A Technical Note on Modern Soil Improvement Techniques

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Abstract

Soil Improvement is essential, when the soil at construction site is either highly compressible or weak or problematic soils. When there is scarcity of suitable construction site and it is essential to construct any infrastructure then ground improvement is the best choice. Soil improvement is the best method to control seepage and drainage problems in Water retaining structures, Earthen Dam, River/Canal Embankment and River and Canal Seepage. Soil Improvement is best choice of construction of traffic roads at hilly area where it is required to provide sufficient bonding properties to soil.

Keywords: Soil Improvement, Geosynthetics, Stone Columns, Ordinary stone columns (OSCs), Geosynthetic-encased stone columns (ESC)

1. Introduction

When the soil at construction site is either highly compressible or weak and is unable to support an infrastructure building or project. Then at this stage either we change the construction site or remove or replace unsuitable soils at construction site or attempt to modify the existing soil at construction site. Then in such case economy decides the best suitable option. If suitable construction site and suitable soils having sufficient bearing capacity is not available at nearby locations then in such case soil improvement is the best choice for a Civil Engineer. The present study mainly focuses on Geosynthetics and soil improvement using reinforcement methods. Stone columns are basically based applications of Geosynthetics and soil reinforcement. In stone columns, we generally use two types' stone columns, "Ordinary stone columns (OSCs), Geosynthetic-encased stone columns (ESC)" [16].

2. Need for Soil Improvement

Soil improvement is required when mechanical properties of soil are not adequate. It is required in soft soils, collapsible soils, organic and peaty soils. It is also required in soils posing swelling and shrinkage properties and in soil deposits like sand and gravel deposits and karst deposits with sinkhole formations. When foundations are on dumps and sanitary landfills then it is essential to improve soil properties. Soil improvement is also required when construction site is old mine pits [16].

3. Objectives of Soil Improvement

Various objectives of soil improvement are listed below

- To increase shear strength of soil
- Reduction compressibility
- Reduce distortion under stress
- Reduce susceptibility to liquefaction
- Reduce normal variability of borrowed materials and foundation soils

- Enable constructive use of waste materials
- Enable water containment and hazardous waste management
- To reduce seepage and drainage problems

4. Soil Improvement Mechanisms

Soil improvement can be done through various mechanisms [16]

- Compaction
- Dewatering
- Reinforcement
- Admixtures and Grouting

4.1. Compaction

In this technique, the state of soil is improved due to high densification. This is a long term improvement technique and change in soil state after adopting it. This technique is adopted for silty, sandy and gravelly soils. The addition of carbide lime to the soil-fly ash mixture caused short-term changes due to initial reactions, inducing increases in the friction angle, in the cohesive intercept, and in the average modulus. Such improvement might be of fundamental importance to allow site workability and speeding construction purposes [14].

4.2. Dewatering

Generally, dewatering means modification of ground by redirecting seepages, lowering the ground water table or in general sense reduction of water content in foundation soil to provide dry workable area. Two types of dewatering techniques available, one is by gravity without application of external forces and another is forced consolidation. This technique is mostly adopted for clayey soils [13].

4.3. Reinforcement

Soil reinforcement is defined as a technique to improve the engineering characteristics of soil. This method improves the soil response by interaction between soil and inclusive reinforcing materials. The improving period depends on the life of inclusive reinforcing materials. State of soil is not changed in this method and it is widely used methods for many types of soils. Soil reinforcement can consist of stone columns, root piles or micro-piles, soil nailing and reinforced earth. Mainly, reinforced earth is a composite material consisting of alternating layers of compacted backfill and man-made reinforcing material. So, the primary purpose of reinforcing soil mass is to improve its stability, to increase its bearing capacity, and to reduce settlements and lateral deformation [15].

