Technical Note on Land Reclamation

Part 2: Instrumentation and Monitoring

1. INTRODUCTION

In recent years, non-dredged reclamation has become one of the favored options for marine reclamation. It is due to environmental constraints on marine mud dredging, stringent restrictions upon offsite disposal of dredged mud, and difficulties in sourcing of suitable sandfill materials.

Geotechnical instrumentation on reclamation projects is equally as critical as those of the urban infrastructure projects. It is a key element of all projects as it will provide geotechnical data and information on compaction level, settlement and displacement of the fills which can be compared with the design models to ensure that the design assumptions are appropriate.

Firstly, the focus of this guideline is to present the different geotechnical instrumentation methods that can be used for reclamation projects and the specificity of such instruments to cope with the unique properties of reclamation. Finally, it will address the automatic monitoring solution that recent development of technologies has made fully automatic monitoring solution viable.

2. OVERVIEW OF FIELD INSTRUMENTATION

Field instrumentation is essentially used to measure ground movement and to assess the degree of consolidation for different soil strata including fill layer. It provides, as required, a continuous record of soil data of the fill on ground. The majorities of the field instruments are installed on land once the marine zone is reclaimed to its land formation level. Field instrumentation can be installed offshore to monitor the change of the soil condition for the marine and the reclaimed soils. It is critical to establish an instrumentation program with adequate methods before commencement of project. The program should effectively cover the monitoring before, during and after the reclamation period. Therefore, the monitored field data from different types of instruments can be used to record and analyze the current settlement, and to predict the degree of primary and secondary consolidation of the ground.

3. THE INSTRUMENTS

3.1 Settlement Marker

Settlement marker is one of the instruments commonly adopted in land reclamation and ground improvement works because of its relatively simple installation and monitoring with low cost as compared with other delicate monitoring equipment with sophisticated technique required.

3.1.1 Survey Nail Settlement Marker

Survey nail settlement marker (Refer to Fig 1) will only be used on hard surface of appropriate structures like concrete pavement, seawall, or nearby existing building structure that monitoring is required. It can be used to check the vertical and horizontal ground movements.

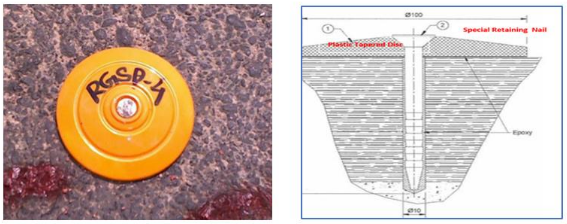


Figure 1 Typical Survey Nail Settlement Marker

Association of Geotechnics and Environmental Specialists (Hong Kong)
(Special thanks to Raymond Chan for preparation of the Guidance Note)

3.1.2 Ground Settlement Marker

The instrument consists of a steel rod (Refer to Fig 2) inserted into ground, and it can be used to complement the monitoring in some specific areas. It can be easily supplied and installed, and therefore, it can provide a quick set of monitoring readings. If more settlement monitoring is required for long term monitoring, a settlement marker is much preferable.

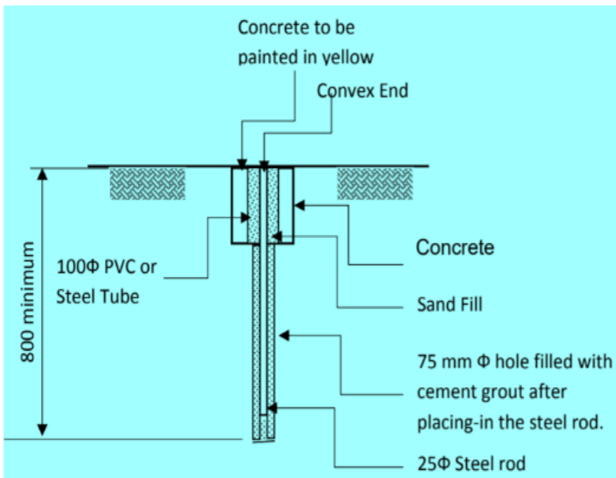


Figure 2 Typical Ground Settlement Marker in Soil

3.1.3 Settlement Marker at Shallow Depth

Settlement marker (Refer to Fig. 3) is typically installed during initial phase of construction and designed to monitor the immediate and long-term ground settlement. It is generally installed to verify design assumptions of settlement and to check whether performance is as predicted with respect to installed prefabricated vertical drains and surcharge. The settlement marker comprises of a base plate attached measuring 19mm OD steel pipe. It is positioned in ground at the prescribed level which settlement is prearranged measurements are required. In order to avoid the downward movement caused by frictional drag-force on surface of the steel pipe, a flexible 50mm OD protective steel tube is installed to encase the steep pipe to free from contact of surrounding soil. During a typical monitoring session, the following information should be recorded:

- Reduced level of the base plate and the top of the settlement marker (I.e., steel pipe).
- Reduced level of the surface of the fill at the location of the settlement marker where practical at each surcharge.

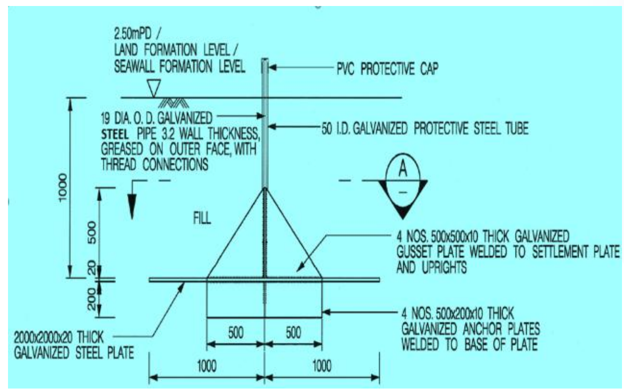


Figure 3 Typical Settlement Marker at Shallow Depth

3.1.4 Marine (Seabed) Settlement Marker

Sub-surface settlement marker is generally installed prior to commencement of marine reclamation at an offshore location. A typical configuration of the marker is shown in Figure 4A.

The marker consists of a 2500mm x 2500mm x 9mm steel plate fixed to a 2500mm x 2500mm x 200mm thick reinforced concrete slab. It is lifted by a derrick barge and is placed at the top of the sand blanket that lay on top of the dredged seabed level or stiff alluvial layer. After levelling of the marker in its horizontal position by diver, the central point of the marker connected by a steel wire to the derrick is checked by the Differential Global Positioning System (DGPS) that is fixed at top of the derrick. A sand dune of around 3m in height is then lay on top of the marker to contribute the four vertical pins of the marker to secure its position such that it would not move or shift by during the subsequent bulk reclamation.

