An Effective Study on Modification of Existing Ground by Improvement of Sub- Soil Properties Using Ground Improvement Techniques

P.V.S.Vara Prasad,Ph.D.,
Civil Engineering Department,
Professor & Principal
Nova's Institute of Technology,
Tangellamudi, Eluru, W.G.Dt, India
E mail: vsvp_1959@yahoo.com

Abstract -- **The poor sub surface conditions of the ground are brought to use by improving the sub-soil properties through ground Improvement techniques. The ground improvement techniques shall increase the bearing capacity of soils, increase the stability of slopes, accelerates the rate of drainage, seepage control, shear strength, settlement characteristics, etc. The particles of granular soil can be re-arranged through a technique of vibration to attain higher density. The another technique is to improve the soil properties is by mechanical mixing of in-situ soft and weak soils with a cementious compound such as lime, cement or a combination of both in different proportions that acts as binder and can be injected into the soil either in a dry (dry method) or slurry (wet method) form. Permeation grouting technique is also adopted by injection of a fluid grout into granular, fissured or fractured ground to produce a compact solidified mass to increase the bearing capacity of soil to bear the increased load. Improvement by reinforcement is also a technique that the reinforcement may be taken in the form of strips, grids, anchors and sheet material, chain, planks, rope vegetation and combination of these (or) other material forms. The applicability of these techniques has a wide range from coarse grained soils to fine grained soils. Depending upon the loading conditions and nature of soils a suitable technique is adopted duly keeping the economical needs also. This article gives the concept and theory of a few ground improvement techniques and describes the practical application of these techniques.**

Keywords: **Ground improvement, bearing capacity, shear strength, reinforcement, grouting, soil properties, stability**

I. INTRODUCTION

Ground improvement is the technique that modifies the soil properties of existing foundation soils to provide better performance under design and operational loading conditions. Earlier the poor soils were often replaced with an engineered fill or by changing the location of the site. Now the ground improvement techniques are brought technically feasible for new protects and to allow utilization of sites though poor subsurface conditions. In short, Ground improvement is executed to increase the bearing capacity, reduce the magnitude of settlements and the time in which it occurs, seepage control, accelerates the rate at which drainage occurs, increase the stability of slopes and mitigation of liquefaction potential, etc. The objectives of GIT are to change unfavorable conditions into those suitable for the support of structures in shallow foundations, or to reduce a down drag forces on deep foundations or to reduce the pavement thickness and to reduce seepage loss and also to protect the dams from uplift pressure.

II. CLASSIFICATION OF GROUND IMPROVEMENT TECHNIQUES:

A. Ground Improvement by deep vibration using vibro compaction.
B. Improvement by increasing effective stresses.
C. Improvement by reinforcement
D. Improvement by structural fills
E. Improvement by admixtures (Deep soil mixing)
F. Improvement by Permeation grouting
G. Soil nailing
H. Improvement by thermal stabilization, etc.

Based on the soil conditions, a suitable method of ground improvement should be considered keeping in view of the economic feasibility as well as the time frame. In practice, ground improvement is widely used in a broad spectrum of construction from industrial, commercial and housing projects to infrastructure, construction for dams, tunnels, ports, roadways and embankments etc.,

A. Ground Improvement Using Vibro compaction

Vibro compaction (VC), also known as Vibro flotation TM was developed in the 1930s in Europe. The process involves the use of a down-hole vibrator (vibroflot), which is to increase bearing capacity, reduce foundation settlements, reduce seismic subsidence and liquefaction potential, and permit construction on loose granular fills.

