APPLICATION NOTE

ONLINE MONITORING OF NUCLEAR POWER PLANTS

Encardio-rite is partnering through an agreement with SITES, France which is a leading Organization in the World in Structural Health Monitoring of Nuclear Power Plants

1 INTRODUCTION

According to International Energy Agency (IEA), by the end of 2019, there were 449 nuclear power reactors in the World supplying around 11 % of the World Energy requirement. The seven Countries having the largest nuclear power generation capacity in the World are:

1.	USA	96 reactors	97,565 MW
2.	France	57 reactors	62,250 MW
3.	China	48 reactors	45,518 MW
4.	Japan	33 reactors	31,679 MW
5.	Russia	38 reactors	28,402 MW
6.	Korea	24 reactors	23,172 MW
7.	Canada	19 reactors	13,554 MW

A total of 53 nuclear reactors are under construction presently, with 10 in China, 7 in India and 4 each in Russia, Korea and UAE.

India has 21 reactors at seven nuclear plant locations with a total capacity of 6,680 MW. Nine more reactors with a capacity of 6700 MW are under construction. Two of these are at Gorakhpur where the project got delayed due to some problems in land acquisition. The remaining seven are expansion of existing capacity at Kalpakkam, Kakrapar, Rajasthan, Kundankulam, Tarapur.

Table 3 gives prospective nuclear power plants to be set-up in India. In cabinet meeting of April 17, 2017, Government of India approved construction of 10 units of India's indigenous Pressurized Heavy Water Reactor (PHWR) with a total installed capacity of 7000 MW. In addition to this, 6 x 1650 = 9,900 MW European Pressurised Reactors (EPR) are proposed to be setup at Jaitapur in association with EDF France. USA is keen to associate in setting up 6 x 1000 = 6,000 MW Westinghouse AP-1000 pressurised water reactors at Kovada. Similarly, Russia is interested is setting up 6 x 1000 = 6,000 pressurised water Voda Vodyanoi Energo Reactors (VVER) at Kavali and 2 x 1000 = 2,000 VVER at Kudankulam.

Table 1: Operational nuclear power plants in India

Power station	Operator	State	Type	Units	MW
Kaiga	NPCIL	Karnataka	PHWR	220 x 4	880
Kakrapar	NPCIL	Gujarat	PHWR	220 x 2	440
Kudankulam	NPCIL	Tamil Nadu	VVER-1000	1000 x 2	2,000
Kalpakkam	NPCIL	Tamil Nadu	PHWR	220 x 2	440
Narora	NPCIL	Uttar Pradesh	PHWR	220 x 2	440
Rajasthan	NPCIL	Rajasthan	PHWR	200 x 1 220 x 4	1,080
Tarapur	NPCIL	Maharashtra	BWR PHWR	160 x 2 540 x 2	1,400
				Total	**6,680**

Table 2: Nuclear power plants and reactors under construction in India

Power station	Operator	State	Type	Units	MW	Target date
Kalpakkam	Bhavini	TN	PFBR	500 x 1	500	2020
Kakrapar Unit 3 & 4	NPCIL	Gujarat	IPHWR-700	700 x 2	1,400	2022
Gorakhpur	NPCIL	Haryana	IPHWR-700	700 x 2	1,400	2025
Rajasthan Unit 7 & 8	NPCIL	Rajasthan	IPHWR-700	700 x 2	1,400	2022
Kudankulam Unit 3 & 4	NPCIL	TN	VVER-1000	1000 x 2	2,000	2025-2026
				Total	**6,700**	

Table 3: Planned nuclear power plants in India

Power station	Operator	State	Type	Units	MW
Jaitapur	NPCIL	Maharashtra	EPR	1650 x 6	9,900
Kovvada	NPCIL	Andhra Pradesh	AP1000	1100 x 6	6,600

Kavali	NPCIL	Andhra Pradesh	VVER	1000 x 6	6000
Gorakhpur	NPCIL	Haryana	IPHWR-700	700 x 2	1,400
Bhimpur	NPCIL	Madhya Pradesh	IPHWR-700	700 x 4	2,800
Mahi Banswara	NPCIL	Rajasthan	IPHWR-700	700 x 4	2,800
Kaiga	NPCIL	Karnataka	IPHWR-700	700 x 2	1,400
Chutka	NPCIL	Madhya Pradesh	IPHWR-700	700 x 2	1,400
Kudankulam Unit 5 and 6	NPCIL	Tamil Nadu	VVER-1000	1000 x 2	2,000
Madras	BHAVINI	Tamil_Nadu	FBR	600 x 2	1,200
Tarapur			AHWR	300 x 1	300
Total					**41,800**

