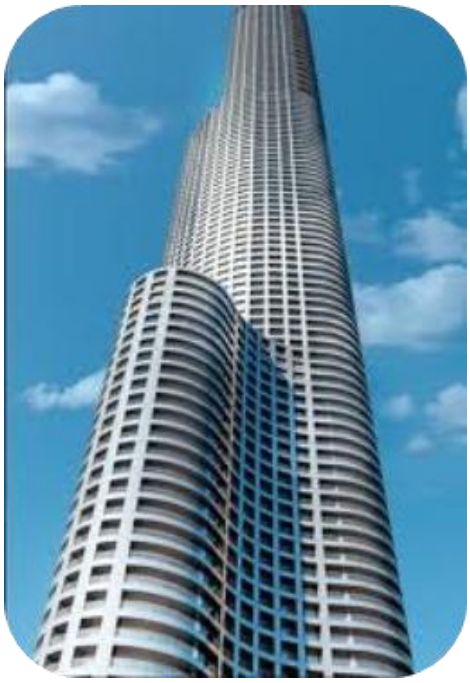
APPLICATION NOTE

ONLINE MONITORING OF BUILDINGS, MONUMENTS & STRUCTURES

1 Introduction

Encardio-rite offers online web based monitoring services for the following:

- Safety of buildings, monuments and structures during nearby construction activity (like underground tunnelling, deep excavation for high rise buildings etc.)
- Safety of existing multiple storey buildings, hotel complexes, corporate offices and buildings of critical importance
- Safety of old and depleted buildings and structures subject to long-term movement or degradation of materials Safety of monuments and structures of historical importance
- Safety of buildings and structures in landslide prone areas (also see application note AN-3002 – “Landslides and role of instrumentation in mitigation of their effect”)
- Monitoring of new construction:
  - To verify the hypothesis and the assumption of design parameters
  - To monitor safety during construction
  - To measure change in parameters during construction
  - To ensure that interface of construction with adjacent structures and foundation is sound
  - To certify the performance of the new construction/excavation



LODHA WORLD ONE RESIDENTIAL TOWER

Note: This a general Application Note provided for the sake of information only. It does not take into consideration individual conditions which may vary from site to site and structure to structure. Moreover, ground/soil conditions and water table also varies from location to location. A final instrumentation plan should therefore always be made by an expert or consultant in the field.

Every precaution has been taken in providing correct information in this Application Note. Encardio-rite Group of Companies neither assume any responsibility for any errors or omissions that may appear in the text nor assumes liability of any damages or losses that result from use of any of the Products in accordance of the information provided in this Application Note.

2 Reference guidelines for building damage classification

Classification of building damage as summarized from **Burland *et al,* 1977 and Boscardin and Cording 1989.**

Building damage classification *(as summarised from Burland et al, 1977 and Boscardin and Cording 1989)*			**Approximately equivalent ground settlements and slopes** *(after Rankin 1988)*	
Risk category	**Description of degree of damage**	**Aprox. crack width (mm) / numbers**	**Max slope of ground**	**Max settlement of building (mm)**
1	Negligible	0.1 to 1	Less than 1:500	Less than 10
2	Slight	1 to 5	Less than 1:500	Less than 10
3	Moderate	5 to 15 / no. > 3	Less than 1:500	Less than 10
4	Severe	15 to 25 / more no. of cracks	Less than 1:500	Less than 10
5	Very severe	> 25 / more number of cracks	Less than 1:500	Less than 10

3 Role of Online Structural Monitoring Instrumentation

For buildings and structures during the construction period, the purpose of instrumentation is mainly to provide early warning, through regular or continuous monitoring, for any excessive and undue ground movements affecting the structure. This allows for implementation of preventive remedial actions well within time.

For buildings and structures already constructed, it is essential to periodically or continuously monitor the health to ensure proper maintenance and hence safety. The term Structural Health Monitoring is attracting great significance lately and is being used more and more today to ensure safety of man and material. The monitoring system consists of a range of instrumentation installed on full-scale structures. The purpose is to assist and inform owner/designer/contractor/architect about continued performance of structures under gradual or sudden changes to their state. The main factors affecting the performance is steel corrosion, degradation of concrete with age, undue settlement/tilt due to soil conditions, vibrations due to traffic, ground water level and atmospheric conditions etc. In such cases, the instruments installed give very important data on the state of the structure. This is reflected in abnormal changes in strain, inclination and settlement values. Another parameter to be closely monitored is the development of cracks in the structure.

Depending on importance, soil conditions, architectural designs, risks and hazards, structures may have different monitoring programmes. The monitoring programme at times can also be mandated by law.