In this method of Vibro compaction, particles of granular soil can be rearranged by vibration to obtain higher density. In non cohesive soils (granular soils), the effective depth of surface compactor and vibratory roller is limited to a few meters below ground level and the larger depths can be reached by deep compaction methods using depth vibrators. The method is referred as Vibro compaction. The vibrator is lowered into the ground under its own weight assisted by water flushing from jets positioned near the tip of the vibrator (i.e. bottom jets). The penetration is more effective if water flow rate is high. On reaching the designated depth, the bottom jets are closed and flushing continued by water from jets positioned near the top of the vibrator. These Jets direct water radially outward, assisting the surrounding sand to fall into the space around the vibrator. The vibrator is maintained at the required/final depth until either the power consumption of the vibrator reaches predetermined amperage or the pre-set time intervals have elapsed, typically 30–60sec, whichever is the sooner. When the amperage/time criterion is satisfied, the vibrator is raised to a pre-determined height, typically 0.5–1.0m, and again is held in position for the pre-set time or until the amperage reaches the target level, whichever is sooner. The vibrator is then lifted for the next compaction step and this procedure continues stepwise until the vibrator reaches the surface. As a result of Vibro compaction, the settlement occurred may range between 5% to 15% of the compaction depth depending on the original density and the desired density. When Vibro compaction is used for large areas, it is typically performed using either a triangular or rectangular grid pattern with probe spacing in the range of 2m to 4m c/c. The spacing depends upon several factors, including the soil type, backfill type, probe type and energy, and the level of improvement required.

1) Quality Management:

The quality management of Vibro compaction works are divided into two categories, namely monitoring of compaction parameters and post-compaction testing. The compaction parameters (depth and power consumption) are monitored using real-time computerized system throughout the construction process. The post-compaction test can be performed at least one week after the compaction work such that the excess pore water reduced to the initial level before compaction.

2) Applicability of the Vibro Compaction

- Vibro compaction is used to increase the bearing capacity of foundations and to reduce their settlements.
- Is used to densification of sand to mitigate the liquefaction potential in earthquake prone zones.
- Vibro may compaction is also used as ground improvement technique to support all type of structures from embankments to chemical plants.
- The use of vibro compaction mainly depends on the type of granular soil to be compacted. Upto 65 m depth Vibro compaction technique can be applied.

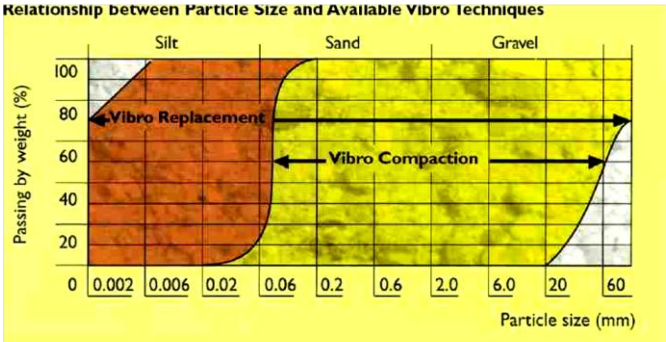

Figure: Applicable soil types for Vibro Compaction and Vibro Replacement.

3) Limitations: The compaction methods are most effective for sands and gravels with less than about 15 to 20 percent fines as shown in Figure. Vibro compaction works preferred for an oil storage terminal works.

B. Improvement by increasing effective stresses.(Using Vibro Replacement)

Vibro Replacement method was first developed in 1956. In this method, a hole is created in the ground and is filled with coarse aggregate in layers. The coarse aggregate is then compacted along with the surrounding soil by use of the depth vibration. If the fine particles cannot respond to the vibration, it needs reinforcing material such as gravels or stones. This process produces vibro stone column that is integral to the surrounding soil. In short the stabilization of soils is by replacing the soil with the help of a depth vibrator, refilling the resulting space with coarse aggregates (gravels or stones) and compacting the same with the vibrator is referred to as Vibro Re-placement. The resulting matrix of compacted soil and stone columns improves the load bearing and settlement characteristics of the ground.

C. Ground Improvement by Reinforcement

A variety of materials including steel, concrete, glass fiber, wood, rubber, aluminum and thermoplastics can be used as reinforcing materials. Reinforcement may be taken in the form of strips, grids, anchors and sheet material, chain, planks, rope vegetation and combination of these (or) other material forms. Strips are formed from aluminum, copper, polymer and glass fibre reinforced plastic(GRP) and bamboos. Grids and geo-grids are also used as reinforcement. Grids are formed from steel in the form of plain (or) galvanized weld mesh (or) from expanded metals. Steel reinforcement may be formed from metal such as galvanized steel sheets, fabric or expanded metal. Composite reinforcement can be formed by combining different materials and material forms such as sheets and strips, grids and strips, strips and anchors depending on the field problem requirement.

