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Subsurface Soil Enhancement to Strengthen the Ground under the Concrete Pavements in Operating Zones.

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ABSTRACT: This paper outlines the suitable techniques employed for soil improvement in Heavy industries, oil & gas refinery, and petrochemical Plants. The materials and procedures will be detailed within this paper, with any exceptions to the specifications clearly indicated. The primary scope of work involves the filling of sand and gravel, as well as the injection of soil cement at designated cavity locations beneath the concrete grade slab in areas where space is limited and accessibility to the ground is challenging. The proposed method aims to fill the voids between the top of the foundation soil and the underside of the slabs, while ensuring the provision of all necessary equipment, tools, and a skilled workforce for geotechnical operations. Each testing location, including DCP Testing, void detection, and the installation of shallow monitoring wells, will be addressed in accordance with the specific site conditions.

KEYWORDS: Soilre inforcement, Soil enhancement, vibro-compaction, Mini-Vibro-Floatation(MVF), grout injection & filling, underground voids/cavities, soil improvement.

I. INTRODUCTION

In operational environments such as oil and gas petrochemical facilities, as well as other areas where space is constrained and accessibility is limited, the significance of ground improvement techniques has become increasingly vital for numerous construction endeavours. These techniques enhance soil strength, reduce compressibility, and improve performance under applied loads. Engineers face challenges with expansive and collapsible soils due to their unique characteristics of significant swelling and shrinkage. Additionally, constructing foundations on sanitary landfills, soft soils, organic soils, and karst formations presents considerable difficulties. Ideally, it is preferable to replace or circumvent such problematic soil layers through appropriate foundation design; however, when this is not feasible, ground improvement serves as the most effective solution for construction sites facing these challenges. This paper provides a comprehensive examination of various contemporary ground improvement techniques and their applications within the field of civil engineering today.

In this paper,the outlined scope of work involves the execution of sand and gravel filling, along with soil-cement injection at designated cavity sites beneath the concrete grade slab. This includes the proposed void filling to address the gaps between the top of the foundation soil and the underside of the slabs, while providing all necessary equipment, tools, and a skilled workforce specialized in geotechnical operations. Each testing location, such as DCP Testing, void detection, and the installation of shallow monitoring wells, will be managed according to the specific site conditions. Compacted soil is defined as soil that has undergone mechanical compression or densification to enhance its density and improve its engineering characteristics. Compaction is a widely used soil enhancement method, particularly in land development projects where the existing soil conditions may not satisfy the required standards for bearing capacity or stability. When compaction is performed on soil located beneath the surface, it is referred to as underground compacted soil.

II. SOIL IMPROVEMENT IMPLEMENTATION TECHNIQUE

The primary objective of this technique is to enhance soil density through the application of mechanical forces, utilizing static and vibratory rollers as well as plate vibrators to ensure effective compaction. Achieving soil compaction is facilitated when the fill material is well graded.

Well-graded soil is defined by a high uniformity coefficient (Cu > 15) and a coefficient of curvature (Cc) ranging from 1 to 3, allowing for greater density to be attained through the use of rollers, tampers, and other mechanical equipment. It is essential to ascertain the optimum moisture content (OMC) and to conduct compaction at or near this moisture level for cohesive soils in order to reach maximum dry density (MDD) using sheep foot rollers. Conversely, for cohesionless soils, optimal compaction is best achieved through the application of vibrations.

Underground soil improvement refers to various techniques and methodsemployed to enhance the properties of soil beneath the ground surface, specialized geotechnical contractor shall be engaged.These methods areoften employed to increase the bearing capacity, reduce settlement, andimprove the overall stability of the underground soil.Underground soil improvement by Mini-Vibro-Floatation (MVF) & groutinjection to enhance the properties of soil beneath the concrete pavingarea employed inside operating areas.

Mini-Vibro-Floatation (MVF): This method is particularly effective for compacting sandy deposits. Compaction is achieved through a combination of vibration and the introduction of water into the surrounding soil. This technique was developed in Germany around 1930 specifically for the treatment of sandy soils. The necessary equipment for vibro-flotation includes a vibro-float with a water sump, a crane, a front-end loader, and a power supply, as illustrated in Fig-1. The vibro-float features a cylindrical penetrator tube approximately 0.38 meters in diameter and 2.0 meters in length, housing an eccentric rotating weight that generates horizontal vibratory motion. This weight can produce a horizontal centrifugal force of about 100 kN at a rotational speed of 1800 rpm.

A typical vibro-float as shown in Fig-1,consists of two parts, the lower part is horizontally vibrating unit, which relates to upper part, a follow up pipe of adjustable length to suit compaction depth. The water pump provideswater to sink the vibro-float into the ground by jetting action, as the vibro-float is lowered from the crane. Vibroflotation, sometimes also mentioned as vibro-compaction.

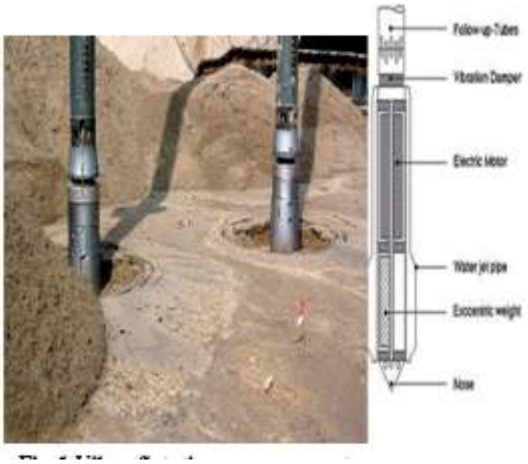

Fig-1 Vibro-flotation arrangement

Vibro-flotation may be defined as a process ofrearrangement of soil grains into a denser state by use of powerful depth vibration. It creates a stable foundation soilby densifying loose sand. The loose sand grains are rearranged into a much compact state by combined action ofvibration and water saturation by jetting.