4 Online Structural Monitoring Instrumentation

4.1 Web Data Monitoring Service (WDMS)

The heart of the online structural monitoring instrumentation systems is the Web Data Monitoring Service offered by Encardio-rite to users anywhere in the World. It is a web-based data-management and presentation tool for data collected by model ESDL-30 range of dataloggers.

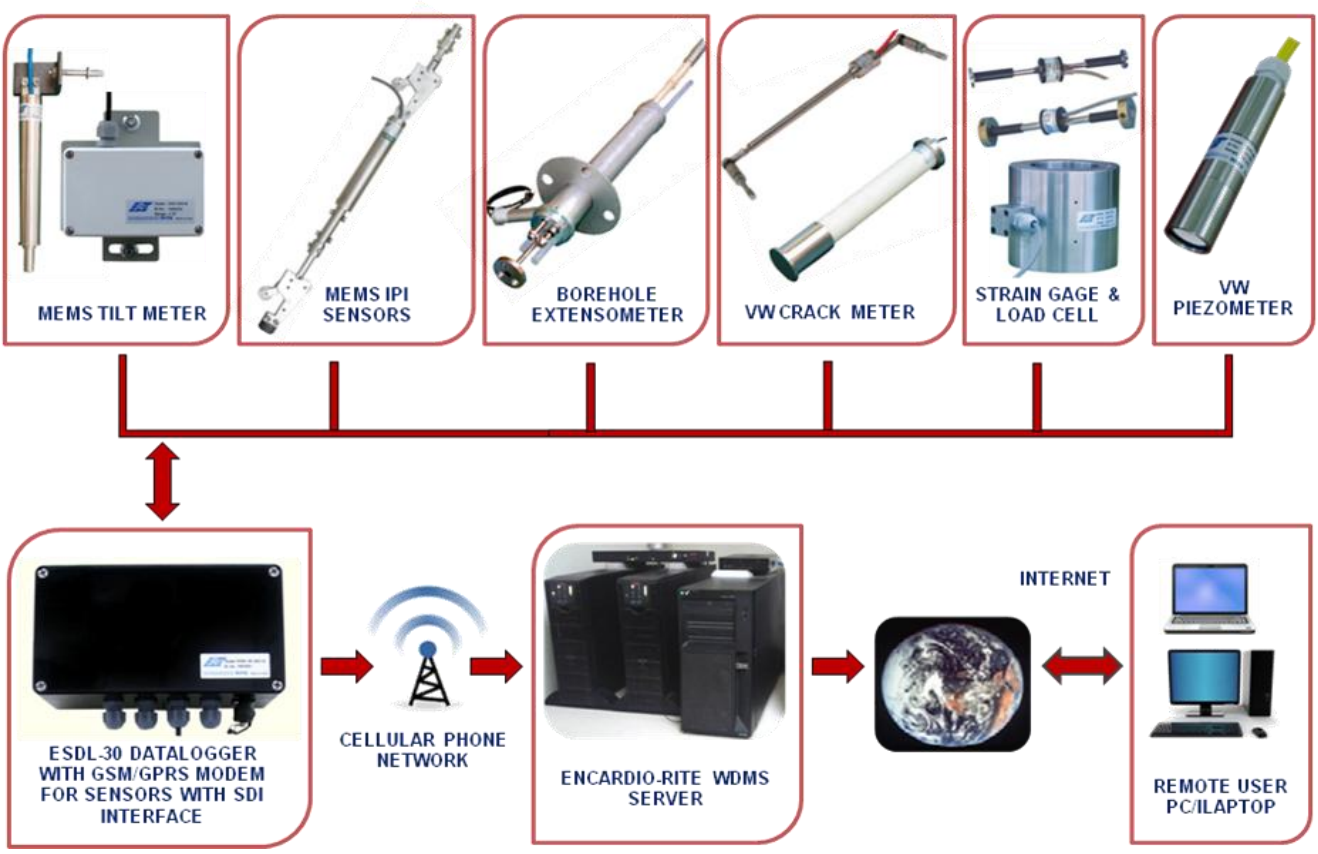
ESDL-30 DATALOGGER

Encardio-rite model ESDL-30 datalogger is designed to log data from sensors with SDI-12 interface. Any sensor with a SDI-12 signal interface can be connected to the datalogger e.g. based on vibrating wire, resistance strain gage or MEMS technology etc. Thus, this single datalogger is suitable for monitoring ground water level, piezometric pressure, stresses in soil/concrete, strain or displacement (lateral displacement in boreholes and cracks), load, temperature, tilt in structures, lateral displacement in boreholes using in-place inclinometers, etc. using Encardio-rite range of sensors with SDI-12 signal interface.