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Table-1 (Applicability of soil Improvement Mechanisms in different Soils)

S.N.	Type of Soil	Compaction	Dewatering	Reinforcement	Admixtures
1	Organic soil	Not applicable	Applicable	Applicable	Applicable
2	Volcanic clay soil	Not applicable	Applicable	Applicable	Applicable
3	Highly plastic clay	Not applicable	Applicable	Applicable	Applicable
4	Lowly plastic clay	Not applicable	Applicable	Applicable	Applicable
5	Silty soil	Applicable	Applicable	Applicable	Applicable
6	Sandy soil	Applicable	Not applicable	Applicable	Applicable
7	Gravel soil	Applicable	Not applicable	Applicable	Not applicable

5. Classification of Soil Improvement

Soil improvement is classified in following ways [21]

- Mechanical Modification
- Hydraulic Modification
- Physical and Chemical Modification
- Modification by inclusion, confinement and reinforcement
- Combination of the above

5.1. Mechanical Modification

Mechanical Modification includes physical manipulation of earth materials, which most commonly refers to controlled densification either by placement and compaction of soils as designed "engineered fills," or "in situ" methods of improvement for deeper applications. Many engineering properties and behaviours can be improved by controlled densification of soils by compaction methods. Other in situ methods of improvement may involve adding material to the ground as is the case for strengthening and reinforcing the ground with non-structural members [21].

5.2. Hydraulic Modification

Where flow, seepage, and drainage characteristics in the ground are altered. This includes lowering of the water table by drainage or dewatering wells, increasing or decreasing permeability of soils, forcing consolidation and pre consolidation to minimize future settlements, reducing compressibility and increasing strength, filtering ground water flow, controlling seepage gradients, and creating hydraulic barriers. Control or alteration of hydraulic characteristics may be attained through a variety of techniques, which may well incorporate improvement methods associated with other ground improvement categories [11].

5.3. Physical and Chemical Modification

"Stabilization" of soils caused by a variety of physiochemical changes in the structure and/or chemical makeup of the soil materials or ground. Soil properties and/or behaviour are modified with the addition of materials that alter basic soil properties through physical mixing processes or injection of materials (grouting), or by thermal treatments involving temperature extremes. The changes tend to be permanent (with the exception of ground freezing), resulting in a material that can have significantly improved characteristics. Recent work with biostabilization, which would include adding/introducing microbial methods, may also be placed in this category [5].

5.4. Modification by inclusion, confinement and reinforcement

This includes use of structural members or other manufactured materials integrated with the ground. These may consist of reinforcement with tensile elements; soil anchors and "nails"; reinforcing geosynthetics; confinement of (usually granular) materials with cribs, gabions, and "webs"; and use of lightweight materials such as polystyrene foam or other lightweight fills. Generally, this type of ground improvement is purely physical through the use of structural components. Reinforcing soil by vegetating the ground surface could also fall into this category [16].

5.5. Combination of the above

Often-times an improvement method may have attributes or benefits that can arguably fall into more than one category by achieving a number of different engineering goals. Because of this, there will necessarily be some overlap between categories of techniques and applications [2].

6. Soil Improvement using Geosynthetics

Geosynthetic is a product made of polymeric/natural material used with soil and rock, or any other related geotechnical engineering materials for the construction of Civil Engineering structure, or system. Goesynthetics has good flexibility and excellent stress-strain behavior. It has excellent filtration characteristics and high water permeability. It does not form by-products and highly resistant to chemical and biological attack. It also provides excellent mechanical protection to soil sustained constructions. It can be used when soil bearing capacity is low and having excessive soil settlement. It can be used soil is soft and has swell characteristics. It may also be used for faster construction and space is limited for construction [19].

6.1. Major functions of Geosynthetics

It has six major functions listed below [21]:

- Separation
- Filtration
- Drainage
- Reinforcement
- Protection
- Fluid Barrier

Table-2 (Important functions of various Geosynthetics, Main function ☼, Secondary function ♣ [21])

Type	Separation	Filtration	Drainage	Rreinforcement	Protection	Fluid Barrier
Non-woven geotextile	☼	☼	♣		☼	☼
Woven geotextile	☼	♣		☼		
Geogrids				☼		
Geomembranes						☼
Geocells	☼			☼		
Geosynthetic clay liner					♣	☼
Geocomposites	♣	♣	☼	♣	☼	☼
Geonet			☼			

Geopipe			☼			

6.2. Categories of Geosynthetics

The Geosynthetics are divided into following main categories such as Geotextiles, Geojute, Geogrids, Geonets, Geospacers, Geomembranes, Geoblanket, Geomats, Geofoam, Geocomposites, Geopipes, Geostrips, Geo coir and Geosynthetic Clay Liners [6].

