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SOIL IMPROVEMENT BY SAND DRAIN /REVIEW

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Abstract

Soil techniques used in stabilizing weak soils such as clay or saline soils are very diverse in terms of the mechanisms used and the material used, in addition to the multiple methods in their implementation. Over time, the construction industry has embraced a number of effective soil improvement techniques for liquefaction mitigation. In this research paper, a review was made on soil stabilization techniques and was reinforced by some research that adopted some of these techniques. The focus was on one of the vertical methods, which is called sand drains, and this method was explained in detail with some research that adopted this method to stabilize the soil. Also in this research, some of the soil's mechanical characteristics represented by (tensile strength), (shear strength) and (Compressibility) of soil, were explained, in addition to mentioning a group of researches that were explained and adopted.

Keywords: Sand Drain, Vertical drains, Compressibility of soil, Soil improvement, shear strength of soil, tensile strength of soil.

Introduction

Over time, the building industry has embraced a number of effective soil improvement techniques for liquefaction mitigation. Most of these methods are founded on the three cementation principles (combining a stabilizing substance (such as grouting) with sandy soil to solidify it), pore water dissipation (Installing permeable drains, such as gravel drains, can help minimize excess pore water pressure in sandy soils), and compaction (increasing the ground's resistance to liquefaction caused by densification of sandy soil by impact or vibration, such as vibro-flotation or dynamic compaction). The applied depth and the impact on the environment are two examples of the variables that determine which approach is best. These techniques, however, are usually most appropriate for comparatively larger undertakings, as their costs are usually too high for residential homes. [1] Local cohesive soils are frequently employed as building materials in an effort to conserve money and lessen the adverse environmental effects of aggregate extraction. Chemical additives (such as cement or lime) or inclusions can be used to change the engineering behavior of these materials if their characteristics do not meet geotechnical criteria. [2] Because it has a direct influence on the decision-making process regarding efficient land management, soil salinity is acknowledged as a significant measure of the quality of the soil and significantly governs land use planning techniques. Furthermore, removing natural vegetation for farming and changing land uses can drastically change the water balance by increasing groundwater recharge. This can raise groundwater levels, cause it to evaporate from the topsoil profile, and cause salts to precipitate in the soil. [3] Due to rapid economic development and population increase, many coastal communities are facing a shortage of available land. In coastal cities, land reclamation has been a common solution to land scarcity. The main filler utilized in land reclamation is dredged slurry. Regretfully, Slurry for dredging has smaller bearing capacity and is described by increased water content, increased compressibility, and small permeability. Dredged sludge must therefore be treated in order to satisfy infrastructure construction criteria. [4] Mechanical characteristics of soil are often unsatisfactory for building in a lot places in the world because of their brittle structure and lack of mechanical strength. These soils may suddenly collapse as a result of environmental factors. For example, freeze-thaw loops and overload pressures cause geotechnical issues like ground settlement, landslides and surface fissures, which can result in the breakdown of manufactured by humans structures. Because of the loose qualities of soil, some buildings, trains, monuments, and roads typically require maintenance and repairs. The earthquake may cause the loose sediments to become less strong and rigid, causing damage to the remaining soil structure. [5] It's an evident fact that constructions ought to be built on high-quality ground. However, in recent decades, the ground conditions on construction sites around the world have deteriorated to unprecedented levels. When constructing any kind of infrastructure and when significant ground settlement or stability failure is anticipated, dredged soils, highly organic soil ground, and loose sandy ground are commonly encountered. Deposits of loose sand beneath a water table can cause significant liquefaction issues during earthquake events, aside from highly or clayey organic soils. [6]

1. Tensile Strength of Soil:

Among the most widely used soil strength indicators in practice to characterize soil resistance to loads is tensile strength. Tensile strength is significantly smaller than compressive strength and shear strength. As a result, when conventional engineering projects use earth as a building material, its tensile strength is often overlooked. Assuming that there is no suction in the soil, neglecting soil tensile strength is rather earthly conservatism construction design. Desiccation cracking, a kind of tensile failure, is widespread in drying soils. It seems in a variety of earth structures, including slopes, landfills, embankments and dams. [7] Figure (1) depicts crack patterns under applied loads and soil conditions. Figure (1) (a and b) shows that when base restraint is employed in prismatic and circular soil beds, Many cracks appear, and they are frequently irregular. The excluded items are lengthy mold tests that simulate a semi-controlled base restriction situation, with numerous transverse cracks irregularly appearing along the specimen's length. Figure (1) (c) When the restriction is used in such a way that the soil contracts uniaxially, consistent tensile stresses emerge, strains can be computed, and breaking sites may be predicted and controlled to a significant extent. The desiccation issue is essentially lowered to an approximate one-dimensional problem where a single desiccation fracture is caused by a relatively uniform tensile stress field, as shown in Figure (1) (c). Therefore, direct measurement can be used to establish the stresses involved in the production of a single desiccation crack. [8]

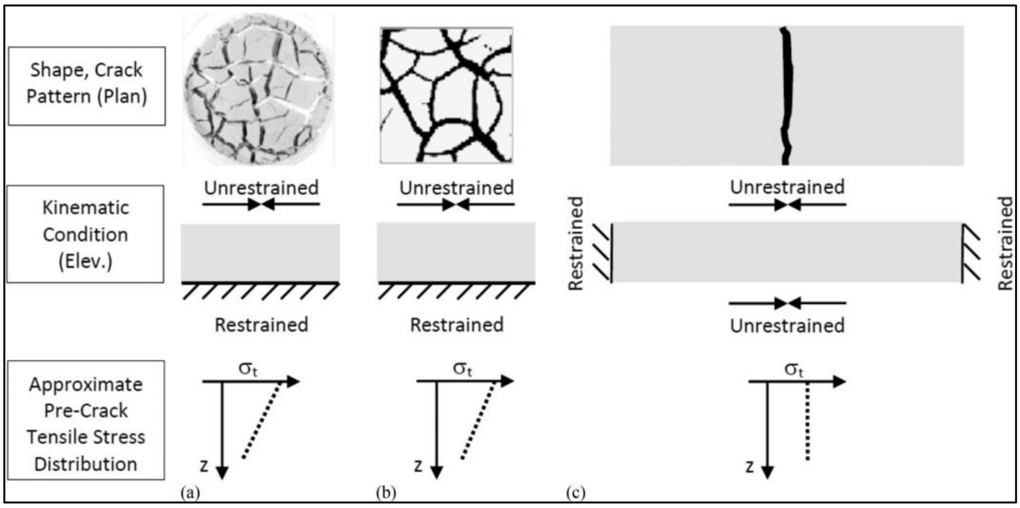

Figure (1) Crack patterns roughly correspond to distributions of tensile stress. [8]