2 PURPOSE OF THE MONITORING SYSTEM

A monitoring system is required to monitor the structural integrity of the containment building and the individual/common raft. This allows assessment of the mechanical behaviour of the building at various stages:

- during construction,
- during the acceptance test and the periodic airtightness tests,
- normal operation.

The system aims to check the mechanical behaviour of the containment within the design limits thought its lifecycle. Use of the system varies from a country to another but SIT (Structural Integrity Test) are performed on a regular basis (for instance before commissioning, after 1 year of operation and then every 10 years).

SIT consist in a pressurization of the containment building simulating an accidental condition inside (for instance 4 bars). Various information returned by the monitoring system are compared to the expected values as per design.

For nuclear power plants, it is strongly recommended that structural health is continuously monitored to ensure the following:

- Safety of personnel, material, nearby communities and the environment.
- Generating long-term reliable data on the various elements of the plant especially foundations, anchoring systems, and containment structures to see that it remains within the design limits thought its lifecycle.
- Data to determine the effects of natural calamities such as earthquake, cyclone, flooding, etc. on the structure.
- Data to plan and schedule predictive and preventive maintenance programs for the plant.

- Parameters measured vary from Country to Country but generally are as follows:Settlement and distortions of the nuclear island raft (Geodetic monitoring of displacement, hydraulic settlement and strain along with temperature measurement)
- Containment distortions (plumb lines and invar wires)
- Local distortions in containment and tendon failures detection (embedded strain gauges + temperature measurement, tiltmeters and local cartography devices in the equipment hatch zone). Surface strain gauges are an option, in addition to embedded ones.
- Pre-stressed cable tension (centre hole load cells),
- Moisture content of concrete
- Pressure within the containment structures
- Environmental factors influencing the structural health

A summary of parameters prepared by SITES on the basis of data from EDF French practices, LAES-2 at Leningrad, SITES involvement in RCC-CW part M workgroup and various recent tenders (HPC, Taiwan 7/8, PAKS 2, Hungary etc.) is as follows:

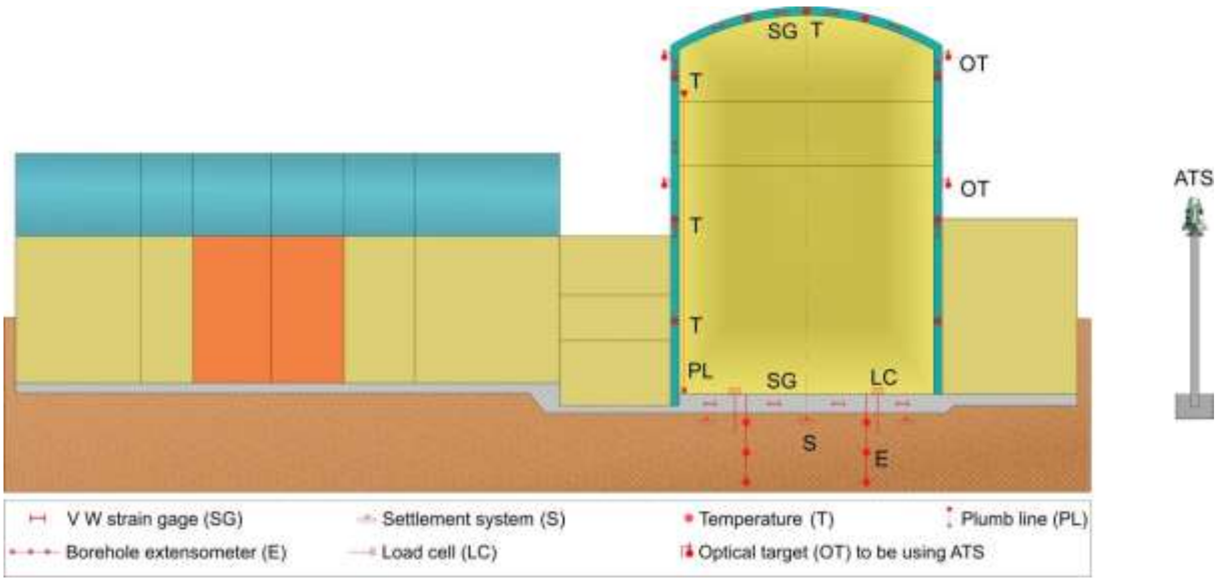
Parameter	**VVER 1200**		**EPR**	
	Sensor	**Indicative qty.**	**Sensor**	**Indicative qty.**
Raft vertical deflection			Hydrostatic levelling system	17
Stress in reinforcement	VW strain gage welded on reinforcement bars	80		
Concrete Strain	VW strain gage	306	VW strain gage	401
Concrete temperature	PT100	110	PT100	207
Post tensioning duct stresses	Bragg lines	6		
Post tensioning load	Load cells	12	Load cells	4
Wall facing extensometers	Bragg sensors	36		
Pendulums	Set of anchorage / ducts / wire / weight	4	Set of anchorage / ducts / wire / weight	9
	Pendulum reading units	16	Pendulum reading units	9
Vertical global deflection	Michelson optic fiber sensor	28	Invar wires + displacement sensor	3
Concrete moisture	TDR	16	TDR	4
Structural tilt			Inclinometer	11

