RITE GEOSYSTEMS

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METASENSING FOR MEGA STRUCTURES

APPLICATION NOTE

ONLINE MONITORING OF NUCLEAR POWER PLANTS

1 INTRODUCTION

Geotechnical and geodetic monitoring is an integral part for ensuring that nuclear safety-related facilities meet design objectives. Due to the highly regulated environment of a Nuclear Power Plant (NPP), an acceptable instrumentation plan has to be developed for monitoring the performance of foundations, excavation support systems, containment, power plant and other facilities at the site. The instrumentation and monitoring of these critical structures are performed during construction and over the life of the facility.

This application note has been developed mainly for India where a large number of nuclear power plants are envisaged to be set-up by NPCIL (PHWR 700) with indigenous technology and in association with the Russians (VVER 1000), Americans (AP 1000) and French (EPR 1650). Encardio-rite, in association with SITES, France is best placed anywhere in the World to provide a comprehensive total solution with leading technology for the safety Instrumentation & Monitoring of Nuclear Power Plants. SITES France, a partner of Encardio-rite through an agreement, is a leading Organization in the World in Structural Health Monitoring of Nuclear Power Plants Encardio-rite well proven digital sensors and automatic dataloggers provide comprehensive monitoring through an Advanced Data Management System which can be installed in a control room with use of minimal cables.

The Data Management System (Drishti from Encardio-rite and Simon-e from SITES) have powerful tools for retrieving data from automatic data loggers, archiving the data in a SQL database, performing the required calculations on the data and presenting the processed data in tabular and most suitable graphical forms for easy interpretation of the logged data and generating alarm messages. It allows storing and organizing data collected from a wide variety of dataloggers.

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 (table 1). Nine more reactors with a capacity of 6,700 MW are under construction (table 2). 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, Kudankulam & Tarapur.

Table 3 lists 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 in associating with setting up 6 x 1000 = 6,000 MW pressurised water Voda Vodyanoi Energo Reactors (VVER) at Kavali and 2 x 1000 = 2,000 MW 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	TN	VVER	1000 x 2	2,000
Kalpakkam	NPCIL	TN	PHWR	220 x 2	440
Narora	NPCIL	UP	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 3 & 4	NPCIL	Gujarat	IPHWR	700 x 2	1,400	2022
Gorakhpur	NPCIL	Haryana	IPHWR	700 x 2	1,400	2025
Rajasthan 7 & 8	NPCIL	Rajasthan	IPHWR	700 x 2	1,400	2022
Kudankulam 3 & 4	NPCIL	TN	VVER	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	AP	AP1000	1100 x 6	**6,600**
Kavali	NPCIL	AP	VVER	1000 x 6	**6000**
Gorakhpur	NPCIL	Haryana	IPHWR	700 x 2	**1,400**
Bhimpur	NPCIL	MP	IPHWR	700 x 4	**2,800**
Mahi Banswara	NPCIL	Rajasthan	IPHWR	700 x 4	**2,800**
Kaiga	NPCIL	Karnataka	IPHWR	700 x 2	**1,400**
Chutka	NPCIL	MP	IPHWR	700 x 2	**1,400**
Kudankulam 5 & 6	NPCIL	TN	VVER	1000 x 2	**2,000**
Madras	BHAVINI	TN	FBR	600 x 2	**1,200**
Tarapur			AHWR	300 x 1	**300**
Total					**41,800**

2 PURPOSE OF THE MONITORING SYSTEM

Nuclear Power Plants are generally built considering a "standard design". Geotechnical and structural design parameters should be monitored to confirm that standard design parameters envelope site specific parameters. In cases where site specific conditions exceed standard design values (e.g. high seismicity, soft foundation material etc.), monitoring offers significant information and value during construction and operation of the plant. A geotechnical instrumentation plan, including "alert" or "trigger" values that result in some action to be taken, is part of monitoring efforts.

The instrumentation program defines the instrument needs, objectives, specifications, quality assurance, locations, installation, parameters to be monitored, monitoring frequency, maintenance, calibration frequency, trouble shooting, data management including interpretation, presentation and reporting. It defines the responsibility of persons involved and their qualifications.

One of the most important aspect of the required monitoring system is 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.
- after exceptional events like earthquake

The system aims to check the mechanical behaviour of the containment within the design limits throughout its lifecycle. Use of the system varies from Country to Country and site to site 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 mandatory for EPR as per RCC-CW standards 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 throughout 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.
- Settlement and distortions of the nuclear island raft (Geodetic monitoring of displacement, hydraulic settlement and strain along with temperature measurement).

  Data collected via the monitoring system at early age provide information to determine predictive model for structure aging. Thus, it is recommended that sensors are connected quickly to the data logging system after installation

  Most Nuclear Power Plants (NPP) are located at rock sites. Settlement usually is an issue only during construction. Some NPP in France have settled by 30 cm since they have been built, and it still continues. The key for design is the not the absolute settlement but differential settlement during construction to maintain the integrity of the conduits between various plant structures.

  Settlement monitoring is necessary when settlement behavior can lead to significant induced stress in the primary structural system.

