Technical Note on Land Reclamation

Part 3: Construction Considerations

1. INTRODUCTION

Reclamation is one of the solutions to the land supply issues in Hong Kong. The construction technology, process and its relationship with design deserves closer examination.

The main purpose of this technical note is to provide general guidance on reclamation works from a construction perspective, including:

- Construction procedures,
- Construction equipment and plant,
- Materials, methods and techniques,
- Instrumentation and monitoring,
- Quality assurance and quality control.

It is also intended to provide some current developments from recent reclamation projects in order to establish sound (if not the best) construction practices, to avoid common misunderstandings and achieve better constructability and outcome.

2. CONSTRUCTION PROCEDURES

2.1 General

The construction of reclamation works in general follows common construction practices with particular attention on the requirements as specified in the Environmental Permits, sequence of construction to suit the land parcel delivery programme as well as the working environment near the waterfront in terms of marine and/or land accessibility.

Reclamation works are normally retained by seawalls that are built first and may be protected by additional breakwaters to counter wave and current effects. For reclamation construction to start, typically seawall or breakwater structures need to be completed in advance, starting with foundation works.

The seawall in general separates the main works area into three parts:

1. Interface areas between existing land and the proposed reclamation,
2. Seawall foundation areas, and
3. Areas inside the reclamation.

The areas inside reclamation can be further divided into the edge area (within a certain distance from the seawall cope line) and the main land mass area. Each area can involve different types of ground improvement works.

Ground improvement is often required in the reclamation area, which starts after completion of a capping layer or once a stable reclamation platform is formed above the sea level. Prefabricated vertical drains (PVD) with surcharging is a conventional ground improvement method used in Hong Kong (Fraser et al., 1990; Ng, 1991; GEO, 1997; Endicott, 2001; Dou & Swann, 2001; Neville-Jones et al., 2004). PVDs can be installed by either marine or land based equipment.

As the reclamation works start, careful sequencing is necessary to avoid disturbance to the underlying soft marine deposits, if present. It is also necessary to maintain a proper leading edge and sloping fill to prevent soil instability or mud wave formation during the reclamation process. The gradient depends on the type of ground treatment below and the material being placed and ranges from 1V:15H to 1V:20H on the leading edge, to 1V:5H temporary sloping seawall (steepest for sandfill) depending on slope height. Underwater filling is usually performed with marine vessels,

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(Special thanks Warren Dou, Roger Lee, Eleonora Di Mario and Xue Bing for preparation of this guideline)

floating equipment or long arm excavators when filling near sea-level.

As the reclamation works proceed above the sea-level, land plant should be subsequentially deployed. The filling works are placed to the final formation level (FFL) in a layered fashion. Depending on the types of ground improvement works in the reclamation area, there may be a surcharging phase. Surcharge materials placed above the FFL accelerate the consolidation process such that underlying soft soils can be improved to achieve long-term performance requirements. At the end of a surcharging process, surcharge material is removed to the FFL ground profile.

A brief description of each step of the above mentioned procedure is covered in Sections 2.2 to 2.7. Common issues encountered are presented in Section 2.7

2.2 Foundation of Seawall / Breakwater

To form the foundation of the seawall / breakwater, typically two types of methods are available, i.e., dredging and non-dredging. The dredging method involves total or partial removal of soft marine soils that are replaced by sand and/or rock fill to form a stronger foundation, whereas the non-dredging method involves ground improvement for the underlying soils.

Ground improvement can take several forms. Those mostly adopted in Hong Kong involve deep cement mixing (DCM), stone columns and sand compaction piles. The DCM technique has achieved a great success in recent reclamation projects in Hong Kong. There are a few cases of non-dredged seawall foundations treated with DCMin Hong Kong (Dou & Wang, 2019; Wang et al., 2019; Cheung et al., 2021a; Cheung et al., 2021b; Cheung et al., 2021c; Cheung et al., 2022; Chung et al., 2022; Yin et al., 2022; Yung et al., 2022; Kang & Cheung, 2023; So et al., 2023; Wong et al., 2023).

2.3 Seawall / Breakwater Construction

After completion of ground improvement for the seawall foundation, construction of a seawall or breakwater may start. The seawall can act as a barrier to confine sediment dispersion during reclamation, as a soil retaining structure of the reclamation fill and can act as an armouring structure to protect reclamation from erosion from waves and current actions. Details can be found in CEO's Port Works Design Manual, Part 4, Section 2.3 (CEO, 2002).