3 STRUCTURAL MONITORING SOLUTIONS

Encardio-rite offers a wide array of rugged sensors, associated data retrieval & telemetry systems and online web-based monitoring services for the long-term safety monitoring of nuclear power plants. The Instrumentation and Control systems produced by Encardio-rite have a proven track record for reliability and long-term performance under harsh conditions.

It also offers newer monitoring technologies such as automatic 3D deformation monitoring using ATS, laser scanning with advanced deformation monitoring software and aerial survey using drones for keeping a tab on the structural health of nuclear power plants.

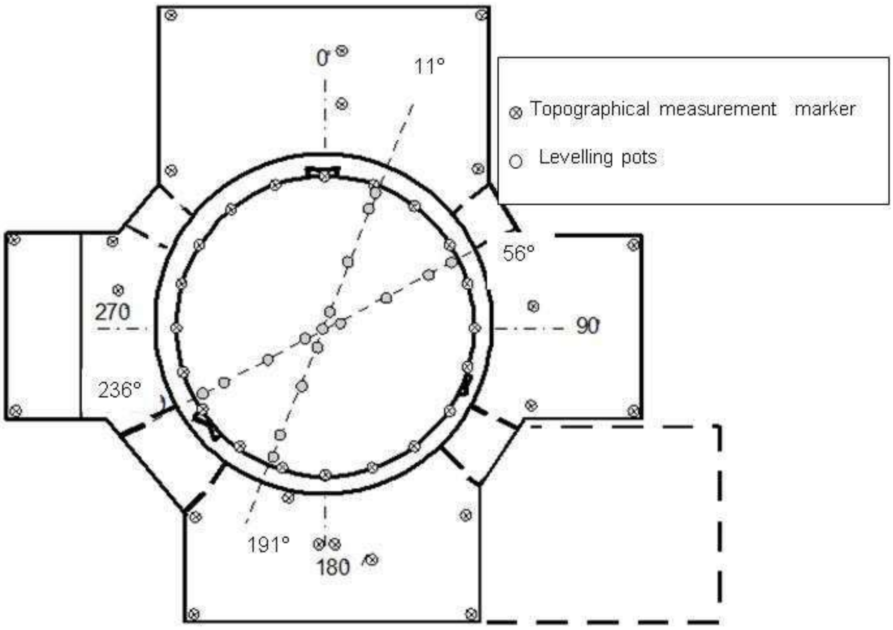
Surface and subsurface sensors that can be used for safety monitoring of nuclear power plants are given below with a typical location plan. It is noteworthy that subsurface monitoring gives important information on the ground/soil movement which may affect the stability of the plant's structure.



- For settlement and deformation monitoring of the nuclear island raft Encardio-rite can provide the following instruments:
  - Model EPS-12-60 topographical marker/pavements settlement points monitored using a digital level with invar staves and model ERT-20P2 mini prism target monitored using a total station. These are used for motoring vertical settlements (z) and 3D movements (x, y & z) respectively. Customized survey targets can be produced on demand.