6.2.1. Geotextiles and GeoJute: Geotextile are permeable fabrics, when used in combination with soil have the ability to reinforce the soil, separate, filter, protect or drain. Geotextiles are typically made from polypropylene or polyester and in three basic forms, woven (resembling mail bag sacking), needle punched (resembling felt), or heat bonded (resembling ironed felt). Geotextiles constitute a group of fabrics made from synthetic polymers, such as polypropylene, polyester, polyethylene, polyamide and PVC or natural fibres, including cotton, jute, coir and bamboo. Geotextiles are commonly used in improving soil properties of soft or problematic soils over which roads, embankments, pipe lines, earth retaining structures and other construction works. Geotextiles are mainly of two types woven and non-woven. Woven geotextiles are manufactured by weaving together narrow strips of film. They perform the functions of separation and reinforcement. Woven geotextiles are referred to by tensile strength, which is the resistance a material has to breaking under tension. Woven geotextiles have a very uniform appearance. Non-woven geotextiles are made using synthetics filaments or fibers. The primary functions of a non-woven geotextile are separation, filtration, and drainage. The manufacturing process of these fabrics involves needle punching as opposed to weaving [20].
Geojute is jute matting, which has been successfully developed by needle-punched non-woven and woven techniques and been used soil reinforcement and erosion control etc. [6].

Figure-1: (a- Woven Geotextiles +b- Non Woven Geotestiles+ c- Geojute)

6.2.2. Geogrids, Geonets and Geospacers: Geogrids are polymeric products formed by joining intersecting ribs. They have large open spaces also known as "apertures". The directions of the ribs are referred to as machine direction (md), orientated in the direction of the manufacturing process or cross ma chine direction (cmd) perpendicular to the machine direction ribs. Geogrids are mainly made from poly - meric materials, typically polypropylene (PP), high density polyethylene (HDPE) and polyester (PET). Geogrids are manufactured as either biaxial or uniaxial. Biaxial geogrids are those that exhibit the same strength in both the machine and cross machine directions while uniaxial geogrids exhibit the primary strength in the machine direction with minimal strength, enough to maintain the aperture structure, in the cross machine direction [18].

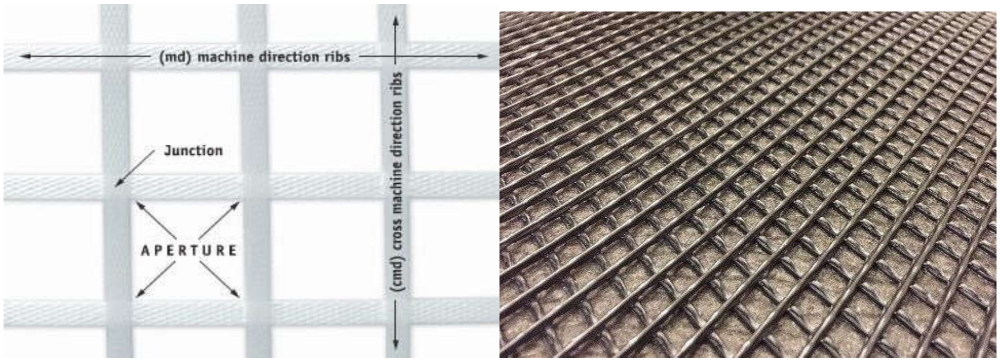

Figure-2: (a- Geogrids +b- Geonets)

Geonets are also planer products and consists of ribs in two directions at different planes. The apertures are of diamond shape. Thickness of Geonets is larger than Geogrids. Geonets are also referred to as Geospacers [23].

6.2.3. Geomembranes, Geoblanket and Geomats: Geomembranes are thin, two dimensional sheets of material with a very low permeability. Geomembranes are flexible and manufactures from synthetic and bituminous materials. They may be strengthened with a fabric or film. Materials which fulfil the same function but are composed of other substances are not to be Geomembranes (e.g. sealant layers of asphaltic concrete, bentonite). The basic difference between Geomembranes and Geotextile is that, Geomembranes are having with very low permeability while Geotextiles has same as sand. Geomembranes may be consider to be impermeable to gas and liquids, this makes them ideal for water proofing and gas proofing barriers between adjacent bodies of soil and fluid [3].
Geoblankets, a biodegradable material make of material such as coconut fibres is an effective sediment control measure in minimizing the erosive effect of rainfall when used to cover bare or newly planted soil. Their use stabilizes the soil to protect new plantings and reduces the potential of sediment resulted from storm water runoff and heavy rainfall [21].
Geomats are three dimensional, permeable structures made of polymeric monofilament and/or other natural or synthetic materials, which have sufficient thickness to retain soil or other fills and that may allow the growth of vegetation through the openings. The thinner sheets are usually named foils. For hydraulic engineering applications a minimum thickness of 2 mm is recommended. It is good practice to cover Geomat with a 30-50 mm thick layer of topsoil. Geomats are used for reinforcement of slopes and coast line. Geomats are also used for protection in hydro erosion and landslides in road construction [10].

