Drilled Displacement Column Technology for ground Improvement in San Francisco

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Abstract:

The Drilled Displacement Column(DDC) technology is used to improve any soft/loose soil, and the process constructs firm-engineered composite ground to support foundations and slabs. DDC uses a displacement drill to compact the soil in the ground, resulting in higher capacity and lower spoils. Significant cavity expansion in the displaced soil produces increased strength and ground improvement. This paper discusses the efficiency of the DDC technology for ground improvement and its execution for a site in San Francisco, California. In this project, the DDC was installed successfully, and ground improvement was achieved, mitigating potential geological hazards. DDCs helps to reduce foundation settlement and transfer building loads to a deeper bearing stratum. To confirm the integrity of the DDCs, load tests were performed on 4 test DDCs to verify that they could support the anticipated loads with acceptable settlements.

Keywords: Drilled Displacement Columns, Liquefaction, Shear Strength.

1. Introduction

When the natural soil does not meet a project's engineering requirements, ground improvement must be made for its execution. Soils often need treatment to support the weight of a building or to withstand the loads imposed by a piece of infrastructure [1]. This can mean improving the ground or installing foundations to transfer the loads to deeper, more competent layers. The mechanism of achieving ground improvement varies by technique and soil conditions. Densification using vibration or displacement is an effective means of improving granular soils [2,3,4]. Reinforcement involves constructing or inserting stiff elements within a soil mass to create an improved composite material. Soil is also enhanced by adding cementitious materials by permeating granular soils or mixing in all soil types [5,6,7].

This paper discusses the efficiency of the Drilled Displacement Column (DDC) technology for ground improvement. The pressure grout effect enhances DDC strengths during construction. DDC increases bearing capacity by improving soil stiffness, reducing soil compressibility, increasing soil resistance to liquefaction, and increasing composite soil shear strength. Construction of DDC columns produces low noise and no vibration in the ground. The composite ground supports heavy loads on conventional foundations, slabs, and mats with uniform and reduced settlement.

2. Drilled Displacement Column Technology

The DDC rig uses a full displacement tool that is shaped to laterally displace and compact the adjacent soil into the ground, forming a strong composite ground. Figure 1 shows the 4 step process of DDC installation. [1]

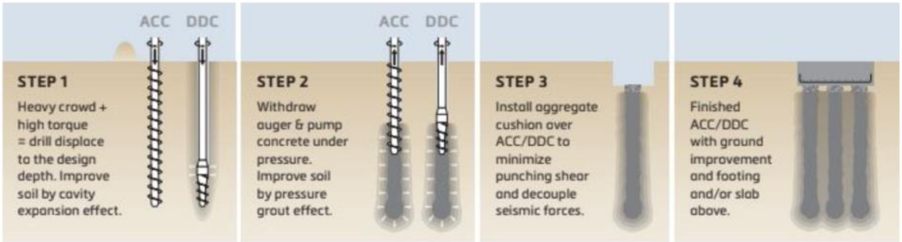

Fig.1. 4-step installation process of DDC

The tool and the pressure grout effect result in a coarse-sided sand-cement column. DDCs are high modulus/controlled stiffness grout columns typically installed through weak, highly compressible soils to reduce settlement and increase bearing capacity. The displaced soil causes cavity expansion, increases shear strength, density, and over-consolidation, reduces the void ratio, and increases the stiffness of the composite ground. This creates deep-ground improvement columns. Figure 2 shows the installation of DDC at site.

Fig.2. DDC installation at the site

3. Site Characteristics

The approximately 3.5-acre site is at the southwest corner of the 16th and Mississippi Streets intersection, just west of the Mission Bay development area. 16th Street binds it to the north, Mississippi Street to the east, condominiums to the west, and 17th Street to the south. The surface parking at the site is separated into two portions by an inverted L-shaped concrete retaining wall in the middle of the site. The wall includes an elevated parking area in the southeast portion of the parking lot. The grade of the elevated parking area is generally around Elevation 19.5 feet but slopes down along the eastern edge to match street grades along Mississippi Street. The paper discusses the ground improvement for the DDC installation for the parking garage.

