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Investigating the Various Technique for Soil Improvement

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ABSTRACT
In a construction project, there are various foundation problems encountered. Soil in its natural form might not always be suitable to completely bear all the structural loads. So the need to improve the soil properties using various techniques. In this project work cement and silicate sand are mix in percentage with laterite to improve the quality of the soil. Various laboratory test where carried out.

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I. INTRODUCTION

Ground improvement, is the modification of soil in foundation so as to give better efficiency under design and/or operational loading conditions at the construction site. Ground improvement changes soil characteristics thereby permitting different types of construction operations. These characteristics may be shear strength, swelling and shrinkage characteristics and bearing capacity. There is an increasing use of these techniques in the construction industry where the soils are having poor subsurface conditions. The ground improvement has been of great concern since early times. Different technologies started to develop since 17th century AD. Today, use of modern methods have made soil improvement relatively easier for the experts in the construction industry. Ground improvement methods have developed markedly over the past five decades to the point where they are almost routinely used in geotechnical design and construction. The impetus for ground improvement has been both the increasing need to use marginal sites for new construction purposes and to mitigate risk of failure or potential poor performance. Every potential construction site presents the design engineer with several alternatives should unsuitable or marginal soil conditions be encountered. These alternatives include: (1) bypassing the poor soil through relocation of the project to a more suitable site or through the use of a deep foundation; (2) removing and replacing the unsuitable soils; (3) designing the planned structure to accommodate the poor/marginal soils; or (4) modifying (improving) the existing soils, either in1place or by removal, treatment and replacement of the existing soils; or (5) completely abandoning the project (ASCE 1978; Mitchell 1981). Through a widevariety of modern ground improvement and geoconstruction technologies, marginal sites and unsuitable in-situ soils can be improved to meet demanding project requirements, making the latter alternative an economically preferred solution in many cases.

Ground improvement is now recognized as a major sub-discipline of Geotechnical Engineering. The growth in ground improvement methods, products, systems, and engineering tools has been tremendous, with a very large body of knowledge and large number of technologies available. Progress in this development has been chronicled by means of many conferences, workshops, papers and reports - far too many for all to be cited herein. However, a few comprehensive references that describe the methods, their design and construction procedures, applications, advantages and limitations, and illustrate how the technologies have developed are noted. An early comprehensive State-of-the-Art (SOA) report on Soil Improvement was presented by Mitchell (1981) at the 10th ICSMFE in Stockholm. Recently, Chu et al. (2009) devoted a large part of their State of the Art report on Construction Processes prepared for the 17th ICSMGE in Alexandria to current developments in Ground Improvement. Within ASCE and the Geo-Institute three committee publications document the progress to 1997: Soil Improvement History, Capabilities, and Outlook (ASCE 1978), Soil Improvement-A Ten Year Update (ASCE 1987), and Ground Improvement, Ground Treatment, Ground Reinforcement-Developments 1987-1997 (ASCE 1997). Numerous specialty sessions have been organized at Geo-Institute conferences, and many Geotechnical Special Publications are now available on different aspects of ground improvement.

II. PROBLEM STATEMENT

The effectiveness of various techniques for soil improvement is a critical aspect of geotechnical engineering. However, there is a lack of comprehensive research that systematically evaluates and compares the performance of these techniques. This knowledge gap poses challenges for engineers and researchers in selecting the most suitable soil improvement technique for specific soil conditions and project requirements. The problem statement for this research project is to investigate the effectiveness of various techniques for soil improvement and provide a comparative analysis of their performance. This study aims to address the following key questions: 1. Which traditional soil improvement techniques, such as compaction, drainage, chemical stabilization, and mechanical stabilization, are most effective in enhancing soil properties? 2. How do modern soil improvement techniques, including soil mixing, soil reinforcement, soil grouting, and electrokinetic stabilization, compare to traditional methods in terms of their effectiveness? 3. What are the specific engineering properties that can be improved using different soil improvement techniques, such as soil bearing capacity, settlement, drainage, and stability? 4. What are the limitations and challenges associated with each soil improvement technique? 5. What are the factors that influence the selection of the most suitable soil improvement technique for a given project? By addressing these research questions, this study aims to provide valuable insights into the effectiveness of various soil improvement techniques. The findings will help engineers and researchers make informed decisions in selecting the most appropriate technique for specific soil conditions, optimizing project costs, and ensuring the long-term stability and sustainability of engineered structures.

III. METHODS OF GROUND IMPROVEMENT

There are many methods for soil stabilization. These techniques mainly depend on the type of strata and purpose of improvement. Soil stabilization can be classified as follows. 1. Soil improvement using Chemicals 2. Soil improvement using mechanical methods 3. Soil improvement without using admixtures 4. Soil improvement using thermal methods 5. Other methods

3.1 Soil Improvement using Chemicals

Some of the chemicals like lime, fly ash and cement are used as additives for soil improvement. Certain additives such as lime, bitumen, fly ash and cement etc. are added onto the soil at site to improve its characteristics. These may be classified as following:

3.1.1 Lime Stabilization

This technique came into picture more than half a century ago. Lime can be used to treat soils in order to improve their workability and load bearing characteristics in a no. of situations. Quicklime delays the reaction time with soil by about 1.25 times the time taken by slaked lime. Use of lime as a stabilizer enhances the long-term permanent strength, stability and stiffness particularly with respect to the action of water and frost especially in fine grained soils and sometimes in in fine grained fractions of granular soils too. Once the soil has been cured using lime, important works such as creating embankments or subgrade of structures can be done with them, hence avoiding the expensive works like excavation and transport. Generally 2-8% of lime may be required for coarse grained soils and 5 to 8% of lime may be required for plastic soils

3.1.2 Cement Stabilization

Cement has been one of the oldest binder in the soil stabilization technique. Soil reacts with cement and the hard mixture obtained from the reaction of pulverized soil, Portland cement and water is known as soil-cement. This is done at site by using special equipment. The cementing action is said to be the result of chemical reactions of cement with siliceous soil during hydration reaction. Nature of soil content, mixing conditions, compaction, curing and type of admixtures used are some of the factors that affect the properties of soil cement. This technique is used in shallow depth stabilization in the case of highways and embankment material and in the stabilization of weak soils at a greater depth such as soft soils and peaty soils. The recent developments have taken place mainly in the optimization of tools and process for mass production.

3.1.3 Fly Ash Stabilization

Fly ash, being a waste product from the thermal power plants is generally used in a variety of operations. Around 15% of the fly ash is utilized in the manufacturing of bricks and cement and the remaining is stored as slurries in lagoons. Hence despite having lesser cementitious properties than in lime and cement, the abundance of fly ash has made it an increasingly popular alternative during recent years. The fly ash is used potentially as a subgrade stabilizer and in land reclamation.

