RITE GEOSYSTEMS

ENCARDIO RITE METASENSING FOR MEGA STRUCTURES

Project Dossier

PROJECT DOSSIER

ONE ZA'ABEEL TWIN TOWERS & 'THE LINK' BRIDGE

PROJECT OVERVIEW

One Za'abeel Mixed-use Development is a landmark project currently under construction in Dubai, U.A.E. It is located between the Dubai World Trade Centre and Za'abeel Park. It comprises of construction of two towers - Tower A with 305 m height and 69 levels (residential, commercial and hotel areas) and Tower B with 240 m height and 59 levels (dedicated to residential apartments).

What makes the project iconic and a true engineering marvel is "The Link" - a suspended bridge that links the two towers at a height of 105 m above the ground. It is ~230 m in length with a cantilever of 66 m projecting from tower A, spanning in the middle of the towers. The world's largest cantilever, The Link, having a cross-section of 18 m2 consists of four levels and will offer a choice of attractions, fine restaurants, lounges with a viewing deck, and a swimming pool on the roof.

Project	**One Za'abeel Mixed Use Development**
Location	Dubai, UAE
Client	Investment Corporation of Dubai
Contractor	APCC Piling and Contracting L.L.C
Consultants	W.S.P
Duration	2015 –ongoing as of Jan 2021

The towers are constructed on either side of the Al Saa'da Road Bridge that passes through the center of the plot. The bridge is an elevated highway road, by Government of Dubai Roads and Transport Authority (RTA), with heavy traffic in peak hours. Construction of six level basement car parking in both the towers includes deep excavation (25~28 m below ground level). The basements are connected by two tunnels located underneath the existing elevated road that bisects the two towers. The common podium at base of towers has four levels.

WHY MONITORING?

Instrumentation monitoring and surveying played a vital role in risk assessment of existing road bridge, deep excavation, tunneling, towers and the link bridge during the construction progress. The project required a complex instrumentation & monitoring regime that comprised precise and near real-time monitoring of horizontal & vertical deformations and geotechnical parameters during the construction process, to monitor and detect any unexpected behavior of the building or bridge, well in time. The monitoring instruments provided early warning, through regular or continuous monitoring, for any excessive and undue movements affecting the construction or nearby infrastructure. This allowed for implementation of preventive remedial actions well within time. The monitoring system helped in reduction of risks, protecting assets and construction.

MONITORING SOLUTION

The monitoring work was divided into three sections

1. Existing road bridge monitoring
2. Deep excavation monitoring
3. Structure monitoring

Monitoring of existing road bridge

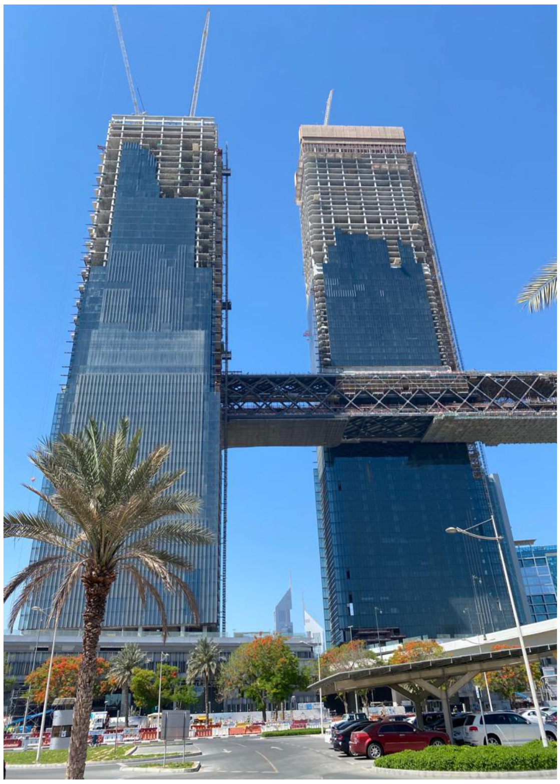
Looking at the criticality of safety monitoring of the Al Saa'da Bridge, automatic online monitoring was decided. Both at the bridge and piers, geotechnical and geodetic instruments were installed with advance automatic dataloggers to monitor effects of deep excavation, tunneling and construction of the high rise buildings.