3.1 Regional geology and seismicity

3.1.1.Regional Geology- Bay Mud Formation

San Francisco's topography is characterized by relatively rugged hills formed by Jurassic-to Cretaceous-aged 2 bedrocks. The bedrock consists of highly deformed and fractured sedimentary rocks of the Franciscan complex. The present topography resulted mainly from the east-west compression of coastal California during the late Pliocene and Pleistocene. The low-lying areas of the San Francisco Peninsula are underlain by Quaternary sediments deposited on eroded Franciscan bedrock. Sediment deposition within the prehistoric bay margin was influenced by oscillating, late Quaternary sea levels that resulted from the advance and retreat of glaciers worldwide. The resulting alternating estuarine and terrestrial sediments correspond to high and low sea-level stands, respectively.

In contrast, Quaternary sediments in the plains landward of the bay are predominantly terrestrial. By the late Pleistocene time, the high sea level associated with the Sangamon (about 125,000 years ago) interglacial resulted in the deposition of the Yerba Buena Mud known locally as "Old Bay Clay", The Yerba Buena Mud was deposited in an estuarine environment similar in character and extent to the present bay. Sea level lowering associated with the onset of Wisconsin glaciation exposed the bay floor and resulted in terrestrial sedimentation, such as the Colma formation, on the Yerba Buena Mud.

3.1.2.Regional Seismicity

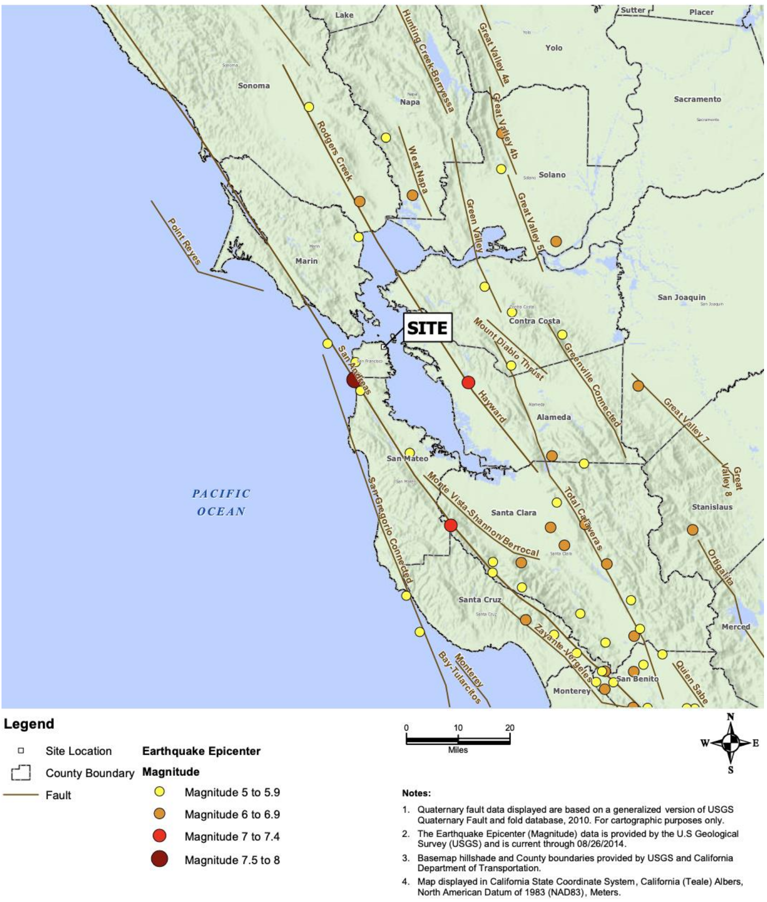

Fig.3. Map Depicting seismicity

Since the project site is in a seismically active region, numerous past earthquakes have been recorded, and moderate to large earthquakes should be anticipated during the service life of the proposed development. The significant faults near the site are the San Andreas, Hayward, and San Gregorio. These and other faults of the region are shown in Figure 3. It also shows the earthquake epicenters for events with a magnitude greater than 5.0 from January 1800 through August 2014. The most recent earthquake to affect the Bay Area occurred on 24 August 2014 and was located on the West Napa fault, approximately 46 kilometers northeast of the site, with an MW of 6.0. The 2014 Working Group for California Earthquake Probabilities (WGCEP) at the U.S. Geologic Survey (USGS) predicted a 72 per cent chance of a magnitude 6.7 or more significant earthquake occurring in the San Francisco Bay Area in 30 years (WGCEP 2015).