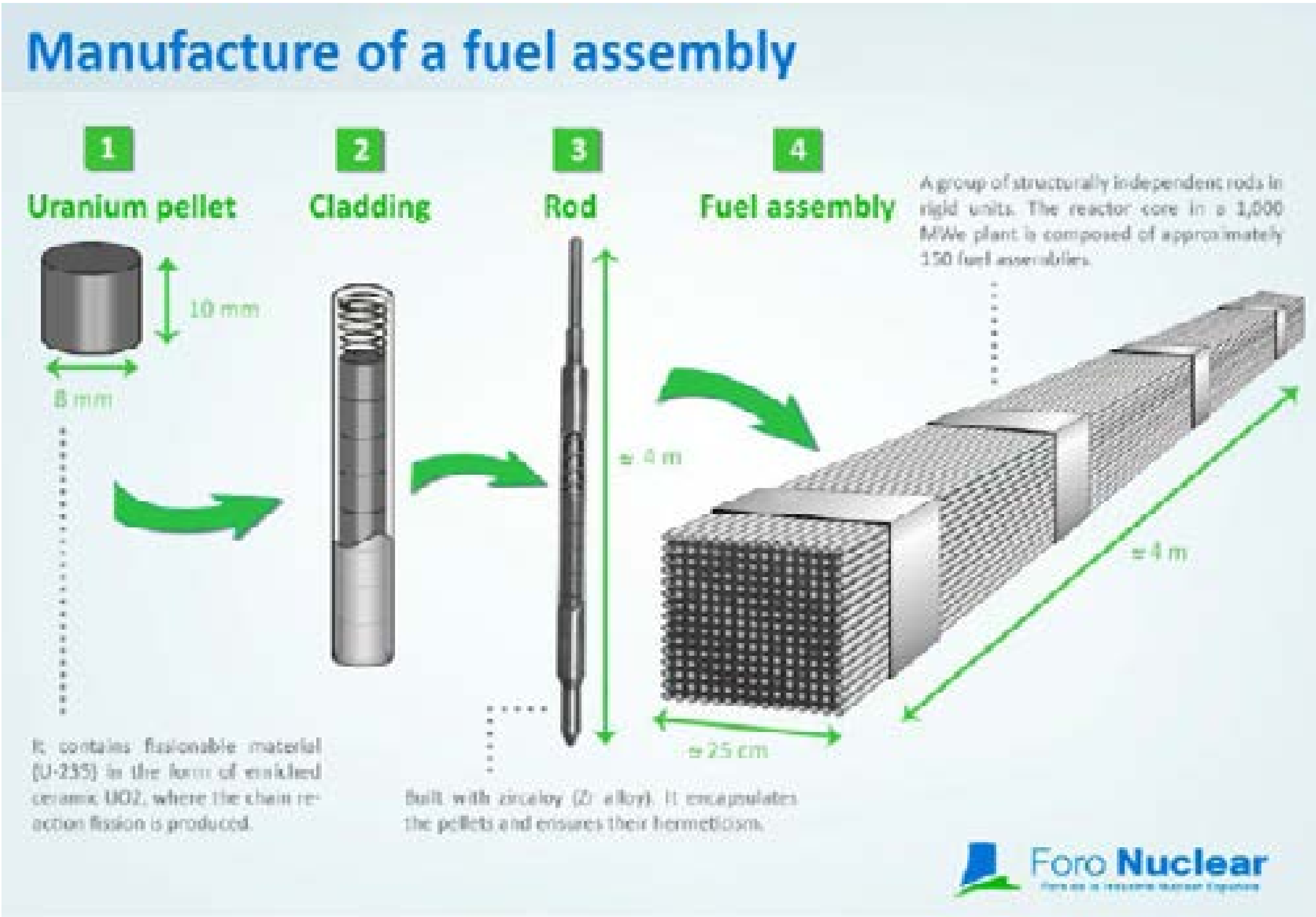
- Containment distortions (plumb lines and invar wires). Plumb line are mostly used to
  - measure general tilting of the containment building during the life of the structure because of potential differential settlement,
  - measure the "barrel effect" during SIT
- Local distortions in containment and 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. These are often used during SIT to measure change of height of the containment due to the pressure.
- Pre-stressed cable tension (centre hole load cells),
- Moisture content of concrete
- Pressure within the containment structures. After content, sensors are only used for ageing assessment purpose.

2.1 Few details on NPP

On a PWR NPP, there are 3 barriers to prevent the spread of nuclear material in the environment which is the basic principle of nuclear safety.