Monitoring during deep excavation works

This was one of the first building project in the city to have 7 basements for car park. Thus, monitoring of deep excavation was very critical. The excavation started after the completion of enabling works in which inclinometers, optical targets were installed on shoring wall to monitor the lateral movement of diaphragm wall and piezometer were installed to ensure the water table to be maintained as per the design.

Monitoring of structure during construction

To monitor the overall structure movement during tower construction, series of instrumentation and monitoring program were adopted and implemented on most of the floors to ensure the building behavior as predicted in model study. Strain gauge, tilt sensor and prism targets were used to measure the strains which developed on columns, lateral movement & rotation of building, building movement during construction.



4. Monitoring of "The Link" bridge & towers, during its lifting

To monitor towers A & B and the Link Bridge during the lifting and installation process. The project required a high degree of automation for the instrumentation & monitoring part because of the need of uploading the measurements virtually in real-time to the client's FTP server. Unique I&M approaches were implemented by Encardio-rite, both in terms of hardware and software, to achieve the best possible accuracy and telemetry speed.

ENCARDIO-RITE'S ROLE

Turnkey services

Encardio-rite got sub-contract for the complete monitoring works that included:

- Supply of geotechnical instruments, precise survey instruments and targets
- Installation of geotechnical instruments for subsurface and surface monitoring and survey targets
- Online monitoring of critical parameters and areas
- Automatic 3D deformation monitoring
- Pre-construction condition monitoring of Al Saa'da Bridge
- Programming and commissioning of data acquisition systems
- Setting up an online web-based data management system (WDMS) and maintenance during the contract period
- Daily & weekly reporting with evaluation & interpretation

INSTRUMENT USED

Instrument	Purpose
Existing bridge and pier monitoring	
Strain gages	Used on the bridge to monitor change in stresses in bridge due to deep excavation and dewatering nearby.
Prism Target	Used on piers of the bridge to monitor 3D movement of bridge to check if there is any structural impact due to ongoing site activities in close vicinity.
Temperature sensor	Used at top, bottom and sides of the bridge deck to correlate monitoring data with ambient temperature changes.
Excavation works and ground monitoring	
Digital Inclinometer	Used to measure lateral movement due to construction activity, during deep excavation for Tower A & B at diaphragm walls, near existing bridge, near tunnel area
Standpipe Piezometer	Used outside the excavation areas to determine the groundwater behavior before, during and after construction activities, near deep excavation works for Tower A & B, near existing bridge

INSTRUMENT USED

Instrument	Purpose
Prism Target	Installed on the Towers, every 10 floors to monitor 3D movements
Strain gages	Installed at selected columns for stress measurement and also to estimate axial shortening which is experienced by load-bearing concrete columns and walls
Tilt meter	Installed on selected columns of different floors, to monitor the horizontal displacement of structure which is an important indicator to assess structural performance and safety
Optical Laser Plummet	To monitor the verticality of the structure
The Link bridge	
Prism Target	Installed at the edges at every 20 m distance along the link bridge to monitor 3D deformation

DATA COLLECTION AND PRESENTATION

Online monitoring was done for geotechnical sensors that were critical. Data from the strain gages, temperature sensors, tiltmeter were collected and transmitted by automatic compact dataloggers.

Data from prism targets was collected and transmitted at desired frequencies by automatic **total stations with control boxes** that had in-house developed software that allowed to control the ATS remotely.

All the data was transmitted to a central server with our in-house developed **web based data management system.**
The data was accessible to all the stake holders, in near real time, with instant alerts and warning system.

Daily, weekly and monthly monitoring reports were submitted combined for geotechnical and geodetic monitoring data-including the online data as well as manually monitored data.