4. Geological Hazards

During a major earthquake, strong to extreme ground shaking is expected to occur at the project site. Strong ground shaking during an earthquake can result in ground failures associated with soil liquefaction, lateral spreading, cyclic densification, and fault rupture.

4.1. Liquefaction

When saturated soil with little cohesion liquefies during a significant earthquake, it experiences a temporary loss of shear strength due to a transient rise in excess pore water pressure generated by strong ground motion. Flow failure, lateral spreading, differential settlement, loss of bearing, ground fissures, and sand boils are evidence of excess pore pressure generation and liquefaction. The site is within a liquefaction hazard zone designated by the California Geological Survey (CGS) seismic hazard zone map for the area titled State of California Seismic Hazard Zones, City and County of San Francisco. Moment Magnitude (MW) of 8.05, corresponding to the characteristic magnitude of the 1906 earthquake on the San Andreas Fault, located about 11.9 km from the site, as shown in Table 1.

Table 1. Fault locations near the site

Fault Name	Distance (km)	Direction from Site	Mean Characteristic Moment Magnitude
N. San Andreas – Peninsula	11.9	West	7.23
N. San Andreas (1906 event)	11.9	West	8.05
N. San Andreas – North Coast	15.9	West	7.51
Total Hayward	17	East	7.00
Total Hayward-Rodgers Creek	17	East	7.33
San Gregorio Connected	18	West	7.50
Mount Diablo Thrust	34	East	6.70
Total Calaveras	35	East	7.03
Rodgers Creek	36	North	7.07
Green Valley Connected	39	East	6.80
Monte Vista-Shannon	39	Southeast	6.50
Point Reyes	43	West	6.90
West Napa	46	Northeast	6.70
Greenville Connected	51	East	7.00

Based on the analysis results, it was concluded that these layers are susceptible to liquefaction (factor of safety against liquefaction less than 1.3) and associated liquefaction-induced settlements following a major earthquake on a nearby active fault.

4.2. Lateral Spreading

Lateral spreading is generally the most pervasive and damaging type of liquefaction-induced ground failure generated by earthquakes. Lateral spreading occurs when a surficial soil layer displaces along a shear zone that forms within a continuous underlying liquefied layer. The surficial blocks are transported downslope or in the direction of a free face, such as a channel, by the earthquake and gravitational forces. Because the potentially liquefiable soil is not continuous nor present at the same depths across the site, liquefaction, if it occurs, should be relatively localized.

4.3. Cyclic Densification

Cyclic densification (seismic densification and differential compaction) can occur during firm ground shaking in loose, granular deposits above the water table, resulting in ground surface settlement. The degree of susceptibility to cyclic densification is directly related to the relative density of the existing granular soil.

4.4. Total Seismically-Induced Settlement

Total seismically-induced settlement is the combined post-earthquake settlement from cyclic densification settlement plus the estimated settlement due to liquefaction (both free-field and building-induced), resulting in estimated complete seismically-induced ground surface settlement.

4.5. Fault Rupture

In a seismically active area, the remote possibility exists for future faulting in areas where no faults previously existed; however, it was concluded that the risk of surface faulting and consequent secondary ground failure at the site is low.

5 . Field Investigation and Subsoil Profile

5.1. Field investigation

Multiple geotechnical and environmental investigations were performed at the site. The approximate locations of these borings are depicted in the Site Plan shown in Figure 4.