3.1.4 Jet Grounding

This is a costly method for soil stabilization. In this method, External stabilizers are injected into the soil. Jet grouting is used across wide range of soils. In this technique in situ geometries of soilcrete (grouted soil) are created, using a grouting monitor attached to the end of a drill stem. Hydraulic Rotary drill is used to reach the design depth. The jets erode and mix the in situ soil as the drill stem and jet grout monitor are rotated and raised. This method is suitable for stabilizing buried zones of relatively limited extent and is not useful for clayey soils because of their low permeability. There are three traditional grout systems, namely single, double and triple fluid systems. In a single-fluid jet grouting system (Figure 1.a.), a high-velocity cement slurry grout is used for eroding and mixing the soil mass. With this grout, functions such as breaking down of soil matrix, removal of excess material and mixing with soil are easily fulfilled. This method is most commonly used for silts and clays. Whereas in the double-fluid jet grouting system (Figure 1.b.), a two-phase internal fluid system with a coaxial air-jet supply line around the grout-jet supply which increases the erosion efficiency. This system is more effective in cohesive soils than the single-fluid system. In the triple-fluid jet grouting system (Figure 1.c.), water jet is surrounded by an air jet, with a lower grout jet to inject cement slurry at a lower pressure. To erode the soil structure, coaxial air and high-velocity water are used with an additional improvement through partial substitution of the finest soil particles.

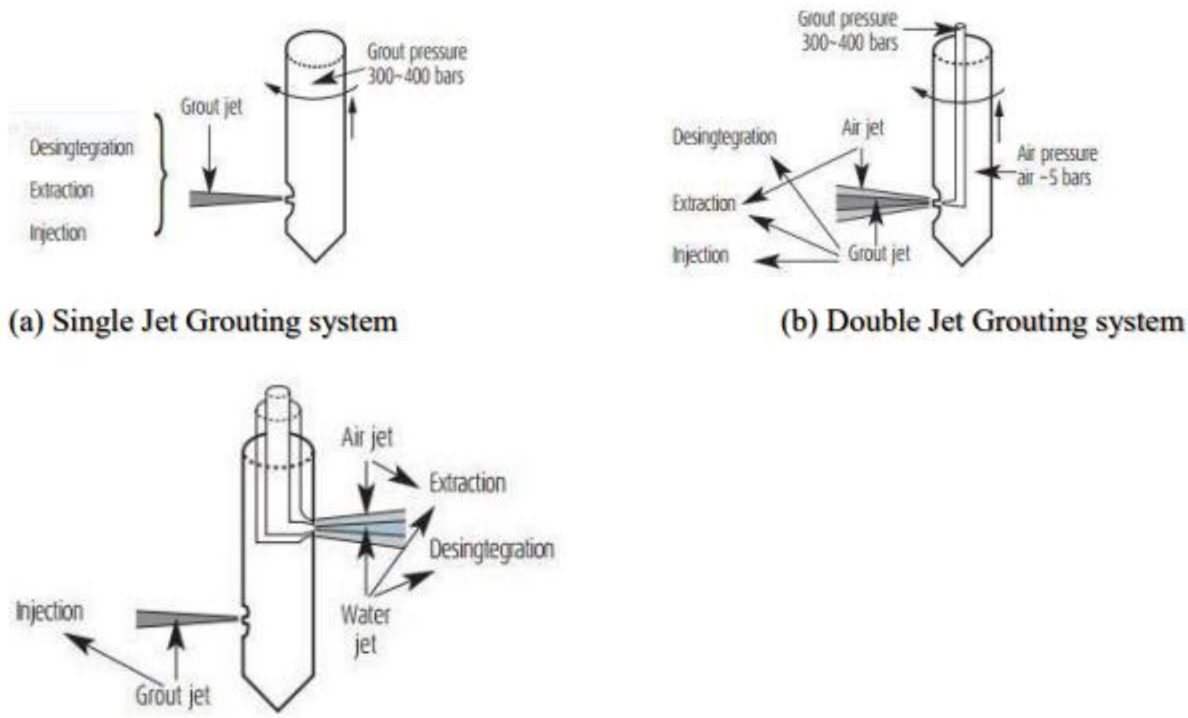

Figure 1: Jet Grounding Systems

3.2 Soil Improvement Using Mechanical Methods

In this method soil is being densified using rollers and vibrators by applying a compressive force on the given soil. These techniques are further classified below.

3.2.1 Stone Column

Though this technique was used first in France in 1830s, the wide range of use of this technique spread especially in Europe since 1950s. In this method, the columns consist of compacted gravel or crushed stone arranged by a vibrator. Stone column technique decreases the compressibility of soft and loose fine graded soils leading to increase in strength, accelerates consolidation effect and reduce the liquefaction potential of soils. Stone columns are more preferable than sand drains because of their granular nature which provides additional shear strength to the surrounding soils. They are mainly used for stabilization of soft soils such as soft clays, silts and silty-sands. The geo-synthetic-reinforced fill and stone column system can provide an economic and effective solution for structures constructed on clay soil. The use of geo-synthetic reinforcement transfers he stress from soil to stone columns due to stiffness difference between the stone columns and soil, and this may prevent large displacement and reduce the total as well as differential settlement. Stone columns are installed using either top- or bottom-feed systems, either with or without jetted water. Most widely used methods for installation of stone columns are: Vibro-Replacement (Wet, Top Feed Method) and VibroDisplacement (Dry, Top and Bottom Feed Method).

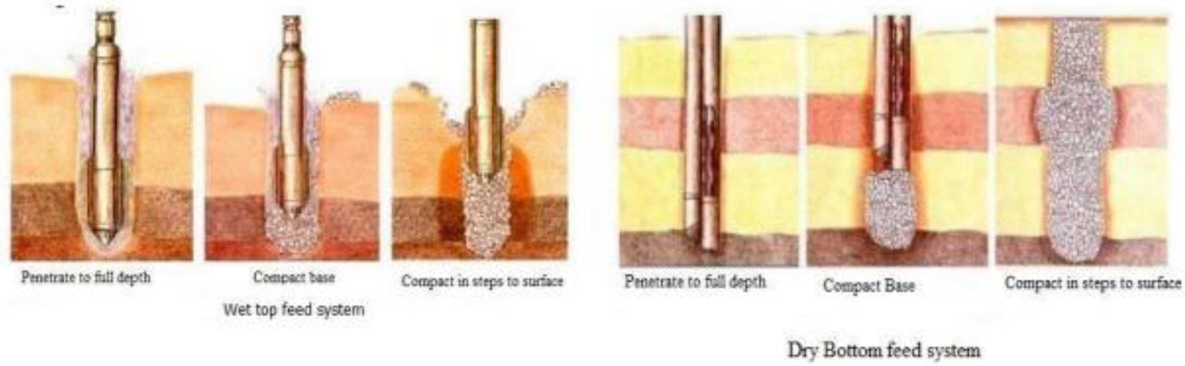

Figure 2: Jet Common used methods of stone coumn technique

3.2.2 Vibro Floatation

Vibro-compaction, sometimes referred to as Vibro-floation, is the rearrangement of soil particles into a denser configuration by the use of powerful depth vibration. Particles of granular soil can achieve 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. Combined action of vibration and water saturation by jetting rearranges loose sand grains into a more compact state. Vibro compaction is performed with specially-designed vibrating probes. Both horizontal and vertical modes of vibration have been used in the past. The probe is first inserted into the ground by both jetting and vibration. After the probe reaches the required depth of compaction, granular material, usually sand, is added from the ground surface to fill the void space created by the vibrator. A compacted radial zone of granular material is created. Its applications are reduction of foundation settlements, reduction of risk of liquefaction due to seismic activity, permit construction on granular fills.