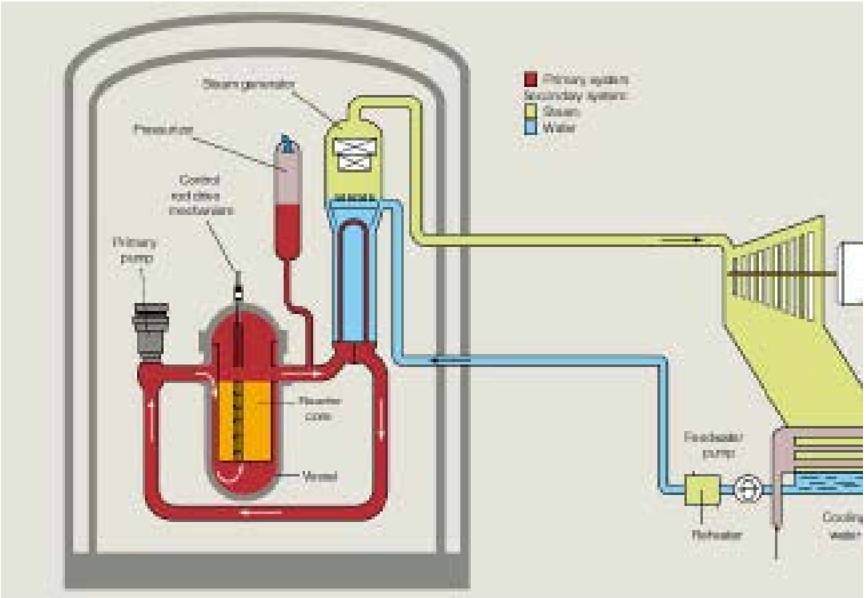
2.1.1 The 1st barrier is the fuel pellet claddings

Nuclear fuel that goes into the reactor core are fuel assemblies. In normal condition, nuclear material should always remain inside the cladding. In accidental conditions, the cladding could melt due to excessive high temperature, liberating nuclear materials in the reactor core. In that case, we count on the 2nd barrier to contain the nuclear materials.



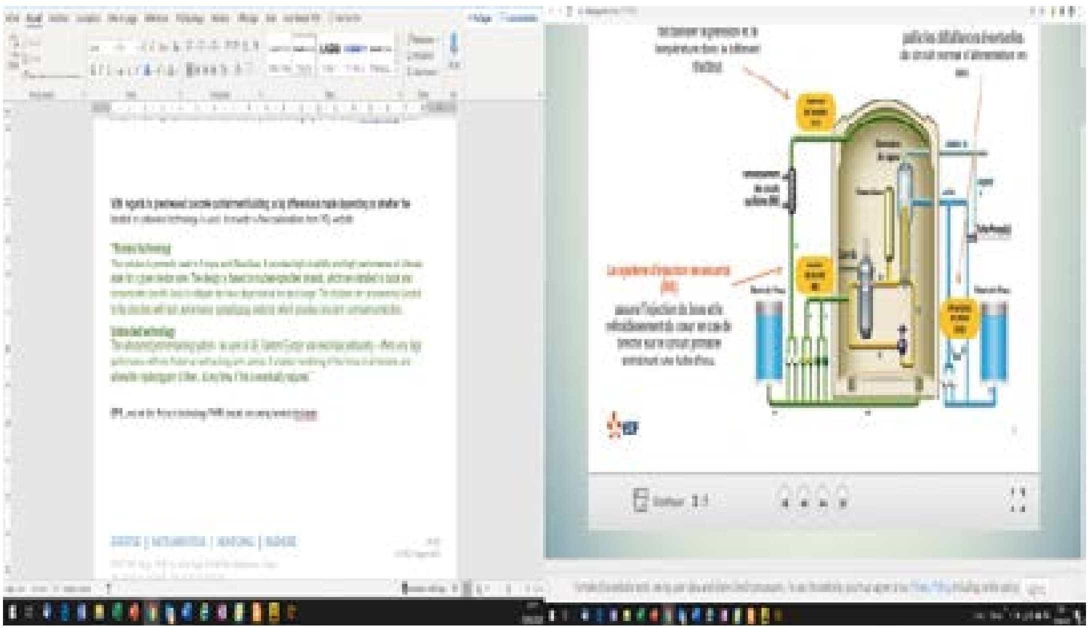
2.1.2 The 2nd barrier is Primary cooling system

If the 1st barrier has failed, the nuclear material should stay in the primary cooling system which is a closed loop located inside the containment building. The water circulating inside the primary cooling system is at 155 bar and between 290°C and 325°C. In case of excessive temperature in accidental conditions, a breach could occur in the primary cooling system pipe. In that case, the nuclear contaminated water would be instantly vaporized increasing the pressure into the containment building, the containment being the 3rd and last barrier.



2.1.3 The 3rd and LAST barrier is the containment building:

In case of water vaporized inside the containment, the pressure inside the containment building could go up to 4 bars until a back-up system (EAS in green hereunder) starts to spread water from the top to make the pressure decrease into the containment building.



2.1.4 The 4 bars value is sometimes called "accidental pressure" or "LOCA accidental pressure".

Note that accidental pressure varies for on NPP design to another. In case of EPR, it is 4 bars, in other technologies in can be less (1 bar). The basic principle of the containment building monitoring is to make sure that the containment building can withstand the accidental pressure through its life span. This is the reason why we are performing Structural Integrity Test (SIT) periodically at 4 bars as you mentioned. Usually it is more than 4 bars for the pre-commissioning SIT, and then 4 bars for SIT after 1 year and then 4 bars each 10 years. Now, when it comes to the containment building, the structure strength fully relies on the post stressing system as concrete is good in compression but poor in traction. With regards to post-stressing system, a big difference is made depending on whether the bonded or unbonded technology is used. Hereunder a few explanations from VSL website

"Bonded technology

This solution is primarily used in Europe and West Asia. It provides high durability and high performance at ultimate state for a given tendon size. The design is based on nuclear-specified strands, which are installed in ducts and stressed with specific tools to mitigate the force dispersion at the anchorage. The tendons are permanently bonded to the structure with high performance cementicious material, which provides long-term corrosion protection.