Figure-3: (a- Geomembranes +b- Geoblanket + c- Geomats)

6.2.4. Geofoam, Geocomposites and Geostrips: Expanded polystyrene (EPS), which is classified as a "Geofoam" material in Geosynthetics terminology has a wide application in the field of Civil Engineering. It can be used for reducing earthquake induced dynamic loads between rigid retaining walls and retained soil backfill. Installing a panel of geofoam immediately behind the reinforced zone could reduce the lateral earth force behind the reinforced zone and overturning moment [4].

A Geocomposite consist of Geotextile and Geogrid; or Geogrid and Geomembrane; or Geotextile, Geogrid and Geomembrane; or any one of these three materials with other materials (e.g. various soils, deformed plastic sheets, steel cables or steel anchors). In other words we can say that Geocomposite is a composite of two or more Geosynthetic materials [19].

Geostrips are Geocomposites having tensile strength in the range 20-200 kN and extension at maximum load in the range 3-15%. Geostrips are in the form of cut fabric or long strips of Geotextiles. Geostrips are generally produced from polypropylene and high density polyethylene [9].

Figure-4: (a- Geofoam +b- Geocomposite)

6.2.5. Geopipes and Geocoir: Another significant product, which has been adopted as a Geosynthetic is plastic pipe. The specific polymer resins used in the manufacturing of plastic pipes are: polyvinyl chloride (PVC), high density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), acrylonitrile butadiene styrene (ABS), and cellulose acetate butyrate (CAB). There is wide variety of civil engineering applications for these products, including railway and highway edge drains, interceptor drains, primary and secondary leachate removal systems. Geopipes provide a well-defined drainage path, making connections with pit holes and manholes relatively simple [20].

Coir Geotextiles protect land surface and promote quick vegetation. Geotextiles are a wonderful treasure of natural echo friendly, erosion control blankets in woven and non-woven preparations. Totally biodegradable, geotextiles help soil stabilization and renew vegetation in varying slopes. Commonly two types of coir are used, brown fibre obtained from mature coconuts and finer white fibre extracted from immature coconuts after soaking up to 10 months [21].

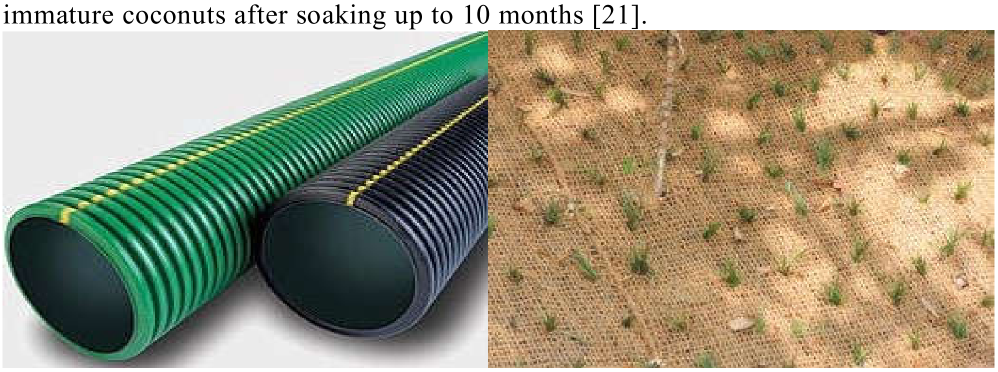

Figure-5: (a- Geopipes +b- Geocoir)