2.4 Ground Improvement for Reclamation

Ground improvement in the main reclamation area can take several forms. Soil compaction methods can be applied to granular soils by vibro-compaction with dynamic compaction impacting the ground surface. Other ground improvement methods can be applied for fine soils that are susceptible to volumetric change, which again fall into two categories. Category 1 is based on the acceleration of the consolidation process. Category 2 is based on inclusion of other higher strength and stiff elements (columns) in the weak soil. In this way, the improved soil strength derives from the composite strength of the treated ground and/or mixed materials.

Category 1:

Prefabricated Vertical Drains (PVD),

Category 2:

Stone Columns, Sand Piles, Sand Compaction Piles which create combined ground improvement effects from shear stiffening and consolidation,

Category 3:

Deep Cement Mixing Columns, Jet Grout Columns. Several methods of improvement for reclamation fill are further discussed in Section 5.

Details of each improvement method can be found in various design manuals. It should be noted that this field is in rapid development, and the construction methods are constantly evolving.

2.5 Sequence of Reclamation Filling to the Final Formation Level

After partial completion of seawalls and on some occasions partial completion of ground improvement works, it is possible to start reclamation works.

In planning the reclamation works, it is important to make proper arrangements such that appropriate measures are made before enclosure of seawall structures. The sequence of seawall construction takes into account access of marine vessels, openings for water discharge, protection from incoming wave effects and containment of contaminated water.

Another consideration is the stability of the seawall itself. The filling process may need to be carefully co-ordinated with ground improvement works such that at any stage, the seawall stability and serviceability shall not be jeopardised.

The filling process is dynamic and oftentimes involves many stages where work fronts change rapidly (Jan & Art Nooy, 2012). It is critically important to stay alert during the filling process, such that any signs of distress or instability can be observed and the construction process can be adjusted accordingly. Another important aspects are the logistics of the material transportation and placement, and the planning of fill delivery / transport pit. Past projects have seen mud wave areas co-incident with the sand delivery pit locations.

2.6 Surcharging and Its Removal

Reclamation design often prescribes a surcharge height with a minimum density requirement for the main reclamation area. This can vary from 2m to 10m of compacted fill, depending on the final design load and residual settlement requirements. The duration of surcharge can take anywhere from 2 months to 1 year subject to the adopted ground improvement method and the ground conditions. In Hong Kong, due to tight work schedules and limited space, it is commonplace for the designer to limit the surcharge time to 9 months if adopting PVDs (Foott et al., 1987; Ng, 1991; GEO, 1997; Endicott, 2001; Dou & Swann, 2001). It should be noted that the purpose of surcharging may not be fulfilled by the end of the design surcharge period, in which case, the surcharge time will need to be extended.

After satisfying the design criteria for the surcharging process, surcharge materials will need to be removed. Oftentimes the surcharge materials are exported out of the construction site or moved to the next surcharging areas within the main reclamation.

2.7 Common Pitfalls and Solutions

The construction process of reclamation often encounters uncertainties. The reclamation methodology should be controlled such that work fronts are stable with minimal generation of mud waves and marine clay remoulding. When faced with instability risks, remedial measures should be implemented to prevent programme delay.

The consolidation process may not occur according to design and this uncertainty should be raised to all stakeholders. In the event of under- consolidation, time recovery methods should be considered, including optimising procedures. The planning of construction activities should allow sufficient flexibility in construction sequence arrangement such that overall impact to construction is minimized.

3. CONSTRUCTION EQUIPMENT

Reclamation often involves work on land and over the sea which are referred to as land operations and marine operations. The marine operations basically consist of ground investigation, geophysical and seabed surveys, dredging and marine-based ground improvement works, such as DCM, PVD, laying geotextile and underwater filling of rockfill / reclamation material. Selection of the appropriate equipment is a key essential for successful reclamation works. The following subsections are a brief description of the most common construction equipment successfully used in reclamation construction in Hong Kong.

3.1 Marine Equipment

Marine equipmqnt for reclamation mainly consist of dredging equipment, ground treatment equipment, filling equipment and marine transportation.

Dredging equipment are in general classified into hydraulic dredger, mechanical dredger, grab dredger, and trailing suction hopper dredger (TSHD) or cutter suction,. However, due to environmental restriction on dumping, seasonal restriction of marine mammals and the impact of contaminates on water, the fully dredged reclamation method has been diminishing and mostly replaced by the non-dredged method, such as the use of Deep Cement Mixing (DCM), Sand Compaction Piles (SCP) (carried out at HKZM Bridge Artificial Islands), Stone Columns (SC), etc.