Vibro compaction may be used as a ground improvement technique to support all type of structures from embankments to chemical plants .Vibro compaction is used to increase the bearing capacity of foundations and to reduce their settlements. Another application is the densification of sand to mitigate the liquefaction potential in earthquake prone zones. Vibro compaction method is not effective for soil having a percent finer more than about 15 to 20 %.

3.2.3 Micro piles

Micro piles are deep foundation elements constructed using high-strength, small-diameter steel casing and/or threaded bar. Micro piles were first used in Italy in the early 1950s for underpinning of those monuments and historic buildings that were getting damaged with time. Micro-piles have a small diameter (up to 300 mm), and have a high load bearing capacity (up to 5000 KN in compression). They can be installed through virtually any ground condition, obstruction and foundation and at any inclination and ensure minimum vibration or other damage to foundation and subsoil. Micro piles be installed in as little headroom as 6' and close to existing walls. The advantage of micro piles is that they can resist compressive, tensile or lateral loads, or even combinations of all the three loads. Micro piles can be designed as soil frictional piles and rock socketed piles either under tension and compression. Micro piles can be used as a foundation for new structures or repair / replacement of existing foundations. Soil strengthening, protection and Arresting / Prevention of movement Embankment are also some of the common applications of micro piles.

3.4.4 Soil Nailing

Soil nailing is a method of earth retention which uses grouted tension-resisting steel elements (nails) designed for permanent or temporary support. The fundamental concept of soil nailing consists of reinforcing the ground by passive inclusions, closely spaced, to create in-situ soil and restrain its displacements. Soil nailing is normally used for stabilizing existing slopes or excavations where top to bottom construction is beneficial as compared to other retaining wall systems. For certain conditions, soil nailing offers a feasible alternate from the viewpoint of technical viability, construction costs and duration when compared to ground anchor walls, which is another popular top-to bottom retaining system. Soil nailing technique has proved well in excavation applications for ground conditions that require vertical or near-vertical cuts. The other field of application of soil nailing is in railway and roadway cut excavations (Figure 3), road widening under an existing bridge end, repair and reconstruction of existing retaining structures, and temporary/permanent excavations in an urban environment. Excavation retaining structures in urban areas for high-rise buildings and underground facilities and construction and retrofitting of bridge abutments with complex boundaries involving wall support under piled foundations are also sometimes done using this technique.

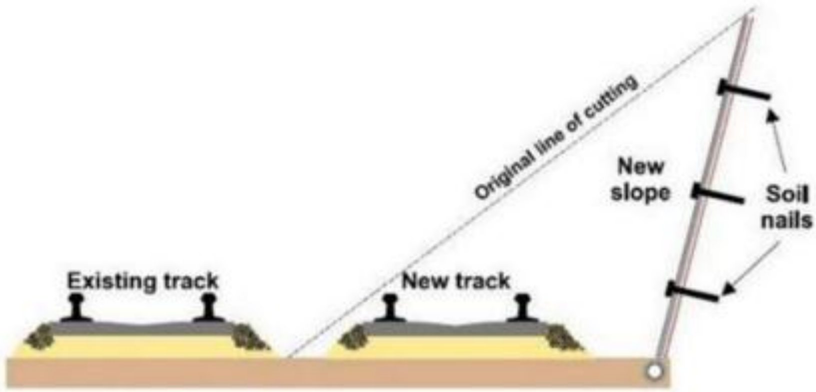

Figure 3: Soil nailing railway construction

3.3 Compaction

Compaction is a traditional soil improvement technique that involves applying mechanical energy to soil to increase its density and improve its load-bearing capacity. This technique is commonly used to reduce soil voids and increase soil strength, stability, and resistance to settlement. Compaction is particularly effective in improving the properties of granular soils. The process of compaction involves the use of compaction equipment, such as rollers or vibratory compactors, to apply mechanical force to the soil. The equipment exerts pressure on the soil, causing the soil particles to rearrange and come closer together. This reduces the air voids and increases the soil density. Compaction can be performed in different stages, including initial compaction, intermediate compaction, and final compaction. Each stage involves progressively increasing the compaction effort to achieve the desired level of soil density. The effectiveness of compaction depends on several factors, including the type of soil, moisture content, compaction energy, and compaction method. Optimal moisture content is crucial for achieving maximum compaction, as it allows for better particle rearrangement and densification. The compaction energy, which is determined by the weight and speed of the compaction equipment, should be carefully controlled to avoid over-compaction or under-compaction. Compaction offers several advantages in soil improvement, including: 1. Increased Load-Bearing Capacity: Compaction increases the soil density, which improves its load-bearing capacity. This is particularly important in construction projects where a stable foundation is required to support structures. 2.Reduced Settlement: By reducing the air voids in the soil, compaction minimizes settlement, ensuring the long-term stability of the engineered structure. 3.Improved Drainage: Compacted soil has better drainage characteristics, as the reduced voids allow for improved water flow through the soil. 4. Enhanced Soil Stability: Compaction improves the stability of the soil by increasing its shear strength and resistance to deformation. However, compaction also has some limitations and considerations: 1. Soil Type: Compaction is most effective in granular soils, such as sands and gravels. It may not be as effective in cohesive soils, such as clays, which have higher water content and tend to be more plastic. 2. Moisture Content: Optimal moisture content is critical for achieving maximum compaction. If the soil is too dry or too wet, it may not compact effectively. 3. Accessibility: Compaction equipment requires sufficient access to the soil surface. In some cases, limited access or confined spaces may pose challenges for compaction. 4. Environmental Considerations: Compaction can have environmental impacts, such as noise and vibration. Proper measures should be taken to minimize these impacts and ensure compliance with environmental regulations. In summary, compaction is a widely used soil improvement technique that increases soil density and improves its load-bearing capacity. It is effective in granular soils and offers benefits such as increased stability, reduced settlement, and improved drainage. However, it is important to consider soil type, moisture content, and environmental factors when applying compaction techniques.