6.2.6. Geosynthetic clay Liners:

Geosynthetic clay liners GCLs are composite material consisting of a thin layer of sodium or calcium bentonite bonded to a layer or layers of Geosynthetic. The Geosynthetics are either geotextiles or a geomembrane. Geotextiles-based GCLs are bonded with an adhesive, needle punching, or stitch-bonding, with the bentonite contained by the geotextiles on both sides. For the geomembrane-supported GCL, the bentonite is bonded to the Geomembrane using a nonpolluting adhesive and a thin open weave spun-bound geotextile is adhered to the bentonite for protection purposes during installation. Due to the flexibility of production and rapid innovation, different types of GCLs are also available depending upon their variation in performances. The primary differences between GCLs are the mineralogy and form of bentonite (e.g., powder versus granular, sodium versus calcium, etc.) used in the GCL, the type of geotextile (e.g., woven versus nonwoven geotextiles) or the addition of a geomembrane, and the bonding methods. The main advantages of the GCL are the limited thickness, the good compliance with differential settlements of underlying soil or waste, easy installation and low cost [1].

Figure-6: (Geosynthetic clay Liner)

7. Soil Improvement using stone columns

Stone columns (or granular piles) are increasingly being used for ground improvement, particularly for flexible structures such as road embankments, oil storage tanks, etc. When the stone columns are installed in extremely soft soils, the lateral confinement offered by the surrounding soil may not be adequate to form the stone column. Consequently, the stone columns installed in such soils will not be able to develop the required load-bearing capacity. In such soils, the required lateral confinement can be induced by encasing the stone columns with a suitable geosynthetic. The encasement, besides increasing the strength and stiffness of the stone column, prevents the lateral squeezing of stones when the column is installed even in extremely soft soils, thus enabling quicker and more economical installation. Soil improvement can be done with mainly two types' stone columns Ordinary stone columns (OSCs) and Geosynthetic-encased stone columns (ESC) [22].

7.1. Mechanism of Load Transfer in stone columns

Stone columns provide the primary functions of reinforcement and drainage and, in addition, improve the strength and deformation properties of soft soil. They increase the unit weight of in-situ soil by replacement, drain rapidly the excess pore pressures generated, act as strong and stiff elements in in-situ soils and carry high shear stress. Stone columns create a composite ground of lower overall compressibility and higher shear strength than the original in-situ soil. When loads are applied, the stone columns and the weak soil move downward, resulting in an important concentration of stress within the stone columns. Load applied at the top of the stone column produces a bulge to a depth of about 2-3 diameters beneath the surface. This bulge in turn increases the lateral stress. When the stone column is subjected to ultimate load, failure takes place (a) by bulging in the top one-third length of the column due to relatively small lateral support or (b) by punching of the toe of the column into the underlying soil [2].

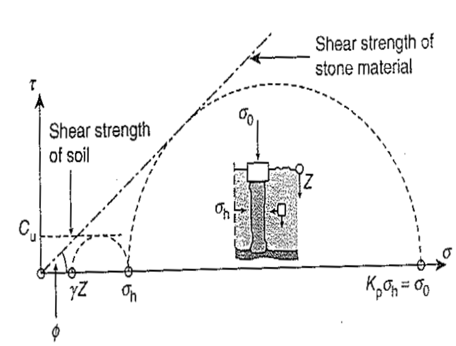

Figure-7: (Mohr circle for stone Colum treated soil)

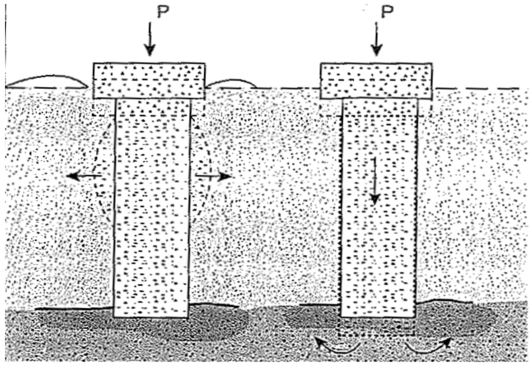

Figure-8: (Brauns's Failure mechanism in stone column)