After reaching the land formation level by the reclamation operation, drilling operation with installation of the instrument will be conducted as below:

1. Relocate the position of the center of the marker by previous records from DGPS by optical survey method.
2. Drill 150mm steel casing to the top of the marker until the top of the steel plate of the marker (Refer to Fig. 4B and 4C) is reached.
3. A steel pipe is wrapped with a layer of plastic sheet on its outer surface at the 1m lowest portion.
4. The steel pipe is lowered inside the 150mm sleeve pipe to reach the top of the marker.
5. Inject quick set cement grout through the steel pipe such that the grout will fill the annular space between the steel pipe and the150mm sleeve pipe.

The top of the 50mm pipe will be measured for settlement as if that would be measured at the installed marker.

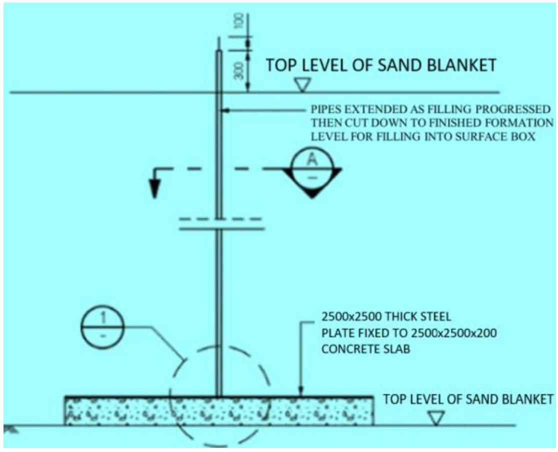


Figure 4A Typical Sub Surface Settlement Marker

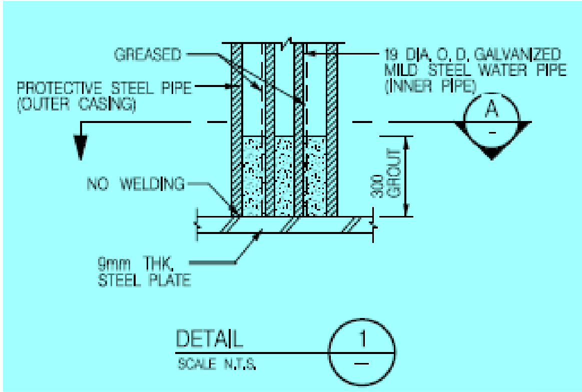


Figure 4B Details for Sub-Surface Settlement Marker (Not to scale)

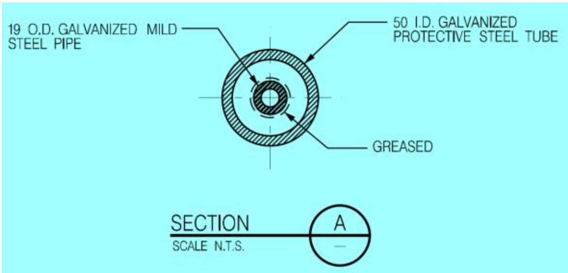


Figure 4C Plan for Sub-surface Settlement Marker

3.2 Extensometer

Extensometer is an instrument used commonly to monitor small displacements in soil, rock and concrete along the axis of a borehole. It can be used to monitor the vertical or horizontal movements of ground in soil or rock layers depending on the borehole orientation for different geotechnical applications such as tunnels, shafts, retaining wall, natural and cut slopes, dam abutments, mining and other open excavations.

To determinate the absolute deformation or movements of the ground, there should be at least one measuring point such that its position is not subject to deformation or movement. This point should either be located at the top or bottom of the casing pipe as the reference point for all the measurement.

In reclaimed area, the reference point is preferably selected at the bottom of the casing pipe. It is generally located within rock or at a depth free from vertical movement of ground.

3.2.1 Magnetic Extensometer

During the propagating along a pipe, the probe measures, either mechanically or electrically, the depths of the respective measuring points along the pipe.

Magnetic Extensometer is generally installed in borehole or on field before reclamation. The system consists of access PVC pipe, magnets positioned along the length of a pipe, and one datum magnet (Refer to Fig 5). The datum magnet should be installed on stable ground such that it is used as the reference point for the measurement for the magnet levels during course of reclamation.

During the installation of the magnets in a borehole, the tips of the spider magnets (Refer to Fig 6) are tied and lowered down along the access pipe to the predetermined levels, and they are temporarily fixed in their respective positions by paper adhesive tapes. The borehole is then backfilled with grout that will be similar in strength as the surrounding ground, and the temporary drilling casing will slowly be lifted. The spiders of the magnets will then be released individually through the respective pull-pins connected by the nylon cables to ground surface. The magnets will be fixed in their respective positions as the spiders expand, and therefore, the magnets are locked into the ground respectively in their positions. The paper adhesive tapes fixed the magnets will gradually be softened by groundwater and deprived of, and the magnets will then be free from movement due to ground settlement movements.

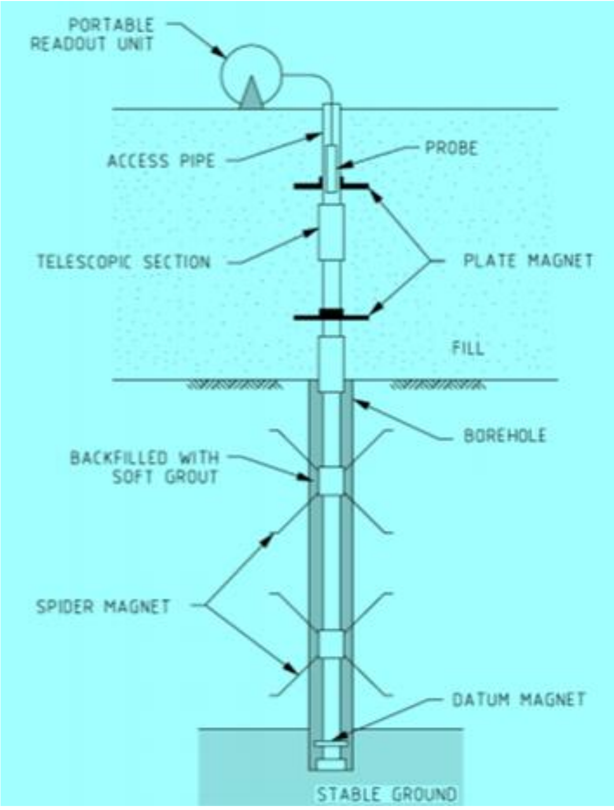


Figure 5 Typical Magnetic Extensometer Installation

During the installation, it is important that there is a good communication between the drilling team and the instrumentation team, which could be two contractors. Besides, it is recommended that there should not be more than ten spiders to be installed in one borehole. It is because each of the spiders has one release wire need to come up to the surface, and it could be entangled into other wires. The entangle might causes the early release of some of the spider magnets at the unexpected levels, and thus the installation will be failed.