In addition to the presence of certain additives, the soil's water content can also have an impact on its tensile strength. The climatic conditions in the area around the soil might also have an impact. **(Zhou, Guoqing, et al, 2015) [9]** This study examined tensile strength characteristics of frozen, warm soils in a laboratory setting. Applying the method of indirect tensile of the Brazilian Splitting Method (BSM), tensile tests were conducted on frozen silty clay (FSC) and frozen clay (FC), two frozen soils, at different temperatures above (-2°C). According to the results of the laboratory tests, the ice content contributes roughly 85% of the overall tensile strength, and the ice's tensile strength increases as the temperature drops, making up the so-called "ice quality" contribution of about 10%. This final element of tensile strength is due to the chemical and physical cementation occurs among the particle surface and the ice water mixture, and it contributes less than 5%. Consequently, the amount of ice in frozen soils has a major impact on the tensile strength of warm frozen soils. **(Correia, Oliveira, et al, 2015) [10]** In this study, the mechanical behavior of "Baixo Mondego" soft soil—which has been chemically stabilized with binders and reinforced or not with brief polypropylene fibers—is examined in relation to the quantity of fiber and the binder. The stabilized material's mechanical properties (compressive strength, stiffness, and tensile strength) enhance when the amount of binder is increased. The amount of fibers added to the paste does not directly correlate with the mechanical properties; instead, the effect of fiber quantity on stiffness, compressive strength, and tensile strength generally shows a non-linear tendency. **(De Sousa Oliveira, Lucas, et al, 2020) [11]** This study uses the TS-Soil gadget and human perception to determine the tensile strength outcomes for the various consistency of the soil levels. The Brazilian Soil Classification System was utilized to categorize the soils used in this investigation. In this research, samples of soil are taken in different areas of the governorate (ceara') belonging to (Brazil). By combining the evaluator's viewpoint with the force used to pause the aggregate, the TS-Soil apparatus enables the establishment of ranges of amounts for the degrees of consistency of dry soil. The procedure of assessing the consistency of dry soil is improved by the qualitative perception linked to tensile strength measurements.

2. Shear Strength of Soil:

Shear strength of soil is a crucial engineering parameter in geotechnical engineering that is undoubtedly used in the audit and design of numerous geotechnical and geo-environmental structures (e.g., retaining walls, earth dams, and road foundations and pavements). Shear strength, Inner Friction Angle, and the units cohesion are three crucial parameters that are impacted by several different factors, that involve the plastic index (PI), liquid limit (LL), moisture content (W), and clay content (CC). Consequently, the following is a presentation of the Shear stress and normal stress's functional relationship on the failure plane of a soil mass: [12]

$\tau = f(\sigma) = \sigma \tan \varphi + c$ …………………………………………… (1)

Soil shear strength can be measured using two different approaches, forced (direct shear) and free shear plane (indirect shear). Instruments with rotary (rotational) or linear (translational), direct shear techniques usually use shear kinematics. The majority of indirect methods rely on soil compression; among these is penetration testing, which estimates the soil's shear strength by using specific empirical dependencies. These measurement techniques are displayed in Table (1). [13]

Table (1) Types Of Techniques For Figuring Out The Shear Strength Of Soil. [14]

Shear Strength Determination			
Direct Methods		**Indirect Method**	
Translation Shear Test	Rotational Shear Test	Compression Test	Penetration Test

(Kim, Nam, et al, 2018) [14] The impact of clay content on the shear strength of clay–sand mixtures is examined in this paper. To create clay–sand combines with different clay material of (30, 25, 20, 15, 10, and 5)%, bentonites and Jumunjin sand were combined. For pure sand the angle of internal friction of the clay–sand combines was 35.7°; it rose to its maximum value of (38.7°) when the clay content reached 10% at 30%, it progressively decreased to (34.0°). But with significant test result scatters, it was discovered that the angle of repose increased as the clay content increased to 25%, which was probably caused by the mixtures' predominance of clay content. Large-size particles made a substantial contribution at little clay contents (up to 10%), there was a linear relationship between the angle of repose and the internal friction angle; at higher clay contents, however, there was no correlation between the two. **(Scaringi, and Di Maio, 2016) [15]** The outcomes of direct shear tests using various shear devices and controlled displacement rates between 10^{-4} and 10^{2} (mm/min) below various normal stresses are presented in this paper. The Costa della Gaveta earthflow's clayey soil, kaolin, betonies, and their integrates with sand at different percentages were all subjected to shear tests under controlled displacement rates. The range of displacement rates of 10^{-4}-10^{2} (mm/min) was examined. When compared to the substance combined with purified water, the results indicate that clay-sand combines with a c.f. content of at least 50% have positive rate effects that rise as the (c.f.) content increases. For rates v within the (mm/min) range, the rate effect becomes significant, with minor variations based on the experimental shear apparatus employed. The Costa Della Gavotte soil, whose (c.f) is roughly

50%, yields outcomes that are in line with those of artificial mixtures. **(Gratchev, and Sassa, 2015) [16]** To look into the effects of shear rate on three natural clays' strength recovery, a test procedure was proposed that entailed applying different shear rates to soil specimens. According to the data in this study, little is known about how soil behaves at higher shear rates. It seems that the shear strength rises somewhat when the shear amount drops from higher shear rates as well as when the slow to fast shear rate increases.

3. Compressibility of Soil:

Previous studies have mostly concentrated on water content, void ratios, and/or atterberg limits, frequently ignoring the influence of the percentage of coarse soil particles, which has a major impact on compressibility behavior. One of the most important engineering factors for soils is their compressibility. The density of granular soils, or the arrangement of their individual particles, determines their compressive stiffness. By subjecting them to confined compression (odometer) and measuring the displacement that results, geotechnical engineers are able to quantify their mechanical behavior. Compressibility of the clay is indicated by the void ratio (e) and the slope of log P vs. deflection (strain εv). The stiffness of clay under initial loading is indicated by the compression index (Cc). The recompression index (Cr) represents the process of unloading and reloading stiffness to a previous load level. Slope angel of the linear portion of the void ratio (e) is used to compute both Cc and Cr. Figure (2) shows the sample's consolidation behavior during the loading sequence as a one-dimensional consolidation curve. [17]