ESDL-30 datalogger has three input channels suitable for connecting and storing data from up to 61 sensors each and transmitting data to a central server through GSM/GPRS for Web Data Monitoring Service by Encardio-rite. It features a wide operating temperature range, dependable stand alone operation, low power consumption, compatibility with many telecommunication options and flexibility to support a variety of measurement and control applications.

Essentially the WDMS consists of a software such as a data collection agent, a data base server and a web server hosted on a high reliability server computer. The host computer periodically collects data from remote data loggers, which can be geographically spread over a large area, over cell phone networks. Users interact with the software using their web-browser, when connected to the Internet, from any location in the world. The only requirement is that each individual data logger site is covered by a cell phone service provider who can provide reliable GSM/GPRS enabled cellular data connection locally.

Multiple authorized users at different locations are allowed to view any data or report from the same site simultaneously. Each user is assigned an individual password for access to the logged data. Graphs & reports can be viewed using popular web browsers like Microsoft internet explorer or Mozilla Fire fox amongst others. The server for the above WDMS services is located at Encardio-rite premises and is maintained 24 x 7. Some simple examples of WDMS service available from Encardio-rite are illustrated below:



The WDMS allows the user to view the data from any sensor connected to the remote DAS over a selected time period in either a tabular spread sheet type format or as a graph. A graphic like a map, ground plan or a photograph is put on the opening screen marked with installed sensors represented as square dots. As soon as the mouse pointer is brought over any sensor 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 any one of the alarm level 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. The user can select the

period of time and starting date for each graph or table and the displayed data will be dynamically updated to reflect the user's selection.

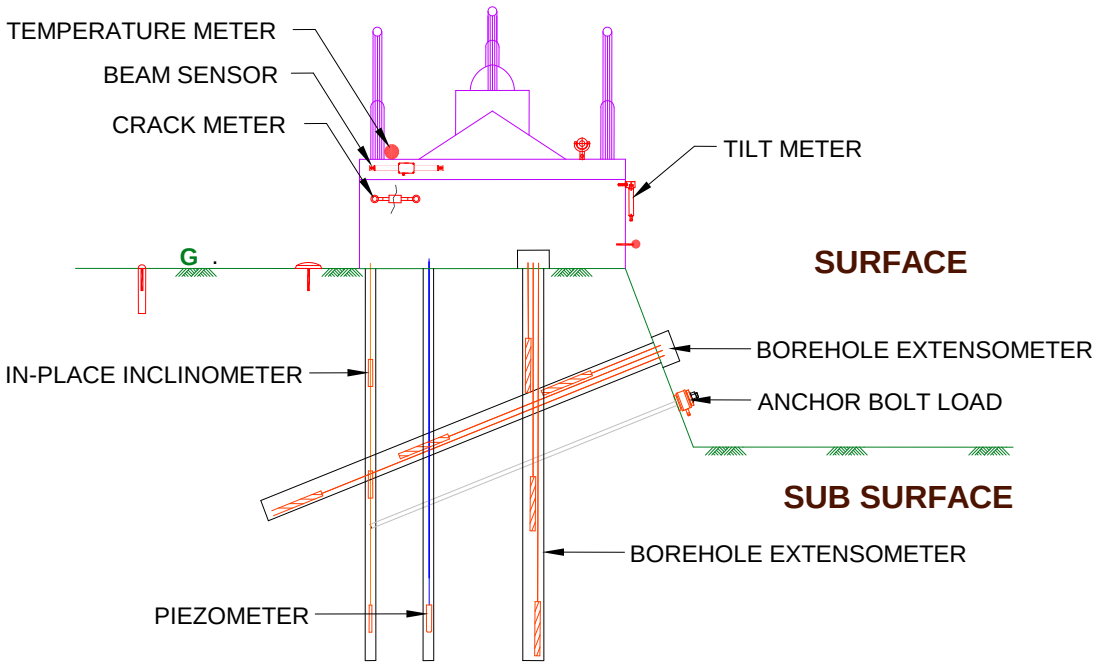
Site administrators can set two alarm limits which are generally considered as "alert level" and "work stoppage level". Other users can only view the data and alarm status but cannot make any changes.

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.

Although the WDMS is a complex mix of hardware and software the web browser interface is very simple to use and intuitive. An 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.

4.2 General sensors layout for monitoring buildings and structures

The following diagram shows examples of instruments used for surface as well as sub-surface monitoring of structures. Subsurface monitoring gives important information on ground/soil movement which may affect the stability of the structure. Serial no. 3.3 - 3.5 describe surface instruments and 3.6 - 3.10 describe sub-surface instruments used for monitoring.