Figure 1 Grab Dredger

Common ground treatment equipment consists of a special machine or rigs installed on a floating barge. For example, DCM rig, hydraulic PVD, tamper for underwater compaction and jet grouting machine.

Figure 2 DCM Barge

Filling materials are usually transported by self-propelling hopper barge or hopper/derrick lighter towed by a tugboat. The initial layers of fill materials, and the sand blanket, are placed on to the seabed, layer by layer, by the grab on the derrick lighter or a sand sprinkler barge with a feeder near the seabed to form the drainage blanket for the PVDs or a protection layer for DCM works. Subsequently, fill material will be placed by the bottom opening hopper or split hopper barge subject to the filling fall height and water turbidity requirements. Note that split bottom hopper barges place reclamation material much faster then derrick lighters with grab placement. In a shallow water environment, a hopper barge is used with its advantages of shallow water draught. Alternatively, floating pipelines may be adopted.

Figure 3 Derrick Lighter

For large scale reclamation, hydraulic sand pumping, and dumping are used to reduce cost and increase efficiency. Transportation of fill materials from the source area to the reclamation site can be carried out by hydraulic transport through pipelines, self-operated pelican barges and derrick barges.

3.2 Land Equipment

Once the fill material rises above water table, land equipment such as dump truck, excavator, bulldozer and road roller are used for the remaining filling work up to the final formation level. Depending on the necessity of ground improvement, some compaction equipment such as roller compaction, dynamic compaction, vibro compaction and rapid impact compaction (RIC) may be adopted.

Depending on the design requirement of the degree of compaction and the required depth, there are two types of fill compaction – surface compaction by conventional roller, polygonal drum, RIC and high energy impact compaction (HEIC); and deep compaction by heavy tamping and dynamic and vibratory compaction to suit different levels of soil densification.

3.3 Special Barges

Special barges are tailored for special purposes, such as accessibility, storage function such as supply of water, cement, fill material and also some testing equipment that requires additional stability. Jack-up barges and floating docks are generally configured to include drilling rigs, cone penetration test (CPT) equipment, storage and accommodation to serve special uses.

Figure 4 Jack-up Barge

4. RECLAMATION MATERIAL

4.1 Types of Filling Material

Suitable filling materials for reclamation include public fill, sand fill, crushed rocks and glass cullet, although public fill and sands are the most commonly used fills in Hong Kong. For most reclamation works, the selection of fill is largely dependent on its availability and cost. In order to maximize the benefit of available fill sources, flexibility for combining different types of fill material should be adopted. The Public Fill Committee and Marine Fill Committee should be consulted for the use of fill and related procedural requirements during the planning of reclamation projects.

The Authorities will make the best use of the public fill and arrange appropriate priority for reclamation. The remaining fill materials are mainly manufactured sand, a by-product of quarries, and its production volume can be adjusted according to demand. Many quarries in the Pearl River Delta area can supply manufactured sand.

4.2 Public Fill

Public fill is derived from inert construction and demolition materials. 'Inert' means that the material will not decompose. They include asphalt, building debris (such as bricks), rock particles and concrete. The material is low cost but may require on-site sorting (which is a cumbersome and a costly process). The supply may be unreliable and limited in availability. The engineering properties may be extremely variable and drainage properties may be poor. Because of the shortage of storage areas to accommodate the public fill generated by the construction industry, priority should be given to its use. It is also the government's policy to maximize the use of public fill in reclamation projects.

Particular aspects to be noted in reclamation when using public fill include:

- The rate of supply of public fill is not easily controllable, being dependent mainly on programming of engineering works and development projects. The impact of fluctuating supply rate on the reclamation programme should be carefully assessed.
- The handling time and facilities required. From past reclamation projects, the handling of public fill is a key concern as land transport is not allowed. Adoption of dumping hall facilities is limited in the harbour, and the conveyor delivery system in fill banks is also limited, and vessel barging for loading and unloading time is slow. All the above limit the production rate of the sorted public fill, which make the sourcing less popular.
- Strict site control is necessary to ensure that public fill does not contain unsuitable material such as marine mud, household refuse, plastic, metal, industrial and chemical wastes, contaminated animal and vegetable matters, and other materials considered unsuitable for reclamation.
- Rock and concrete over 250 mm particle size would impede subsequent piling and has to be broken down to this size or placed in areas zoned for open space and roads.