1) Applicability of Reinforcement: Jones (1985) identifies several soil reinforcement field application, namely, bridge works, dams, embankments, foundations, highways, housing, railways, root pile systems, pipe works, waterway structures, and underground structures. Rigid procedures for design should be avoided and adequate judgment is needed when using earth reinforcing techniques.

D. Improvement by structural fill

The shear properties of soil can be improved, as theoretically any soil could be used to form earth reinforced structure. The soil used is usually well grades cohesion less fill (or) a good cohesive friction fill although pure cohesive soil have been used with success. The advantage of cohesion less fills are that they are stable, free draining, not susceptible to frost and relatively non-cohesive to reinforcing elements. Only disadvantage is its cost. In case of cohesive soils, the main advantage is availability but there may be long –term durability problem together with distortion of structures. Sometimes the use of waste material fill for reinforced soil structure is attractive from an environmental as well as economic point of view. Mine wastes and pulverized fuel ash are the wastes usually employed.

E. Ground Improvement Using Deep Soil Mixing

Deep soil mixing technique involves the construction of in-ground shear walls to: (1) reduce the earthquake-induced shear strains of the treated zones, (2) increase the composite shear strength of the treated zones and (3) prevent the migration of the excess pore water pressure between the untreated and treated zones. This technique has a wide range of applicability, and can work in soils with high fines content
Deep Soil Mixing (DSM) technology is a form of soil improvement by mechanical mixing of in-situ soft and weak soils with cementations compounds such as lime, cement or a combination of both in different proportions (CDIT, 2002). The mixture is often referred to as the binder. The binder is injected into the soil either in a dry (dry method) or slurry (wet method) forms. In case of dry method, the moisture in the soil is utilized for the binding process. Whereas in the case of wet method, the slurry of grout with appropriate water-binder ratio is mixed thoroughly with in-situ soil. The technique forms columns within the treated zone that improves shear and compressibility parameters of in-situ loose/soft soils. The technique ensures adequate bearing capacity whilst limiting settlement within serviceability limits. Typically un- drained shear strength of the columns ranges between 100 and 2000 k Pa where as load carrying capacity of the columns ranges between 20T and 50T depending on the method of mixing, characteristics of the in-situ soil, binder content and column diameter.

Cement in the order of 5 to 10% of the dry soil weight, is best for use in sandy soil.In these materials compressive strengths are more than 10 MN/m^2.Lime is effective in both expansive plastic clays and in structural clays. Compressive strengths of the order of 1 to 2 MN/m^2 can be obtained.
Brown and Bowman (1979) have used soil lime columns beneath light structures and road embankments to reduce settlement resulting from consolidation of thick deposits of soft glacial clays. Un-slaked (or) quick lime was mixed with clay and the columns up to 10m & 50 cm in dia were constructed.
Brown and Bowman's (1979) study has revealed that the increase in shear strength from lime mixing was most significant in fresh and brackish water deposited glacial clays, but in soft organic clays and salt water-deposited clays the strength increase was low.

1) Quality Control: Quality control during execution is most important to ensure uniform improvement of the soil and to ascertain the required amount of binder has been mixed uniformly over the entire depth of treatment. For this purpose, the mixing units can be equipped with automated computerized recording devices to measure the real-time operating parameters such as depth of mixing tool, volume or weight of binder used, flow rate of grout, rotation speed and rate of penetration and withdrawal. After allowing for sufficient curing period (typically, 3 to 4 weeks), the mixed columns can also be tested using single/group column plate load tests, unconfined compressive strength tests on cored/backflow samples, visual examination of exposed columns, etc.,

2) Applicability of the Deep Soil Mixing:
   - It applicability is on wide range of weak and soils such as loose sands, soft marine clays, ultra soft slimes, weak silty clays and sandy silts.
   - Typical applications include foundations of embankment fill for roads, highways, railways and runways; slope stabilization, stabilization of cuts and excavations; foundations for structures (Topolnicki, 2004 and Raju et. al., 2005).
   - This technology can be used for vibration reduction applications and to partially reduce water paths for water tight applications. The choice of dry or wet Deep Soil Mixing largely depends on many factors such as characteristics of in-situ soil to be treated, type of structure to be founded, type of application, performance criteria, etc.