IV. GROUND IMPROVEMENT DESIGN AND DATA ANALYSIS

The design of a ground improvement method for a particular problem is dependent upon the function of the improvement and the method(s) selected to carry out the function. The function will establish whether settlement, stability, density, geometry, and/or other parameters are the critical design parameters. Some technologies have well-established design procedures, some have a variety of published design procedures, some have proprietary design procedures, and for others design procedures are still being developed. In the second part of the paper, the design of particular ground improvement technologies is further addressed. For a particular technology, specific input and output items appropriate to the technology can be determined. These can be categorized in terms of Performance Criteria/Indicators,

4.1 Items For Analysis and Design

Subsurface Conditions, Loading Conditions, Material Characteristics, Geometry, and Construction Techniques. Examples of specific items in each category are listed in Table 1.

Table 1: Input and Output Items for Analysis and Design.

Categories of Input and output for analysis and design procedures	Some Example Items
Performance Criteria/Indicators	Minimum factor of safety values, load and resistance factor values, allowable settlements, allowable lateral deformations, reliability, drainage, time
Subsurface Conditions	Stratigraphy, ground water level, particle size distribution, plasticity, unit weight, relative density, water content, strength, compressibility, chemistry, organic content, variability
Loading Conditions	Traffic load, embankment pressure, structure loads, earthquake acceleration and duration, water pressures
Material Characteristics	Unit weight, water content, particle size distribution, internal friction angle, shear strength, inclusion dimensions, compressive strength, tensile strength, compressibility, modulus, stiffness, interface friction angle, permeability, equivalent opening size
Construction Techniques geometry	Method of installation and/or densification, e.g., vibrocompaction Diameter, spacing, depth, thickness, length, area, slope

4.2 Frame Work for the System

The development of the information system required planning on several levels. The framework for development required defining (1) overall system characteristics, (2) the user, (3) the knowledge, (4) the operating system, and (5) the approach to the system. The details of this development are summarized in Schaefer et al. (2011) and contained in the web-based system development report (Douglas et al. 2011). The overall system developed is termed an information and guidance system because this system is meant to guide the user in selecting appropriate geoconstruction technologies for the project at hand. The knowledge base is contained in tables and the inference engine is shown graphically through flow charts. The flow charts and tables were programmed into a web-based system for ease of use. The system is intended to be used by both technical and nontechnical personnel, although to different levels. The knowledge for identifying potentially applicable technologies to a set of geotechnical and loading conditions comes from the R02 team's work efforts, including the development of Comprehensive Technology Summaries (CTS), Design Procedure Assessments, and QC/QA Assessments for each of the technologies listed in Table 3. CTS development entailed development of an in-depth technology overview that included advantages, potential disadvantages, applicable soil types, depth/height limits, groundwater conditions, material properties, project specific constraints, equipment needs, and environmental considerations. Additionally, for each technology case histories, design procedures, QC/QA procedures and specifications were collected. The assessment efforts then qualitatively and quantitatively assessed the present design and QC/QA methods. The development of these CTS and assessment documents provided significant technical information related to each technology and the application of that technology with regard to geotechnical and loading conditions. Available FHWA manuals and guidance documents were identified in the CTS and assessment work efforts, and the information in those documents has been incorporated into the system.

The web-based system is programmed utilizing Adobe ColdFusion® software in conjunction with a Microsoft Access® database. This combination of software allowed the tables developed as part of the selection system to be ported to a database which could be dynamically queried via the web. The desired characteristics of the operating system were (Chouicha and Siller 1994): 1. Built-in mechanisms such as searching, control, and backtracking. 2. An internal database to hold the knowledge base. 3. Tools with windows, menus, frames, and drop boxes. 4. The ability to house the system on a server and allow the program to be run by multiple users via the World Wide Web. Like most geotechnical analytical solutions, the results of the analysis must be measured against the opinion of an experienced geotechnical engineer practicing in the local area of the project. The system was developed with a ―keep the system simple‖ philosophy, using two approaches. The first approach is that the system conservatively removes potentially inapplicable technologies during the process. The second approach, which will be a common theme throughout the selection procedure, is that the final selection of the appropriate technology will be the responsibility of the user. The system will lead the user to multiple technologies and provide all the means for technology explanation, design, and cost estimating. This system does not replace the project Geotechnical Engineer. The Geotechnical Engineer's ―engineering judgment‖ is the final selection process, which takes into consideration the following: construction cost, maintenance cost, design and quality control issues, performance and safety (pavement smoothness; hazards caused by maintenance operations; potential failures), inconvenience (a tangible factor, especially for heavily traveled roadways or long detours); environmental aspects, and aesthetic aspects (appearance of completed work with respect to its surroundings) (Johnson 1975 and Holtz 1989).

4.2.1 The Web Based Information System

The homepage for the web-based information system is shown in Figure 3. The title of the web page is shown in the upper left. Along the left hand side of the page are buttons to the home page, project background, geotechnical design process, the catalog of technologies, the technology selection system, glossary, abbreviations, frequently asked questions, submit a comment, links, and an about this website, that are always available to the user. The part outlined in the bold box will change as other pages are selected. In subsequent screen shots only the material within the bold box will be shown. As shown within the bold box in Figure 3, there are four main parts to the system: Geotechnical Design Process, Catalog of Technologies, Technology Selection, and Glossary.

The Geotechnical Design Process page is included to alert the user to the basic background information needed to conduct geotechnical design such as project loading conditions and constraints, soil site conditions, and evaluation of alternatives. The page contains links to FHWA documents on review of geotechnical reports, evaluation of soil and rock properties, subsurface investigation and instrumentation. Additionally, links to several state departments of transportation geotechnical design manuals are provided. During the development of the system it was realized that a large number of technical terms and abbreviations were used and that in some cases different technologies used terms in different ways. Thus, an Abbreviations and Glossary is included with the system so that system users are able to find definitions of terms used in the various documents. The technologies can be accessed in several ways. The Catalog of Technologies page provides a listing of the 46 ground improvement and geoconstruction technologies in the system that addresses the three element areas. Two traditional technologies—excavation and replacement, and traditional compaction—are included as they are often-used ―base‖ technologies, to which ground improvement and geoconstruction methods are compared. The list of technologies in the catalog is shown in Table 3. The name of each technology is a hot-link button on the website that takes the user to a web page for that technology, which will be discussed in more detail subsequently. The Technology Selection page provides two further means of accessing technologies: through a classification system and through an interactive selection system. In the classification system, the technologies are grouped in the categories shown in Table 4. Thus an experienced engineer can access solutions according to particular categories of problems. The interactive selection system provides the user the opportunity to assess technologies based on several applications. An information and guidance procedure has been developed for each ―application‖ area shown in Figure 2 and as defined in the R02 project work scope. In developing the system, the importance of properly identifying the potential applications was recognized. The Interactive Selection System is entered through the screenshot shown in Figure 4, wherein the first decision in the process is to select the potential application. In the selection system the list of applicable technologies is shown on the right-hand side of the page (see Figure 4), all of which are hot-linked to the respective technology pages. At the start of the selection all technologies will be shown on the right hand side, and as decisions are made, non-applicable technologies will be grayed out.