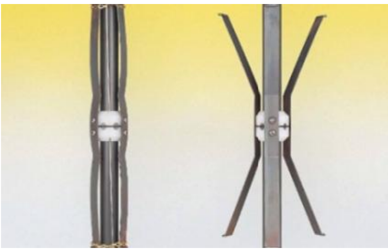


Figure 6 Spider Anchor for Magnetic Extensometer

As the existing ground level is progressively raised by reclamation, the plate magnets (Refer to Fig 5 again) which are installed when the existing access pipe connected to the spider magnets is being extended to accommodate the surcharge of the fill. They are positioned at the designated levels in intervals, and they are then covered with fill material that is compacted to the same specification as the surrounding fill.

3.2.2 Rod Extensometer

The rod extensometer (Refer to Fig 7) consists of anchors, rods inside protective pipe, and a reference head (Measuring head). It monitors changes in the distance between one or more downhole anchors and a reference head at the borehole collar.

Readings are obtained by measuring the distance between the top of the rod and a reference head. A change in this distance indicates that movement has occurred. The level for the reference head should be seated on a firm position that is free from subsidence. It should be checked from time to time for movement by precise levelling method for correction in level measurements from the rods.

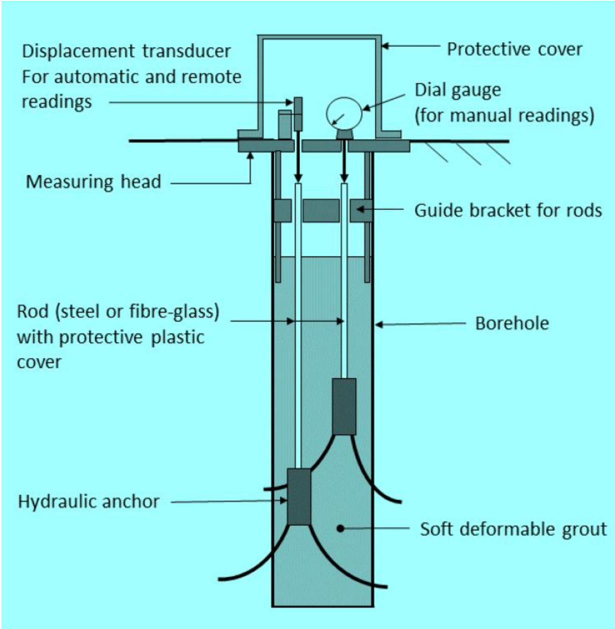


Figure 7 Typical Rod Extensometer in Soil (Courtesy from Geotechnical Observation)

A depth micrometer can be used to manually measure the distance moved for the rod from the reference head. Alternatively, it can be measured by electric displacement transducer (May be the type of Linear vibrating wire displacement transducer (LVWDT)), and the readings can be taken automatically and stored in a data logger for remote transmission purpose.

An extensometer can monitor up to six points along the borehole of typical diameter of 100mm. Typical applications of rod extensometer include monitoring settlement in foundations, above tunnels, heave in excavations, deformation in abutments and walls. The resulting data can be used to determine the zone, rate, and acceleration of movements, and to calculate strain. Despite the rod extensometer can be extended, it will not be easy to reassemble the reference head instruments for each extension and trimming. The main weakness is the travel distance of LVWDT is limited, and it is not recommended for large ground movement situation such as reclaimed area.

3.3 Inclinometer

3.3.1 Access Pipe Inclinometer

Inclinometer is a device for monitoring displacement normal to the axis of an access pipe by means of passing a measuring probe along the pipe. The probe contains a gravity sensing transducer designed to measure inclination with respect to the vertical. The access pipe may be installed in either a borehole or in fill, and in most application, it is installed in a near vertical alignment, so that the inclinometer provide data for defining subsurface horizontal displacement. However, there is a type of the horizontal pipe for inclinometer could be installed below embankment to measure the vertical settlement.

The plastic or metallic casing of the inclinometer tube generally has four orthogonal grooves in length of 3m (1.5m length is also available), and the casings are connected by means of couplers. The "glue and snap" type of the inclinometer casings (Refer to Fig 8) is more commonly used now. The two pieces of casings are coupled together without the need of specific tool, and therefore, it shortens much the time instrument installation time.

Since the internal guide grooves for the inclinometer probe are precision machined and provide effective control of spiral, straightness, groove shape and depth. The alignment is maintained by screws in the casing and longitudinal slots in the couplings.

Figure 8 Typical Inclinometer Casing and Standard Coupler

3.3.2 In-place Inclinometer

The system consists of several in-place sensors that are installed in inclinometer casing (Refer to Fig 9). The casing is typically installed in a vertical borehole that passes through a suspected zone of movement into stable ground below. Inclination measurements from the sensors are processed to provide graphs of the casing profile and changes in the profile. In most applications, sensors are connected to a data acquisition system, and readings are transmitted to processing software that can trigger alarms based on displacements or rate of change.

Despite the in-place inclinometer available in the market for years, it is not commonly adopted due to difficulty for installation and data management. Firstly, the number of sensors in chain (i.e., generally at 2m intervals) in a borehole or casing are limited and congested for installation. The total weight of the instrument chain makes the installation becoming difficult and daunting. Besides, the maintenance of such instrument is always complicated. It is quite often that an instrument within the chain to be failed after installation, and it is required to be fixed again or re-installed.

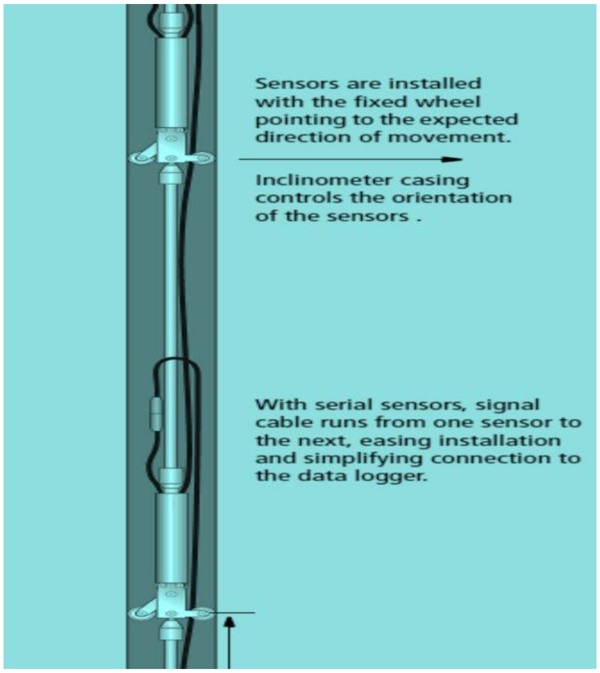


Figure 9 In place inclinometer Sensor

3.4 Shape Array

Shape Accel Arrays (SAAs or SAs) are recently adopted at a few local infrastructures to monitor ground movements at a relatively high frequency of interrogation. There are significant benefits in the use of SAAs over the traditional manually and automatically operated inclinometers.