    Topographical markers are equally distributed throughout the pre-stressing gallery where inner containment wall vertical tendons are tensioned (refer to the figure below for a typical arrangement). These are also installed for settlement monitoring of other important buildings in the nuclear island comprising of the containment building, auxiliary building, and the fuel handling area.
  - Model ESM-30V liquid level settlement system. Fluid-filled vessels/pots of the system with low range vibrating wire fore transducers with in-built thermistors are embedded in the common raft foundation measuring the settlement of the portion of the raft under the reactor building. For the typical location of the pots of the system, refer to the below figure. The system is suitable for remote monitoring.
  - Encardio-rite model EDS-70V electrical multipoint borehole extensometer system with vibrating wire displacement transducers for monitoring relative vertical movements. The head of the extensometer is anchored to the raft foundation and it measures the vertical movement of the raft and various underlying strata, in which the system's anchors are located. These movements are measured with reference to deep and

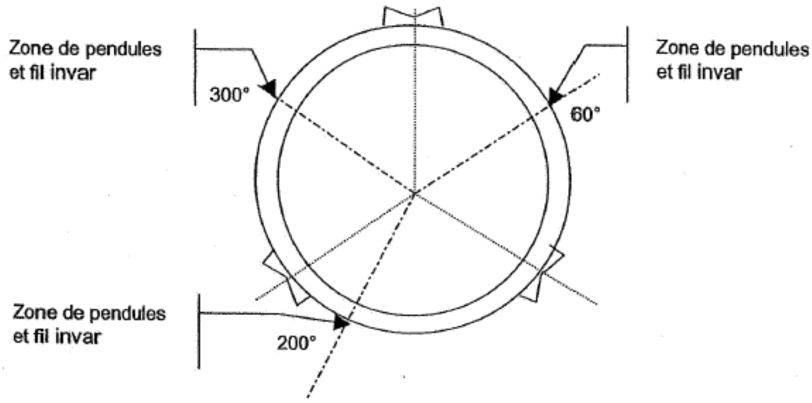
stable rock in which the deepest anchor is embedded. The system is suitable for remote monitoring.



Typical locations of topographical markers and hydraulic settlement system pots in the raft

- For global deformation monitoring of the cylindrical wall of the containments, the Encardio-rite model EDS-50 normal plumb line with model EPR-01S telecoordinometer to monitor relative horizontal movements in x & y planes. They give critical deformation at different levels owing to the following:
    - Horizontal deformation of the inner wall under the effect of prestressing and test pressure
    - Deferred and irreversible deformations due to concrete shrinkage, creep and relaxation of prestressing tendons
    - Deformation induced by temperature variations

  Normal pendulums comprising of invar wires are generally installed at 3 different levels each at three radial vertical lines at critical locations. The pendulum reading tables and readouts are located at the required elevations in the containment annulus. For the typical location of the pendulums with invar wire in the containment structure refer to the figure below:



Typical locations for the normal plumb lines with invar wire

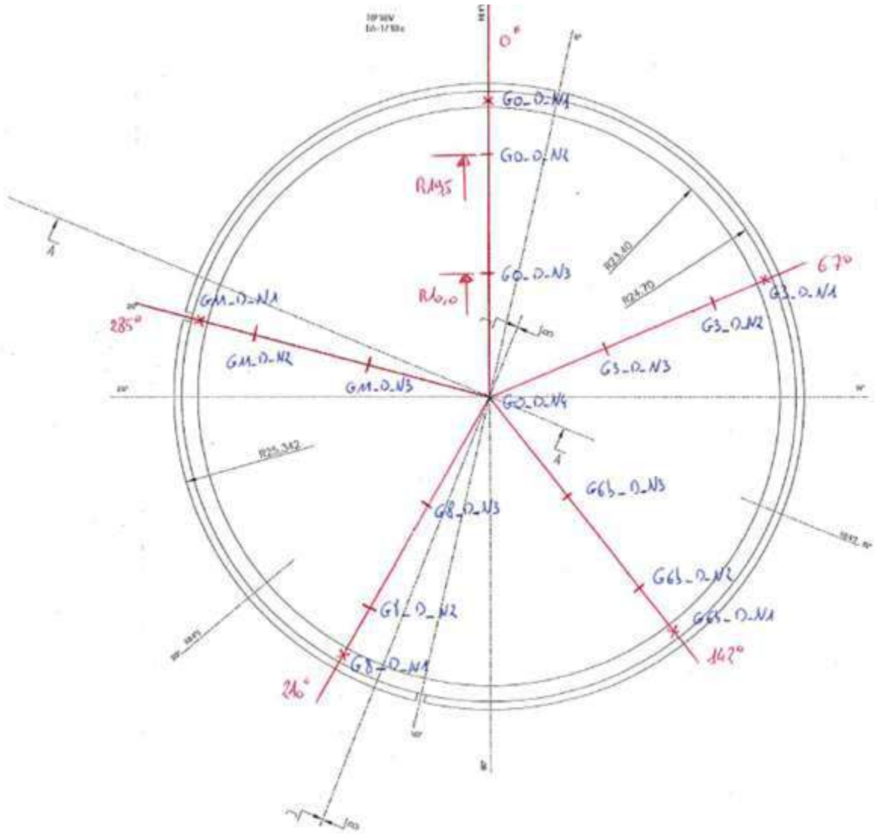
- For the measurement of local strains in the containments, dome, raft and other structures of the plant during construction, periodic testing and in normal operation Encardio-rite model EDS-11V hermetically sealed vibrating wire strain gage or model EDS-21V-E extended range vibrating wire strain gage is embedded. These are placed in the concrete structures to measure local strain in the inner face, outer face and the center. Based on the averaged results, and modulus of concrete elasticity, stress can be derived.

  The embedment strain gages are installed first in the cages generally made of 10 mm dia. rebars in the following configuration:

  - cage of triple type, housing 3 no. strain gages: 1 no. each in tangential, vertical and radial positions.
  - cage of double type, housing 2 no. strain gages: 1 no. each in tangential and vertical positions.

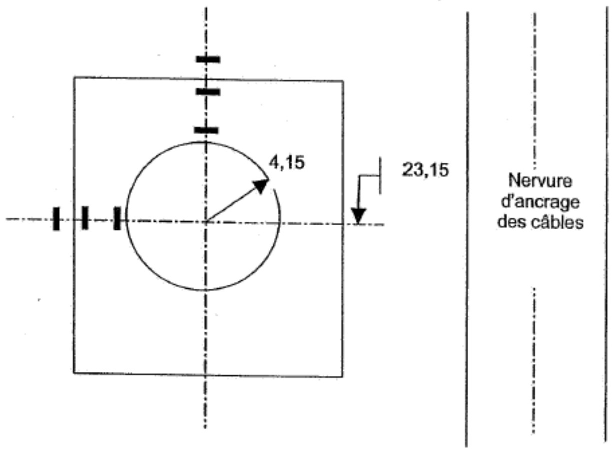
  Typical layout of the strain gages in a nuclear power plant is as follows:

  - In the inner containment wall at around 14 vertical lines along the circumference with a triple type cage at 3 or 6 different levels in each.
  - In the dome a triple type cage each at around 5 radial lines at 3 different radii; and 3 no. triple type cages in the center.
  - In the common raft at two different levels 1 no. triple type at the centre, and a triple type each at 3 different radii.
  - In the equipment hatch area at double type at 3 points each on a vertical & a horizontal line passing through the axis of the sleeve.



Typical location of strain gages at the common raft

For determining the temperature at the location of the strain gage, each gage has an inbuilt thermistor (YSI 44005).



Typical location of strain gages in the equipment hatch

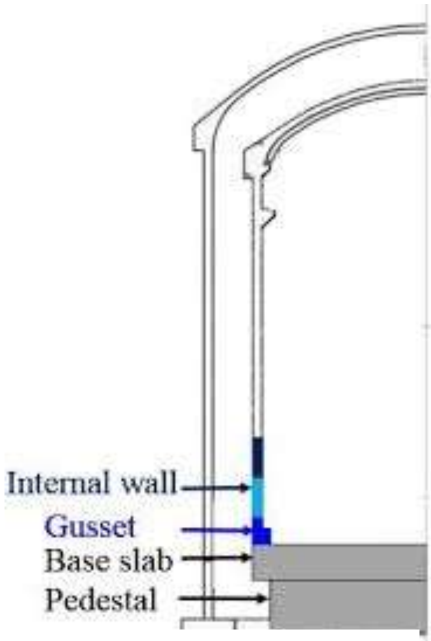
- For monitoring the rotational movement of the containment's gusset (refer to figure below) at its junction with the foundation Encardio-rite model EAN-92M tilt meters with SDI-12 output are installed at the key locations along the circumference. These tilt meters, made of stainless steel are electron beam welded with a vacuum of 1/1000 Torr inside it. These can also be installed at the ring at the junction between the dome and the cylindrical part of the containment at the key locations to measure the rotational movement.