After clicking on one of the four application areas shown in Figure 4, the user will encounter a page requesting additional information to narrow the list of candidate technologies for the particular application. The number of possible queries for additional information is quite large and is dependent upon the application selected. The requested input and order of queries to the user were selected after considering the effect of the requested information on the determination of the potential technologies list. The potential queries (in no particular order) generated during development of the system are:

- What type of project is being constructed?
- What is the size of the project being constructed?
- Are there any project constraints to be considered in selecting a possible technology?
- What is the soil type that needs to be improved?
- To what depth do to the unstable soils extend?
- At what depth do the unstable soils start?
- Is there a ―crust or ―rubble fil at the ground surface?
- What is the depth to the water table?
- How does the water table fluctuate?
- What constraints exist? (i.e., utilities, material sources, existing adjacent structures, etc.)
- What is the desired outcome of the improvement? (i.e., decrease settlement, decrease construction time, increase bearing capacity, etc.)
- What technologies does the user already have experience with?

The questions used to narrow the technologies are dependent upon the application selected. Generally, three or four questions are used to develop a short-list; which can then be further defined with answering additional questions. To illustrate the use of the system, solutions for Construction Over Unstable Soils are presented herein in more detail

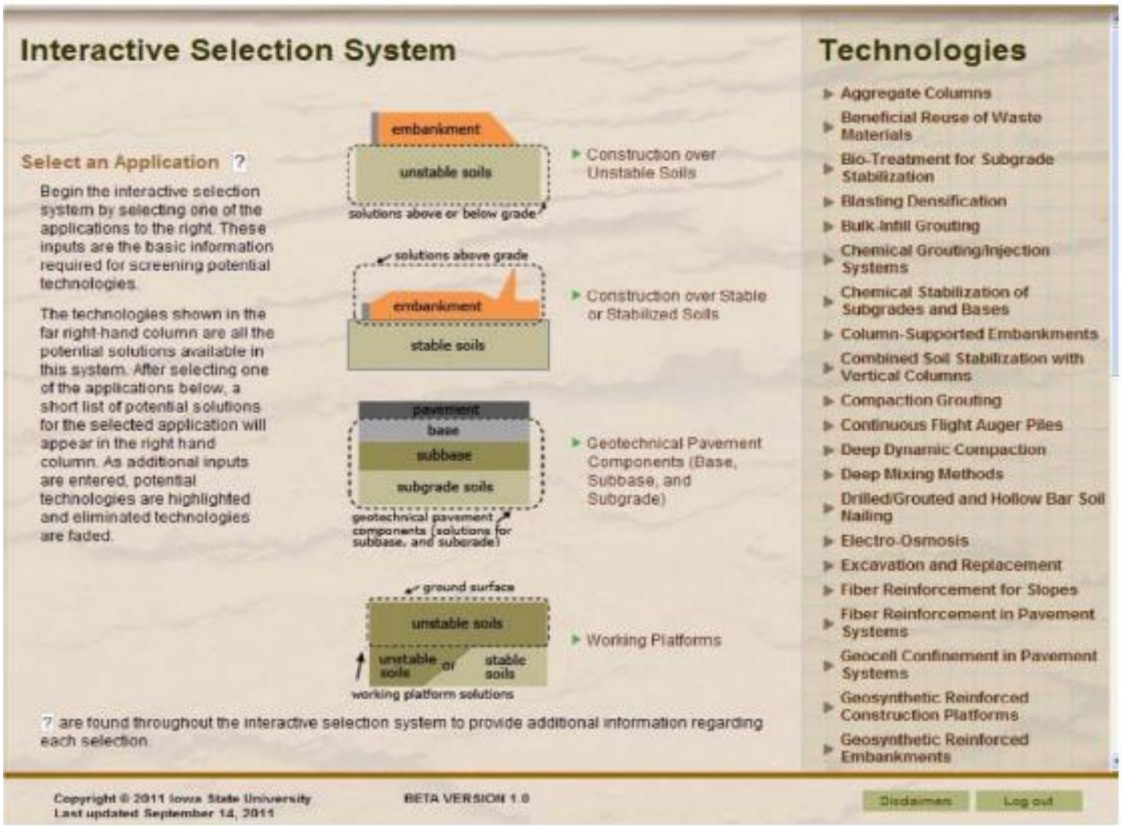

Figure 1: Screenshot for the interactive selection system page.

4.2.2 Construction of Over Unstable Soils

Selecting the Construction Over Unstable Soils application leads to a decision process for foundation soil improvement or reduced loading. This application is focused on ground improvement to support embankments of any height or transportation structures such as walls or box culverts over unstable soils. This system is focused on identifying geoconstruction solutions to these problems; however, users must also consider that structural solutions to such problems may be preferred alternatives. From the list of potential queries, the two questions ―What is the soil condition that needs to be improvedand ―To what depth do to the unstable soils extend?were selected as the initial questions to reduce the number of potential technologies for this application. These two queries were found to be most useful in providing a preliminary short list of applicable technologies. A screenshot of the first page for theConstruction Over Unstable Soils application is shown in Figure 5. The list of technologies shown on the right of this page has narrowed from the complete list shown on the previous Interactive Selection System page (Figure 4). The unstable soil conditions considered in the system are:

- Unsaturated and saturated, fine-grained soils
- Unsaturated, loose, granular soils
- Saturated, loose, granular soils
- Voids – sinkholes, abandoned mines, etc.
- Problem soils and sites – expansive, collapsing, dispersive, organic, existing fill, and landfills