Unbonded technology

The unbonded post-tensioning system - as used in US, Eastern Europe and east Asia particularly - offers very high performance with low friction as well as long-term service. It enables monitoring of the forces in all tendons and allows the replacing any of them, at any time, if this is eventually required."

EPR, and all the French technology PWR reactors are using bonded technology. VVER is using unbonded design.

When it comes to assess the remaining capacity of a post-stressing system, the way to do it differs if its bonded or unbounded design:

- Unbonded design:

  - Direct post-stressing tendon weight: specialized company perform tendon lift-off and measure directly the force remain in the cable
  - Indirect post-stressing assessment: use of the containment monitoring system

- Bonded design like EPR:

  - The only way to assess the containment building strength is to compare the actual behaviour of the structure given by the monitoring system to the expected values given by calculations.
    To conclude: For an EPR unit, the containment monitoring system is vital because it is the only way to assess the strength of the 3rd and last nuclear barrier. The containment monitoring system (called EAU) is a requirement of the RCC-CW which is the standard used for EPR civil works design. EAU system lifespan is around 100 years (from construction to deconstruction). Depending on nuclear safety regulators from different countries, EAU system is sometimes classified as a Nuclear Safety Related System or at least classified as a system contributing to the nuclear safety.

3 BRIEF SUMMARY OF PARAMETERS MONITORED IN CONTAINMENTS

A summary of parameters to be monitored as prepared by SITES on the basis of data from EDF French practices, SITES involvement in RCC-CW part M workgroup and various recent tenders from China, Hungary and Russia etc. is as follows:

Table 4: Summary of parameters to be measured

	VVER 1200		EPR	
Parameter	Sensor	Indicative qty.	Sensor	Indicative qty.
Raft vertical deflection			Hydrostatic levelling system	17
Stress in reinforcement	VW strain gage welded on reinforcement bars	80		80
Concrete Strain	VW strain gage	306	VW strain gage	401
Concrete temperature	PT100	110	PT100	207
Post tensioning duct stresses	Bragg lines	6		80
Post tensioning load	Load cells	12	Load cells	4
Wall facing	Bragg sensors	36		

Parameter	VVER 1200 Sensor	VVER 1200 Indicative qty.	EPR Sensor	EPR Indicative qty.
extensometers				
Pendulums	Set of anchorage / ducts / wire / weight Pendulum reading units	4 16	Set of anchorage / ducts / wire / weight Pendulum reading units	9 9
Vertical global deflection	Michelson optic fiber sensor	28	Invar wires + displacement sensor	3
Concrete moisture	TDR	16	TDR	4
Structural tilt			Inclinometer	11

The monitoring can include measurement of pore pressures in cohesive soils, vertical movement that accompany soil expansion/consolidation that occurs with stress relief (heave) during excavation and recompression with reloading and backfill, and determination of load application. The monitoring program typically includes piezometers, multiple point borehole extensometers, strain gauges and/or deep rock/soil anchors placed prior to the excavation process etc.

3.1 Instrumentation for monitoring of a VVER-1000 containment in India

Instrumentation specified for monitoring is approximately/generally as follows:

1.	VW strain gauge (sister bar 530 mm) ± 2,000 μs		125 no.
2	Shrinkage cone (no stress strain meter 210 ϕ x 350 ϕ x 700 L		14 no.
3	VW force sensors (reinforced bars 610 mm L):		390 no.
3.1	40 mm (-380 kN to 120 kN)	185 no.	
3.2	40 mm (-30 kN to 470 kN)	45 no.	
3.3	28 mm (-190 kN to 80 kN)	96 no.	
3.4	28 mm (-190 kN to 80 kN)	64 no.	

4.	VW displacement range 40 mm between inner outer containment	25 no.
5.	VW temperature sensors	180 no
6.	VW read-out	6 no.

3.2 Instrumentation for monitoring inner containment of NPCIL 2 x 700 MW reactors

Instrumentation specified for monitoring is approximately/generally as follows:

1.	Resistance strain gauge, 120 ohms & accessories for mounting on surface of pre-stressed concrete wall (100-120 mm long) and steel covers during Reactor Building Pressure Proof Test (specification no. PC-E-00093 / REV-0)	20 no
2.	VW embedment strain gauge ~ 150 mm L, ± 1,500 μ strain, accuracy +1 % FS for strain and +2 % FS for temperature	250 no.
3.	Embedded corrosion monitoring sensor	50 no.
4.	Load cell 500 MT with 6 VW gauges, 160 mm ID, 260 mm OD + bearing plates + MS plate ID 158, OD 460, W 30 mm – per reactor Hydraulic jacks with 480 mm Φ MS plate Threaded jack along with hydraulic pump	10 no. 4 no. 1 no.
5.	Readout unit to simultaneously monitor all six sensors of one load cell and display the average value. Values of individual sensors to be also stored and displayed on demand	2 no.
6.	Regular VW readout loggers	6 no.