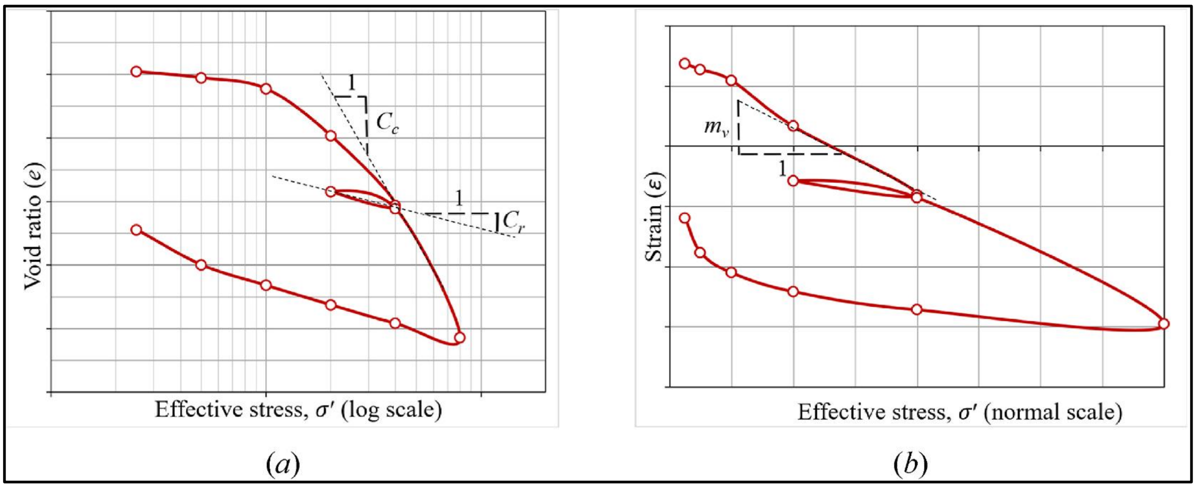

Figure (2) The parameters (a) Cc and Cr, and (b) mv are used to illustrate typical one-dimensional consolidation curves. [17]

Estimating how soil will behave in changing conditions is made easier with the use of compressibility data from laboratory consolidation tests, specifically the connection between consolidation pressure (P) and void ratio (e). Given the possible repercussions of differential settlement leading to abrupt failures of overlying structures, it is imperative to comprehend the behavior of volume change in soils. The overall stability of the earth structures can also be impacted by changes in volume brought on by contaminant interaction, which can spiral out of control and affect other engineering properties like strength and deformation behavior. [18] **(Jiang,**

Wang, et al, 2020) [19] This study examines how structure and liquid limit affect soft soil secondary compressibility. Structural mechanics is demonstrated by the relationship between soil structure and mechanical behavior. Mesri offers a wide range of inorganic clays and silts, the C/Cc values for the soft soils in Shanghai, Tianjin, Suzhou, and Ningbo are 0.031, 0.034, 0.030, and 0.036, respectively. The Ningbo soft soil has the greatest C/Cc value, which is in line with its maximum Cc compression index. C/Cc can be used to estimate C based on the compression index Cc that was determined by the compression test.

4. Technical Improvement of Soil:

Numerous methods for improving the ground have been created and used in numerous building projects. They fall into four groups: drainage, admixture stabilization, replacement, and densification. Table (2) Classification Techniques of Ground Improvement. [6]

Table (2) Classification Techniques of Ground Improvement. [6]

Classification of Techniques for Ground Improvement				
Principle Of Improvement	**Replacement**	**Densification**	**Drainage**	**Admixture Stabilization**
Engineering Method	Excavation Replacement	Impact Compaction	Preloading	Jet Mixing
		Compaction By Displacement And Vibration	Preloading With Vertical Drain	Mechanical Mixing
	Compulsory Replacement	Vibration Compaction	Dewatering	Grouting
			Chemical Dewatering	

Why do we try to improve the properties of problematic soils rather than relying on deep foundations to reach strong deposits? The answer to this question is clear. First off, it is far less expensive to improve the soil than to use a deep foundation. Second, if we don't have enough room, we might have to use soil properties instead of piles. Das (1983) divided soil improvement techniques into a number of general approaches. As an illustration, consider deep compaction using compaction piles, preloading, sand drains, vibro flotation, stabilizing admixtures, thorough mixing, sand columns, stone columns, jet grouting, and shallow compaction. Consolidation, soil replacement, and the use of columns were the three primary categories. Figure (3) illustrates the detailed classification of each of these techniques into numerous methods. [20]

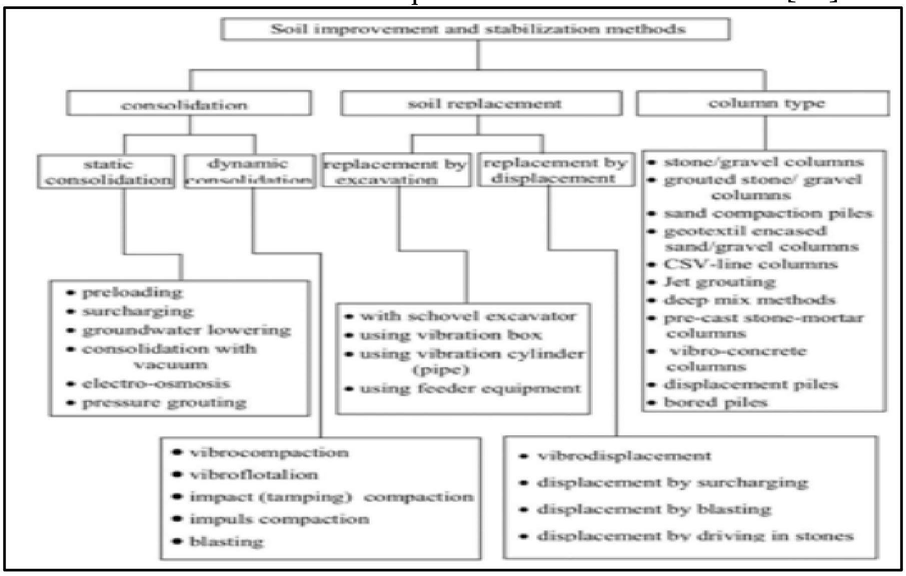

Figure (3) Classification of Soil Improvement Techniques [20]