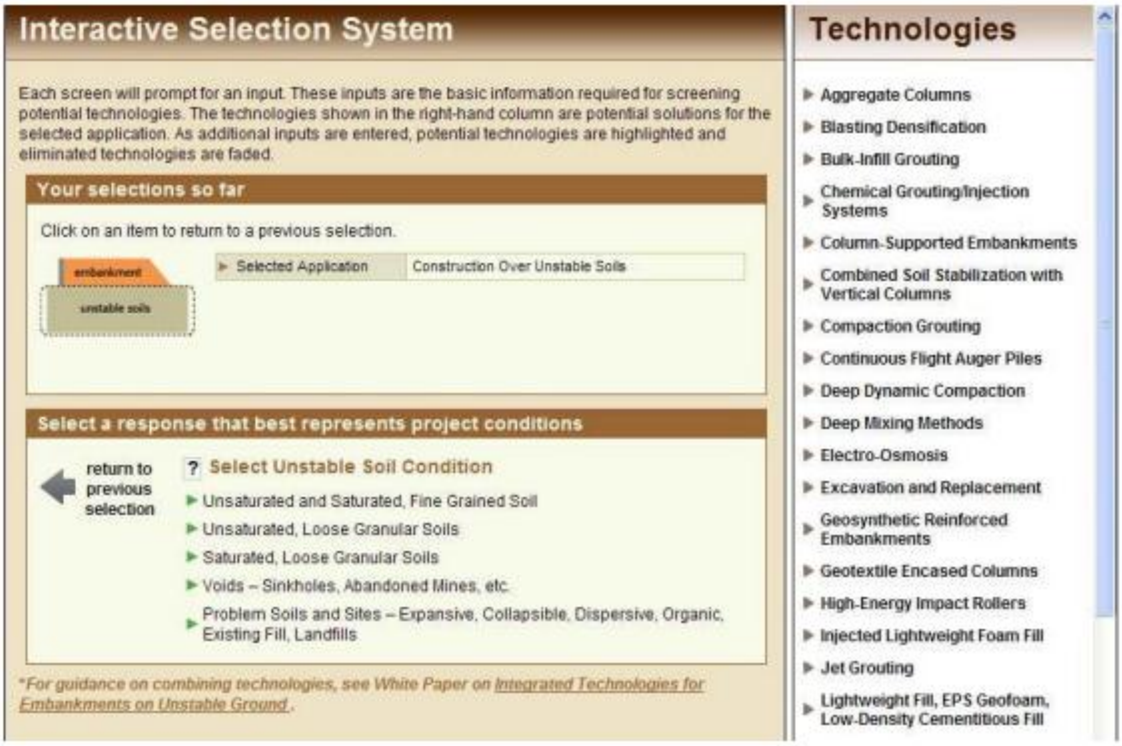

Figure 5: Screenshot for the first construction over unstable soils page

The screenshot after answering the soil type is shown in Figure 6. On the right-hand side of the screenshot it can be seen that several technologies are grayed out, indicating that they generally are not appropriate for the soil type selected (unsaturated and saturated, fine-grained soil). The next question to be answered is the depth range for improvement. The depth ranges selected for inclusion in the system are • 0 – 5 feet (ft) (0 – 1.5 meters (m)) • 5 – 10 ft (1.5 – 3 m) • 10 – 20 ft (3 – 6 m) • 20 – 50 ft (6 – 15 m) • Greater than 50 ft (15 m) After answering the unstable soil depth question additional technologies may be grayed out on the right-hand side. At this point the user can stop and assess the candidate list of technology solutions or enter additional project-specific information as shown in Figure 7. Since many of these technologies are used in combination with other ground improvement methods, guidance on combining technologies is contained in the linked Integrated Technologies for Embankments on Unstable Ground white paper (see Figure 5 or 6)

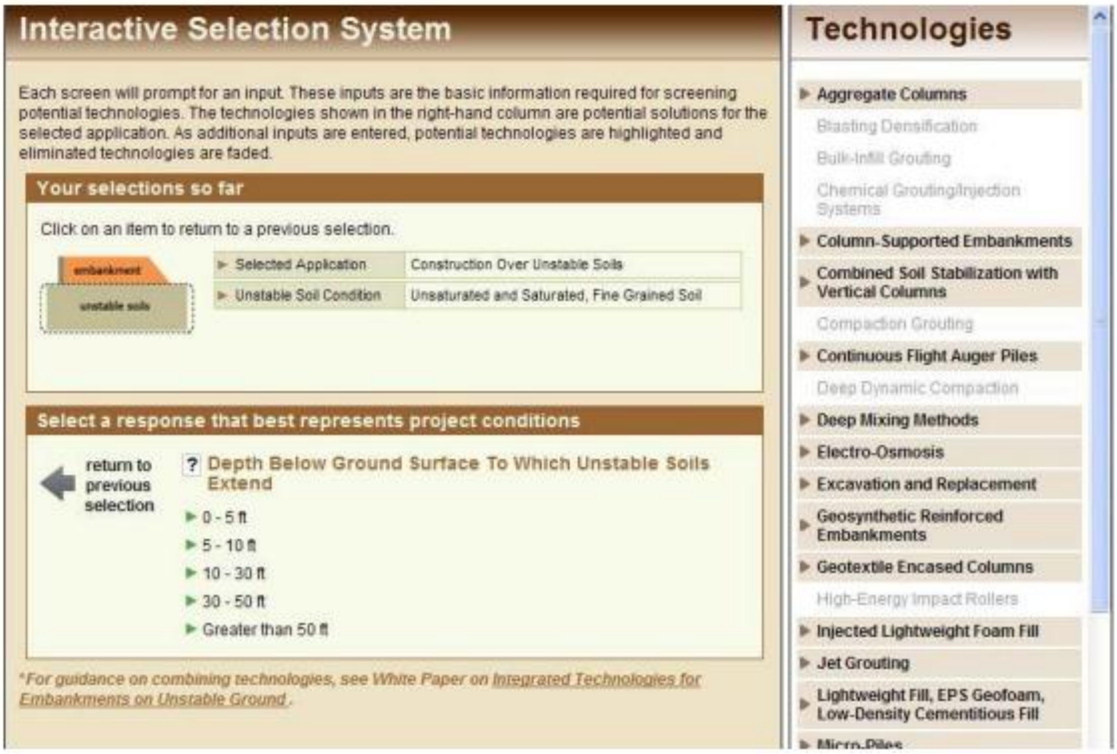

Figure 6: Screenshot for the second construction over unstable soils page

A final technology selection screenshot in Figure 8 shows the resulting candidate technologies on the right-hand side of the page, when the questions have been answered as shown. It can be seen that the list of technologies applicable to the selected conditions has been narrowed. At this point one can click on any of the highlighted technologies to obtain technology specific information. For example, clicking on Prefabricated Vertical Drains and Fill Preloading will bring up the screenshot shown in Figure 9. The documents listed can be accessed through hot-links on the website. Ratings are provided for each technology on the degree of technology establishment and a technology's potential application to SHRP 2 objectives. As shown in Figure 9 a number of information documents about a given technology are accessible from the system. The list of documents available is shown in Table 5, which also indicates the format for the document. These documents are hot-linked and can be opened from this page or the box shown can be clicked and the selected documents can be printed or saved to a file for further use.