4.3 SURFACE MONITORING INSTRUMENTS

4.3.1 Tilt Meter

To online monitor tilt of buildings that may be caused due to differential ground settlement, a suitable sensor is the model EAN-92M bi-axial tiltmeter with the SDI-12 interface. The tilt meter should ideally be installed at an indoor location or in shade to prevent effect of large temperature fluctuations on the monitored results. Users may use two or more of tiltmeters to monitor tilt of buildings with time.

For individual as well as for multiple installations, model ESDL-30 datalogger is suggested. Reading should possible be retrieved in the morning hours when temperature induced stresses in the buildings are minimum.

Tilt meter installed with datalogger

The adjoining picture shows a biaxial tiltmeter with a ESDL-30 datalogger installed on a building. For safety monitoring of existing structures two or more such systems may be mounted at proper locations, data being available online with alarms through Encardio-rite Web Monitoring Services. For buildings and structures built on hill and mountains, this is a good low cost service for monitoring their stability with time. It may give fore warning of ground movement during rainfalls.

For manual monitoring of tilt the model EAN-70M portable tilt meter with aluminium die cast tilt plates is available. Please refer to pages 22 & 23 of Consolidated Catalog 2013-14 for a range of other tilt sensors available for different applications.

4.3.2 Crack width and temperature

With time cracks develop in buildings, structures and monuments. Monitoring change in their width provides important information. To online monitor changes in crack width, a suitable sensor is the model EDJ-40V vibrating wire crack meter. Users may use several of these at representative locations to monitor development of cracks in buildings with time. The model EDJ-40V sensor also has a thermistor incorporated in it such that temperature can also be simultaneously monitored.

For online monitoring, EDJ-40V with SDI-12 signal interface is used with model ESDL-30 datalogger for logging in data. The data is transmitted to a central server through GSM/GPRS for Web Data Monitoring Service by Encardio-rite.

Temperature can also be independently monitored by using model ETT-10TH thermistor probe. Several

Crack meter being installed at Basilica-Torino, Italy

other options for monitoring temperature are listed in Consolidated Catalog 2013-14 on page 16.

The adjacent pictures show crack gages being mounted on the dome of a Basilica at Torino, Italy for online web based monitoring by our associates G D Test using crack gages provided by Encardio-rite. Several tilt meters were also mounted in this structure for online monitoring.

For manual monitoring of cracks Encardio-rite models EDJ-40C and EDJ-41M crack gages are available. Please refer to page 17 of Consolidated Catalog 2013-14.

4.4 SUB-SURFACE MONITORING INSTRUMENTS

4.4.1 In-place inclinometers for lateral movement in the ground

In-place inclinometers (IPI) are used for continuous monitoring of lateral movement of the ground at construction sites involving deep excavation. Such lateral movement of the ground may affect the safety of adjoining structures. For example, take a multi storey building to be constructed in an area having a lot of construction around. The construction of the multi storey building will require a deep foundation and maybe also a diaphragm wall depending upon the ground conditions. In such applications IPIs installed in the diaphragm wall and the ground between the excavation and adjoining structures, helps in controlling the construction process for ensuring safety.

IPIs with Web Data Monitoring Service are also used in hilly areas and mountains where buildings and structures are constructed on slopes and need online monitoring for safety.

For online monitoring of lateral movement in boreholes, Encardio-rite offers model EAN-52MV Vertical In-place Inclinometer System with SDI-12 interface sensors. The model ESDL-30 datalogger has three input channels suitable for connecting and storing data from up to 61 sensors each and transmitting data to a central server through GSM/GPRS for Web Data Monitoring Service by Encardio-rite.

For manual monitoring Encardio-rite model EAN-26M digital inclinometer system with mobile read-out logger with InclinoView analaysis software is available and used worldwide. The detail datasheets of these are available at our website.

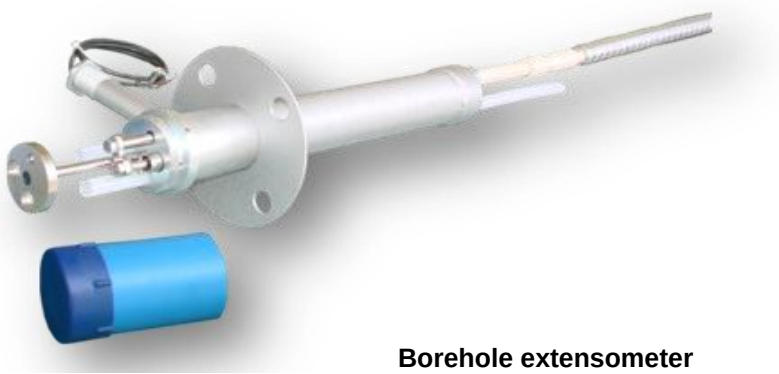
In-place inclinometer sensor

4.4.2 Borehole extensometer

Encardio-rite models EDS-71V single channel and EDS-70V 2-6 channel borehole extensometer (BHE) is extensively used for online monitoring of sub-surface ground settlement during construction activity. In case the BHE is mounted in a horizontal borehole, it gives important information on lateral movement.