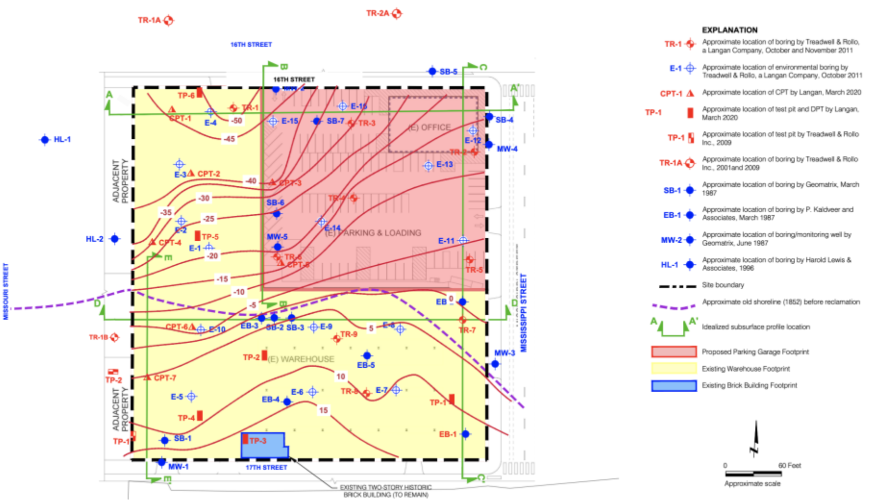

Fig.4. Site map showing the location of the Investigation tests

The CPTs were performed by hydraulically pushing a 1.7-inch-diameter, cone-tipped probe into the ground with a projected area of 15 square centimetres. To provide a reaction to the force required to advance the probe, the cone tip measures tip resistance, and the friction sleeve behind the cone tip measures frictional resistance. Electrical strain gauges or load cells within the cone continuously measured the cone tip resistance and frictional resistance during the entire depth of each probing. A computer-processed accumulated data to provide engineering information, such as the types and approximate strength characteristics of the soil encountered, was generated. CPT-5 obtained from the parking garage is given in the figure 5. The CPT logs show tip resistance and friction ratio by depth, as well as interpreted SPT N- Values and interpreted soil classifications. Soil types were estimated using the classification chart.