At the reclamation site, public fill will either be bottom dumped by barges or placed by grab, depending on the water depth. Usually, completion of the reclamation to the required formation level is not possible using marine equipment and direct grab placement, the use of temporary stockpiles and final placement of fill using dump trucks and spreading equipment (such as bulldozers or long arm excavators) is commonly adopted.

Public fill can be directly end-tipped onto the reclamation in a controlled manner. Normally, end tipping can be carried out in two stages, firstly to a general level just above the seawater level and later to the formation level of the reclamation.

Sampans should be used to pick up floating material from the water within the reclamation site. Such material is unsightly and can be hazardous to shipping if allowed to drift into open waters. Floating refuse containment booms should be used to surround the site to contain the debris and to facilitate removal by the sampans.

4.3 Marine Sand Fill

The use of marine sand as fill can be economically viable for a reclamation project where a marine borrow area is within a reasonable distance of the site and where the size of the project justifies the use of sophisticated dredgers, which have high mobilization costs. Equipment such as trailing suction hopper dredgers may dredge marine sand fill at relatively low costs, depending on the thickness of the overburden at the marine borrow area. Dredgers can deposit marine sand in the reclamation by bottom dumping or by pumping, depending on the access and water depth available. The maximum fines content (smaller than 63 μm) of the marine fill used in reclamation should always be less than 30% but for hydraulically placed fill, it is usually limited to about 10%.

If the marine sand is to be compacted by vibro-compaction, the maximum fines content requirement will need to be more stringent (<10%). This requirement applies to fill as delivered to the reclamation site, and not necessarily to in-situ material in the borrow area. Sampling and testing at the source to check the grading of material for compliance is one method to confirm that the required specification for the sand delivered to the site is satisfied. Samples should also be taken at the reclamation site, to check if segregation of material has occurred during placement, with a view to ensuring that the fines are well distributed within the reclamation.

For proper control of the works on site, the tests for the suitability of sand fill (marine or quarry) and the uniformity of the as-placed material should be controlled.

Well-graded sand is preferable as reclamation fill, but it is more costly to pump such sand through discharging pipes. Wearing of the inner surface of a discharge pipe will be more significant with coarse and well-graded sand. Fine sand is easier to pump hydraulically through a discharge pipe and is less vulnerable to the pumping and discharging process. In addition to that, the granular material should not contain more than 10% of unsuitable material such as clay, peat, plant, or other fine materials.

Unsuitable material of more than 10% will lead to compaction issues. Fill materials should not include a large quantity of marine shells as they will lead to immediate settlement under the static and dynamic loads. Therefore, the percentage of shell content should be limited to less than 10%.

Sand fill is a suitable material to be used as reclamation, with good drainage properties and easy compaction. It should be noted that the local marine sand fill sources have mostly been exhausted within Hong Kong and are now difficult to extract. Marine borrowing is also very restricted in the Mainland.

4.4 Crushed Rock Fill

Crushed rock from local land sources should not normally be used for reclamation in view of the shortage of public filling capacity, but should be used as foundation materials or processed to produce aggregate products, as far as possible. If available for reclamation, it is usually a by-product of works projects involving large quantities of soil or rock excavation and removal, having a project programme that ties in with that of the reclamation project. Where crushed rock over 250 mm particle size is used, it should preferably be placed in areas where no building development will take place, to avoid impeding piling or excavation works in the future.

4.5 Treated Fill

Some material is required to be treated before being used as a reclamation fill material. Treated material is modified, such as mixing

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with cement, to satisfy the engineering properties of public fill in Hong Kong. The engineering properties may vary and good quality control procedures must be implemented to meet the requirements of material properties of the treated fill.

4.6 Sourcing of Fill Materials from Nearby Regions

For critical materials, such as marine sand, Hong Kong can explore opportunities of importing from South East Asia. For other materials, such as rock and manufactured sand, sources closer to Hong Kong should be considered, e.g., within a radius of 300 kilometres. Besides cost, this can help to save time and overcome the associated challenges with supply chain logistics and weather reliability.

Quarries in Guangdong, China, are accessible by approximately 200 kilometres of road and could prove to be the most cost-effective and practical supply source. It may still be costly, but is more feasible logistically and worth considering for reasons of proximity, accessibility to fit-for-purpose materials and quality control.