Used together with in-place inclinometers, BHE provide important information on X, Y and Z subsurface movement in the ground during construction activity.

For online monitoring, EDS-71V/EDS-70V sensors are used with SDI-12 signal interface. These can be then connected to model ESDL-30 datalogger for logging in data. The data is transmitted to a



Borehole extensometer

central server through GSM/GPRS for Web Data Monitoring Service by Encardio-rite.

For manual monitoring with a micrometer depth gage, Encardio-rite models EDS-64U/D single channel and EDS-63U/D 2-6 channel BHE are available.

For details refer to page 19 of Consolidated catalog 2013-14.

4.4.3 Piezometer

Encardio-rite model EPP-30V piezometer is recommended for online monitoring of ground water pressure/level near the construction site, between building and excavation and underground works.

VW Piezometer

An online piezometric pressure monitoring system provides very important information on safety, especially during the rainy season for any structure built on a hill.

For online monitoring, vibrating wire piezometers are used with SDI-12 signal interface and connected to model ESDL-30 datalogger for logging in data. The data is transmitted to a central server through GSM/GPRS for Web Data Monitoring Service by Encardio-rite.

For manual monitoring of water level or piezometric pressure in the ground Encardio-rite provides the following instruments:

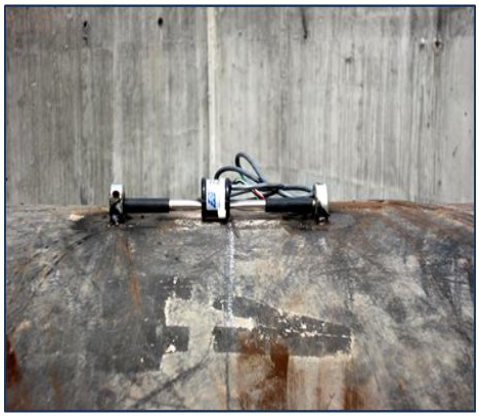
- Model EPP-10 casagrande piezometer
- Model EPP-10SP standpipe
- Model EPP-10/6 water level sounder.

A wide range of piezometers are listed on pages 6 & & of Consolidated catalog 2013-14

4.4.4 Strain gages and load cells

Construction of deep foundations may result in lateral movement and settlement of the surrounding structures in case the latter fall in the zone of influence of the construction activity. This may necessitate the construction of a diaphragm wall or sheet piles around the area to be excavated. During excavation, struts or anchors may be used to contain the lateral movement. For monitoring of struts or anchors, the following sensors are available from Encardio-rite:

Anchor bolt load cell



Strain gage

- EDS-20V-AW arc weldable strain gage for monitoring stress in struts (page 14 Consolidated catalog 2013-14)
- ELC-32V centre hole anchor bolt load cell

Adjacent pictures show installations of these sensors.

5 Laser Scanning

Encardio-rite recommends conducting a Laser scan of the structure. Laser scanning is a mapping method and geometric documentation of buildings, architectural and archaeological monuments which require a high degree of analysis, are inaccessible or difficult to access or must not be touched. It creates a virtual reality of the structure. It is based on a very dense three-dimensional coordinate map of the surface areas to be mapped in fast output of several thousand to one million points per second. Depending on the situation and on the user's needs, horizontal, perpendicular or diagonal sections, views, images, videos, orthophotographs, elevations images, contour equivalents, three-dimensional digital models, designated distortions and a plethora of other analyses can be derived from the scanner in the invisible spectrum. The cracks and other defects can be documented. If done over regular intervals the change in the structure can also be monitored.

6 Case studies:

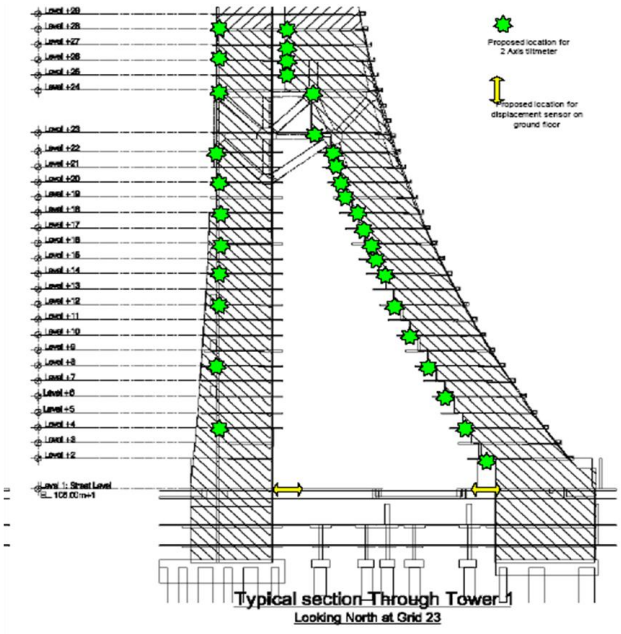
6.1 Monitoring buildings and foundations