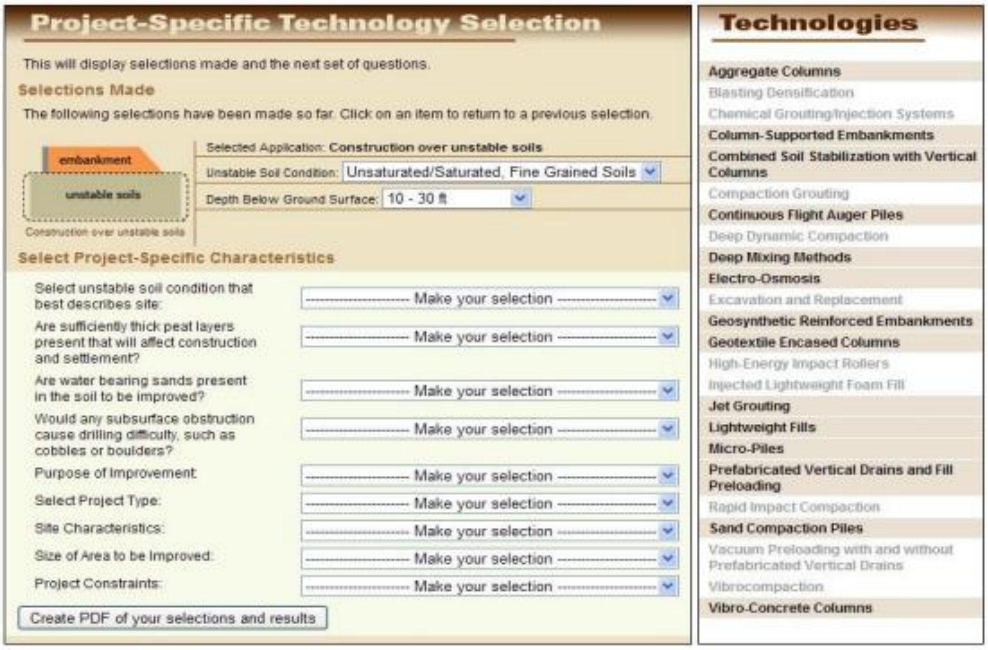

Figure 7: Screenshot for the project-specific technology selection for construction over unstable soils.

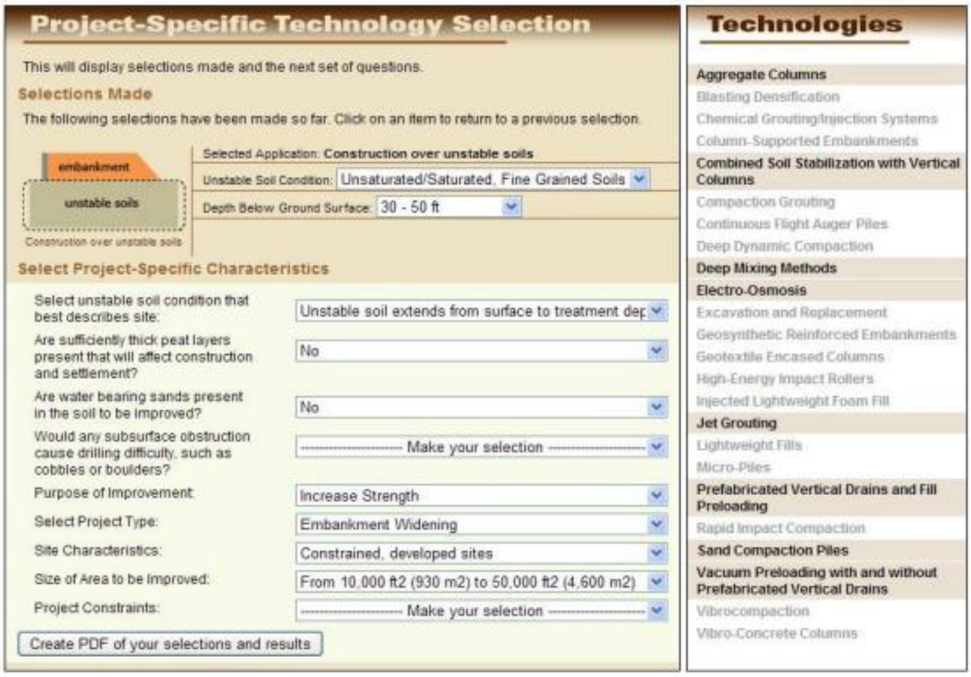

Figure 8: Screenshot for the project-specif technology for construction over unstable soils.

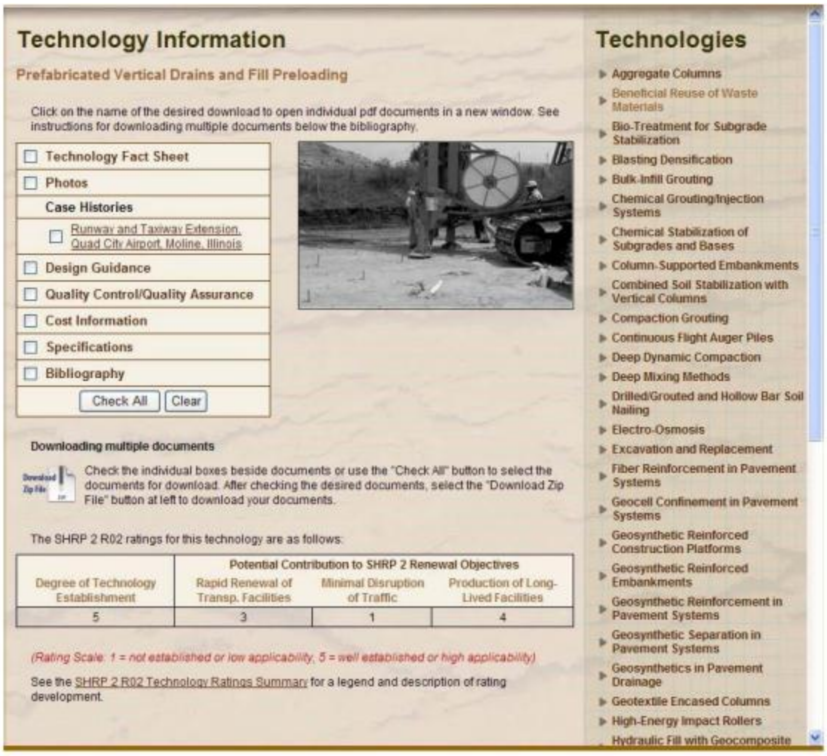

Figure 9: Screenshor for the prefabircated vertical drains and fill preloading technology showing list of available documents

4.3 Comparison of Soil Improvement Technique (Using Silicate and Sand)

Table 2: COMPACTION TEST RESULTS BSL		
COMPOSITION	MAXIMUM DRY DENSITY (g/cm3)	OPTIMUM MOISTURE CONTENT (%)
0% CEMENT 0% SILICATE SAND	1.715	16.0
1% CEMENT 6% SILICATE SAND	1.732	17.8
2% CEMENT 8% SILICATE SAND	1.753	17.3
3% CEMENT 10% SILICATE SAND	1.766	17.0
4% CEMENT 12% SILICATE SAND	1.740	18.3
5% CEMENT 14% SILICATE SAND	1.733	18.5

Table 3: COMPACTION TEST RESULTS BSH		
COMPOSITION	MAXIMUM DRY DENSITY (g/cm3)	OPTIMUM MOISTURE CONTENT (%)
0% CEMENT 0% SILICATE SAND	1.874	15.3
1% CEMENT 6% SILICATE SAND	1.870	15.3
2% CEMENT 8% SILICATE SAND	1.869	16.5
3% CEMENT 10% SILICATE SAND	1.874	16.0
4% CEMENT 12% SILICATE SAND	1.896	15.0
5% CEMENT 14% SILICATE SAND	1.891	15.0