5. TREATMENT OF RECLAMATION FILL

5.1 Filling and Leading Edge

Underwater placement is usually carried out by dumping/placement using a derrick lighter with grabber, hopper barge and excavator on pontoon, for small reclamation projects in Hong Kong. Fill discharged by pipeline, rainbowing and spraying methods are used in large scale projects. It is important that the filling rate by both methods should be well controlled and as required in the Environmental Permit.

5.2 Compaction of Fill

The engineering properties of fill material are usually specified as levels of compaction to be achieved under water and above water. The following requirements are typically used in Hong Kong:

- Degree of compaction: expressed as the ratio (in %) of the in-situ dry density to the maximum dry density. Values range from 90% to 95%, for testing of fill above water.
- Relative density: 60% or higher for underwater fill.
- Absolute value of bulk density
- Minimum CPT cone tip resistance or standard penetration test (SPT) N value

The specified performance targets for the above methods could vary, depending on the proposed development on the reclaimed land.

In order to achieve the required engineering properties, fill materials usually require densification / compaction. Conventional roller compaction, dynamic compaction and vibro-compaction are the commonly used ground improvement techniques in reclamation projects.

5.2.1 Roller Compaction

Roller compaction is a conventional method used on the surface of a reclamation area to increase the fill material density, shear strength, and stiffness. The roller compaction equipment exerts static pressure and/or dynamic loading using vibrations with low amplitude and high frequency that re-arranges the grains into a denser state.

This compaction method is undertaken on the surface of the site using vibratory rollers, plates and/or tampers. It is often used for material above the sea level for granular materials such as public fill, rock fill or sand. Most of the vibratory rollers have a smooth drum and are suitable for granular materials only. Vibratory rollers have weights that typically range between 4 and 25 tonnes.

The influence depth of vibratory rollers is limited and varies between 300mm and 800mm, depending on the type of soil to be compacted and the equipment used. However, a compactable layer thickness of 300mm is common practice in Hong Kong.

5.2.2 Dynamic Compaction

Dynamic compaction involves repeated dropping of heavy weights onto the ground surface. Large amounts of energy are transferred to the soil in the form of impact forces and waves, particularly shear waves. This results in a densely packed particle arrangement.

Dynamic compaction is suitable for most soils except cohesive soil below the water table. The pounders used for dynamic compaction may be concrete blocks, steel plates, or thick steel shells filled with concrete or sand, and may range from one or two tonnes up to 200 tonnes in weight. Drop heights up to 40m have been used. Dynamic compaction can also be carried out underwater.

The major planning parameters for dynamic compaction include the extent and depth of treatment, and the degree of improvement required. The former is related to the location and structural characteristics of settlement-sensitive development on the reclamation as well as the possibility of damage to nearby buildings or facilities due to the compaction works. The latter normally refers to the required relative density measured by direct and indirect tests and is related to the required bearing capacity or tolerable settlement under working load of the proposed structures.

A site trial can be performed to determine the optimal parameters required.

5.2.3 Rapid Impact Compaction

Rapid Impact Compaction (RIC) consists of an excavator-mounted, hydraulic pile-driving hammer repeatedly striking a circular plate that rests on the ground. It compacts the shallow, loose and, granular soils. Energy is transferred to the underlying loose granular soils thereby rearranging the particles into a denser formation.

The location of impact is typically arranged in a grid pattern, with spacing determined by the subsurface conditions and foundation loading and geometry. The soil treated by this method results in increased density and shear strength, which results in increased bearing capacity and minimized settlement.

RIC densifies loose granular fill up to 3-4m deep. Additional benefits of rapid compaction include: an increase of the bearing capacity of the soils, minimization of settlement, and the creation of uniformity of foundation surface. Rapid Impact Compaction is an innovative solution when compared to the time and cost of excavation and re-compaction.

Again, a site trial should be performed to determine the optimal parameters and pattern of compaction required.

5.2.4 Vibro-compaction

Vibro-compaction is achieved by penetration and controlled retraction of a vibrating vibroflot in sandy soils below water level. Under a high frequency vibration and with the assistance of a water jet or compressed air, the particles are allowed to be rearranged into a denser matrix. The degree of compaction is controlled by the energy input and spacing of the compaction points. A centre to centre spacing of 2.5 to 4 m is typical for clean sand fill. The method is used for granular soils with certain grading properties.