6.1.1 Marina Bay Hotel Tower, Singapore

Marina Bay Sands is a famous landmark of Singapore well known for its iconic buildings. The development was said to be one of the most challenging construction projects in the world due to the architectural design and soil conditions.

Encardio-rite supplied a good number of geotechnical instruments/sensors for the 64 storey Marina Bay Sands Hotel Tower through its associate Tritech at Singapore.

Almost 250 numbers of tilt sensors were installed and monitored for structure movements. Around 400 numbers of VW strain gages (with built in thermistors) along with displacement sensors and load cells were installed and monitored for cast-in, post tensioning and strut monitoring. Readings from all the installed sensors were available online (real time) to the related authorities (during construction) via wireless web base data server.



Typical schematic of tilt meter installation locations at Marina Bay Sands Hotel Tower

6.1.2 Residence of Mr. Kanwer Kohli , Bhumiadhar, Nainital District, India

Residence of Mr. Kanwer Kohli is a 4-storey structure on a sloping hill at Bhumiadhar. They have an average rainfall of around 110 cm mainly concentrated in the months of July, August and September. This results in a very heavy flow of water around the building during the monsoon period.

The safety of the building is being monitored since January 2012 by using two numbers of Encardio-rite model EAN-92M biaxial tiltmeters mounted on the front left and rear right corners.

Since September 2014, the sensors have been put on online web based monitoring using model ESDL-30 datalogger with GSM/GPRS transmission. The system is set to give automatic alarm on the mobile in case the tilt varies beyond pre-defined values.


Residence building on sloping hill

6.1.3 Lodha World One Residential Tower, Mumbai, India

World One Tower with 117 storeys is being built on a 17-acre site at Worli (south-central Mumbai). It will be the world's tallest residential building with a height of over 450 m. Encardio-rite supplied a range of instrumentation including the following sensors:

- Sister bars – 174 no.
- Reflective targets – 65 no.
- Building settlement points – 60 no.
- Crack meters – 5 no.
- Two point borehole extensometer - 10 sets
- Automatic data acquisition system with online monitoring – 2 sets

6.1.4 Convention Center, Doha, Qatar

The Convention Center, a 108 storey building, has proven to attract attention around the world for the iconic bent steel structure spanning 250 meters in the shape of the native Sidra tree that grows up to support the overhanging roof structure.

Encardio-rite supplied instrumentation for the foundation works to its associate Ammico Construction Co. at Doha. The instrumentation included following sensors:

- Sister bars – 70 no.
- Anchor load cell 1500 kN – 6 no.
- Inclinometers – 35 borehole (average depth 30 m)
- Water level sounders – 15 no.
- Jack out pressure cells – 9 no.


Convention Center

6.1.5 Al Quds Endowment Tower, Doha, Qatar

This 420 m 100 floors Al Quds tower project represents a real challenge to afford the creation of greatest landmark of Doha. Encardio-rite supplied geotechnical instrumentation for the foundation works for Al Quds tower, Doha to its associate Ammico Construction Co. at Doha.

The instrumentation installed included inclinometer, sister bar strain gages and jackout pressure cells for diaphragm wall; anchor bolt load cells, tilt meters and few crack meters.

- Inclinometer - 20 no. of borehole (average 30 m deep)
- Jack-out pressure cell in diaphragm wall -15 no.
- Anchor bolt Load cell – 12 no.
- Sister bars – 30 no.
- Tilt plates – 10 no. with one set of Portable tilt meter
- Crack meter – 10 no.

6.1.6 Corniche Hotel, Khalidiya, Abu Dhabi, UAE

The elegant and beautiful 35-storey building has been designed by Surbana Consultant Pte. Ltd. of Singapore to reflect the maritime heritage of Abu Dhabi. Since the excavation was deep, following instruments were used to protect adjacent structures and reduce ground movement.

- Inclinometer – 8 no.
- Strut load cell (5000 KN) 2.5 m from Weller on pipe strut – 23 no.
- Spot weldable strain gage in all three layer of strutting – 68 no.
- VW piezometer – 7 no.
- Water standpipe – 7 no.
- Tilt plate on sensitive structures within zone of influence – 4 no.
- Crack gage on nearby sensitive structures within zone of influence – 58 no.
- Vibration & noise recorder at four locations – 1 no.