It was described that the shape arrays (G. E. Swarbrick et (2015) contain a chain of rigid segments connected by flexible joints (Refer to Fig 10). The joints are designed to resist twist but allow the segments to tilt in any direction. The Shape Arrays are interconnected with one or multiple accelerometers within each segment. Before installation, the Shape Array will be delivered to site with a reel coiled as any cable does. Its installation is simply unwinding the Shape Arrays into an inclinometer casing (Refer to Fig 10A and 10B). The Shape Arrays will then be compressed to remain in-place inside a smooth casing or inclinometer casing. A computer software will be used to calculate the profile of the casing in accordance with the accelerometer data.

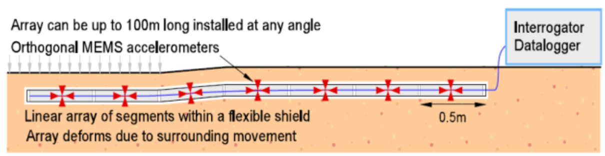
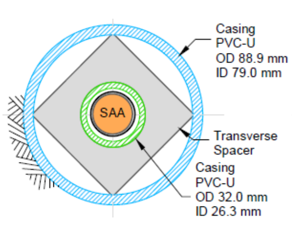
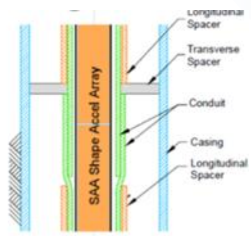


Figure 10 Linear Shape Arrays in Within A Flexible Shield or Casing

Its advantage is that it can be installed into inclinometer casings that can no longer be read with a manual probe. On the other hand, the system designed for application geometry, and it is difficult to lengthen or shorten.



(A)



(B)

Figure 10A Plain Section for Shape Array

Fig 10B Elevation for Shape Array

Shape Arrays, as shown in Fig 10C, have recently be installed in one of the reclamation infrastructures in Hong Kong. The shape arrays are submerged in marine soft mud and lay horizontally above the top levels of the constructed deep mixing panels whereas some of the shape arrays are installed in the vertical inclinometer casings inside the panels. It is noted that only the vertical installation can monitor as 3D mode. For horizontal installation, it only can monitor as 2D mode.

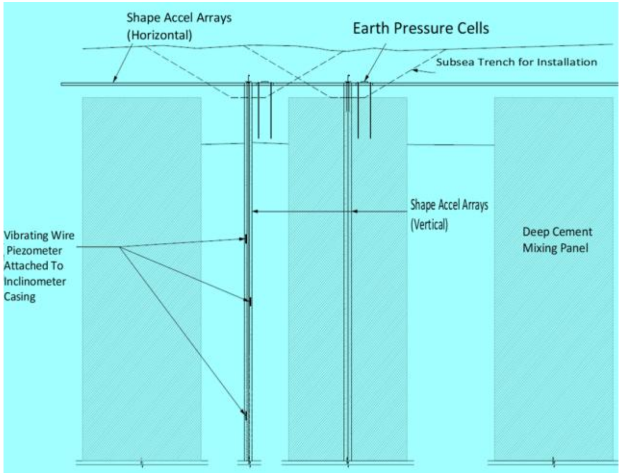


Figure 10C Installation of Shape Arrays in Horizontal and Vertical Orientations

3.5 Instruments for Groundwater and Pore Pressure Measurement

Although there are different types of advance instruments for measurement of groundwater level and pore pressure, the traditional access observation well and piezometer are still used widely.

3.5.1 Observation Well (Standpipe)

An observation well a long-perforated pipe installed in a borehole (Refer to Fig 11) and filled with sand filter. It creates a vertical connection of ground water between strata as there is no bentonite seal intermittently around the sand filter zone except the sealing at top of hole. The water level measured within an observation well corresponds to the head in the most permeable zone or the phreatic water table in common ground.

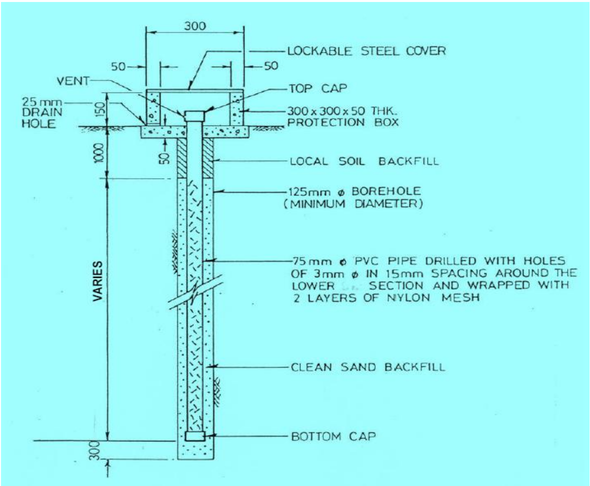


Figure 11 Typical Observation Well

3.5.2 Standpipe Piezometer

A standpipe piezometer (Refer to Fig 12) is a device equipped with a short porous plastic tip (Refer to Fig 13) that is jointed to a riser pipe, and the riser pipe will be completely sealed within ground. The perforated tip surrounded by a sand filter layer such that pore water pressure can be measured within a ground stratum.

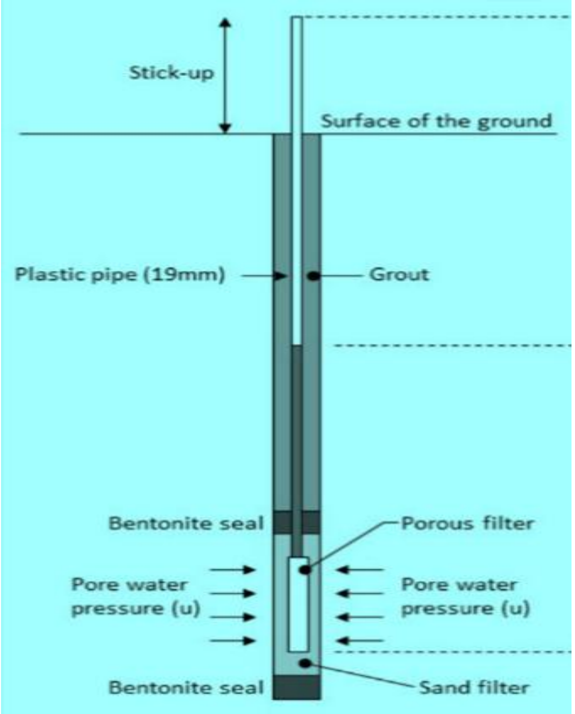


Figure 12 Typical Standpipe Piezometer

Piezometer is used to monitor local pore water pressure in soil or in rock joints around the designed sand filter layer.

The observation well and piezometer could be very similar looking. They are usually placed together in the same borehole at different levels to reduce high cost for drilling of two separate holes for the installation.