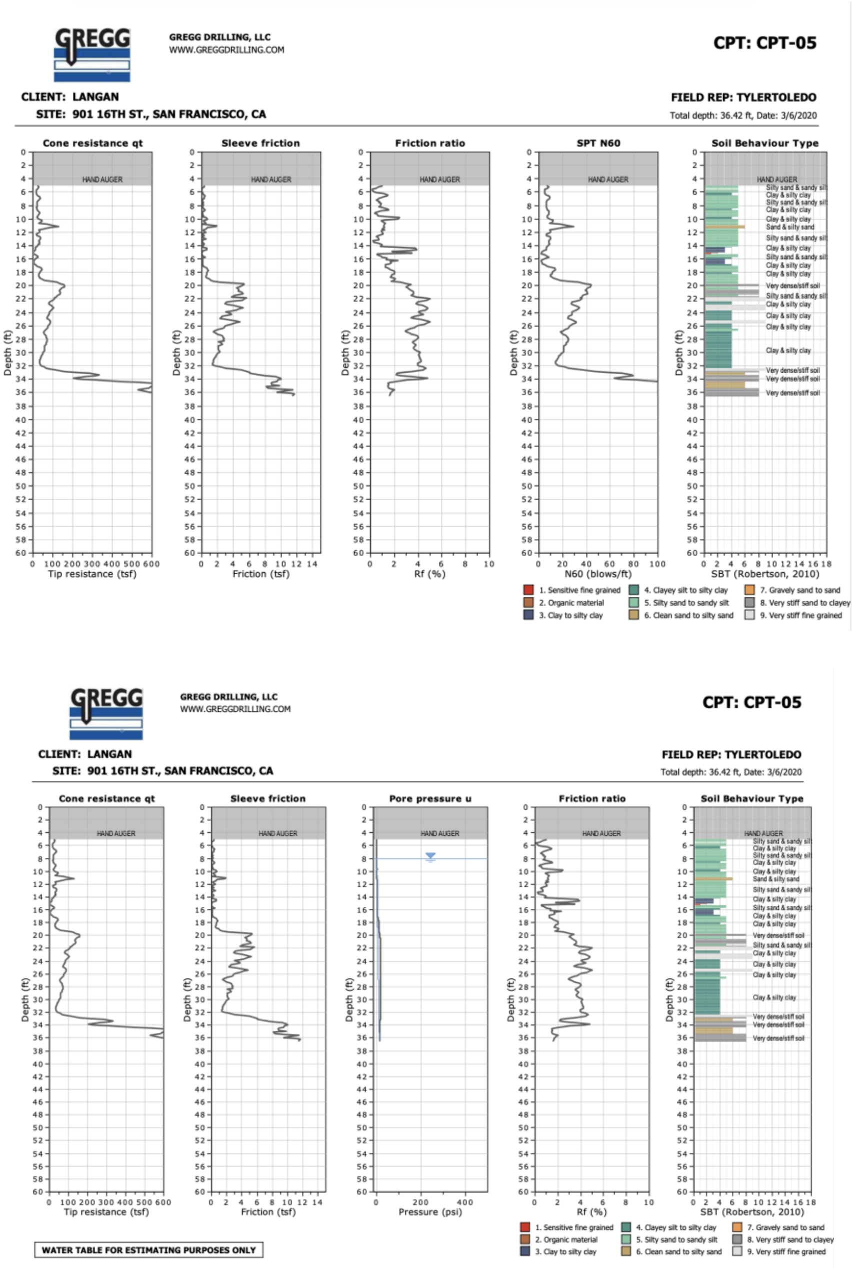

Fig.5. Cone Penetration Test Data (CPT-5)

5.2. Subsurface conditions

Fill: the site is blanketed by approximately 7 to 20 feet of heterogeneous fill, except in the southern portion, where rock is shallow, and there is little or no fill. The fill consists of gravel, sand, silt, and clay mixtures with varying amounts of construction debris and rubble, including concrete, rebar, brick, and timber fragments. Based on the environmental assessment, the fill is contaminated by coal tar and other substances.

Bay Mud: A weak and compressible marine clay deposit, referred to as Bay Mud, is present beneath the fill in some areas of the site. Where present, the Bay Mud ranges from 3 to 13 feet thick.

Sand and Clay: Sand, silty sand, clayey sand, silty clay, and clay were encountered below the Bay Mud or fill in most of the borings and the CPTs.

Bedrock: The top of bedrock was encountered at depths ranging from 1 to 67 feet below ground surface (bgs), corresponding to about Elevations 15 to -52 feet. The rock encountered is weak and deeply weathered; however, localised areas of hard rock should be expected beneath the site. The surface of the bedrock is close to existing street grades along the south boundary and slopes downward to the north and northwest. The estimated contours of the top of bedrock elevations are presented in Figure below.

Groundwater: The groundwater was encountered at depths ranging from 7 to 17-1/2 feet, corresponding to an Elevation of 12 to 4 feet.

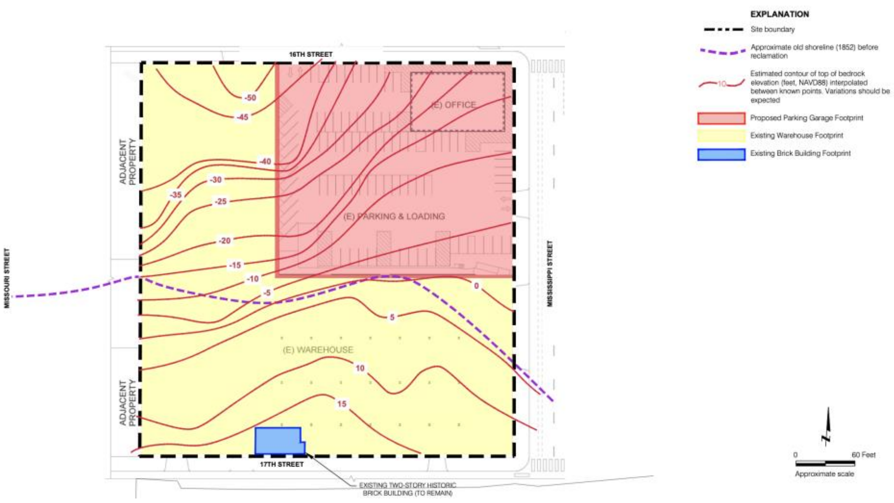

Fig.6. Site map showing top bedrock elevation

6 Foundation consideration and installation

6.1. Foundation Consideration

Since there is unimproved fill and Bay Mud beneath the garage footprint, they are unsuitable for foundation support. The existing, undocumented, non-engineered fill is loose to dense, granular and soft to stiff where cohesive. The fill below and above the groundwater level is subject to liquefaction and seismic densification, respectively. The Bay Mud underlying the fill is variable in its thickness, weak, and compressible. An estimate of up to 51⁄2 inches of the seismically-induced settlement could occur in the fill and, depending on the new loads, if a shallow foundation in the form of a mat is used and the amount of new fill placed, consolidation (settlement) of the Bay Mud could range from 2 to 9 inches. These materials are not suitable for supporting the proposed garage structure in its current state. Therefore, either deep foundations that bypass these poor soils and extend into competent soil and rock below should be used, or ground improvement should be performed. It was concluded that ground improvement would be performed and that DDCs would be the site's most economical and appropriate ground improvement methodology. Figure 7 below shows site images.