3) Soil-lime column applications:
   - Is to decrease the relative skin friction on piles.
   - Top prevent the lateral displacement of soil around pile foundation from creep.
   - To increase stability of clay slopes.
   - To reduce the lateral earth pressure on retaining structures and a placement of sheet piles in deep excavation to prevent bottom heave(Hunt 1986)

4) Limitations: Deep Soil Mixing technology is applicable to broad spectrum of soils, but due considerations shall be given to peaty soils with high organic content in terms of achievable strength and required curing period. Systematic series of trial mixing with varying binder contents and subsequent laboratory tests after allowing for varying curing periods will ensure reliable design parameters such as achieved strength, required binder content and curing period. Another limitation of DSM technique is treatment of soils in ex-landfill areas, where large content of waste dump soils is to be improved.

F. Ground Improvement Using Permeation Grouting

Permeation grouting is the injection of a fluid grout into granular, fissured or fractured ground to produce a solidified mass to carry increased load and/or fill voids and fissures to control water flow. The primary role of permeation grouting is to improve the strength, imperviousness and stiffness of the soil or rock formations. The process is quiet flexible and it can be designed with a minimal disruption at the surface and therefore, it is advantageous for use in urban areas or areas with limited access.

During grouting process, injection pressures are usually limited to prevent fracturing or volume change in the natural soil/rock formation. Maximum injection pressure can be taken about 20kPa per meter of depth. Based on the field trials and soil conditions, the injection pressures and the grout volumes can be determined to meet the intended performance. The process is limited to relatively coarse-grained soils so as to enable the grout to flow through the formation to replace the void spaces or joints. Particulate grouts (e.g. cement or betonites) are generally used for medium to coarse grained sands, such that the particles in the grout can easily percolate through the formation. Micro fine cement is also used for fine grained sands where Ordinary Portland Cement cannot percolate through the formation. Chemical grouts (e.g. silicates)are used in formations with smaller pore spaces, but are limited to soils coarser than fine grained sands. The typical spacing for permeation grouting holes is between 4 to 8 feet.
8.0.1 Compaction grouting: Compaction grouting, one of the few US born ground improvement techniques, was developed by Ed Graf and Jim Warner in California in the 1950s. This technique densifies the soils by injection of a low mobility, low slump mortar grout. The grout bulb expands through injected additional grout, compacting the surrounding soils through

Compression.The improvement in the surrounding soils, the soil mass is reinforced by the resulting grout column, further reducing settlement and increasing shear strength. This method is used to reduce foundation settlements, reduce seismic subsidence and liquefaction potential, permit construction on loose granular fills, reduce settlements in collapsible soils, and reduce sinkhole potential or stabilize existing sinkholes in karst regions.

1. Quality Management: The quality control during permeation grouting is very important to ascertain the effectiveness of the technique. The process parameters such as grout pressure, flow rate, volume of grout for corresponding depth can be monitored throughout the construction process. Post construction in-situ permeability tests can also be conducted after sufficient curing period inorder to validate the effectiveness of permeation grouting.

2) Applicability of the Permeation Grouting:

- The Permeation Grouting is very effective in sands, gravels, coarser size materials (e.g. boulders and cobbles) and fissured/ jointed/ fractured rock formations.
- The technique is well suited for a wide variety of applications, such as foundation retrofitting, dam rehabilitation, subsidence and liquifaction mitigation, barriers, tunneling and mining operations, offshore construction, etc. Applications can be categorized into the following general areas, site improvement, foundation rehabilitation, excavation support, groundwater control, and contaminant/pollution control (Karol ,1990).

3) Limitations: Permeation grouting is not suitable in cohesive soils such as silts and clays. The other types of grouting techniques such as fracturing grouting and jet grouting can be considered to improve such soils.