Monitoring reports included interpretations of variations observed in instrument data with respect to the construction progress in the respective area. In case of any variation observed in data, field report or incidence report was included. The reports also included site progress pictures, instrumentation layout drawings.

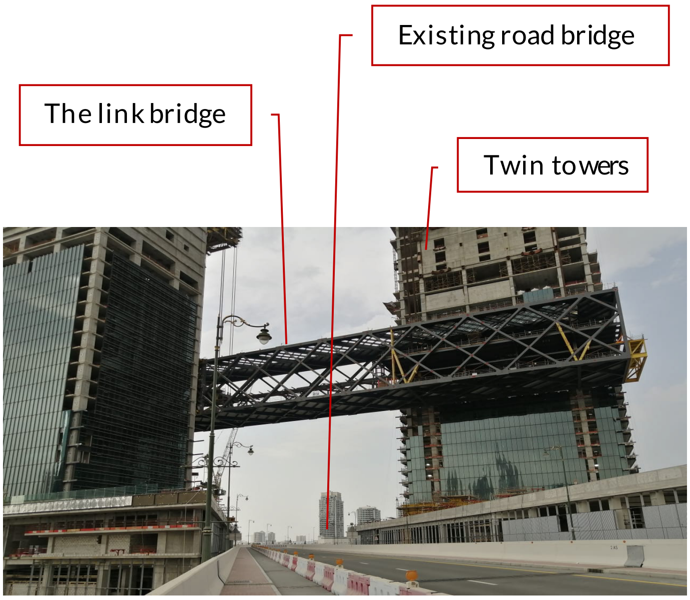
The comprehensive reports/alerts helped the stake holder in precise evaluation of field data and implementing preventive/corrective actions timely where required.

KEY HIGHLIGHTS OF MONITORING INSTRUMENTS PROVIDED IN THE PROJECT

1. Existing bridge monitoring

a) Strain gage: Change in stress was obtained by multiplying the measured change in strain by the modulus of elasticity of concrete. As the road bridge had busy traffic, monitoring was critical. As decided by the Consultant, the strain gages were monitored every 15 minutes with automatic dataloggers.
The data was transmitted in real time to our database management system. All the stake holders could view the data in meaningful information, at their desktops, laptops, notepads or mobile phone. Moving average of the data was considered, to ensure accuracies and address 'outliers' like traffic movements on bridge, temperature effect, heavy vehicle movements for construction, etc.
Though the strain gages had in-built thermistors for temperature readings, additional temperature sensors were also installed on the bridge to discern between structural movements due to ambient temperature and to also understand seasonal adjustment factors due to temperature. An incidence regarding effect of temperature on the strain gage reading was seen during the period of November 13-27, 2016. A temperature variation of 4.4°C was observed, which was an unusual variation in such a short period for this geographical location. During this period, a variation of 10 micro strain was observed in the installed strain gage data. It was quite evidently due to change in temperature in the region. A correction of 10 micro strains per 4.4°C was thus implemented in the strain gage data to provide correct readings.

b) **Prism targets** : Monitoring 3D movements of the existing road bridge were vital to ensure there was no structural impact on the bridge due to ongoing site activities. Prism targets were installed on the bridge to monitor 3D movements. Three automatic total station with control boxes were used to collect and transmit the prism targets data at every 20 minutes. The data was presented in graphical format wherein as a summary of the day, daily monitoring reports of 3D deformation data using the values from 7 AM to 7 PM from the automatic monitoring were plotted and displayed.
The data from prism targets was also put in Tony Gee's spreadsheet. This spreadsheet was developed by bridge designer-Tony Gee, in which differential settlements and lateral movement of the bridge were taken into account. Pier movements were checked against the actual design capacity of the bridge deck section. The system automatically compared the results inputted into the Tony Gee spreadsheet to pre-set alert values and provided the alarms when required (Green as "OK" while Orange denoted "Action" or "Overloaded" alarm).