Please note that in all these NPPs the monitoring can include measurement of pore pressure in cohesive soils, vertical movement that accompany soil expansion/consolidation that occurs with stress relief (heave) during excavation and recompression with reloading and backfill. The monitoring program typically includes piezometers, multiple point borehole extensometers, inclinometers, strain gauges and/or deep rock/soil anchor load cells placed prior to the excavation process.

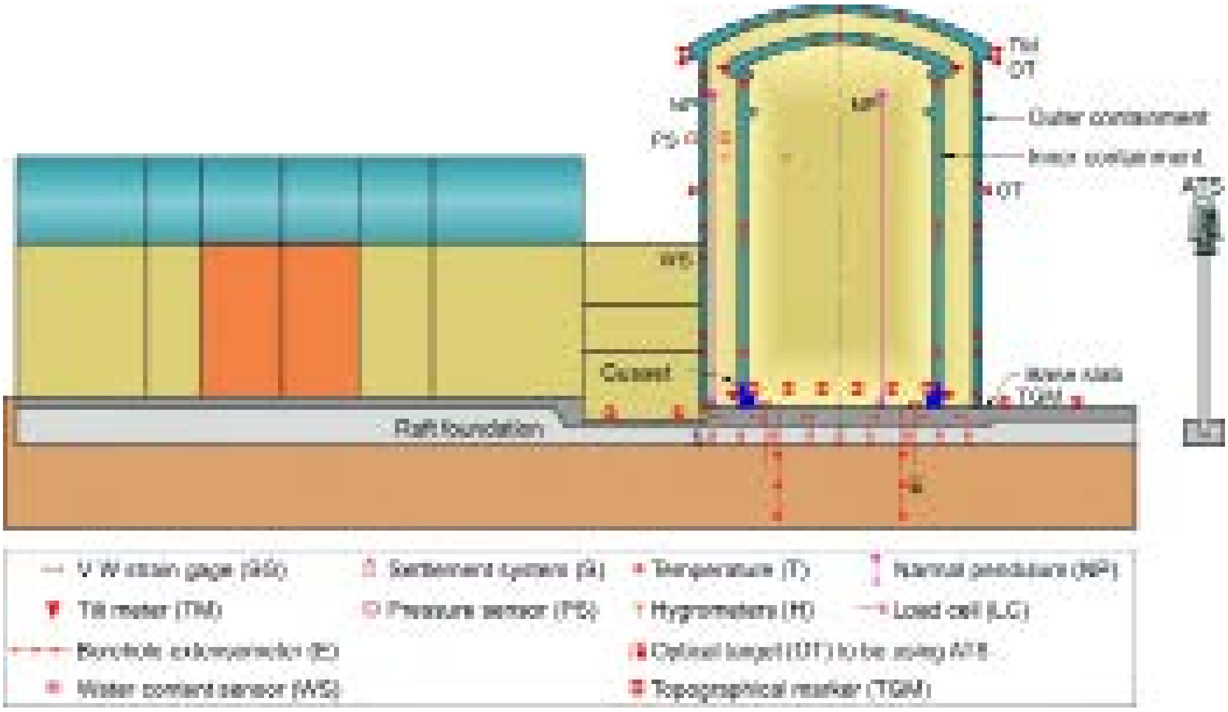
4 STRUCTURAL MONITORING SOLUTIONS

Structural monitoring solutions described in this section are mainly based on those followed by EDF France in European Pressurised Reactors (EPR) built by them (similar to 6 x 1650 MW offered by them for Jaitapur). However, this section has been updated with modern proven technology to offer online monitoring of almost all the parameters.

Encardio-rite offers a wide array of rugged sensors, associated data retrieval & telemetry systems and online web-based monitoring systems 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.