G. Soil nailing

Soil nailing is an in situ technique for reinforcing, stabilizing, and retaining excavations and deep cuts through the introduction of relatively small, closely spaced inclusions (usually steel bars) into a soil mass. Soil nailing is used for temporary or permanent excavations support/retaining walls, stabilization of tunnel portals, stabilization of slopes, and repairing retaining walls. The procedure requires that the soil retains temporarily on vertical face till a row of nails at facing are installed. Therefore, cohesive soil or weathered rock is best suited for this technique. Soil nails are not easily performed in cohesion less granular soils, soft plastic clays, or organics/peats.

1) Equipment: Earth moving equipment (such as a dozer or backhoe) to excavate the soil, a drill rig to install the nails, a grout mixer and pump (for grouted nails), and a shotcrete mixer and pump (if the face is to be stabilized with shotcrete).

2) Procedure: The earth moving equipment (such as a dozer or backhoe) excavates the soil of depths, typically 3 to 6 ft (1 to 2 m). Then a drill rig is used to drill and grout the nails in place, typically on 3 to 6 ft (1 to 2 m) centers. After each row of nails is installed, the excavated face is stabilized by fastening a welded wire mesh to the nails and then placing shotcrete.

3) Materials: Soil nails that consist of steel tubing, steel angles, or high-strength fiber rods. Grouted nails can usually be installed within Portland cement grout slurry. The facing can be prefabricated concrete or steel panels, but is usually shotcrete, reinforced with welded wire mesh, rebar or steel or polyester fibers.

4) Design: Soil nails can be designed to give a soil mass an apparent cohesion by transferring tensile forces into the ground. Frictional interaction between the ground and the steel can restrain the ground movement. The main engineering concern is to ensure that the ground–interaction is effectively mobilized to restrain ground displacements and can secure the structural stability with an appropriate factor of safety. two main categories of design methods are 1. Limit equilibrium design methods 2. Working stress design methods. Many software design programs are available including one developed in 1991 by CALTRANS called Snail. Soil nail walls are generally not designed to withstand fluid pressures. As such drainage systems are incorporated into the wall, such as geo-textile facing, or drilled in place relief wells and slotted plastic collection piping. Surface drainage control above and behind the retaining wall is also critical. Extreme care should be exercised when the existing structure is adjacent to the top of as soil nail wall. The soil nail reinforced mass tends to deflect slightly as the mass stabilizes under the load. This movement may cause damage to the adjacent structure.

5) Quality control: The location and lengths of the nails are important to monitor and document. In addition, the grout used in the installation of grouted nails can be sampled and tested to confirm that it exceeds the design strength. Tension tests can also be performed on test nails to confirm that the design bond is achieved.

H. Improvement by Thermal stabilization:

This technology is an alternative for stabilizing weak foundation soils upon which buildings, bridges, roads or other structures are to be constructed. In this method the heating of soil results in increased strength and decreased compressibility. Consequently, thermal treatment methods have been used as a means of soil improvement in construction operations to stabilize weak foundation soils, and for the stabilization of landslides and slopes subject to failure. Earlier efforts have involved the use of conventional heating methods on surface applications or boreholes filled with fossil fuels or mechanical burner units. Due to high cost of treatment, low burning temperatures, complexity of the process, and uncertainty of the results have limited the use of this technique to relatively few construction applications. Stabilization of soils can be done by heating and also by cooling. It is technically feasible to stabilize fine grained soils by heating. The effect of temperatures and changes in the soil properties are as follows:

a) Temperature at 100^0C - Cause drying and significant increase in the strength of soils with decrease in their compressibility.

b) Temperature at 500^0C - Causes permanent change in the structure of clays duly resulting in decrease of plasticity and moisture absorption capacity.

c) Temperature at 1000^0C – Causes fusion of the clay particles into a solid substance like a brick.

Burning of liquid or gas fuels in bore holes or injection of hot air into 0.15 m to 0.20 m dia bore hole can produce 1.3 to 2.5 m diameter stabilized zones after continuous treat of about 10 days.