Ground improvement is the transformation process the soil in a foundation to make it more efficient under design and/or operational loading conditions on a construction site. By altering the properties of the soil, ground improvement enables a variety of construction activities. Shear strength, shrinkage properties, bearing capacity, and swelling are some examples of these characteristics. When the subsurface conditions of the soils are poor, these techniques are being used more and more in the construction industry. Since the beginning, the ground improvement has been a major concern. Since the 17th century AD, new technologies have emerged. Experts in the construction industry now find it relatively easier to improve soil thanks to the use of modern techniques. [21] Any nation's transportation infrastructure has a major impact on its social, economic, cultural, and industrial development. The only way to provide everyone with the best service is through highway and railroad transportation. There is a lack of suitable land for building projects as a result of the recent development of infrastructure, including buildings, roads, railroads, and other structures. As a result, the engineers will inevitably use weaker and inferior soil for construction. Ground improvement techniques have increased significance and demand for a wide range of construction projects in today's environment. The soil's strength, compressibility, and performance under applied loading are all improved by ground improvement techniques. Because of their exceptionally high swelling and shrinkage action, expansive and collapsible soils present challenges for engineers. It can be challenging to build a foundation on karst deposits, soft soils, organic soils, and sanitary landfills. For such construction project sites, it is better to use a suitable foundation design to replace or avoid such soil strata; if this is not feasible, ground improvement is the best option. [22] Ground improvement is process of modifying the current foundation of the site soils to enhance performance under operational and/or design loading conditions. For new projects, ground improvement techniques are being used more and more to enable the use of sites with subsurface conditions that are poor. These poor soils were previously regarded as technically impractical or economically unjustifiable, and they are frequently replaced with an engineered fill or the project's location is altered. To put it briefly, ground improvement is done to improve the bearing capacity, decrease the size of settlements and the time it takes for them to occur, delay seepage, speed up drainage, make slopes more stable, lessen the chance of liquefaction, etc. suitable techniques for ground improvement ought to be chosen depending on the state of the soil, considering both the time frame and the economic viability. The type of strata and the goal of the improvement largely determine the ground improvement techniques that can be used. The available techniques are listed in Table (3) below, [23]

Table (3) Techniques for Ground Improvement That Are Available [23]

Cohesive Soils	Cohesion less Soils
Vertical Drains	Compaction piles
Vacuum Dewatering	Vibrio compaction
Stone columns	Stone-columns
In-situ deep mixing	Dynamic compaction
	Compaction by deep blasting
	Grouting

Numerous construction companies employed various soil improvement techniques, but they did not place much emphasis on their verification. Both before and after soil improvement, the soil must be verified. Ground improvement has been required in the majority of cases. In general, "ground improvement" refers to the use of different techniques to change a soil's properties in order to improve its engineering performance. [24] Even when prefabricated vertical drains are used, soft soils may necessitate the construction of an embankment in phases, which could significantly increase the overall construction time. Lateral berms and basal geosynthetic reinforcement might also be required to preserve stability in extremely soft soils. The requirement that post-construction residual (secondary) settlements be minimal could be a design restriction. A thicker embankment is necessary to accomplish this goal, though, in order for secondary settlements to form during construction in the form of primary settlements. [25] The primary purposes of soil improvement for slopes and foundations [26]:

- ❖ Expanding the bearing capacity.
- ❖ Accelerating consolidation and managing deformations.
- ❖ Providing excavations and slopes with lateral stability.
- ❖ Increasing resistance to liquefaction of loose, saturated granular deposits and implementing environmental control measures such as seepage cut-off.

Additionally, the foundation soils and problematic slopes can be improved by [26]:

- ❖ Lowering the weight and, consequently, the strain on the slope or foundation.
- ❖ Eliminating the problematic soils and substituting them with more capable materials.
- ❖ Increasing the problem materials' shear strength and decreasing their compressibility.
- ❖ Reinforcing embankments on unstable slopes or soft foundations.

The consequences of unstable soil are equally disastrous, encompassing everything from the base sinkage ,and slope failures to the total breakdown of mine dumps, tunnels, buildings above, and other structures. If chosen site's soil lacks the necessary structural characteristics (appropriate swelling factor, bearing capacity, internal angle of friction, and cohesiveness). It turns into essential to use outside resources to enhance these qualities. [27] **(Hirkane, Gore, et al, 2014) [23]** This essay explains the theory and concept of several ground improvement methods as well as how they are used in practice. Based on the extracted results, we have determined that PVD is more expensive than stone columns. Additionally, it has been observed that PVD settlement goes beyond stone columns. **(Hore and Ansary, 2020) [24]** The analysis of various soil improvement methods and a comparison of these methods' models is the aim of this study. Analysis has been done on the SPT measurements both before and after construction. Following soil improvement, there is a significant increase in the (SPT) profile. The (SPT) value following (DC) is higher than the (SPT) value following (SCP) in both approaches. **(Serridge, C. J, 2006) [28]** Vibro stone columns are one of the soil stabilization techniques used in the urban environment of the United Kingdom that were examined in this study. Urban areas have expanded to include new building construction and related infrastructure due to high population density and increased traffic volumes. Using stone columns for ground treatment or improvement offers a way to change the behavior of the ground, improving its characteristics and lowering its heterogeneity. However, a satisfactory characterization of the geotechnical characteristics of the weakly constructed ground and/or natural soil deposits covering the competent soil layers or rock is necessary for the economic design of such schemes. The dry bottom feed method has mostly taken the place of technique of wet top feed stone columns in the UK due to environmental constraints, and vibrio concrete plug technology has been developed in response to worries that stone columns on brownfield sites could create pathways for contaminants to migrate into underlying sensitive ground waters or aquifers. **(Onah, Nwonu, et al, 2022) [29]** The feasibility of treating soft clay with lime and biopolymers was examined in this study using a complementary and comparative methodology. Earthwork of some kind is usually required when highway infrastructure projects are being carried out. One type of ground improvement must be incorporated into the overall project planning and execution when such a soil deposit's spatial existence spans significantly both depth-wise and longitudinally. Lime and guar gum (GG) were evaluated for the stabilization of soft clay. The consistency limits and UCS of clay soil were significantly improved by lime stabilization. Furthermore, it was evident that a longer curing time led to a higher UCS gain. Considering the effectiveness and economy of the process of stabilizing the soil, 3% lime is advised as the ideal additive content. The stabilization of clay soil with GG produced a UCS gain that reached its peak at (0.6%), GG content. Additionally, it had been found that UCS only improved after 7 days of curing, after which strength attenuated due to the GG's biodegradation by soil microorganisms. It is not advised to use GG content above 0.6% since it was found to be harmful to the improvement of soil strength. Given the effectiveness and economy of the soil stabilization process, lime is advised as the ideal additive content. **(Karkush, and Yassin, 2020) [30]** This study examined how to get better the geotechnical features of clayey, soft soil by utilizing sustainable materials. Since some natural resources, like gravel, cannot be replenished, their use must be curtailed and substituted with more economical, environmentally friendly, and recycled materials. Natural aggregates can be substituted with recycled crushed concrete aggregates that have been demolished from older structures. Soft soil was mixed with five different percentages of recycled crushed concrete (5, 10, 15, 20), and (30) to enhance the soft soil's geotechnical qualities. The plastic limit, liquid limit, and specific gravity all rise with the addition of crushed concrete, but the plasticity index essentially stays the same. After the crushed concrete is added, the soft soil gets coarser. The addition of crushed concrete raised the constrained modulus of elasticity while decreasing the consolidation coefficient, swelling index, and compression index. **(Safa, 2016) [31]** The behavior of consolidation of (PVD,improved soil) in the Fao region was investigated experimentally and numerically in this thesis. A sample of soil was collected from the Al-Faw area in the Basra Governorate because the soil there is extremely salinized. One technique for stabilizing weak soils is the PVD method, which has been used to treat and stabilize the soil. One dependable method for quickening the consolidation settlement of Fao soft silty clay is the Prefabricated Vertical Drain (PVD). One dependable method for quickening the consolidation settlement of Fao soft silty clay is the Prefabricated Vertical Drain (PVD). The amount of time required to achieve 90% consolidation is significantly influenced by the PVD spacing and distribution pattern. A number of soil stabilization methods have been discussed, and one method is covered in detail in the topics that follow.