Inclinometer at Corniche Hotel

6.2 Monitoring historical monuments/restoration

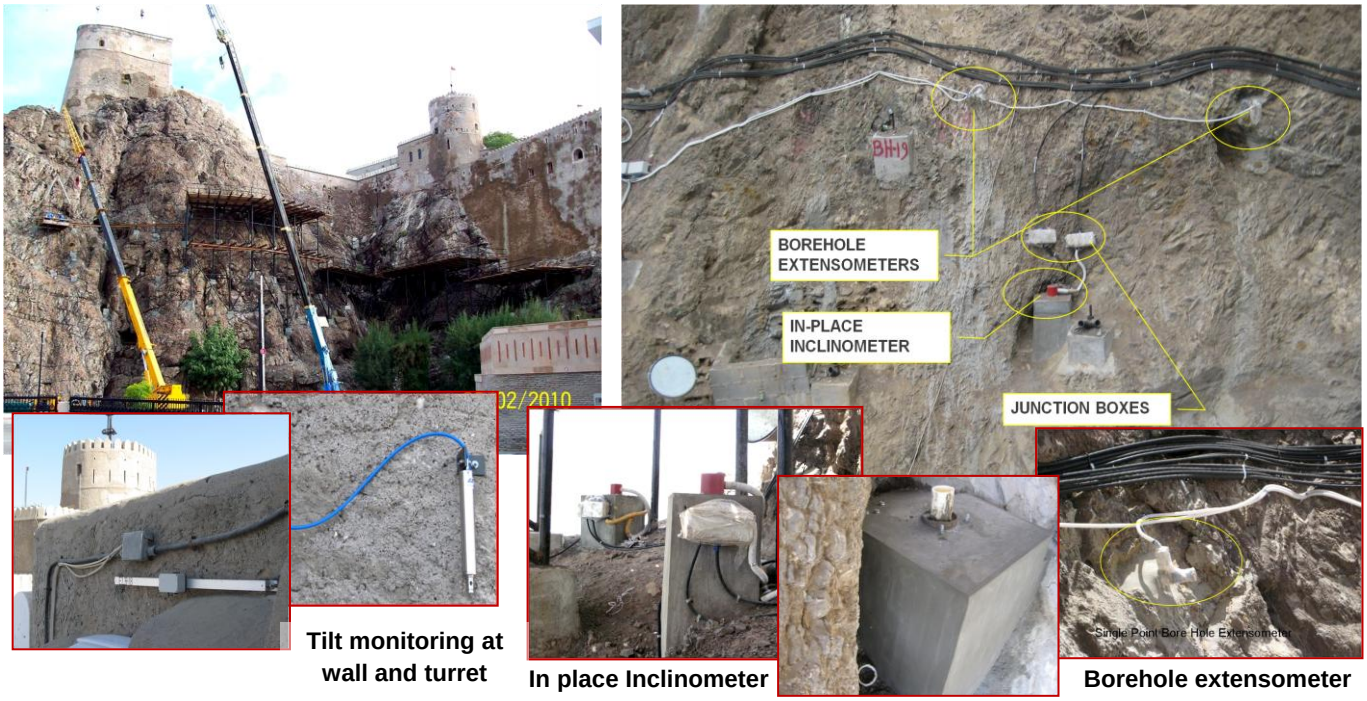
6.2.1 Al Mirani Fort, Muscat, Oman

Al Mirani Fort stands on the contours of a rock mass which goes to a maximum height of 41 m. A concerted renovation programme was initiated to restore Mirani Fort to its original majesty. Consultants were hired to prepare a report on protection of the fort & suggest long term performance monitoring. The purpose was to identify any weak rock conditions that require rock stabilising work. Al Manar were entrusted the work of rock stabilising of the rock foundation using various methods including pressure grouting and rock bolting.

Encardio-rite was entrusted with the job of instrumentation and long term monitoring of the fort. The instrumentation was done on the east side towards the palace (zone 1) and south side facing a mosque (zone 2) to monitor performance before and after pressure grouting, rock bolting etc. The basic instrumentation scheme consisted of:

- In-place inclinometer sensors to monitor subsurface lateral movement in 14 vertical boreholes in zone 1 & zone 2 – 149 no.

- Tilt meter to monitor surface tilt of walls and turret - 22 no.
- Single point borehole extensometers to monitor horizontal movement in 28 horizontal boreholes in zone 1 & zone 2 – 28 sets
- Temperature meter – 6 no.