Table 4: UNCONFINED COMPRESSION STRENGTH BSL				
COMPOSITION	AGE (DAYS)	PROVING RING READINGS	AXIAL LOAD (KN)	UCS (KN/m2)
0% CEMENT 0% SILICATE SAND	1	1.20	0.166	146.38
	7	1.20	0.166	146.38
	4	1.20	0.166	146.38
	28	1.20	0.166	146.38
1% CEMENT 6% SILICATE SAND	1	1.33	0.1840	162.25
	7	2.70	0.3726	328.57
	4	2.60	0.3588	316.40
	28	2.83	0.391	344.79

2% CEMENT 8% SILICATE SAND	1	2.67	0.368	324.0
	7	3.10	0.4278	377.25
	4	3.46	0.4780	421.86
	28	3.70	0.5110	450.61
3% CEMENT 10% SILICATE SAND	1	5.67	0.782	689.59
	7	6.00	0.828	730.16
	4	7.00	0.966	851.85
	28	7.83	1.08	952.38
4% CEMENT 12% SILICATE SAND	1	7.67	1.058	932.98
	7	8.00	1.104	973.54
	4	10.80	1.490	1314
	28	1.20	0.166	146.38
5% CEMENT 14% SILICATE SAND	1	11.76	1.623	1431.22
	7	9.10	1.258	1109.35
	4	12.30	1.700	1500.88
	28	12.53	1.720	1524.81

Table 5: UNCONFINED COMPRESSION STRENGTH BSH

COMPOSITION	AGE (DAYS)	PROVING RING READINGS	AXIAL LOAD (KN)	UCS (KN/m2)
0% CEMENT 0% SILICATE SAND	1	2.97	0.410	361.55
	7	2.97	0.410	361.55
	4	2.97	0.410	361.55
	28	2.97	0.410	361.55
1% CEMENT 6% SILICATE SAND	1	3.83	0.529	466.49
	7	6.40	0.882	788.86
	4	4.87	0.672	595.59
	28	3.77	0.520	458.55
2% CEMENT 8% SILICATE SAND	1	4.67	0.644	567.90
	7	7.90	1.090	961.38
	4	6.47	0.892	786.59
	28	5.73	0.791	697.53
3% CEMENT 10% SILICATE SAND	1	8.97	1.237	1091.00
	7	9.00	1.242	1095.00
	4	10.40	1.435	1265.43
	28	10.27	1.417	1249.55
4% CEMENT 12% SILICATE SAND	1	10.17	1.403	1237.20
	7	10.70	1.786	1302.12
	4	11.77	1.624	1432.09
	28	13.33	1.840	1622.57
5% CEMENT 14% SILICATE SAND	1	12.00	1.656	1460.32
	7	15.83	2.183	1926.80
	4	15.00	2.070	1825.39
	28	17.00	2.346	2068.78

COMPOSITION	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)
0% CEMENT	56.90	39.30	17.6

0% SILICATE SAND			
1% CEMENT 6% SILICATE SAND	52.60	30.00	22.60
2% CEMENT 8% SILICATE SAND	52.50	31.80	20.70
3% CEMENT 10% SILICATE SAND	52.70	30.30	22.40
4% CEMENT 12% SILICATE SAND	51.80	2830	23.50
5% CEMENT 14% SILICATE SAND	50.50	31.30	19.20

V. LABORATORY TESTING

Laboratory testing was conducted to evaluate the geotechnical properties of the soils. The laboratory testing procedures followed were in general conformance with those recommended in British Standard BS 1377 (1990) and the soils were classified according to the American Association for State Highway and Transportation Officials System for Classifying Soils (ASSHTO). The parent material were stabilized with 1%, 2%, 3%, 4% and 5% cement as well as 6%, 8%, 10% 12% and 14% silicate sand. The laboratory tests performed included the following:-

Grain Size Distribution

Particulate materials are made up of a range and distribution of particle sizes. In most geotechnical applications, this distribution spans over varying sizes of particles. Grain size denotes the percentage of particles within a specified particle size range across all sizes represented for the sample. This tests were carried out on representative soil samples taken. Sample contained more than 70% material passing through No.200 sieve. The results of these tests are shown in Appendix (A)

Atterberg Limits

These tests were carried out on representative soil samples taken and mixed with different percentages of cement and silicate sand. It’s clear that the liquid limit decreases with increasing the percentage of cement and sand samples. The plastic limit values shows a decrease with increase in the percentage of both materials (i.e. cement and silicate sand). The tests show a moderate plasticity index (17.6% - 23.5%) values. This indicates that the fines (i.e. silt and clays) are moderately plastic. The results of these tests are shown in Appendix (…).

Unconfined Compression Strength

The shear strength established from Unconfined compression test results were to check the possibility of bearing capacity failures. Most of the values obtained were high. Thus, indicating that when soils stabilised with silicate sand can withstand high bearing loads. The results of these tests are shown in Appendix (…).

Specific Gravity

Specific gravity of the soil was found using the density bottle Method. Specific Gravity came out to be 2.71 for laterite and 2.64 for sand. The results of these tests are shown in Appendix (…).

Compaction Characteristics: The compaction test results shows variation in the optimum moisture content and maximum dry density with the peak value at 3% Cement 10% Silicate Sand for BSL and 4%Cement 12% Silicate Sand for BSH. The decrease in the maximum dry density for all the three samples could be attributed to the mixture of the soil and silicate sand which has a lower specific gravity similar to the soil. It could also be attributed to the filling of the soil voids by this sand. However, the increase in the moisture content as the percentage of cement increases implies that more moisture or water is needed in order to compact the soil – cement – silicate sand mixture. The results of these tests are shown in Appendix (…).

California Bearing Ratio: California bearing ratio is one of the common tests used in the design of subgrade, sub-base or pavement. It is also used to determine the strength characteristics of stabilized soil. From the tests carried out, there was sharp rise or increase in the CBR value. However, the highest CBR value obtained is at 4% Cement 12% Silicate Sand.

VI. CONCLUSION

The results of the test carried out on samples shows that: ¬ The sample has poor geotechnical properties. ¬ The geotechnical properties of these sample could be improved upon by stabilizing it with cement and silicate sand. ¬ Silicate sand could be used as a stabilizing material for Lateritic soil. ¬ Silicate sand is not an excellent stabilizer but could be used to improve the geotechnical properties of lateritic soils. ¬ At 4% Cement 12% Silicate Sand stabilization, laterite could be used as sub-base materials in road construction. ¬ The optimum percentage of the cement – silicate sand mixture by weight for the improvement of strength characteristics is 4% for cement and 12% silicate sand.

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