FACTS ABOUT

An Information Update from the IADC

SOIL IMPROVEMENT

WHAT IS SOIL IMPROVEMENT?

In the dredging industry soil improvement is typically implemented to:

- prevent excessive settlement of reclaimed land when it is being used for construction purposes (roads, airports, bridge and other foundations);
- enhance the soil stiffness and density to prevent liquefaction which can lead to damage to structures in earthquake-sensitive regions;
- improve the shear strength of the soil to prevent slip failure and increase the bearing capacity of the soil;
- immobilise or stabilise contaminants in dredged soil in order to mitigate and preferably eliminate environmental impacts.

Soil improvement techniques vary depending on the characteristics of the soils and subsoils. Some techniques are applied to consolidate existing loose subsoils and some are specifically for compaction of newly reclaimed soil.

WHY IS SOIL IMPROVEMENT IMPORTANT?

Typically, potential reclamation sites are shallow coastal zones or marshy lowlands. The soil in these areas often consists of thick layers of soft clay or silts. Reclamation work increases the load on these soft layers, causing widespread settling.

Waiting for the natural settlement of this land is time-consuming and thus costly and may put a project in jeopardy if it cannot be accomplished in a designated period of time. To accelerate the settlement process, dredging contractors have developed specialised solutions to consolidate these soft soils. In addition, newly reclaimed soil is often in a loose state and may not meet the demands of the planned infrastructure and therefore needs to be improved.

WHAT IS THE DIFFERENCE BETWEEN CONSOLIDATION AND COMPACTION?

A distinction is made between consolidation techniques for cohesive soils (clay, silt) and compaction techniques used to solidify granular soils. The consolidation phase has become an essential part of soil improvement and several techniques have been developed to stabilise new ground. Amongst these are preloading or surcharging the area that is subject to consolidation with a temporary load of sand, using Prefabricated Vertical Drains (PVDs), sand drains and a system known variously as BeauDrain, Intensive Forced Compaction (IFCO) or Press-To-Drain (PTD) as well as vacuum consolidation. These are all methods in which soil improvement takes place over a longer period of time. Compaction is done by methods such as smooth rollers, High Energy Impact Compaction (HEIC), or Dynamic Compaction (DC) – also known as heavy tamping – or Rapid Impact Compactors (RIC) and vibroflotation.

WHAT IS DYNAMIC COMPACTION?

Dynamic Compaction (DC) is a method in which a heavy weight, known as a pounder, is suspended from a crane and is dropped to the ground. It is usually used for deep compaction. The treatment depth is generally up to about 12 metres and is related to the soil type, the weight of the pounder (from 8 to 35 tonnes) and the drop height (from 7 to 30 metres).

WHAT IS RAPID IMPACT COMPACTION?

Rapid Impact Compaction (RIC) takes place on the surface of the reclamation area and involves a hydraulic hammer attached to a crane. The hammer is dropped frequently, about one hit per second, and its weight (anywhere between 9 and 18 tonnes) causes the material to compact to a depth of up to about 5 metres.

WHAT IS HIGH ENERGY IMPACT COMPACTION?

The High Energy Impact Compaction (HEIC), used to compact the upper 2 or 3 metres of newly reclaimed land, consists of a non-circular, asymmetric compactor module towed along the ground by a tractor. In every rotation, the module rises up on its contact point with ground and drops to

Above: Wick drains are used to hasten the removal of water from reclaimed land. A stitching rig is being filled with a new reel of wick drain. The wick anchor plates in the ground mark the location of each wick prior to installation.

Left, compaction is being carried out with bulldozers in front of the discharge pipe. Right, HEIC is done by impact rollers equipped with modules weighing upwards of 8 tonnes pulled over the new land by tractors.

create an impact energy, which provides the compaction. The impact compaction mechanism enables the compaction energy to reach deeper levels than can be reached by normal static bulldozers or vibratory compaction methods.

WHAT IS EXPLOSIVE COMPACTION?

Explosive Compaction (EC) is a technique in which an explosive charge is placed in a borehole of loose soil such as sand, silty sand or gravel. Multiple charges are detonated in a close timeframe causing liquefaction of the soil, followed by dissipation of the water pressure that leads to consolidation over several hours, which then increases over several weeks. This is an economical, though somewhat untested, compaction method. One advantage of EC is that it can reach as far down as 50 metres, a normally unreachable depth. One disadvantage is that this kind of blasting requires careful calibration to prevent impacts to surrounding infrastructure.

WHAT IS VIBROFLOTATION?

Certain kinds of vibration can loosen cohesionless soil to be re-arranged so that the soil becomes extremely dense. This compaction is permanent and increases the bearing density of the soil, thus reducing the chances of settlement or of liquefaction from seismic tremors. Vibroflotation is done with a vibro-flot – a probe with water or air jets that creates vibrations. It is especially effective in soils with a silt content of up to 20 percent and can be applied to depths in excess of 20 metres.