Compaction depth of 25 m is common but up to 35 m has been achieved. A compaction trial should be performed to determine the optimal values of spacing and depth.

6. QUALITY ASSURANCE AND QUALITY CONTROL

Quality control in land reclamation projects is mainly focused on:

- Installation of band drain/PVD or other ground improvement methods,
- Avoiding the creation of mud waves and tip failures from placing fill,
- Incomplete consolidation (such as 90%) at hand over date which can result in considerable or excessive ongoing settlements including secondary settlements,
- Required over-consolidation ratio (OCR) to be achieved in marine clay to control the residual settlement,
- Consolidation properties of very soft marine clays vary from one site to another, and
- Rates of surcharging should be controlled having regard to the bearing pressure of the soft marine clays before they consolidate and gain in strength.

6.1 Instrumentation and Monitoring

Field instrumentation monitoring provides continuous records and data to verify the reclamation performance.

Instrumentation is suggested to be installed prior to reclamation filling work or as early as possible. It is commonly arranged in a cluster pattern extended throughout the surcharge placement operations. Practically, there are two types of instrumentation for reclamation, which are 'Instruments for monitoring ground movement/deformation' and 'Instruments for monitoring pore water pressure'. The most important task is to assess the residual settlement of the site and the degree of consolidation of marine clay. During the process of consolidation, the instrumentation monitoring data can be analysed by means of Asaoka's (1978) method, the Hyperbolic method (Tan et al., 1991), Bergado et al.'s (1991) back-analysis method, and interpretation of pore pressures measured from piezometers.

6.2 Instrumentation for Settlement Monitoring

Settlement is usually measured by deep settlement plates, surface settlement plates and extensometers.

A deep settlement plate is installed on the seabed with some protection against damage during filling. The settlement rod will be installed when fill material reaches above the water level at +2.5mPD. The required extensions are made whenever necessary during filling. Settlement plates can also be installed on the platform where PVDs are installed on land. The settlement rods need to be extended when the fill level is raised to the surcharge level. The riser rod should be protected with a friction reducer sleeve pipe. Protection during surcharging is necessary to avoid damage during filling. Measurements are taken using survey methods.

The surface settlement plates can measure the total settlement of the ground. Generally, the top of the settlement rod is measured by a survey method to monitor the settlement of the ground.

Extensometers are used to measure the subsurface settlement of fill, marine deposit and other soil strata. Precise measurements of settlement in each soil stratum are given by the magnetic targets of extensometers. Plate magnetic targets shall be installed in the fill material above water and spider magnet targets should be installed at the interface of the soil strata.

6.3 Instrumentation for Deformation Monitoring

Inclinometers are installed to measure subsurface lateral movement during filling or during consolidation. They are installed at or near the edge of the surcharge embankment or seawall to provide data for slope stability. Inclinometers provide absolute measurement of lateral movements.

An inclinometer should be anchored at the base in a hard formation where there is little lateral movement. Since an inclinometer measures relative movement to the toe, any movement at the toe would lead to an under estimation of lateral displacement.

However, other site observations will also be useful indicators of the reclamation stability conditions such as:

- tension cracks appearing at the top and side slope of the reclamation,
- settlement at the centre of the reclamation showing a rapid increase in rate,
- sounding survey results indicating wavy curve profiles of the seabed near the edge of the reclamation,
- filling rate sudden increases,
- fill excessive stockpile of fill volume.

6.4 Piezometric Monitoring

Piezometers are installed in the compressible layer, especially in the marine clay to observe pore water pressure dissipation during the preloading period. Three types of piezometers are usually used in reclamation projects:

- Pneumatic piezometer
- Vibrating wire piezometer and
- Casagrande piezometer

Piezometers are installed in a borehole or drillhole. Each piezometer should be installed at a predetermined depth. Pneumatic and vibrating wire piezometers should be calibrated for the local environment before installation.

Piezometers generally measure pressure or water head above the measurement level. The measured values are generally translated into piezometric head or excess pore pressure. Data are usually presented together with construction stages and activities. However, care should be taken in analysing piezometer results. Piezometer readings should be corrected by taking into account piezometer tip settlement. Uncorrected piezometer monitoring data would lead to an under-estimation of the degree of consolidation.