SURVEY INPUTS

Top Survey Point Values average- LATERAL										
P6	P7	P8	P9a	P9b	P10	P11	P12	P13	P14	
-0.3	-0.7	0.5	0.5	0.5	-0.9	-0.3	0	0	0	mm

Average value of prisms P6N-2 and P6N-5 for lateral movement to bridge

Bottom Survey Point Values average- LATERAL										
P6	P7	P8	P9a	P9b	P10	P11	P12	P13	P14	
0.1	-0.2	-1.5	0.7	0.7	-0.2	-0.1	0	0	0	mm

Average value of prisms P6N-1 and P6N-6 for lateral movement to bridge

Vertical displacement average										
P6	P7	P8	P9a	P9b	P10	P11	P12	P13	P14	
-0.6	0.3	0.0	-0.6	-0.6	0.3	0.9	0	0	0	mm

Average value of prisms P6N-1 and P6N-6 for vertical movement bridge

RESULTS

Lateral Bearing Capacity Result									
P6	P7	P8	P9a	P9b	P10	P11	P12	P13	P14
OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

Vertical Bearing Capacity Result									
P6	P7	P8	P9a	P9b	P10	P11	P12	P13	P14
OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

Pier Rotation Check								
P6	P7	P8	P9	P10	P11	P12	P13	P14
OK	OK	OK	OK	OK	OK	OK	OK	OK

Max Deck Stresses S2			
Point 1	Point 2	Point 3	Point 4
-1.62E+00	1.64E+00	-1.29E+00	1.00E+00
OK	OK	OK	OK

Max Deck Stresses S3			
Point 1	Point 2	Point 3	Point 4
-5.20E-01	-1.71E-01	-2.35E+00	2.52E+00
OK	OK	OK	OK

Figure 1 : Tony Gee spreadsheet with data from prism targets and showing alert status

3D deformation data verification by contractor

As per the directives of the main contractor, the bridge was jacked up at the mid-span to achieve a vertically upwards displacement of 10 mm. Readings of 3D prism automatically collected by the ATS showed a movement close to the above value. The exercise proved the sound functioning of the measurement system implemented.

2. Deep excavation monitoring

a) Inclinometer

Inclinometer were installed in diaphragm walls to measure lateral movement in diaphragm walls (D-wall) during deep excavation works. The D-walls went more than 45 m below ground level, which was quite deep - first of its kind with 7 basement levels. Thus, lateral deformation of D-wall was expected during excavation and became critical for monitoring. In a particular incidence, inclinometers data represented significant lateral movement. This alerted shoring contractor who then used anchoring to support D-walls near the bridge. The impact of anchoring was visible in our inclinometer readings, as they got stable after anchoring.