Figure 13 Typical Slotted PVC Pipe for Casagrade Piezometer

3.5.3 Vibrating Wire Piezometer

Vibrating Wire (VW) Piezometer shown in Fig 14 contains a high tensile steel wire with a fixed anchor at one end, and another end is attached to a diaphragm that is in contact with groundwater . The wire is electrically plucked such that a resonant frequency of vibration generated will be proportional to the tension in the wire. This frequency induces an alternating current in a coil which is detected by the readout unit and can then be converted to a pressure.

Vibrating wire piezometer has been used throughout construction projects for many years, and its reliability and installation method have well been documented. It can be installed inside an existing standpipe piezometer or fully embedded into ground with slurry grouted in a borehole. The first method is used to upgrade a manual monitoring method to a fully automatic one. The fully embedded installation method is frequently used in reclamation projects as it completely rules out the risk of buckling of the PVC casing of the standpipe piezometer.

VW piezometer is one of the instruments to be automated by collecting and storing data at data loggers that are capable of exciting and reading them.

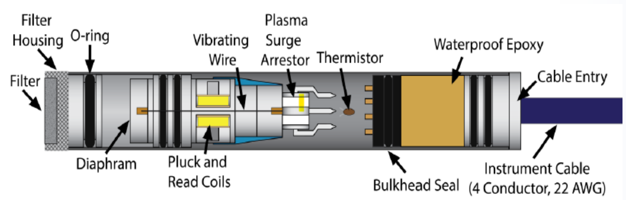


Figure 14 Typical Vibrating Wire (VW) Piezometer

Previously, the VW piezometer has not been commonly adopted as one of the automatic monitoring systems. It is because the data logger always suffered from short working life for the built-in battery. However, the new logger is becoming available now on market in recent years after improvement. The new logger is usually single/multi-channeled, small, easy to be installed and equipped with a long-life battery. Therefore, it does not require any main power source or even solar panel.

4. EXTENSION OF INSTRUMENT

Excessive settlement will happen between the time of the instrument installation and the major extent of the primary consolidation of the reclaimed area is taken place. Therefore, the extension of instrument should be conducted at different stages of the reclamation period.

4.1 Extension for Change in Ground Levels

Typically, instruments will be installed below ground or on the reclaimed area level, and the reclamation level will be further increased until the final formation level is reached. To maintain function for the instruments, they must be extended in line with the level of the formation level of the reclaimed land. The method of extending the instrument is generally not complicated. It is, for example, most of the manufacturers will provide the inclinometer casings with their respective "Repair Kits" which can be used to extend the inclinometer, extensometer, piezometer and standpipe casings. The standard PVC casings of the respective types of instruments can easily be extended. For settlement markers, all steel rods will be connected by threaded ends for extension.

Some of the instruments like rod extensometer and in-place inclinometer are difficult to be extended or trimmed. As it is one of the disadvantages of these systems, the instrumentation and monitoring plan with adequate instrument should be deliberately considered at the early stage of design such that the instrument could finish their mission for the monitoring before the need for extension or trimming, and some of the existing and nearby instruments could be extended and take readings to take over the mission of the lost instrument that could not be extended.

It should be noted of importance of recording adequate reading before and after each stage of extensions and cutting-downs of instrument in order to maintain the data to be continuous and meaningful.

It is crucial that the coordination and planning of the extension of the instruments should be in line with the reclamation work in progress (Refer to Fig 15A to 16C). The extension work generally involves two different contractors, namely, the reclamation contractor and the instrumentation and monitoring contractor. It is inherently difficult for the two contractors to have good communication with transparency of their respective operation. Therefore, it is recommended to facilitate as much as possible the communication and planning forecast for those operations of instrument extensions.

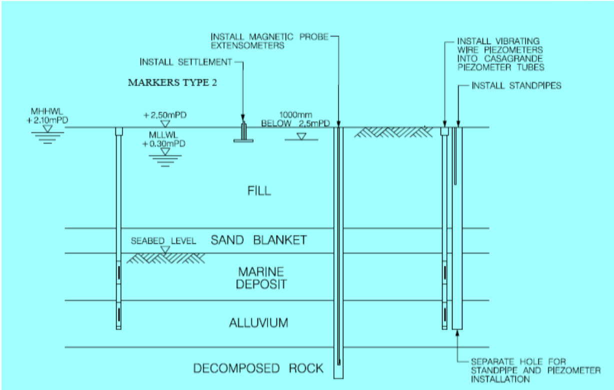


Figure 15A Instrumentation After Filling

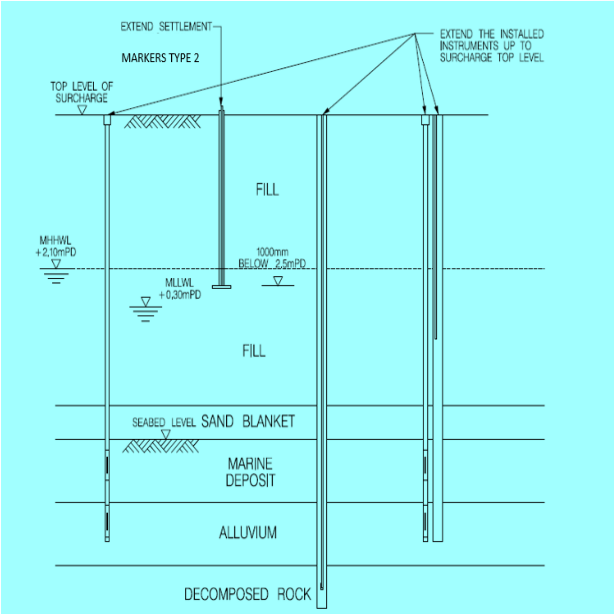


Figure 15B Extend Instrument to the Surcharge Level

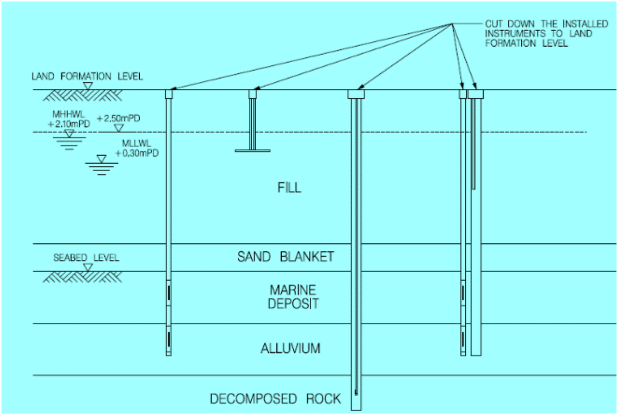


Fig 15C Cutting Down of Instrument After Surcharge Removal

4.2 Extension for Inclinometer

The large settlement can potentially damage all the vertical casings of an inclinometer installed as it will push the casings to be buckled.