Fig.7. Parking garage site

6.2. DDC Installation

A total of 509 DDCs were installed for the ground improvement purpose of the parking garage. Each DDC has drilled a Bauer BG-28 drill rig with a 40-foot-long, 16-inch-diameter displacement auger. Once refusal or target depth is met, the depth is confirmed, and the contractor begins grouting. Refusal for this project is defined as the rig being unable to advance more than 6 inches for one minute and can be further verified by lifting off the tracks when full crowd force is applied to the drill. The installation data was analyzed and recorded. A typical analysis of the production pile installation is given below. A typical installation data analysis of 7th September 2022 is given below. Figure 8 depicts the actual v/s design length of the installed piles, Figures 9, 10 and 11 shows the completion chart, Grout Factor frequency and Design v/s actual grout volumes.

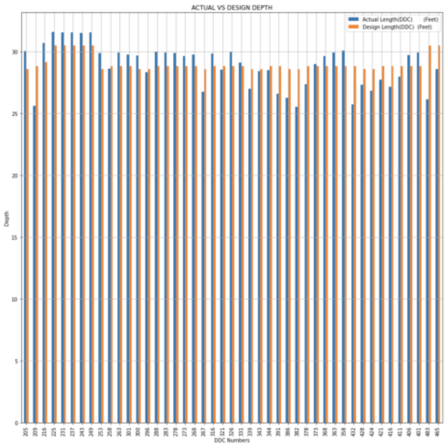

Fig.8. Actual v/s design length of piles installed

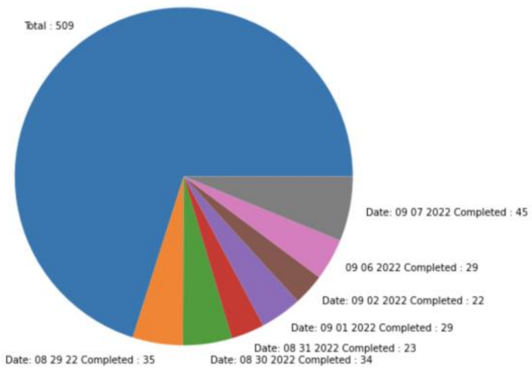

Fig.9. Installation chart

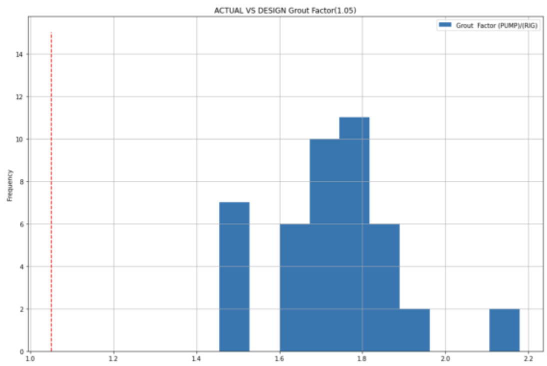

Fig.10. Grout Factor Frequency

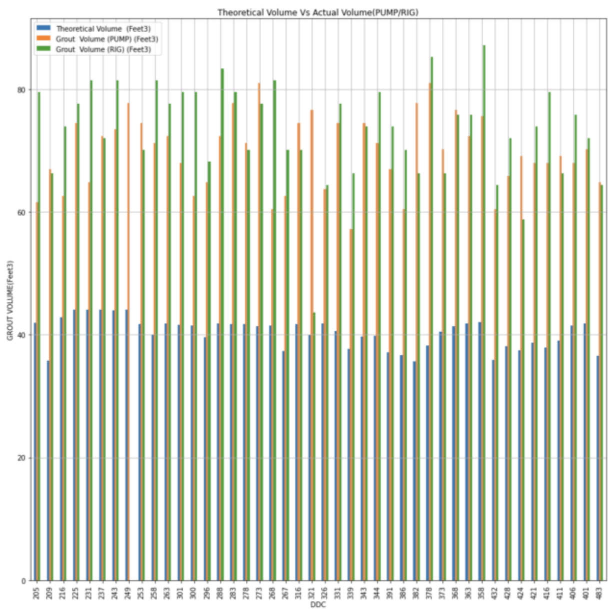

Fig.11. Design v/s actual grout volumes

Each DDCs were inspected and checked that it has achieved the design depth or was terminated at refusal. The grout factor of the Rig and the pump was calibrated periodically