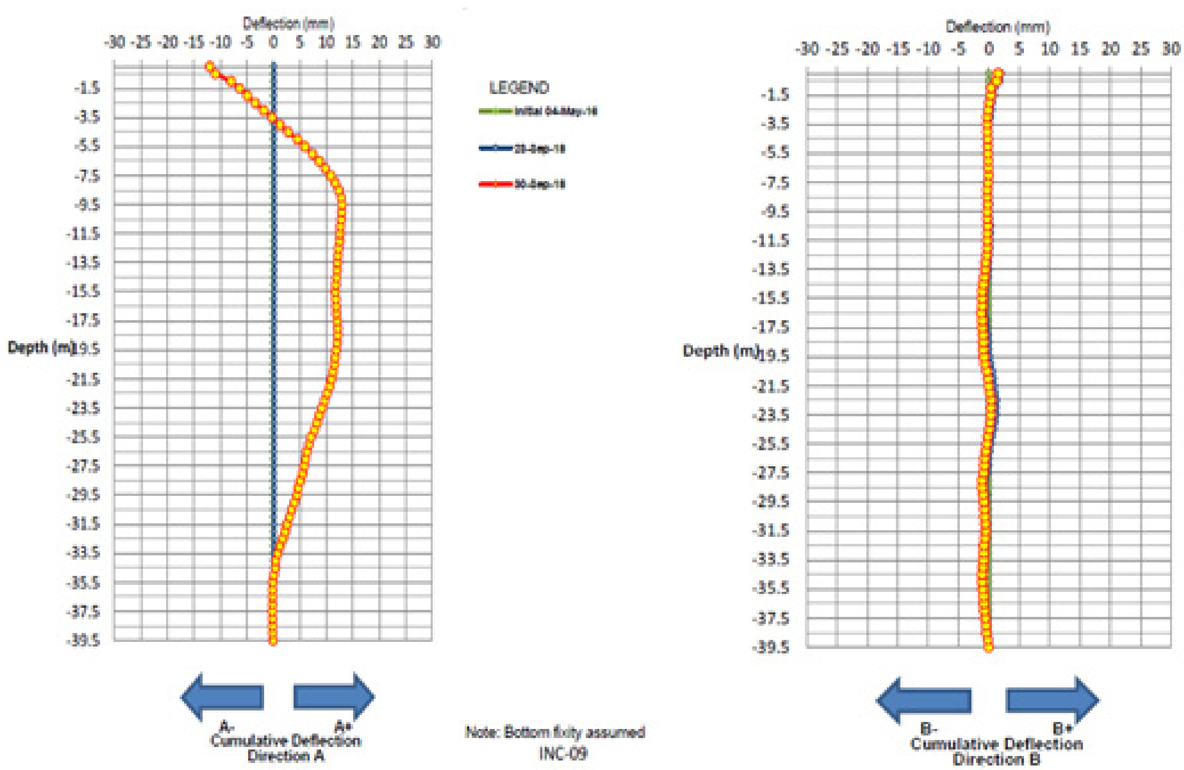


Figure 2 : Inclinometer data showing movement of up to 15 mm.

b) Standpipe piezometer
In deep excavations de-watering plays a vital role. One has to do controlled dewatering during excavation, to ensure that the groundwater level outside the shoring does not go down below certain pre-defined levels by consultant. Thus, de-watering monitoring is very critical. It ensured that it is neither too fast nor too slow; else it could affect the ground conditions resulting in structural movement. Use of standpipe piezometers were used to monitor cross effects of water levels that were interpreted with any detected movement.
In a particular case, water level data started to show an increase when dewatering was stopped. Corrective control was immediately taken by contractor, and the reading got stable.