Typically, an inclinometer casing can sustain up to 1% of its length in vertical settlement, which means that a 70m inclinometer casing can sustain up to 70mm of settlement at its location. If settlement is more than expected, some preventive measures should be taken to cope with it by minimizing the buckle of the casings. One of the measures takes the form of telescopic coupler (Refer to Fig 16A) which is specially designed coupling to be inserted between two lengths of inclinometer casings.

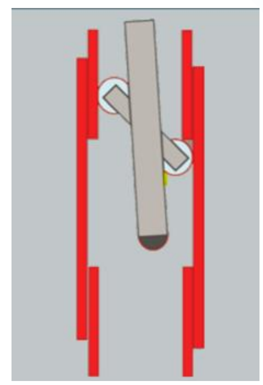
The coupler allows the axial movement of the casings to prevent from buckling due to the large settlement. The telescopic coupler can accommodate a compression / extension of 150mm. The change in length of the coupler between the non-extended and the extended states for the standard coupler under movement in ground. The locations of those telescoping couplers need to be designed and agreed before installation. It is recommended to increase the quantities and locations of those couplers as far as possible so that if one would fail the others could take over. However, it should be noted that one of the disadvantages for the telescoping coupler is that step error may be occurred due to coupling movement or material settlement as shown in Fig 16B.

This method of using telescopic couplings could be considered to implement on some of the instruments of access casing types like inclinometer and extensometer as far practicable. However, it should be noted that if the telescopic couplings at casing are applied for extensometers, the telescopic couplings usually restrict the numbers and positions of sliding magnets such that readings taken due to settlement taken by the magnets may be affected. Therefore, the designer should deliberate the locations of nearby magnets to be far enough from the couplings, or to assess the readings acquired from the affected magnets are still valid.

It is unlikely to be applied for Casagrande type piezometer or observation well. It is because the leakage of water through the joints between the coupler and the casings will occur. It should also be considered for the plate and spider extensometer that the PVC casings may not be strong enough to stand for the vertical force, and they would eventually be broken.

(A)

Figure 16A Standard Coupler in Non-extended and Extended States.



(B)

Figure 16B Step Error Due to Coupling Movement or Material

4.3 Extension of Shape Accel Arrays

SAA has recently provided a continual deformation profile throughout multiple dam raises with ease of installation as shown in Fig 17.

When it is time to raise the tailings dam, Shape Accel Array Vertical (SAAV) Lift Extension segments can be added between the top and base assemblies to increase the total sensorized length. SAAV Extend's connectors are keyed to ensure azimuth is maintained as Lift Extension segments are added in the field.

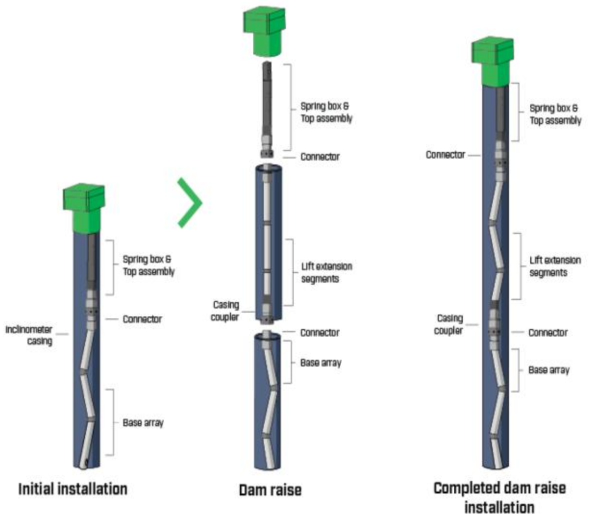


Figure 17 Typical Installation for Extension of SAAV (Courtesy of Measurand)

5. PROTECTION OF INSTRUMENT

Protection of instrument from damage during the subsequent construction works is a key aspect of the monitoring scope. As an instrument is damaged, the monitoring data will be lost. Re-installation could take several days or even weeks depending on site conditions. The challenge for reclamation project, as explained in previous paragraph, is that the instruments will often need to be extended to match with the progress of the fill reclamation. Thus, their protection needs to be flexible enough to be removed and reinstalled in line with the progress. Instruments, survey marks and stations shall be protected by suitable barricades, notices, signs or marker-buoys. For protection of the expensive and valuable instruments on site against the large impact from lorry or heavy machineries, rigid steel frames as shown in Figure 18 should be erected and fixed securely in ground. Construction shall be carried out in a manner to avoid damage the instruments.

Figure 18 Typical Protection Frame for Intrument on Site Installation/Extension

6. MONITORING

Traditionally, the method of monitoring on reclamation project is manually operated. But there are few key potential restrictions with reclamation project or optimization that need to be kept in mind. Moreover, as always with manual method there are some limitations.

6.1 Manual Monitoring

6.1.1 Monitoring of Settlement Marker

The conventional monitoring method for settlement gauges is by means of optical levelling survey. It is a robust but accurate. The major drawback in the case of reclamation project is that it requires a benchmark point as a stable reference point which absolute level is known. Obviously, it is difficult to provide this benchmark for an offshore reclamation project.

An alternative solution is adopting some of the temporary benchmarks which absolute levels are acquired through the DGPS measurement, and still being used a starting point of the optical survey run. This method does not require the “Temporary Benchmark” to be stable as its true elevation would be known through DGPS measurement and can be readjusted, it will however affect the accuracy of the measurement as DGPS measurement has an accuracy of few mm at the best, thus accuracy of the monitoring on the settlement marker could not be any better.

An alternative method is the use of Realtime Kinematic Goble Positioning System (RTK GPS) direct measurement on each of the settlement gauges. It is directly acquired survey data from the GPS measurement at each of the settlement gauges, and therefore, it rules out the need of intermittent benchmarks. The major drawback of this method is that the accuracy of +/-10mm can only be acquired from the RTK GPS measurement.

6.1.2 Monitoring of Extensometer

Monitoring of multi-point borehole extensometer is straight forward and like that of standpipe piezometer method. The reading device consists of a coiled housed within a probe, the probe is attached to a readout unit (Refer to Fig 19) via survey tape. The probe is lowered down the extensometer casing, when reaching the top and bottom levels of a spider magnet or plate magnet, the readout unit will emit a "Beep" sound respectively the magnet. Therefore, the two locations should be recorded for taking the average reading to represent the measured location for the magnet.

The extensometer casing is generally seated in rock or non-settled zone, and the datum magnet will be installed at its bottom as a reference point to calculate the respective settlements at each of the spiders and plate magnets. It generally rules out the use of the top of the extensometer casing as the reference point to avoid from the adverse effect on settlement of the ground.