6.5 Reporting and Monitoring Frequency

Instrument monitoring is carried out at regular intervals and normally reported daily, weekly and monthly during the construction period. During the soil improvement period, instruments are monitored at intervals of up to three times a week during filling and surcharge placement. After the completion of reclamation, the frequency may often be reduced to weekly, fortnightly or monthly, depending on the sensitivity of the monitored features.

6.6 Location of Instruments

Instruments can be installed before the start of placement of fill so that measurements can be taken prior to and during the course of filling. Instrumentation should be concentrated in critical areas, such as those where the marine mud is thick or particularly weak. Since lateral deformation of the marine mud, is generally more prominent at the edge of a reclamation, some instrumentation should be placed near the seawall or leading edge of the reclamation where possible to effectively monitor the stability.

In general, instruments should not be installed in future building areas or other areas where piling may be required, as the instruments may be damaged. The ideal locations for long-term monitoring are in areas zoned for future roads, footpaths, cycle tracks, amenity areas and open spaces. Instruments may involve underwater installation and may need protection to withstand the marine environment and fill placement operations.

For instruments installed prior to commencement of filling, protection can be achieved by housing all the instruments of each cluster in a rigid sleeve above the seabed. Fixed temporary staging should be erected to support and protect the sleeve. The temporary staging should be rigid and strong enough to ensure that the sleeve can stand above the seabed in a stable manner. Due care should be exercised to avoid damaging the instrumentation while placing fill in the vicinity. For instance, grab placing of fill instead of bottom dumping may be adopted adjacent to the instruments.

If installation of instruments by marine equipment prior to commencement of fill placement is not feasible, instruments should be installed immediately after the reclamation is filled up to above water level so that monitoring can be started at the earliest opportunity.

6.7 Interpretation of Monitoring Data

The principle of verification of settlement involves back-analysis of field monitoring data. This can be carried out by fitting different values of coefficient of consolidation (vertical and horizontal) into the consolidation equations and comparing the resultant settlement-time relationships with the actual settlement-time curve plotted from field settlement data. Both Terzaghi's one-dimensional consolidation theory and Barron's radial consolidation theory for vertical and horizontal drainage respectively can be applied in the back-analysis.

Alternatively, Asaoka's method also utilises the settlement monitoring data, through simple graphical means, to verify the final settlement due to primary consolidation calculated in the design stage. The results provide additional information for the designer to assess the settlement condition of the reclamation. Asaoka's method is based on observational settlement prediction.

6.8 Environmental and Social (E&S) Management

Environmental impact can be categorized as onshore and offshore environmental impacts. A structured and periodical monitoring regime is required to monitor impacts to the environment, and to impose mitigation measures when necessary. Adaptive management must be applied to cater for any changes required in the environmental management, based on monitoring results.

Typical examples of offshore environmental impacts are impacts to the seabed e.g. corals, seagrasses and benthic communities. This can be direct impacts where these sensitive receivers may be damaged by dredging, or indirect impacts where less light is available due to turbid water conditions (e.g. lower water quality). In addition, impacts to marine megafauna such as whales and dolphins should be addressed.

Examples of onshore environmental impacts are air quality, noise impacts, waste generation and impacts to terrestrial wildlife. Related to air quality are the emissions of greenhouse gases, which are to be monitored and minimized. In cases where projects are located in a Critical Habitat, and when endangered flora or fauna species are present, there is a potential need for habitat restoration or compensation

The reclamation work shall be executed in accordance with the Environmental Permit (EP), Environmental Impact Assessment (EIA), Environmental Monitoring and Audit (EM&A) Manual. These documents specify the scope of environmental monitoring and mechanisms to avoid and mitigate any adverse impact to the environment. Besides the monitoring schemes, the EP and EM&A Manual impose various necessary restrictions and limitations in respect of the methods of construction.

On the social aspect, mitigation measures should be in place to minimize such impacts on the surrounding communities. A structured mechanism to receive complaints, feedback or questions from external stakeholders should be used in addition to stakeholder management mechanisms that can enable channels of communication with Key Stakeholders that may hold influence on the successful completion of the works.

7. SUMMARY

This technical note provides an outline of Considerations for Reclamation Works in Hong Kong. Although this document provides an introductory base for reclamation work, its objective is primarily to provide awareness of industry standard construction considerations and methods in addition to providing an overview for the seasoned practitioner.

This document will be continuously fine-tuned and kept up-to-date. We at AGS(HK) welcome any suggestions on updates, amendments or additions.

8. REFERENCES

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