Figure 12 below shows the calibration process of the rig grout factor using a cuboid container for measurement. Figure 13 shows the auger used for the installation process and Figure 14 shows the lowering process of the rebar.

Fig.12. Recalibration of Rig grout factor

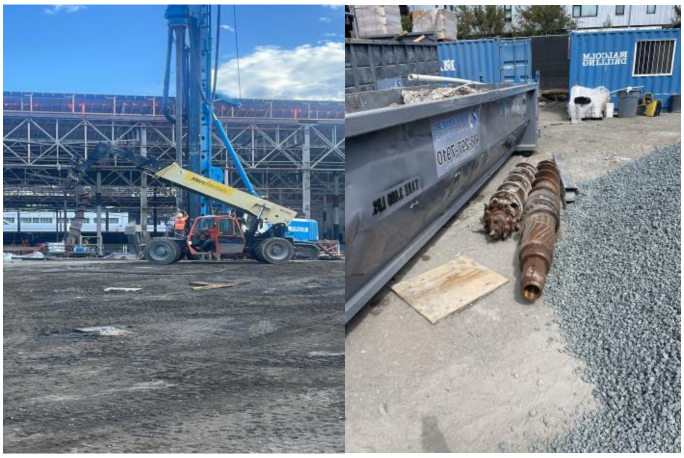

Fig.13. Auger used for installation

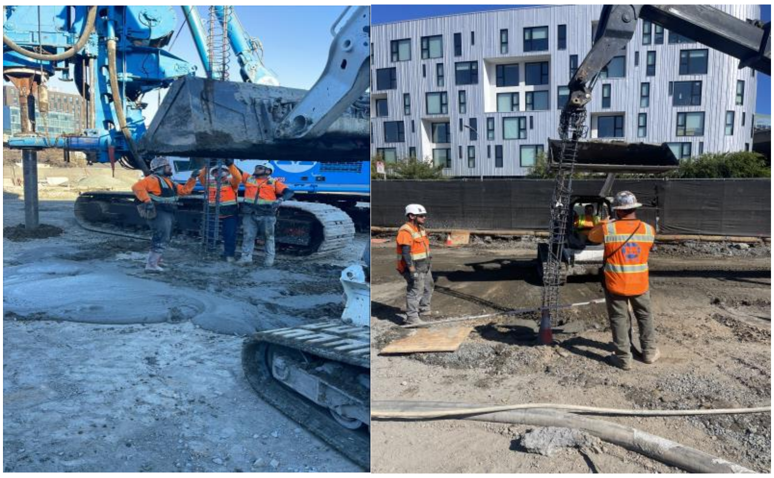

Fig.15. Lowering the rebars

7 Conclusion

The DDC process constructs firm-engineered composite ground to support foundations and slabs. DDC uses a displacement drill to compact the soil, resulting in higher capacity and lower spoils. For DDC, significant cavity expansion in the displaced soil produces increased strength and ground improvement. The pressure grout effect enhances DDC strengths during construction. In this project, the DDC was installed successfully, and ground improvement was achieved, mitigating potential geological hazards. DDCs were to reduce foundation settlement and transfer building loads to a deeper bearing stratum. To confirm the integrity of the DDCs, load tests were performed on 4 test DDCs to verify that they could support the anticipated loads with acceptable settlements. Then, the production DDCs were installed with the same criteria as the test DDCs. The concrete slabs were designed to span between foundation elements and not rely on the subgrade for support, so the slab would support itself even if the near-surface soil, which is the fill, is liquefied.

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