HOW DOES SOIL IMPROVEMENT REDUCE ENVIRONMENTAL IMPACTS?

Soil improvement is also applied to improve the mechanical characteristics of contaminated soft soil by immobilising heavy metals and other soil contaminants. Many techniques have been developed to immobilise contaminated sediments. These include dewatering the sediment to reduce the quantity of soil, or combining the sediment with additives, such as mixing sediment with cement which allows the recycle use of the sediment as construction and/or reclamation material.

HOW DOES SOIL IMPROVEMENT HELP IN EARTHQUAKE-PRONE REGIONS?

In certain regions of the world like Japan and California, the frequency of seismic activity can be threatening to maritime construction. This can be a serious issue when installing offshore equipment and other marine structures such as tunnels, wharfs, ports, airports in the sea. Here too, methods, such as compaction, soil replacement and admixtures, have made steady advances in developing countermeasures for coping with the threat of seismic instability by limiting the chances of soil liquefaction.

WHY IS SOIL LIQUEFACTION DANGEROUS?

Liquefaction occurs in saturated soils, i.e., soils in which the space between individual soil particles is completely filled with water. The water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Water pressure in soil is generally relatively low. However, when an earthquake occurs, the shaking can cause the water pressure to increase to a degree where the soil particles begin to move around and create an unstable situation. Such an increase in water pressure can also be activated by construction-related activities such as blasting. Liquefaction decreases the strength of the soil and reduces the capacity of the soil to support the foundations of buildings, bridges and other structures. The possibility of liquefaction can occur in existing loose soils as well as in reclaimed land.

WHAT ARE VERTICAL OR WICK DRAINS?

Soil stabilisation using Prefabricated Vertical Drains (PVDs) or wick drains are applied in areas with loose, compressible and water-saturated soils such as clay and silty clays. These soils are characterised by a very weak soil skeleton and a large pore space, usually filled with water (pore water). When a load such as a road embankment, a hydraulic fill or a dike, is placed on soft compressible soils, significant settlements may occur. These settlements can create serious problems. Any increase in load can also result in an increase of pore water pressure. In soils with low permeability, this water dissipates very slowly, gradually flowing from the stressed zone. Increased pore pressure may also cause soil instability and slip plane failures may result.

A vertical drainage system – drains are generally placed in a square or triangular pattern, spaced at about 1 to 3 metres – allows for faster removal of excess pore water, thus decreasing the risk of slip plane failure. The consolidation of soft cohesive soils using vertical drains can reduce settlement time from years to months ensuring that bearing capacity is adequate and construction can commence rapidly.

WHAT IS VACUUM CONSOLIDATION?

Vacuum consolidation is a process whereby vacuum pressure is applied to an area where PVDs have already been installed. The purpose is to potentially increase the drains' effectiveness. Generally, this technique requires the application of a surcharge loading to squeeze water out of the soft clay soils. Such loading must be equal to or in excess of the service loading to which the developed land will be subjected. In vacuum consolidation, the vacuum pressure applied contributes to the surcharge loading, and therefore actual surcharge heights are reduced. An additional important advantage of the vacuum is the isotropic nature of the vacuum pressure and the correlated improvement of the stability under preloading, reducing considerably the risk of slope failure resulting from the surcharge.

WHAT ARE THE BEAUDRAIN, IFCO AND PTD SYSTEMS?

Several new systems for forced consolidation by pumping off groundwater have been developed. Variations of this technique are called IFCO, PTD and BeauDrain. The BeauDrain-IFCO-PTD concept combines existing, proven methods such as vertical drainage (wick drains), atmospheric loading (vacuum consolidation), and the possibility to apply additional surcharge to accelerate the consolidation process of soft, compressible soils. The IFCO and PTD have slots made in the sand a short distance from each other at a depth of about 7 metres, with a drain at the bottom. The excess groundwater flows away from the surrounding land through this drain at a faster pace. The BeauDrain system works with closely placed rows of vertical wick drains, all connected to a horizontal collection drain. The horizontal collection drain is installed at a depth of approximately 1 to 2 metres below the top of the compressible strata and is connected to a vacuum pump, which through pressure, removes excess water.

CAN SOIL REPLACEMENT BE A MEANS OF SOIL IMPROVEMENT?