5.1 Objective of Techniques for Ground Improvement

The goals of methods for improving the ground are [23]:

- ✓ For new projects, techniques for ground improvement are being used more and more to enable the use of sites with subsurface conditions that are not ideal.

- ✓ In the past, these poor soils were viewed as technically impractical or economically unjustifiable, and they were frequently replaced with an engineered fill or the project's location was altered.
- ✓ To put it briefly, the purpose of the ground improvement is to raise bearing capacity, decrease the size of settlements, and shorten time.

An environmental assessment project must consider a variety of factors, such as the potential for acidification, aquatic toxicity, human toxicity, eutrophication (Considering the contamination of aquatic environments), global warming, the depletion of non-renewable resources, the depletion of ozone, terrestrial ecotoxicity, and the creation of photochemical oxidants. [32]

5.2 Benefits of Ground Improvement Techniques

The following five main areas are where ground improvement methods have been found to be beneficial. [33]:

- ❖ Using a less expensive foundation system.
- ❖ Decrease in the acquisition of right-of-ways.
- ❖ Less disruption to the environment.
- ❖ Shorter time spent on construction.
- ❖ Better traffic management in construction zones.

5. Vertical Drains:

The vertical drain method is frequently used in conjunction with the preloading, surcharge, or vacuum methods to speed up consolidation through the drainage path's shortening. In addition to sand drains, prefabricated band-shaped drains are widely used. These drains can be quickly installed at great depths and into the seabed. If enough time is available, compressing soft soils before building using static loading is a common practice to attain the necessary strengthening and consolidation. The method involves applying a pressure (preload) to the ground that is equal to or greater than the contact pressure of the superstructure prior to its construction. Soft soil consolidation by preload increases the soil's shear strength and reduces residual settlement. Typically, such a preload cannot be applied all at once on soft ground. Thus, preloading must be done in stages while the ground's strength increases. As a result, the method is inexpensive, but it takes a long time to improve the soil. The vacuum preloading method increases the effective stress in the soil by lowering the pore pressure rather than applying a preload to the ground surface. This method is distinguished by the absence of a stability problem because earth filling for loading is not required. [6] A new technique called vertical drains speeds up consolidation by installing drains under a surcharge load to drain relatively impervious soils. Water can leave the soil more quickly thanks to drains. The amount of time needed to drain clay layers can therefore be shortened from years to months. Sand drains and prefabricated vertical drains are two of the most common types. [34] The drainage path length will increase when the soil preloading is applied to soft soil with low permeability. This problem could lengthen the time it takes for water to escape the subsurface beneath the fill or preloading, which should be as short as feasible. As a result, vertical drains are required in this scenario, which reduces the length of the drainage path. These vertical drains accelerate the flow of water out of the subsoil construction area, cutting the time it takes for the soil to consolidate from years to replacing it with granular soil, with the greatest effect when using a trench pattern. The trench pattern's measurements are B, which is the width of the foundation, with a depth of (1.5B) and a width that is stretched by B/2 on each side. Second, when it comes to increasing bearing capacity, widening the replacement is more effective than deepening it. [20] The band drains have a composite design with an inner core that is corrugated or studded and covered in a filter cloth, which is typically a non-woven geotextile. Figure (4) Prefabricated vertical drains have the following benefits: [23]:

- ✓ Simple, quick installation is feasible.
- ✓ Constructed from consistent materials, it is portable and easy to store.
- ✓ Compared to rigs used for similar sand drains, the equipment required is lighter.
- ✓ Cheaper than conventional sand drains.

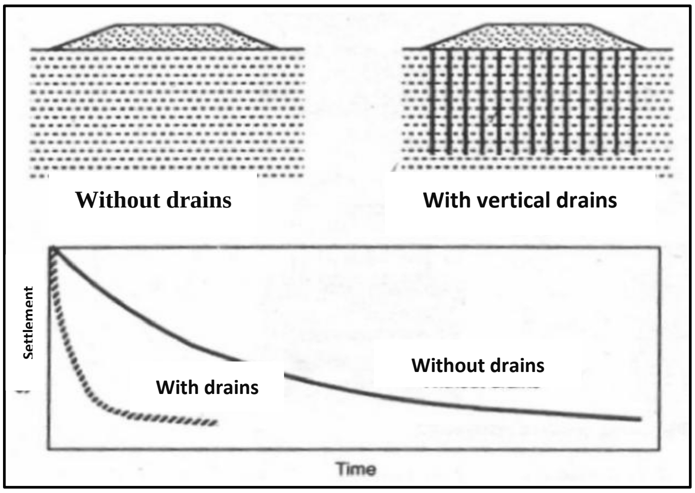

Figure (4) The Advantages of Vertical Drains [23]

Because they reduce the distance that water must pass through the soil's permeable vertical drains, vertical drains are used to accelerate consolidation and thereby increase the fine-grained soils' bearing capacity and shear strength, also known as impervious soils. The long-term settlement is thus constrained. Another name for them is band drain or wick drain. Prefabricated vertical drains and sand drains (PVD) are the two most popular varieties of vertical drains, figure (5). [21]