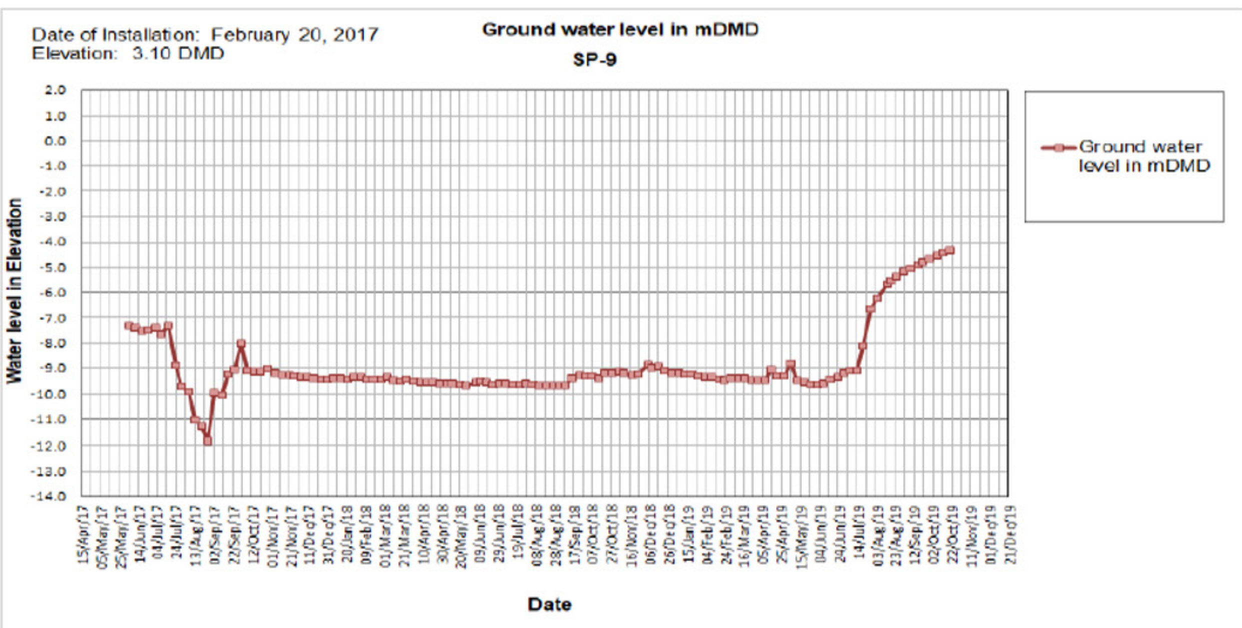


Figure 3 : Ground water level data showing rise in water level when dewatering stopped.

3. Structure monitoring

a) Prism targets
Prism targets were used for external monitoring of structure wherein eight monitoring prisms were installed per tower every ten floors. To monitor the prism targets on building, the survey team prepared a primary network. Stable pillars were used for this to get more accurate readings.
As the tower height increased with construction progress, it became difficult to monitor from the established primary network. Thus, a secondary network was established to get precise readings. The team kept checking the network periodically. In case any change occurred, the errors for tweaked. 12 Beacons of Primary Network, 14 Beacons of Secondary Network were established. Measurements were done using GNSS and High accuracy Total Stations & Digital Levels.

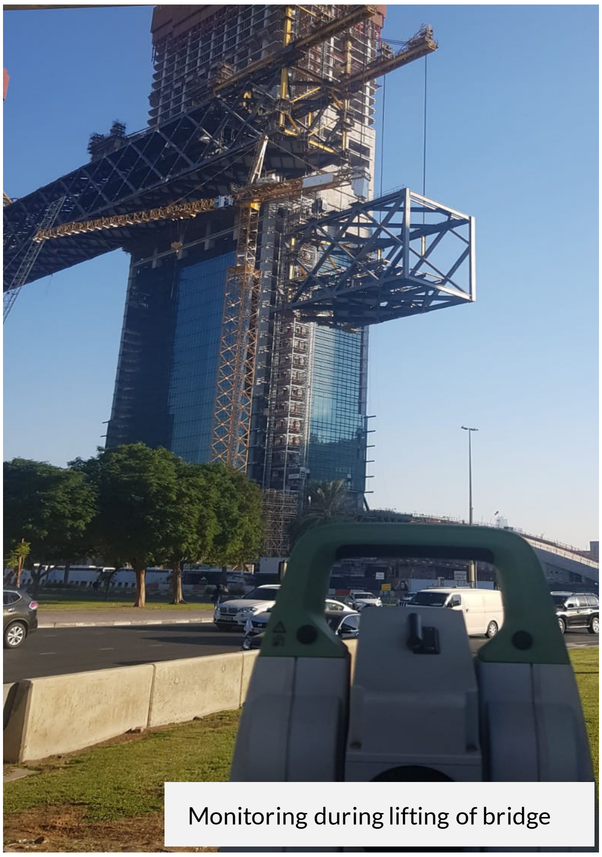
b) Strain gages
Arc weldable and embedment strain gages were installed in selected columns of the Towers A & B for stress measurement. The strain gages were also used to estimate axial shortening experienced in load-bearing concrete columns and walls. This can be expressed as summation of elastic strain caused by load application, shrinkage strain caused by drying of concrete and creep strain induced by sustained stress over a long-term period.
Concrete columns and walls can potentially shorten at different rates within the same floor resulting in differential shortening. The strain gages were installed across a number of floors, from initial construction period to the completion of the structure with full service loads applied.