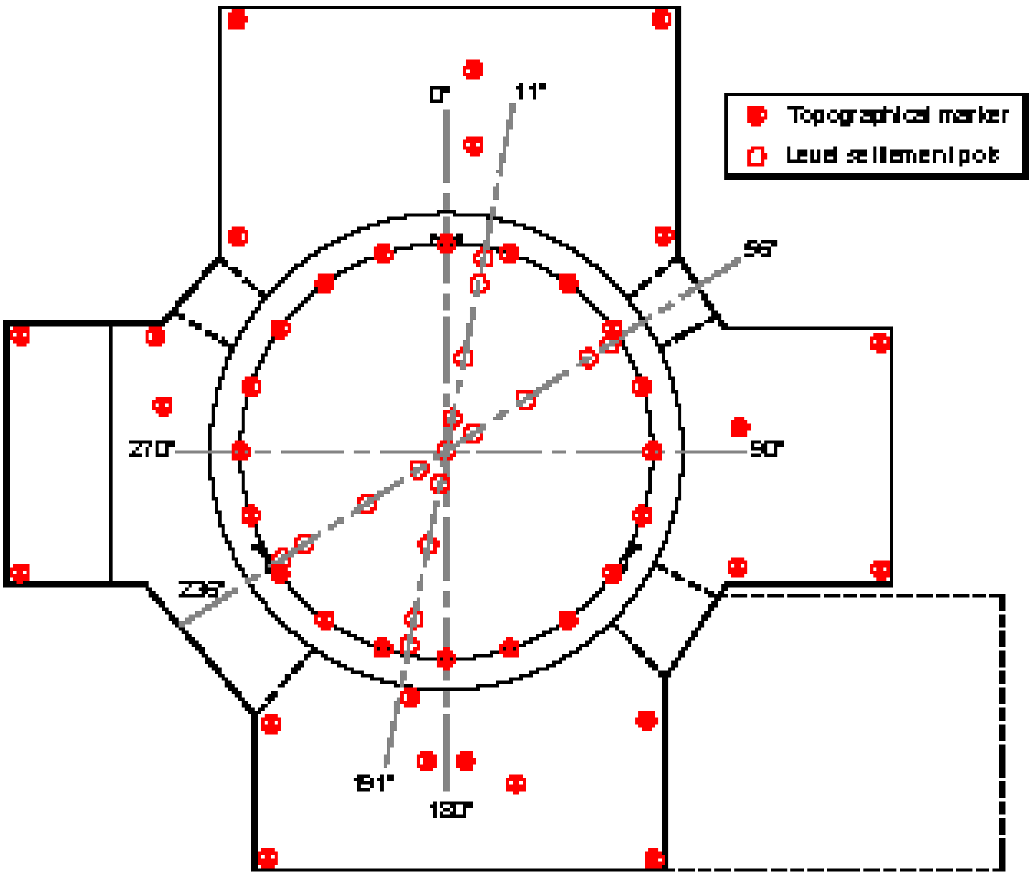
Surface and subsurface sensors that can be used for safety monitoring of nuclear power plants are given below with a typical location plan. It is noteworthy that subsurface monitoring gives important information on the ground/soil movement which may affect the stability of the plant's structure.



Typical instrumentation location plan of a Nuclear Power Plant

- For settlement and deformation monitoring of the nuclear island raft, Encardio-rite can provide the following instruments:
  - Model EPS-12-60 topographical marker/pavement 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.7
  - Model ESM-30V liquid level settlement system - fluid-filled vessels/pots of the system with low range vibrating wire force 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 typical location of the pots of the system, refer to the figure below. 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 movement. The head of the extensometer is anchored to the raft foundation and 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

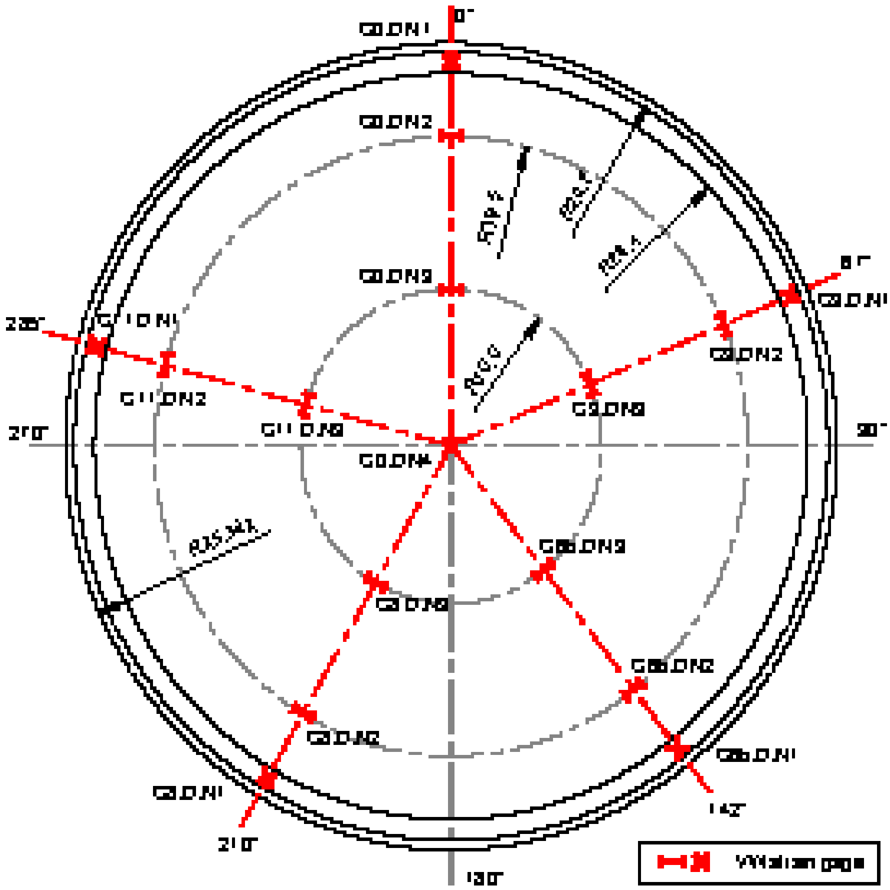
- For global deformation monitoring of the cylindrical wall of the containments, the Encardio-rite model EDS-50 normal plumb line with model EPR-01S tele-coordinometer is available to monitor relative horizontal movement in x & y planes. They give critical deformation at different levels owing to the 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 typical location of pendulums with invar wire in the containment structure refer to figure below. The system is suitable for online monitoring.