- For monitoring the variations in the tension in the prestressing tendons used for stabilizing the foundation of the reactor Encardio-rite model ELC-30S resistive strain gage type with 8 no. foil type strain gages or ELC-32V vibrating wire type center hole load cell with up to 8 no. VW elements are available. Normally, purely vertical tendons are chosen for monitoring the tension.

- For the measurement of the temperature distribution throughout the wall thickness Encardio-rite model ETT-10V vibrating wire temperature or model ETT-10PT RTD platinum resistance temperature sensor are embedded at critical locations in the containment's dome, walls, and the base slab.

  Temperature sensors are also embedded around the steam penetrations in the containment to monitor the concrete temperature.

  Additional temperature sensors are installed at key locations inside the reactor building, within the containment annulus and outside the reactor building in the open air to determine the temperature gradients.



Location of the gusset in the containment structure

- To monitor moisture content in the air or humidity, Encardio rite EWH-101T hygrometers are installed inside the containment and in the space between the inner and outer containment.

- Water content sensors are embedded in concrete at different depths in the containment wall thickness at key locations to monitor its water content with time to monitor its aging process. Reference water content sensors from the same batch as the embedded water content sensors are supplied to estimate the aging of non-accessible sensors.
- To monitor pressure, sensors are installed inside the reactor building, in space between the containment walls and outside reactor building (for atmospheric pressure measurements).

The following sensors may also be considered for structural health monitoring:

- Encardio-rite model ESDL-30MT SDI-12 data logger with in-built tiltmeter to measure and log tilt data (to be installed ideally at an indoor location or in shade to prevent the effect of large temperature fluctuations on the monitoring results). ESDL-30MT is provided with an integral GSM/GPRS modem for storing and transmitting data to a central server.
- Encardio-rite model EDJ-40V vibrating wire crack meter to monitor structural cracks.

Encardio-rite provides two options to automatically log, store and transmit data to a central server from the above-mentioned sensors:

- Model ESDL-30 SDI-12 data logger with an integral GSM/GPRS modem. Interface cards are available for conversion of sensor outputs to SDI-12 digital output, where the sensors do not have an SDI-12 interface output.
- Model EDAS-10 based on Campbell Scientific's CR1000 measurement and control module with GSM/GPRS modem.

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.

It is to be noted that quantities of the above sensors and systems vary from country to country depending upon local nuclear safety authority's regulations and assessments. Usually, the authorities require compliances of the instruments with standards like DIN, IEC, GOST, etc. Local soil features also govern the types and quantities of these. Encardio-rite products comply with major international standards. It can also apply for any special certification required for a particular project.

For 24X7 near real-time data access Encardio-rite provides online web data monitoring service (WDMS) that presents the data of the above sensors as graphs, tables, overlaid on georeferenced maps, site plans, etc. It enables automatic alarms to the authorized users at different locations, on their computers/laptops. More details are given in the following section 5.

On-line monitoring using the above instrumentation gives a timely warning on any impending danger. The purpose is to assist and inform the stakeholders about the continued performance of structures under gradual or sudden changes to their state. The main factors affecting the performance are the degradation of the structure with age, undue settlement/tilt due to soil conditions or nearby construction activity, vibrations due to heavy machinery, groundwater level, atmospheric conditions, etc. This may be reflected in abnormal changes in the monitored values.

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

The heart of the online structural monitoring instrumentation system is a Public Cloud-Based Web Data Monitoring Service offered by Encardio-rite for retrieving data from the field data loggers, archiving the data in a SQL database, processing the data and presenting the processed data in

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

tabular and most suitable graphical forms for easy interpretation of the logged data. The tables and graphs related to any site or sites can be accessed by authorized personnel who can log in to their site using the supplied login ID and access password from anywhere in the world over the internet.