Figure 19 Measuring Probe for Casing Type Extensometer

6.1.3 Monitoring of Inclinometer

Despite it is technically simple for inclinometer monitoring, it requires a high level of quality of process during course of the monitoring to obtain a meaningful and accurate data. The process can be split into the following steps:

1. Lower the inclinometer probe (Refer to Fig 20) to the bottom of the inclinometer casing.
2. Wait for temperature stability (usually 5 mins).
3. Take readings repeatedly along the inclinometer casing, usually every 0.5m interval.
4. Once the top of the casing is reached, repeat the complete operation by rotating the probe by 180 degrees.
5. Go through the above four steps at the orthogonal groove of the casing.

The true inclination value at a specific depth will be the average of the two readings taken from the directions from the two opposite axes on site. As the inclinometer probe is basically a gravity sensor, the average values of the two readings from the orthogonal directions can eliminate any of the "face error" on the inclinometer probe. This face error arises from the fact that the axis of the inclinometer probe is not in parallel with the axis of the servo-accelerometer sensor within the probe. As this face error or check sum is a value of angle between the axis of the probe, the sensor should therefore be remained constant. Stability of this face error is important and may be the critical for quality check of an inclinometer data. Unfortunately, it is so often overlooked during the monitoring process by site technicians.

Figure 20 Inclinometer Probe

The selection of reference point at bottom or top of the casing should be careful interpreted. It is, for example, that the vertical profile of the reading points is found to move towards the MTRC tunnel as the reference point at bottom of the pipe is adopted. However, the profile will be interpreted to move away from the existing tunnel if the reference point at top of the pipe is adopted.

Finally, another issue specific to reclamation, and specifically the use of telescopic coupler is the settlement of the top of the casing. As the inclinometer readings are made at specific depth compared to the top of the casing, the location of the reading in absolute level (mPD) will therefore change during the construction period. To take this effect on board, the top level of the inclinometer needs to be regularly recorded and a computer program is used to interpolate the inclination of the casing at the same elevations as the initial set of data.

6.1.4 Monitoring of Observation Well and Standpipe Piezometer

For measurement of water table inside an observation well or standpipe piezometer, an electric probe is connected to a cable that is embedded a graduated plastic tape, and the tape is coiled intro a sensing unit (Refer to Fig 21). When the probe is in contact with water, the sensor inside the unit will emit a "Beep" sound, and the depth of the water level can be read from the tape.

As the depth of the piezometric tip is known, the pore water pressure is strictly equal to the hydrostatic water head of the water column measured.

Figure 21 Observation Well / Standpipe Piezometer Sensing Unit

6.1.4.1 Differences Between Standpipe and Piezometer in Groundwater Monitoring

The observation well measures the water pressure along the length of the entire riser pipe, whereas piezometer measures groundwater with its piezometric head (I.e., hydrostatic head if no groundwater flow) at the bottom sealed section of the pipe. It is important to understand the differences in functions for measurement of water level and pore pressure between observation well and piezometer, but it is frequently mis-understood by some of the young engineers.

Observation well cannot detect a perched water table. However, many factors in the soil are better detected with groups of piezometers. It is for example, piezometer can detect the depth of the water pressure in the soil, and they can also detect water flow and strata permeability.

In deep excavation, water cut-off to a sufficient depth below the final excavation level is required to prevent significant ingress of groundwater into the cofferdam. The water cut-off could either be provided by the cofferdam wall itself or by means of toe grouting. Varying degrees of effectiveness of the water cut-off gives rise to different patterns of groundwater movement and pore water pressure distribution (Technical Note No. 8).

Effective Water Cut-off

If a cofferdam achieves completely (I.e., 100%) effective water cut-off, the groundwater inside and outside the cofferdam will be completely disconnected in a hydrostatic condition. The difference in the hydrostatic head cannot cause groundwater flow through the cofferdam walls and/or toe grout curtain. In this condition, the water pressure distributions, both inside and outside the cofferdam, depend solely on the hydrostatic heads as shown in Fig 22. If a perforated standpipe (S, the same name as observation well) and a piezometer (P) are placed both inside and outside the cofferdam, the water levels measured inside the standpipes simply represent the levels of the free groundwater table, whereas the water levels inside the piezometers represent the pore water pressures at the depths of the piezometer tips, which in this case are the same as the hydrostatic water pressures.

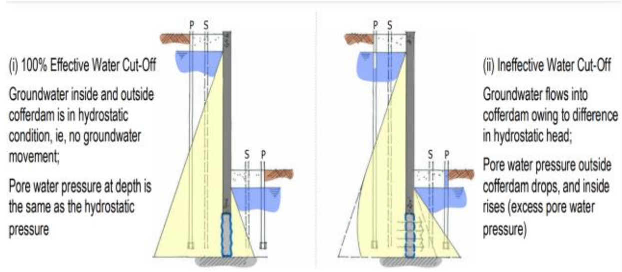


Figure 22 Effective and Ineffective Water Cut-off at Cofferdam

Ineffective Water Cut-off

In the case where the water cut-off is not completely effective, there will be a flow of groundwater into the cofferdam. Such groundwater flow will continue until the water level on both sides of the cofferdam wall is the same. Outside the cofferdam, the pore water pressure measured by the piezometer will start to decrease due to the groundwater movement at depth. However, owing to the ingress of groundwater inside the cofferdam, the water table will start to rise (if no dewatering). Inside the cofferdam, the water table inside the perforated standpipe (S) measured represents the free groundwater table. In the case where groundwater ingress is substantial, a rise in the water level will be seen. For the piezometer (P), depending on the magnitude of the pore water pressure, it would probably be observed that the piezometric water level is rising above the free groundwater table. This is the so-called excess hydrostatic water pressure (or excess pore water pressure). It is crucial to reduce the excess pore water pressure, if it exists, by effective means like dewatering to prevent hydraulic instability at the toe of the cofferdam walls.

6.1.5 Disadvantages for Manual Monitoring

The main difficulties with manual monitoring are accessibility, safety and manpower intensive. Access can be difficult for some reclamation projects like offshore locations, and some projects with multiple separated areas need to be accessed which will require multiple teams to complete and suffer from time for logistic transfer from one area to another.

As reclamation is still in progress and monitoring is maintained, it is likely that some areas will not be accessible for a short period of time due to the backfilling operation and safety concerns. In summary, it is not cost effective, and it increases risk of missing some of the monitoring data as compared with automatic monitoring system.

6.2 Automatic Monitoring System

The System can be subdivided to automation and web-based data management with reporting.

6.2.1 Automation

Automation is adopted with a series of advanced instruments and technologies to collect and monitor geotechnical data in efficient and optimized operation such that human intervention is ruled out, but the performance is superior to manual operation.

For the manually collected instruments like observation well, standpipe piezometer, pneumatic piezometer and magnetic extensometer, monitoring data could not automatically collected and stored by data loggers. Therefore, data are taken manually and stored in excel file, and they will be stored at designated Portable Computer (PC) at site office and then transmitted to the designated remote PC. Alternatively, data can be transmitted to designated remote PC by mobile device using mobile device through 3G or 4G internet.