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.

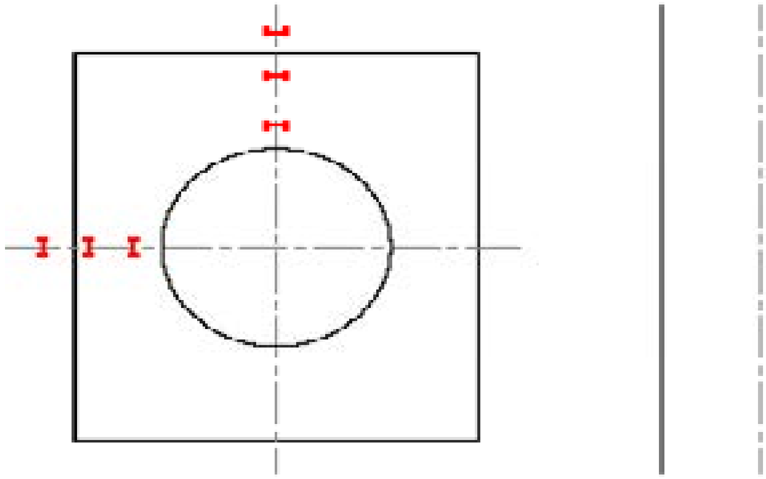
The embedment strain gages are installed first in cages generally made of 10 mm dia. rebars in the following configuration: cage of triple type, housing 3 no. strain gages: 1 no. each in tangential, vertical and radial positions.

- 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 a 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

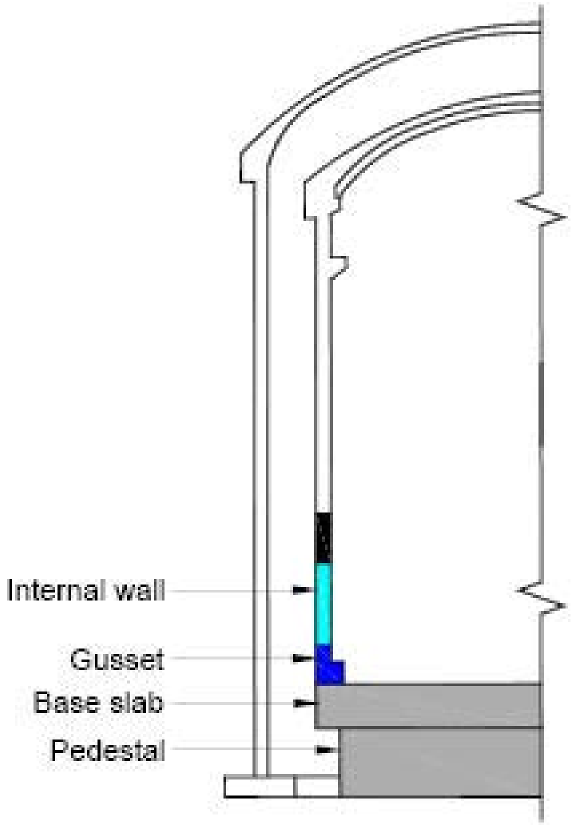
For determining the temperature at the location of the strain gage, each gage has an inbuilt thermistor (YSI 44005).



Typical location of strain gages in the equipment hatch

- For monitoring the rotational movement of the containment's gusset (refer to figure on next page) 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 6 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 sensors 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.
- 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.
- Please note that a required instrumentation during the operation of the plant is EARTHQUAKE monitoring – both high

and low frequency Accelerographs. The plant may be required to automatically shut itself when an earthquake beyond operation limits occurs. Encardio-rite model ESDA-120S digital feedback Broad Band Seismometer and model EADA-350F digital force feedback Strong Motion Accelerometer are available, manufactured in India under license from Gaiacode, UK.



Location of the gusset in the containment structure

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

- Model EDAS-10 based on Campbell Scientific's CR1000X measurement and control module with GSM/GPRS modem.
- Model ESDL-30 SDI-12 data logger with an integral GSM/GPRS modem. Interface cards are available from Encardio-rite for conversion of sensor outputs to SDI-12 digital output, where the sensors do not have an integral SDI-12 interface output.

Any sensor with an SDI-12 signal interface can be connected to the datalogger e.g. based on vibrating wire, resistance strain gage or MEMS technology etc. The datalogger can be connected to up to 61 SDI-12 sensors through a three-conductor cable. It can be programmed to take a measurement from 5 seconds to 168 hours in linear mode from each of the sensor. Each sensor has an individual name (address) – 0 - 9, a - z or A - Z. The sensors are normally in the sleep mode. At the time of data retrieval, the datalogger gives a wakeup call to the sensor, which transfers the data to the datalogger and then again goes to sleep.

Encardio rite provides a range of shielded armoured/non-armoured 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 length 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 and site to site 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 the sensors. Encardio-rite products comply with major international standards.

For 24X7 near real-time data access, Encardio-rite provides online web data monitoring system (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 section 5.