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

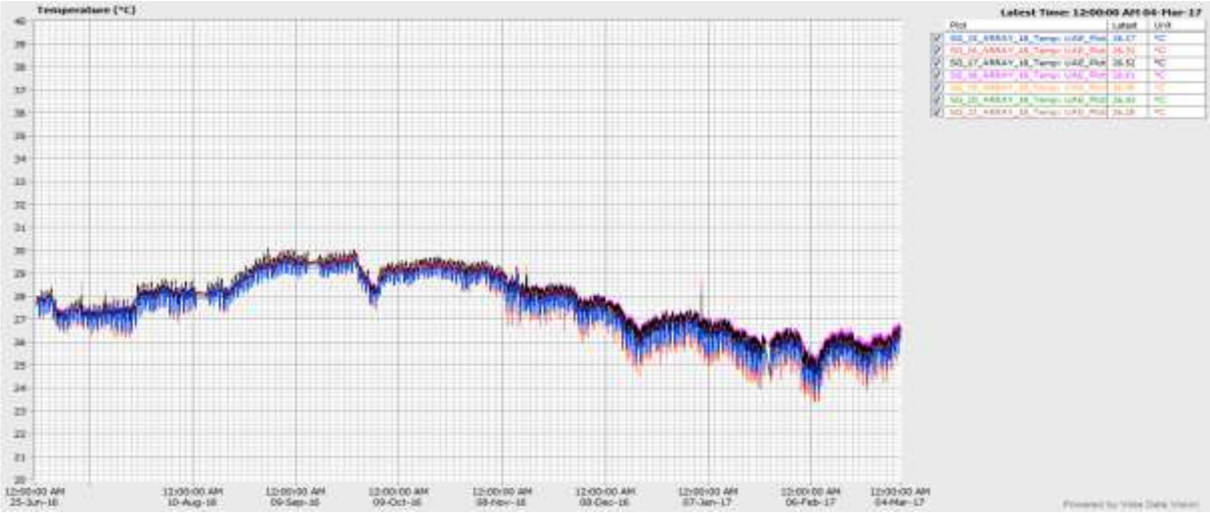
A graphic like a map, ground plan or a photograph of the plant can be put on the opening screen marked with the position of installed sensor/sensors with a square dot or hotspot near its symbol. As soon as the mouse pointer is brought over the hot spot location the corresponding sensor details like sensor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

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.

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.

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

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.



Typical online data

5 STRUCTURAL SURVEY

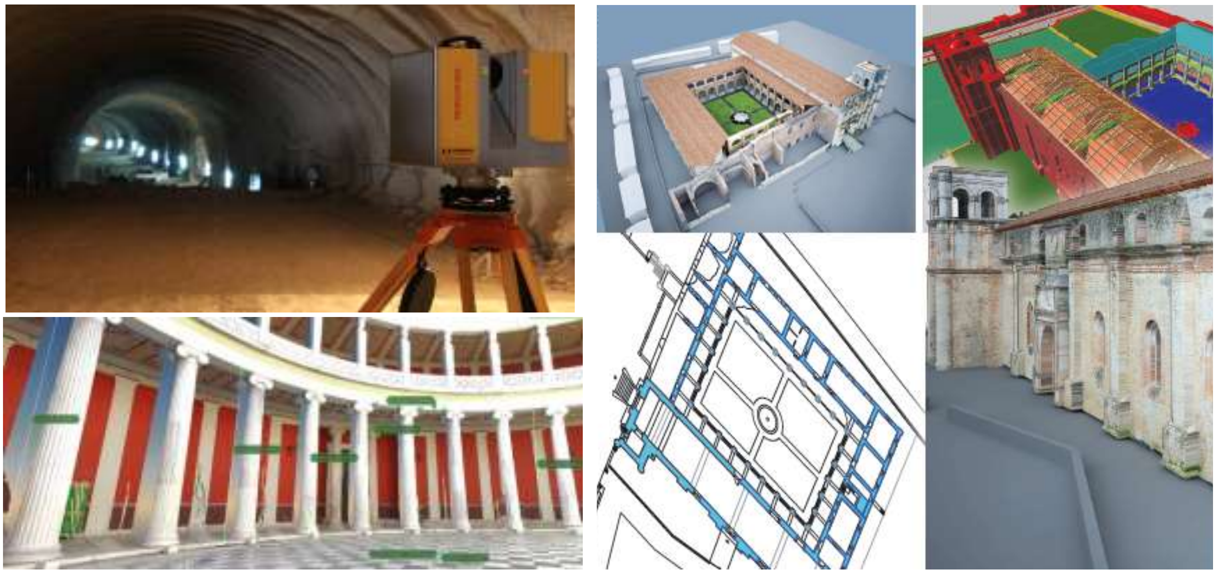
Encardio-rite group of companies and the Moniterra group of affiliated companies are associated together to offer a complete solution for safety monitoring. With our combined experience in online structural surveys and monitoring, we are today one of the most formidable companies in the world in this field.