Plasma arc technology can create plasma using almost any type of gas (oxygen, nitrogen, carbon monoxide, air, etc.) and in a wide range of pressures (vacuum to 20 atmospheres). The plasma arc has a wide spectrum of temperatures ranging from 1500°C to over 7000°C, or approximately 1000°C hotter than the surface of the sun. The plasma arc torch uses copper electrodes to create a non-transferred arc. The plasma torch and electrodes are water-cooled and the average life of the electrodes ranges between 200 to 500 hours of operation. The plasma torch is lowered to the bottom of cased borehole. At approximately 200°C soil plasticity begins decreasing until it is reduced to zero at around 500°C. Swelling is reduced to zero at temperatures above 750°C and shear strength rises continuously throughout this range of temperatures. At temperatures above 900°C the soil begins to fuse into brick-like material. Finally, the soil melts and later hardens in a rock-like material (similar to obsidian) at temperatures above 1,100°C.

Stabilization by cooling in clayey soil particles can increase inter particle repulsion that results a small loss in particle strength. Freezing of pore water in the soil is the effective method of thermal stabilization. Water in a soil freezes to below 0°C with initial freezing and further decreasing temperature and as more soil freezes can increase will rapidly increase the soil strength. Frozen soil is far stronger and less pervious and act as barrier to seepage flow or soil deformation.

III. CONCLUSIONS

Ground Improvement techniques forms technically sound and cost effective solution where the sub soils are weak and needs to be treated to enable the intended construction. Its applicability has been proven in the recent past for a wide range of structures such as roads, runways, ports, power plants, railways, dams, slope stabilization, excavations, tunneling and other infrastructure facilities (Raju V.R. ,2004).Improvement by reinforcement may be taken in the form of strips, grids, anchors and sheet material, chain, planks, rope vegetation and combination of these (or) other material forms. Soil nailing technique is used for reinforcing, stabilizing, and retaining excavations and deep cuts through the introduction of relatively small, closely spaced steel bars into a soil mass. These techniques have been used all over the world for a wide range of soils starting from loose sands, silts, marine clays to weak rocks. Each technique has its one range of applicability base on soil characteristics, overhead and permitting requirements, etc. Based on the soil conditions, loading intensity and intended performance, an appropriate ground improvement technique can be designed to attain the desired performance.

REFERENCES

- Coastal Development Institute of Technology (CDIT) ,2002. *The Deep Mixing Method-Principle, Design and Construction*, A. A.Balkema Publishers.[1]
- Karol, R.H. 1990. Chemical Grouting, Marcel Dekker Inc., New York (USA), 465 p.Priebe, H.J. 1995. *The Design of Vibro Replacement, Ground Engineering*, December , pp. 31-37. [2]
- Raju, V.R, Abdullah A.. 2005. *Ground Treatment Using Dry Deep Soil Mixing for a Railway Embankment in Malaysia.* Proc. Int.Conf. on Deep Mixing best Practice and Recent Advances, Stockholm (Sweden). [3]
- Raju,V.R., Wegner, R. Harikrishna, Y. 2004. *Ground Improvement using Vibrotechniques in Asia 1994 – 2004 – A 10 yrs review, 5th International Conference on Ground Improvement Techniques*, Malaysia, 2004. [4]
- Topolnicki, M. 2004. In-situ Soil Mixing, *Ground Improvement (2nd Edition)*, Edited by Moseley, M.P. and Kirsch, K, SponPress. 2004, pp. 331-428. [5]
- Circeo, L. J., Jr. and Mayne, P. W., *In-Situ Thermal Stabilization of Road and Airfield Foundation Soils using Plasma Arc Technology, Forth International Conference on Bearing Capacity of Roads and Airfields* - Proceedings., July 17-21 1994, Minneapolis, Minnesota. Vol. 2, pp. 899-916. [6]
- Spinoff. (NASA) 1994 pp. 104-105. [7]
- Engineering Design and Construction., Civil Engineering News. (ASCE) Apr. 1994. [8]
- Circeo, L. J., Jr. and Mayne, P. W.,*Plasma Torch Holds Promise for Strengthening, Stabilizing Weak Foundation Soils In-Situ*, Georgia Tech Research News, Oct. 1993. [9]
- Camacho, S. L., *Harnessing Artificial Lightning*, The World & I., Dec. 1991, pp. 310- 317. [10]
- Boulanger, Ross, and I.M. Idriss. *Soil Liquefaction During Earthquakes.* Oakland: EERI, 2008. Print. [11]
- *Ground Improvement techniques* by Dr.P.Purushothama Raj.[12]