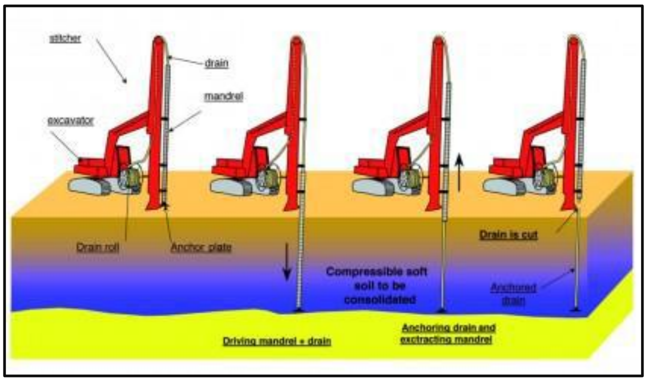

Figure (5) Vertical Drain Cross Section [21]

(Chu, Bo, et al, 2004) [36] The practical aspects of employing vertical drains in soil improvement projects were examined in this study. This paper's goal is to draw attention to a few useful factors when using PVDs in soil improvement initiatives. Discussed are elements that impact vertical drain performance, including the drain's quality, the choice of soil variables, the smear effect, and the kind of mandrels. Techniques for performing quality control tests on PVDs are described. **(Chang, Rathje, et al, 2004) [37]** This study examined the direct assessment of prefabricated vertical drains' efficacy in liquefiable sand. A novel in situ liquefaction testing method was used in the program, which measures the response of soil-pore water coupled by creating waves with a large hydraulic vibrator that travel through an instrument that is embedded area. The findings of this worksheet show that drainage by itself can reduce the amount of settlement in loose, saturated sands under high dynamic loading, speed up post-shaking pore pressure dissipation, and significantly reduce pore pressure generation. Furthermore, the results demonstrate that the recently created in situ liquefaction testing method may serve as a substitute for quantitatively assessing the impacts of different liquefaction remediation strategies. **(Bergado, Balasubramaniam, et al, 2002) [38]** This study examines the performance of a test embankment constructed on soft Bangkok clay at full scale at the location of the new Bangkok International Airport in Thailand, complete with prefabricated vertical drains (PVDs). Reaching a maximum elevation of 4.2 m, side slopes of (3H: 1V), and baseline measurements of (40m) by (40 m), the embankment had a square plan. Compared to the corresponding values derived from settlement measurements, the degree of consolidation determined by pore pressure measurements was lower. The values calculated from the consolidation settlements and The field measurements' water-content decreases concur. **(Sakleshpur, Prezzi, et al, 2018) [39]** A review of recent analytical, laboratory, numerical, and field studies that used preloading with PVDs to improve soft ground is presented in this paper. The paper focuses on traditional PVDs that do not employ vacuum, thermal, or electro-osmosis methods. Two case studies that demonstrate the effectiveness of PVDs in the field are included to supplement the review. **(Dey, 2008) [40]** This essay offers a succinct overview of vertical drains, highlighting their functional traits, various installation methods, and possible benefits and drawbacks. An outline of the theoretical factors that will be considered when designing the vertical drains is provided. To address smear effects and smear zone characterization, a typical case study from the past is presented. The findings show that the vertical drains' horizontal permeability is significantly impacted by smear phenomena. **(Huang, Li, et al, 2020) [41]** The prefabricated vertical drain solutions for the equal-strain consolidation of unsaturated foundation, considering drain resistance and the smear effect, are analytically developed in this paper based on the consolidation theory put forth by Fred Lund. Using an analytical process, this study examined the unsaturated PVD foundation's consolidation qualities, including its drain resistance and smear effect. Various degeneration (into saturated soils, soils without saturation that have a smear effect, and drain-resistant unsaturated soils, respectively) and comparison techniques are used to confirm the generality and dependability of the obtained solutions. The presence of drain resistance causes the excess pore pressure distributions along the way of vertical direction to change with z. additionally, the top boundary and the dissipation patterns in the modeling that incorporates the vertical flow are not the same, where the excess pore pressures are not equal to zero. **(Wang, Han, et al, 2020) [42]** This work examined the apparent clogging effect when dredged soil was vacuum- induced consolidated using prefabricated vertical drains. Fine particles clogged the PVD filters, particularly on the side that came into contact with the soil. Nonetheless, the filter's cross-plane permeability was still four orders of magnitude greater than the surrounding soil's. The overall vacuum-induced consolidation clogging phenomenon was not significantly impacted by filter clogging. Since the final PSDs of the model soil at different locations were uniform, substantial migration of particles in results of the experiment did not support pure clay.

6.1 Factor Effect of Vertical Drains (Analysis Systems)

By shortening the soil's drainage channel, a deep vertical drain aims to quickly release excess pore water pressures. [35], all essentially came from Terzaghi's, (one-dimensional consolidation theory). [43] The factors influencing the analysis system are as follows.

6.1.1 Effective diameter of drains

By decreasing the domain's permeability, a drain's installation has an impact on the nearby soil. The analysis accounts for this by assuming a decrease in the nominal diameter of the drain or a smaller total magnitude of the permeability coefficient for each soil stratum. The sand drains' effective diameter could be higher or lower than their nominal diameter. When sand drains are installed using washing techniques, they might have regular forms, and the sand may seep into the surrounding soil, growing the drain's effective diameter. [35]

6.1.2 Pattern, Spacing, and Depth of Drains

The drains' pattern and spacing are now comparatively well standardized. Grid spacing of 1-4 meters, either square or triangular is typically utilized, with (1.5m-2.5m) being the most widely used. The depth of treatment is frequently just the depth of soft or impermeable soils at sites, and for depths between 5 and 20 meters, full-depth vertical drains can often prove to be an extremely economical solution. The cost of installing the drain increases significantly beyond a depth of 20 meters. The main cause of this is the quick raised in Force needed. to install the drain even typically consolidated soils become (30m) to (40 m) below the surface, firm to stiff. [35]

6.1.3 Unit Cost of Drain

The price of sand can be crucial for sand wicks and drains. The cost of labor to prefabricate the drain on-site for sand wicks could be rather high. This usually means that the cost of the drain is 50–60% higher per unit than that of a band drain. The wrapped pipe drains' content costs are also high, to the point where they are frequently not cost-effective. When it comes to the cost of basic materials, the band drains are without a doubt the least expensive. Nevertheless, this expense may account for up to 40% of the cost per meter of installation. [35]

6.2 Theoretical Considerations

Finding the drain spacing that, under the given ground conditions, will provide the necessary level of consolidation in a given amount of time for any given drain type and size is the challenge of designing a vertical drain scheme. Both horizontal vertical and drainage through the soil should be considered in any design strategy in order to simulate the current circumstance. The following is an expression for consolidation brought on by vertical drainage based on one-dimensional consolidation: [43]

$$U_V = 1 - \frac{8}{2\pi}\sum_{N=0}^{N=\infty}\frac{1}{(2N+1)^2} \times exp\left[-(2N+1)^2\pi^2\frac{C_V t}{H^2}\right] \ldots\ldots\ldots\ldots (2)$$

where,

(U_v) is the typical level of consolidation brought on solely by vertical drainage;

(c_v) The vertical consolidation coefficient.