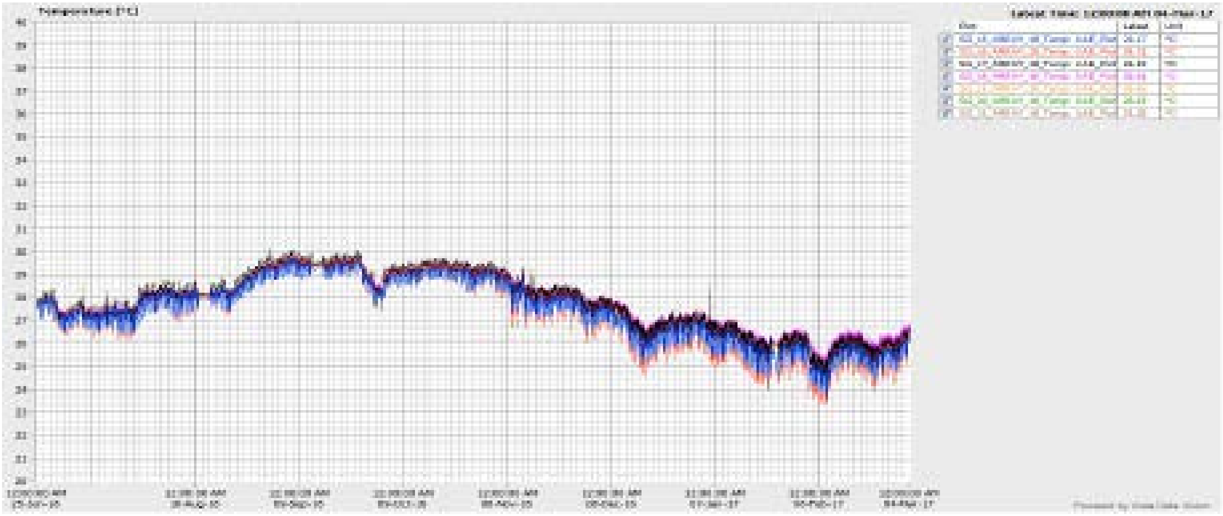
On-line monitoring using the above instrumentation gives a timely warning on any impending danger. The purpose is to assist and inform the stakeholders about the continued performance of structures under gradual or sudden changes to their state. The main factors affecting the performance are the degradation 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.

5 PUBLIC CLOUD-BASED WEB DATA MONITORING SYSTEM (WDMS)

The heart of the online structural monitoring instrumentation system is a Public Cloud-Based Web Data Monitoring System 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 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.

Remote real-time monitoring system with SDI-12 digital interface

Data from Encardio-rite cloud-based web monitoring system 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.



Typical online data

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.

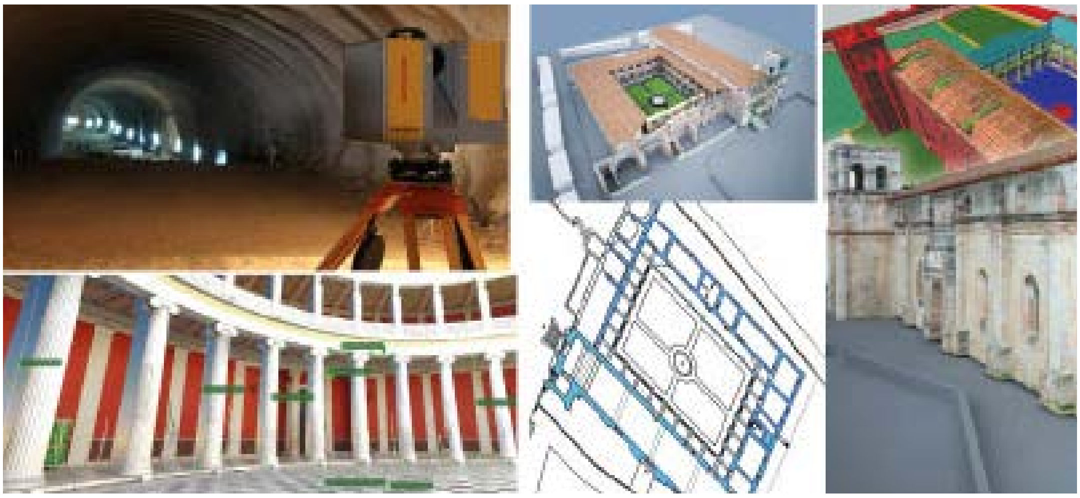
The web browser interface is very simple to use and intuitive. Any user who is only interested in viewing the data and reports will take just a few minutes to get familiar with the operation of the system.

6 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.

6.1 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 are 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 provides:

- 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

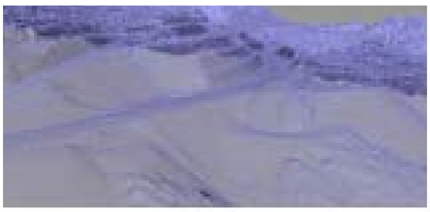
6.2 Aerial Mapping using Unmanned Aerial Vehicles (UAV/Drone)

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

Mesh 3D



Texture 3D

Texture 3D

Video

6.3 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 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

7 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.

In association with SITES France, Encardio-rite Group of Companies offers the most reliable and advanced Instrumentation and Data Management System for safety of the Nuclear Power Plant, associated personnel, materials, nearby communities and the environment.