III. SOIL IMPROVEMENT METHODOLOGY

This section offers further clarification regarding the scope, including its technical importance and the anticipated challenges that may arise. The project will be carried out in three distinct phases.

Stage I: Aggregate-Sand Mixture Mass Filling.

A small aggregate, measuring no more than ½ inch (13mm), will be introduced into the ground using the Mini-Vibro-Floatation (MVF) method. This process involves manual insertion through openings of either 4 or 6 inches in diameter. A steel probe, designed as a 2x2 inch angle and fitted with a water jetting hose and vibrator, will facilitate the placement of the aggregate beneath the slabs. The combination of water jetting and vibrations will enable the probe to penetrate the soil while simultaneously delivering the aggregate. This method will enhance the density of the surrounding soil and fill any voids. Essentially, a small or micro stone column will be created beneath the slab. The vibrator will ensure adequate compaction during the aggregate placement, which will continue until the vibro-float reaches its limit. It is advisable to maintain a distance of 1.5 m to 3 m between compaction points, using minimal water to achieve optimal compaction and avoid flooding. Additionally, sand may be introduced during the gravel placement to minimize voids. This operation will be carried out in stages, with close monitoring of the gravel filling process. A high consumption of gravel will suggest loose soil conditions, necessitating the creation of additional openings for the MVF system and closer spacing for gravel feed into the area.The gravel-sand feed will be taken to a level that keep 100 mm openingsbelow the level of the slab. This opening is intended for the entranceof the injection of the soil-cement grout in stage II.

A **Dynamic Cone Penetration (DCP)** test will be carried out prior to the filling of the gap with a sand-aggregate mixture and subsequent densification using MVF. This assessment will take place at two or three designated sites to evaluate the current density of the shallow soil before the filling process. The DCP test will measure the density of the shallow soil up to a depth of 4 meters or until refusal, whichever is encountered first. The testing locations to ensure the absence of underground utilities. The DCP test will focus on assessing the soil compaction within the top two meters beneath the slab, as the mini-vibro flotation will not penetrate deeper than this. It is crucial to understand that the density of the fill material (sand-aggregate mixture) cannot be evaluated through the DCP test due to the presence of aggregate, which would lead to refusal during testing. Nevertheless, if refusal is encountered at the fill locations during MVF, it will be interpreted as an indication of dense soil material.
Permeation grouts for filling voids Permeation grouts are utilized for void filling in subsurface applications. This method involves the injection of grout into the soil toenhance ground stability, decrease permeability, and effectively fill any voids or cavities present.

Stage II: Soil-Cement Grout Injection/Filling

Once all cavities have been filled with the necessary gravel-sand using the MVF, it is anticipated that some areas may remain unfilled due to the limitations of the filling locations. If required, a soil-cement grout composed of sand blended with fine-grained soil (such as bentonite or limestone powder) and a low percentage of Portland cement mixed with water and a plasticizer will be pressurized and pumped to address these inaccessible voids. The grouting process will be conducted in stages to ensure complete filling of the cavities after the dissipation of water and drying. Injection will occur through existing openings in the slabs. The optimal formulation of the soil-cement grout will be established following tests on various mixing ratios. The mix design will prioritize both flowability and strength, aiming for a grout that minimizes cement content to facilitate future excavation while still achieving strength characteristics comparable to or exceeding those of the sand-gravel mixtures. Material testing and mix design optimization will be performed and validated in a laboratory setting to ensure the grout's flowability and quality. This will guarantee that the grout can effectively fill small gaps at low pumping pressures (within one or two bar) while providing adequate support for the slabs and footings. Following the final grouting stage, a brief validation using Ground Penetration Radar (GPR) will be conducted to assess whether the gaps have been adequately filled. Alternatively, small cores of approximately 2 inches (51 mm) will be drilled at locations distant from the injection points to evaluate any remaining voids using inspection cameras. Should any area suggest a potential void between the soil or grout and the slab, an additional core will be drilled to fill those gaps. It is important to note that GPR technology has inherent limitations, and the accuracy of results may be influenced by the surrounding environment.

Stage III: Closing of the Openings

Concrete will be utilized to seal the injection or testing openings, following verification that the areas beneath these openings are adequately filled. It is the specialized contractor's responsibility to ensure that all underground voids and cavities are thoroughly compacted. Additionally, the extracted cores must be reinserted after being coated in a cementation slurry to enhance adhesion at the outer edges, ensuring a secure bond with the slab.

IV. QUALITY CONTROL AND QUALITY ASSURANCE (QA/QC)

An Inspection Test Plan (ITP) will be developed to guarantee quality assurance and quality control (QA/QC). This document will encompass all phases of work and the required documentation for approval, including the method statement, material quantities, laboratory test results, deductions for gaps, and Requests for Inspection (RFI), among others.

V. CONCLUSION

Enhancing the subsurface soil beneath concrete pavements in operation plants and area is vital for stability and longevity. Methods like MicroVibro floating with soil-cement injection compact and densify weak soil, while grout filling strengthens voided area to improve load capacity. Additionally, DCP testing helps identify weakness under the pavement concrete slab, enabling targeted repairs and sealing of cracks or openings to restoreintegrity. Together, these techniques ensure durable, cost-effective, and efficient ground improvement for heavy-dutyoperation environments and not easyaccessible site

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