(t) The time elapsed.

(H) Height of the soil section between a free drainage surface and an impervious one.

It is more difficult to determine the average level of consolidation caused by horizontal drainage. In actuality, Drains are set up in a grid pattern that is either rectangular or triangular, Consequently, the issue is not axisymmetric. (No) analytical responses are available for real-world situations. The problem is usually approximated as that of a cylindrical drain placed in the center of a cylinder of consolidating soil. [35]

6. Sand Drains Method:

Before a building or foundation is constructed, sand drains are one type of vertical drain that can hasten the consolidation and settlement of soft clay, clayey soil, and typically or slightly over-consolidated clayey soil. Installing the sand drains involves creating vertical holes at predetermined times and then backfilling with sand after the undesirable soil has been jetted out. One of three methods could be used to apply the drilling: mandrel-driven pipes, hollow steel piles, continuous flight augers, or rotary drilling. As soon as the drilling holes are filled with sand, the surcharge will be applied on top of the soil. Water moves from high to low potential energy. as a result of this surcharge, which will raise the water pressure in the pores at the soft clay and force it to dissipate to the sand drains. Sand columns have a lower potential energy target because water flows through them more quickly, and sand drains more quickly than soft soil. Although only 1-2 percent of the soil is replaced by sand drains or sand columns, the soil's bearing capacity may be increased by more than 10% [20]. They strengthen the soft soil where they are placed. Figure 6 illustrates the sand drain technique. Although sand drains only replace (1%) to (2%) of soil volume, the overall increase in bearing capacity may be greater than 10%. However, they also have certain drawbacks: [34]

- ✓ When hollow mandrels are pushed down to install sand drains, the soil around each drain is disturbed. The water flow (move) to the drain may be decreased as a result.
- ✓ During filling, the sand may bulge, which could lead to cavities.
- ✓ Large diameter sand drains may cause construction (and/or) financial issues.

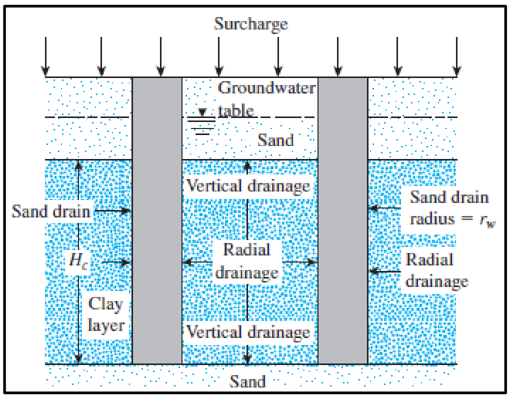

Figure (6) Method of Sand Drains [34]

Water particles' longest horizontal travel path should be a fraction of their longest vertical travel path due to the proper spacing. Drains shorten the water particles' path of travel and speed up the consolidation process. Consolidation time factor because of vertical drains.

$Tv = Cv.\ t \backslash d^2$ .... (3)

Where Cv = Consolidation coefficient for vertical drainage, d = drainage path.

Radial flow consolidation coefficient, which is mainly involved in flow to sand drains, is typically higher than that for vertical flow in one-dimensional consolidation because the horizontal permeability of layered deposits is frequently significantly greater than the vertical permeability. Figure (7) illustrates the water from each well's zone of influence, which is the square and hexagonal area. Creates a mixture of radial and vertical flows as it gathers into the well and flows vertically towards the free-draining boundary. When sand drains are installed, the area surrounding the well's edge becomes more dispersed, and the horizontal permeability in that area decreases. This phenomenon, known as smear, prevents the flow in the direction of the well. The effects of the smear can be considered by establishing the well's diameter to half of the diameter that is actually installed.

The uses of this technique: [22]

- ✓ Usually, Preloading is used in conjunction with sand drains.
- ✓ Sand drains could be installed in current fills to relieve excess hydrostatic force in the absence of surcharge loading.
- ✓

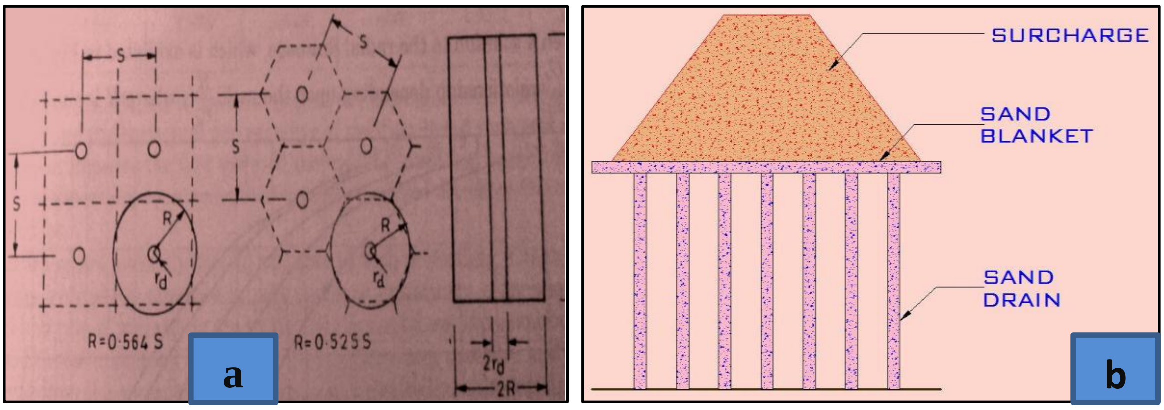

Figure (7) (a) Sand Drain Spacing [22] (b) Surcharged Sand Drain [21]

(Harada, And Ohbayashi, 2017) [44] In addition to describing other techniques that are derived from the conventional SCP method as liquefaction countermeasures, this work sheet gives an outline of the traditional SCP approach, encompassing its idea, background, tools, and application. Apart from the conventional SCP approach, two modified versions are presented for broader application, the sand injection-type SCP method and the non-vibratory SCP method. **(Naseer, 2021) [45]** Developing small-scale laboratory models to examine the impact of floating columns in clayey soil with silty deposits is the goal of this project. A 37 mm circular column was used for the laboratory tests, and the outcomes of the treated and untreated ground were contrasted. Impact of sand columns on soils with varying loading patterns, slenderness ratios (L/D), and shear strengths (low-medium-high) are investigated. In comparison to weak soil, it was found that sand columns are more effective at achieving comparatively higher shear strengths. Additionally, the impact of the length-to-diameter ratio is examined. The greatest increase in strength is attained at