Tilt monitoring at wall and turret

In place Inclinometer

Borehole extensometer

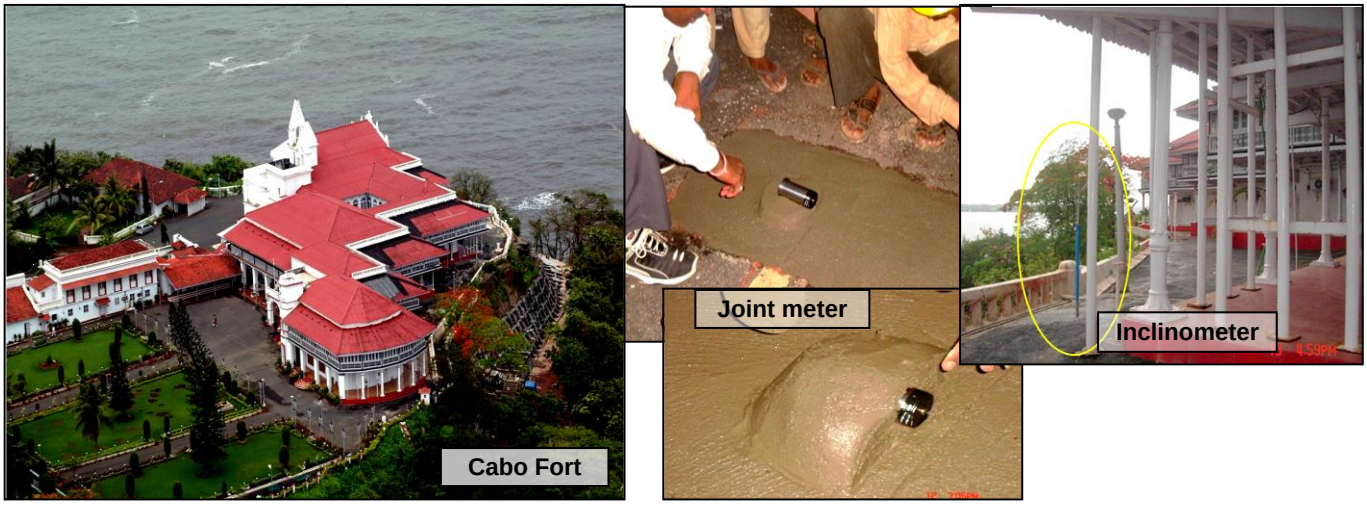
Instrumentation at Al Mirani Fort, Oman

- Automatic data acquisition system with online monitoring

6.2.2 Cabo Fort, Goa, India

Encardio-rite supplied and installed instruments at Cabo Fort, Governor Bungalow - Goa. The project execution was through Water Resources Department (WRD), in association with ITD Cementation. We have supplied and installed Web Based Data monitoring (WDMS) for the Cabo Fort with following sensors:

- Inplace inclinometers sensors – 117 no.
- Digital Inclinometer – 2 set
- VW Piezometer – 6 no.



Installations at Cabo Fort, Goa

- VW crack meters – 8 no.
- Few jointmeters
- Also Rock anchors were installed in the staggered grid on the slope outside the Cabo Fort.

6.2.3 Expansion of Al Masjide Al Harem, Saudi Arabia

Encardio-rite has instrumented the foundation of the Al Masjide Al Harem, Saudi Arabia during its expansion works. The instruments installed included following sensors that were installed in rafts, sections for pillars and elevators:

- Earth pressure cell – 40 no.
- Concrete pressure cell – 105 no.
- Piezometer – 30 no.
- Embedment strain gage – 100 no.
- Sister bars – 350 no.
- Automatic data acquisition systems for continuous monitoring

Installations at Al Masjide Harem

7 Conclusion

The data observed from the geotechnical instrumentation described above plays a vital role in providing verification of design assumptions, manage the construction in a safe and controlled manner, safeguarding existing buildings and other structures and monitoring long term behaviour.

The programme for implementation of instrumentation requires advance planning. The procurement, installation and initialization of instrumentation requires sufficient time to enable base readings to be taken, in most cases, before any construction activities commence within the zone of influence. There is no substitute or shortcuts for getting reliable and meaningful data from the instruments. 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 an experience in manufacturing and monitoring of almost half a century, are one of the best service provider in the field.

ENCARDIO-RITE ELECTRONICS PVT. LTD.
A-7, Industrial Estate, Talkatora Road Lucknow, UP - 226011, India | P: +91 522 2661039-42 | Email: geotech@encardio.com | www.encardio.com
International: UAE | Qatar | Bahrain | Greece | Singapore | USA | Bhutan
India: Lucknow | Delhi | Kolkata | Mumbai | Chennai | Bangalore | Hyderabad | J&K