To reduce settlement and improve shear strength and stiffness, complete or partial soil replacement can be a viable form of soil improvement. This means removing unsuitable soil and replacing it with sand with better characteristics. Or it can be a combination of removing and replacing soil and then reinforcing it with compacted stone columns, sand-compacted piling, a variety of soil mixing techniques, or local mixing of soils in a grid. Where a grid of geotextile-encased sand columns, piles, or in-situ mixed columns is used, a bridging mattress may be required across the site to transfer the surface loadings into the discrete soil supports. Significantly less or no surcharging is required with these techniques and they generally provide savings in time. These treatments are, however, typically more costly as soil replacement requires finding better material – which may be at a distant location. It also means disposing of the lesser quality material. Disposal, especially if the soil is contaminated, may prove difficult. In such cases stabilising contaminated soil may be a better choice.

WHAT ARE ADMIXTURES AND IN-SITU SOIL MIXING?

In parts of the world where soft subsoil is a serious problem for maritime construction, using admixtures to stabilise the soil may be a solution. This method is variously known as the cement deep mixing method, soil cement columns / piles, auger mixing, cement soil mixing, rotary mixing or just soil mixing. The basis of all these mixing systems is that cement hardener is first mixed with water in slurry form which is then ejected into the soil by high power pumps. Simultaneously, during this injection phase, the soil is stirred thoroughly by rotating mixing blades. The cement reacts with the pore water of the soil, resulting in an in-situ hardening process. The soil is thus improved to the standards required at a specific location in a timely and economical manner. Cement mixing methods are often applied for the foundation of breakwaters, revetment and wharfs; seismic reinforcement of marine structures; foundations of bridge piers, tanks, railroads, roads, river dikes and buildings; and countermeasures for liquefaction.

WHAT IS THE SAND DRAIN SYSTEM?

The sand drain system comprises a sand drain driver that pushes sand through a casing to the subsoil. It also allows the mixing of soil improvement ingredients, such as cement and anti-separating agents, before it is poured into the casing. When the mixture dries, it forms sand posts or piles that can be placed in the sub-sea soil and will provide greater bearing capacity. A specially developed sand drain vessel equipped with casings has been developed. The vessel can mix the soil improvement ingredients on board to make sand piles, which can then be driven into the seabed to the required depth at the desired location. A specialised sand drain pontoon can place up to 12 drains simultaneously.

HOW ARE GEOTEXTILES USED FOR SOIL IMPROVEMENT?

Geotextiles have many applications including filtration and drainage. Specific types of geotextiles can be used for

A pneumatic conveyor vessel: dredged soil is mixed on board with a stabilising agent like cement. The stabilised soil is then used nearby.

embankment stabilisation and improving the bearing capacity of soft soil foundations on marine projects. Attention must be given to the composition of the geotextile for specific situations. Using a suitable geotextile can increase safety against underground failure and reduce the settlement of the subsoil foundation.

WHAT ARE OTHER ADVANTAGES OF SOIL IMPROVEMENT?

Some types of soil improvement methods can also provide a cost-effective means of reducing soil contamination. Dewatering contaminated soil has a twofold effect. Some of the improved soil can be reused for construction projects, eliminating the need to mine new pit sand. The remaining unusable sediment is reduced in quantity decreasing the amount of space needed for storage, which is always a costly, environmentally sensitive issue. In addition, when additives such as cement are used during soil improvement they both increase the bearing capacity of soils for construction works and also immobilise contaminated marine sediments. In all cases, the effects of consolidation and compaction can and should be checked with a Standard Penetration Test (SPT) or Cone Penetration Test (CPT) and other monitoring systems.

IS SOIL IMPROVEMENT ALWAYS NECESSARY?

In the case of reclaimed land, consolidation left to its natural course can take many years. Given the urgent need for expansion this is a long time to wait to be able to build new infrastructure on the new land. In fact, if the new land is not usable for construction purposes within a reasonable timeframe and the facilities being built are delayed until the land has settled enough to support infrastructure, the project may be jeopardised. A lengthy turnaround period can thus have crucial social and financial implications, since for both economic and social reasons the reclaimed land is usually needed as soon as possible. The ground improvement techniques being used today have significantly shortened the timeframe for preparing the new land for use and therefore secured the economic viability of many projects.

IS ONE SOIL IMPROVEMENT SYSTEM PREFERABLE OVER ANOTHER?

Many options exist to successfully accelerate the consolidation of soils and dredged sediment for the development of newly reclaimed land as well as compaction methods to stabilise subsoils in vulnerable seismic areas. Each technique has its own advantages and disadvantages in relation to time, cost and performance. Therefore the best plan is always to contact specialist contractors to evaluate the entire project and consider its specific needs regarding soil conditions. Although this evaluation stage may bring additional costs, proper preparation, be it through undertaking trials or field and laboratory testing and/or intense performance monitoring, will ultimately be recovered in the heightened efficiency with which the land is secured. A well-managed soil improvement system appropriate to the site will enhance the prospects of on-time and safe project delivery.

FOR FURTHER READING AND INFORMATION

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