L/D equal the loading capacity falls as the L/D ratio rises. The bulging of the sand column in the composite ground is the cause of this. As a result, Four times the diameter of a partially penetrating column was determined to be its critical length. **(Singh, and Hattab, 1979) [46]** The main goal of this paper's experimental investigation of the inward radial drainage of remolded kaolin clay to a central model sand drain is to evaluate the impact of different installation and spacing techniques on the soil's consolidation properties. Three different Rowe consolidation cell sizes (76, 152, and 254 mm in diameter) have been used in the design and implementation of an experimental program. Early on in the program, four installation techniques were employed. The auger, closed (circular) mandrel, open mandrel, and jetted mandrel. **(Hansbo, 1960) [47]** In this research paper, which is based on the same author's special book, the design equations used in the sand-drain method are discussed in detail along with the factors that influence it. **(Aparna, and Bindu, 2023) [48]** This study examined the use of waste materials in clayey soil as an alternative to sand drains. Due in part to the lack of high-quality sand, a less expensive material was used instead. The current study attempted to use waste materials like fly ash (FA), coir pith (CP), rice husk ash (RHA), and quarry dust (QD) as a vertical drain in clayey soils. For comparison, sand drain (SD) has been used. For the study, Kuttand Clay (KC) and Cochin Marine Clay (CMC) were chosen. The consolidation rate and coefficient of permeability of soil with vertical drains are significantly influenced by the drain's density. The permeability of the drain decreases as its density rises. When compared to fly ash and rice husk ash drains, the rate of consolidation with quarry dust, sand, and coir pith drains is higher. The raised permeability of coir pith, quarry dust, and sand could be the cause. **(Dip, 2017) [49]** The thesis includes the prefabricated vertical drain and sand drain designs for the Khan Jahan Ali Airport Runway. While maintaining a constant degree of consolidation, consolidation coefficient, and thickness of the soft soil layer, sand drains of any given diameter require less consolidation time than PVD. When all other factors are held constant, the triangular pattern of PVD or sand drain takes less time to consolidate than the square pattern. Compared to unilateral flow, bilateral flow also takes less time. **(Bouckovalas, Papadimitriou, et al, 2011) [50]** The groundbreaking paper reviews Seed and Booker's work on designing infinitely permeable drains to mitigate liquefaction. According to their fundamental presumptions in mathematics, the rate at which earthquake-induced excess pore pressure generation occurs ignores the consequences of changing sand fabric under cyclic loads, which ultimately results in an underestimation of the drain effectiveness. The study creates a new set of drain design charts and offers a qualitative evaluation of their impact on drain effectiveness. **(Holtz, 2019) [51]** Sand drains are the two earliest techniques for lowering settlements and boosting the foundations' shear strength on soft clays. The late 1920s and early 1930s saw the creation of both. These early advancements are discussed, along with some unique tools created for paper drain installation. **(Landau, 1966) [52]** This paper's goals are to examine the variables that are taken into consideration when designing sand drain installations for use in stabilizing embankment foundations and to establish the idea of "grid efficiency" as a framework for evaluating the effectiveness of drains installed using different techniques. The field results of the Whitestone Expressway project's sand drain areas provide every indication that the hollow shaft flight auger method of installing sand drains minimizes soil disturbance, resulting in a highly effective method. For stabilizing soils without the need to make up for any disturbances by applying the sand drain design principle. **(Widomski, Sobczuk, et al, 2010) [53]** In Olszanka, Poland, a method of controlling slope erosion was created that consists of horizontal terraces with drainage ditches filled with sand. On steep slopes, this system combines two methods of erosion control: reducing soil transformations and boosting surface water infiltration into the subsoil. A fruit farm in Olszanka is home to the new system for controlling soil erosion. The Olszanka-developed and tested soil erosion control system manages soil erosion in the valley bottom and on steep slopes (6–15% and higher). Comprehend how the conductivity and retention capacity of the fill sand are changed by transport of sediment in drainage ditches (The drainage ditch fill's capacity to discharge water and its rate of infiltration would both be reduced by increased flow resistance.).

Numerous minor uncertainties surrounding the use of sand drains must be addressed through extensive field research. These consist of things such as: [54]

- ✓ Smear.
- ✓ Disturbance.
- ✓ Allowable drain sizes and spacing when using driven closed-end mandrels.
- ✓ The second compression method.

In actuality, item 4 above is a significant research study that calls for extensive theoretical, laboratory, and field research.

7. Conclusion:

There are numerous approaches to soil stabilization, which are referred to as soil stabilization techniques. These approaches were first identified in the early 1900s, and as time progressed, additional approaches were added to improve and fortify the soil. This study is organized into three primary sections, each of which discusses a particular subject using evidence from books, conferences, and published research.

- In the first section, an introduction to soil was presented, including the factors that affect soil stability and the importance of soil in building construction. As it is considered the most important part before but laying the foundation, which is the main pillar in construction. To obtain a safe building within a long period of operational time, the soil must be stable and safe and not subject to collapse or subsidence. Some of the mechanical characteristics of the soil have been mentioned (Shear Strength, tensile strength, and compressibility) of soil, which is among the crucial characteristics. Through which the stability of soil is known by knowing the factors that affect these properties such as (moisture content, temperature, groundwater, impurities, salts and other factors) and many researchers have conducted research on these properties and some of them have been mentioned.
- The second part of the research is concerned with soil stabilization techniques. The classifications of soil stabilization techniques were mentioned and summarized through a table and a diagram and knowledge of the available methods of soil stabilization techniques and how to apply these methods through the use of mechanisms, equipment and materials, with the most important characteristics that occur when strengthening weak soils.
- The third part was dedicated to one of the soil stabilization techniques, which is known as (sand drains), which is one of the techniques derived from the vertical drains method of soil stabilization. Many researchers have conducted a study on this method and some of this research has been mentioned. It has been noted through the aforementioned research

that the soil stabilization technique using (sand drains) has shown great effectiveness to stabilize weak soil while giving good soil resistance.

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Conflict of Interest:
The writers want to emphasize, this article's publication has not resulted in any conflicts of interest.

Author Contribution Statement
To create a useful research paper for researchers that would direct them in the field of review and information gathering, the authors helped compile and summarize a large number of sources and thoroughly examine the suggested topic from all angles.

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