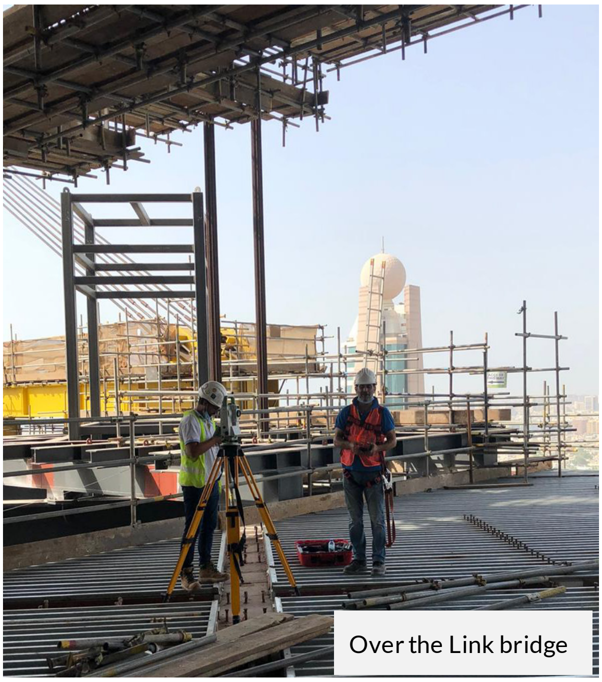
c) Laser Plummet
This was the first experience of Encardio-rite with structure verticality monitoring which was successfully accomplished. The horizontal alignment of the structure was monitored along a vertical axis by using a high accuracy Geo Laser plummet having an accuracy of ±1 mm ~ 3 mm/200 m.
To establish a Vertical Axes Network, ten openings on each slab of Tower A & B, were made without any obstruction from bottom to top. Every measurement in the grid was recorded as the monitoring reading. It was then converted into picture, recorded and sent to the data base. Each hole had a unique code shown in each picture. The picture also included day, time, position and measurement (laser projection). This prevented any risk of error.

4. The Link Bridge and structure monitoring during bridge lifting

The iconic Link Bridge floating between 24-27th floor of the towers is around 100 m above the ground. It is one of the world's longest cantilever link bridge with ~ 226 m length. It took around 12 days to lift it to the position.

a) Prism targets
To measure the deformation, prism targets were used at the bridge edge at every 20 m interval as well as on the structure. Monitoring of link bridge and structure continued during lifting phase and also after it was fixed with the structure. The prism targets were monitored with automatic total station and in-house developed control boxes. Unique methods were devised to cover the link bridge monitoring, as it would be lifted, as the position of the 3D optical targets installed on the bridge would change continuously as the lifting progressed. Special arrangements were implemented to ensure that the processed data was available on the online database management system within just 2 minutes of each reading cycle.


Monitoring during lifting of bridge


Over the Link bridge

The Link Bridge was lifted 77.580 m in the first phase, as shown in the change in elevation (DZ) graph of one of the 3D targets installed on the link bridge. The data was available online - easily accessible to evaluate and determine the lift progress over a day, a week, between any two definite dates and overall (as shown in the graph below) just with a few mouse clicks.