5.1 Laser scanning

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

Recent developments, especially in the software, have made it a very convenient and cost-effective tool to accurately monitor structural deformations in 3D. 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 several other analyses 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 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 – discrepancies

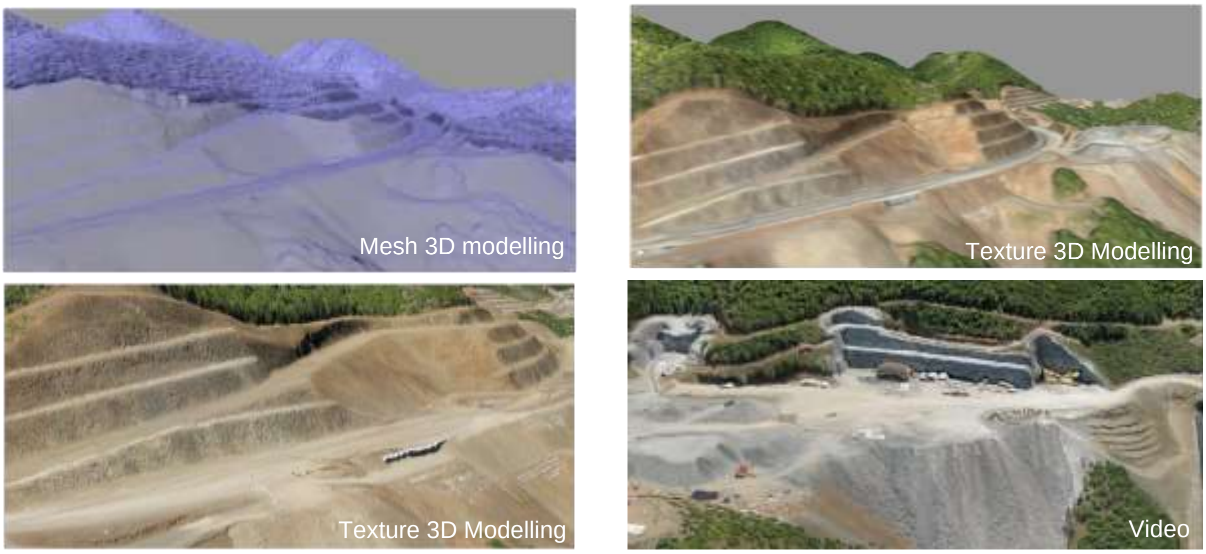
5.2 Aerial Mapping using Unmanned Aerial Vehicles (UAV/Drone)

Inspection of huge and complex structures like Nuclear Power Plants 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 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



5.3 Automatic deformation monitoring system (ATS)

The Real-Time 3D deformation monitoring system is a systematic tracking of any alteration that may take place in the shape or dimension of a Nuclear Power Plant's structure as a result of stress, load, aging, etc.

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

The whole system can be controlled/re-configured remotely after installation at the site. The on-site system transmits the collected raw data to a remote server/computer via GPRS/GPS. Raw data is processed into meaningful results by specialized software. 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.

6 CONCLUSION

The data observed from the structural instrumentation for Nuclear Power Plants described above plays a vital role in safeguarding its structure, nearby communities and environment at large, providing timely warnings to take corrective measures. Owing to the extremely critical nature of the above energy complexes, the instruments used and the manpower deployed for installation, monitoring and maintenance of instruments have therefore 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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