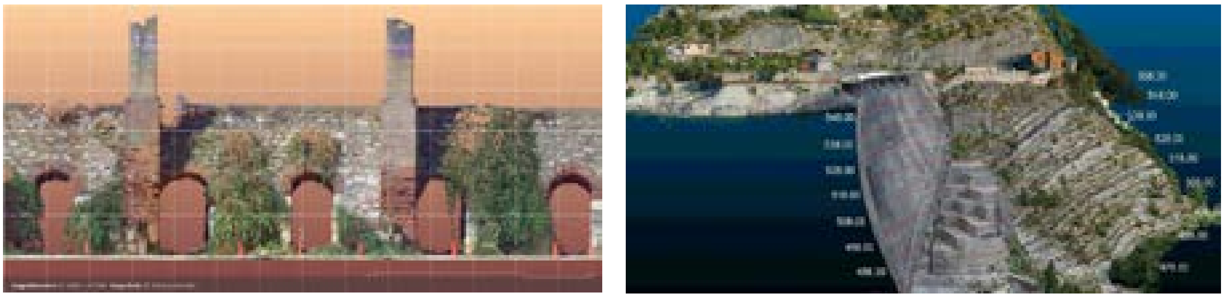


AUTOMATIC SURVEYING SYSTEM (ATS)

10 AERIAL SURVEY WITH UNMANNED AERIAL VEHICLES (UAV)/DRONES

This is a rapid and safe way of collecting data from a large-scale objects such as dams, where frequent geospatial and/or imaging information is needed for topo-survey prior to construction, monitor progress of a running project and also after construction for regular inspection and maintenance.

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 the monitoring campaign.



LASER SCANNING

SURVEY BY DRONE / UAV (UNMANNED AERIAL VEHICLE)

11 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. 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 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
- Layout plan can be incorporated with the 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
- Generate combined charts of related parameters
- Create graphs from any combination of parameters and time period
- Instant automatic alerts via SMS or email to authorized personnel
- 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.

TYPICAL LONG-TERM ONLINE DATA FROM A DAM

12 CONCLUSION

An online monitoring solution for large dams is not expensive compared to what is spent later on in revival of dams, rescue operations and rehabilitation. By monitoring dam performance, corrective action may become possible earlier than the occurrence of any failure. Most dam failures that have occurred could have been avoided if the structure's behaviour had been inspected, monitored and analyzed continuously and proper corrective measures had been taken timely.

Type and nature of dam decide the number of instruments to be used and at what locations they are to be embedded in the dam. There should be close cooperation between the designers, instrumentation specialists, monitoring data analysts and site authorities to achieve the goal of the instrumentation program. To obtain 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.

The collection and analysis of large quantities of data from the huge area require centralised 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 do the processing and analysis of the collected raw data and provide accurate data, rapidly, enabling efficient alarm systems. Today, it is practically impossible to consider monitoring of a large dam without an automated monitoring system.

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