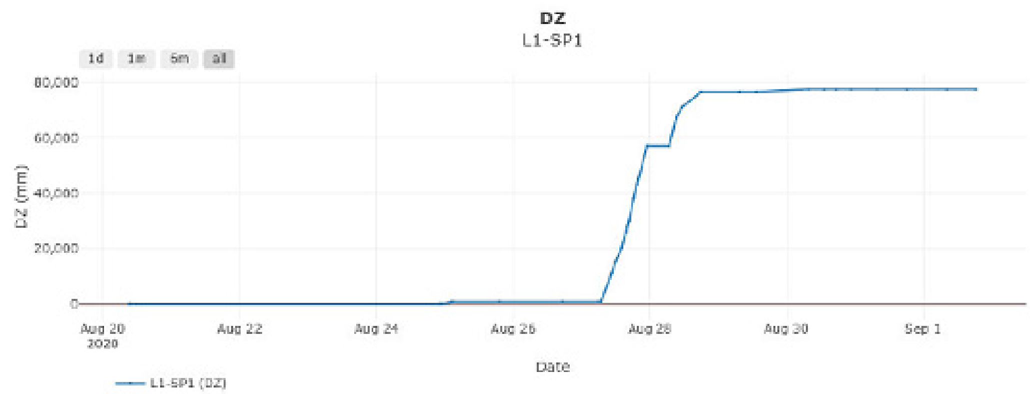
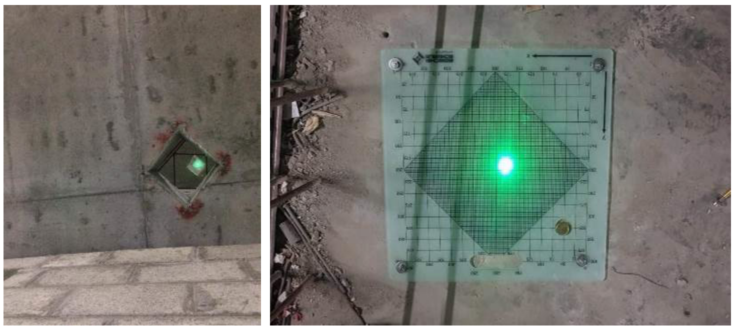


Figure 4 : Graph showing change in elevation of the Link Bridge during its lifting procedure

b) Laser Plummet

Monitoring of the horizontal movements was carried out on each of the towers using a laser plummet. A plummet was placed in each of the tower's lowest basement and measurements were taken using its beam up to the highest accessible slab. By recording the position of the laser beam in the installed grid plates, graphs of the movement of the slabs with time were produced. This exercise was done for every opening of both the towers, daily after the lifting procedure and X and Y graphs of the movements with time were produced in the local coordinates system.



Projection of the laser beam on the highest floor and laser plummet beam visible on the installed grid plate

CHALLENGES

- Installation of prism targets on the Link Bridge was a challenging task. However, it was accomplished safely, strictly following safety protocols, and in time, due to installation team's extensive experience
- Monitoring of Link Bridge was challenging as it was difficult to have line of sight for monitoring the prism targets used for 3D movement of the bridge. Moreover, the position of prism targets changed continuously as the lifting progressed, for which special methods had to be implemented to provide precise data.
- Maximizing the baseline data was challenging. One had to understand the seasonal adjustments and effects. Team had to handle unexpected factors that affected the monitoring conditions.
- Monitoring the verticality of such high towers was quite challenging.
- Changing line of site for optical surveying, as construction works progressed, posed a challenge. Survey team tried to pre-determine the line of sight with modelling software, thinking ahead about the access for monitoring.

Installation of the prism targets on the Link Bridge

• Due to construction activities, dirt used to deposit on the prism targets. Cleaning the prisms at height at regular intervals was challenging, as it required pre-planning to get lifting equipment for access.
• Installation of strain gages in the existing bridge was challenging, as installation was done inside bridge viaduct with confined space and little natural light from the service openings. No artificial sources of lighting could be used. A lot of preparation work was done by team following the 'confined space safety norms'.
• Power source for the automatic total stations (ATS) and control boxes became challenging as they were fixed in the median. Thus, direct power from power line could not be given. Diesel generator had issues of power drop outs, or sudden surges, due to which some data was lost. It was decided to use solar power, but solar panel again lost charging due to mist. Finally team designed a system to have 3 day autonomy combined with diesel generator and solar panels, as shown in adjacent image.

RESULT

Encardio-rite's World class instruments and expertise in the field helped to monitor such iconic structure meeting the precision standards required for the project. Monitoring data was made available to all stakeholders seamlessly almost in the real time, in meaningful information, with advance warnings and alerts. This was possible with a combination of rugged sensors, advanced data collection, transmission, web-based data monitoring service and last but not the least an experienced and dedicated team.
The monitoring results helped in reducing risks, protecting existing assets and giving confidence to the construction process and successful completion of the project. Thus, the role of instrumentation and monitoring in the project was not only limited to design optimization and construction control but also to ensure the safety and stability of work at construction site and of the infrastructure within zone of influence.

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