For the electronically based instruments like VW piezometer, in-place inclinometer, rod extensometer equipped with displacement transducer at reference head and shape array, data can be electronically collected and stored in data logger. The data will further be transmitted to designated remote PC by data transmission unit.

Despite automation is much beneficial as compared with manual monitoring, it should be noted that non-useful and unbelievable could be produced if appropriate manual overview, intervention and management are not implemented at site. It is for example, if extension and cutdown information is not properly recorded and input into the system, the related auto-monitoring records will be completely incorrect.

6.2.2 Web-based Database Management and Reporting System

For the system, data from various devices and sensors can be collected and retrieved in real time from anywhere in the world. Such systems ensure that all the relevant parameters and their trends can be quickly visualized and analyzed graphically.

Basically, all the data collected in the Monitoring Zone (Refer to Fig 23), either manually or electronically, can transmitted and the data can be transmitted eventually to the designated receivers by Internet.

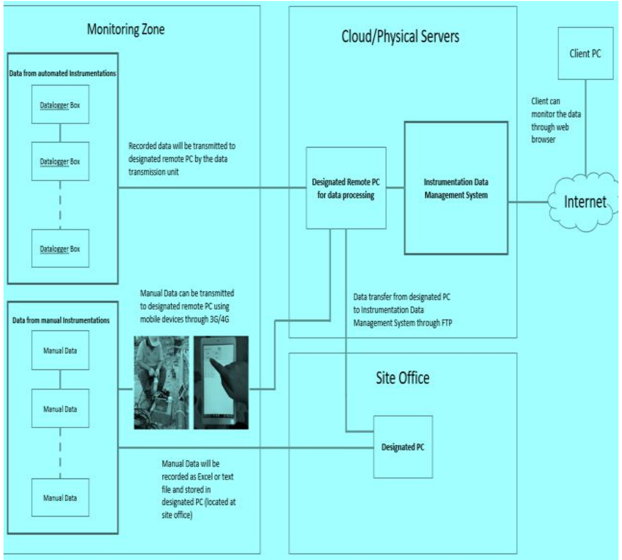


Figure 23 Data Flow of Automated Instrumentation System

6.2.3 Advantages of Automatic Monitoring System

The advantages for automation are:

- Despite the installation costs for automatic instruments are higher than that of the manual types, it can be recovered by lowering manpower costs for monitoring operation with less manpower involved for long period of monitoring.
- It makes analyzing the data easier and reduces labor costs by automating manual processes.
- Automated methods are more reliable and much more precise than the average manual method.
- The dependence on the technique of the individual technologist is eliminated.
- It minimizes workplace hazards to keep workers safe.
- It can send out reporting data automatically, and sometimes real-time data reporting could be made as required.
- Because of web based data access, messages for exceedance alert can be quickly transmitted for action to be taken place.
- Safety and continuity of road and railway operation can be maintained during construction works.

6.2.4 Communication Networks of Automation System for Monitoring

In today's competitive communication marketplace, quick and real-time transmission of information becomes the key factor for reliable delivery to customer satisfaction. The operational and commercial demands of communication require a high-performance data transmission network that supports both existing functionalities and future operational requirements. There are several communication methods as below:

1. By power line communication,
2. By optical fiber communication,
3. By wireless radio communication.
4. By internet network.

In this section, the opportunities and challenges of hybrid communication networks are discussed for automation applications.

There are numbers of wireless network systems suitable for site use such as Loadsensing's LoRaWAN, WISENs mesh network, Senceive's FlatMesh or GeoWAN systems. The systems provide different instrument sensors like load cells, vibrating wire, tiltmeter sensors for measurement and monitoring. The sensors are connected by cable to the respective data loggers of the wireless nodes, whereas the nodes are configurated by an App connected installed on a mobile phone. When the sensors transmit the data and store the data on the loggers of the wireless nodes, the data will further be transmitted from the wireless nodes to the Gateway or Gateways (Refer to Fig 24A). The data is then stored in a data server or cloud storage and can be transferred to an external server through different integration options (HTTP API Call, MQTT, and FTP Push) amongst others. If the customer has a third-party software, he would be able to visualize and manage the data. Loadsensing has its own web-based user interface software such that which allows the user to visualize the data on real time, and to transfer the data and download this data in CSV file.

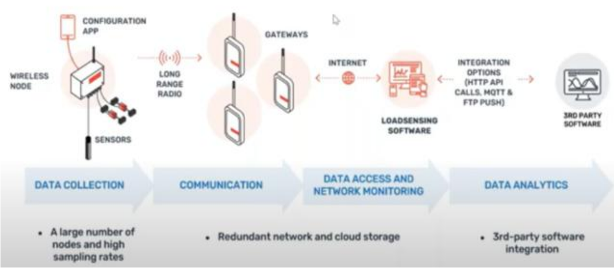


Figure 24A Typical Details for Communication Methods for Full Automation (Courtesy of Worldsensing)

Because of optimization of radio protocol, the radio range on this logger can reach 10 to 15 kilometers in line of sight or in non-line of sight depending on the intensity of the radio wave (Refer to Fig 24B). The logger can work with a long lifespan battery from one to ten years, and a radio which makes it a perfect solution for monitoring large area with multiple sensors of different instruments spread around the area. This radio system proves working effectively, and it has widely been adopted in some of the local infrastructure projects for VW piezometers and tiltmeters.

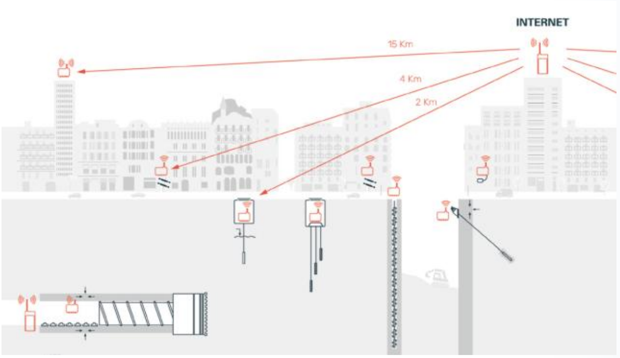


Figure 24B A Typical Wireless Communication amongst Nodes with Different Sensors and Gateways (Courtesy of Worldsensing)

6.2.5 Automatic Monitoring for Settlement Marker

The recent development in monitoring technology with DGPS has made a small low-power DGPS station to be available in market. The station (Refer to Fig 25) can be installed permanently on the points to be monitored and is empowered through a solar panel such that the data is transmitted either through radio or 4G network. This method, based on DGPS, still requires some "benchmarks" but as compared to the optical method where the benchmark need to be "on site", the DGPS benchmarks can be a few kilometers away which makes it very practical for offshore reclamation projects. After the DGPS sensor has been installed, continuous data can be acquired to achieve reasonable accuracy by averaging data to obtain a daily average value.

Figure 25 Permanent DGPS Station to Monitor Settlement Marker.

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