7.2. Design Principles and Construction of stone columns

For design of stone columns, the effect of stone column construction is considered in terms of a parameter known as improvement factor. It is defined as the ratio of compression modulus of treated ground to that of untreated ground. The improvement factor indicates the factor by which the compression modulus increases for a grid of stone columns and the extent by which the settlement of the foundation will be reduced. The design of stone columns can be done using the design curves assuming stone column material is incompressible. Another assumption is that bulk density of column and soil is neglected. Practical design charts for evaluation of settlement of footing supported on stone column treated ground have been presented by Priebe (1995), considering the load distribution as well as reduced lateral support on columns situated underneath footing edges [16].

$$\beta = \frac{Settlement\ of\ unimproved\ soil}{Settlement\ of\ improved\ soil}$$

$$\beta = 1 + a_c\left[\frac{0.5 + f(v,a_c)}{K_{a,C}\, f(v,a_c)} - 1\right] \text{ and } f(v,a_c) = \frac{1-v^2}{1-v-2v^2}\,\frac{(1-2v)(1-a_c)}{1-2v+a_c}$$

where a_c (area replacement ratio) = A_C/A_E, A_C = cross sectional area of column, A_E = cross sectional area of unit cell and n = Poisson's ratio of soil [8].

Depending upon site soil and available equipment, the stone columns can be installed by any of the following methods mentioned below.

- ❖ Vibro-compaction method
- ❖ Vibro-replacement method
- ❖ Vibro-composer method
- ❖ Cased bore hole method
- ❖ Geotextile encased stone columns

7.2.1. Vibro-Compaction method:

Vibro-Compaction method is most effective for non-cohesive soils and used to improve the density of cohesionless soils. In this method soils are densified using mechanical vibrations with the help of vibrating probe. The degree of improvement will depend on many factors including soil conditions, type of equipment, procedures adopted and skills of the site staff. The effectiveness of vibro-Compaction can be readily investigated using Standard penetration test (SPT) or Cone penetration test (CPT) tests. Densifying the soils with vibro-compaction can considerably reduce the risk of seismically induced liquefaction. Typical depths for vibro compaction methods vary from 3 to 15m, but it can be as shallow as a one meter and as deep as 50 meter. Vibro-compaction is not effective where the granular soil contains more 12 to 15 percent silt or more than 2 percent clay. It is not effective for low permeable soils [12].

7.2.2. Vibro-replacement method:

To reduce limitations of the Vibro-Compaction method, the Vibro-replacement method was developed. Vibro Replacement is a technique of constructing stone columns through fill material and weak soils to improve their load bearing and settlement characteristics. Unlike clean granular soils, fine grained soils (such as clays and silts) do not densify effectively under vibrations. Hence, it is necessary to form stone columns to reinforce and improve fill materials, weak cohesive and mixed soils. The stone columns and intervening soil form an integrated foundation support system having low compressibility and improved load bearing capacity. In cohesive soils, excess pore water pressure is readily dissipated by the stone columns and for this reason, reduced settlements occur at a faster rate than is normally the case with cohesive soils. The method is applicable for Mixed deposits of clay, silt and sand, Soft and ultra-soft silts (slimes) Soft and ultra-soft clays, Garbage fills. Typical depths for Vibro Replacement methods vary from 20 to 40m [17].

7.2.3. Vibro- composer method:

The vibro-composer method involves driving casing pipe to the desired depth using a heavy vertical vibratory hammer located at the top of the pipe. The casing is filled with a specified volume of sand and the casing is then repeatedly extracted and partially reddriven using the vibratory hammer, starting from the bottom. The process is repeated until a fully penetrating compacted granular pile is formed. The method is popular in Japan and used for soft clay improvement in the presence of high groundwater levels. The resulting pile in this is termed as compaction pile [8].

7.2.4. Cased bore hole method:

In this method, the piles are constructed by ramming granular materials into the prebored holes in stages using a heavy weight 1-2t, falling freely from a height of 1-1.5m. The piles constructed by this method are most commonly called rammed stone columns. These piles incorporate the additional benefits of heavy tamping as they, in effect are preloaded. This method is a good substitute for vibratory campaction, considering its low cost. The method is however not applicable to sensitive soils due to disturbance and subsequent remoulding. A certain distance should be kept to existing buildings to limit settlement of new buildings due to vibration and drilling operations [2].

7.2.5. Geotextile encased stone columns:

In very soft nearly liquid soils, vibro-replacement is not effective due to the lack of lateral support of the soil. A geotextile coating may be used around the column to ensure filter stability and to activate tensile forces to avoid lateral spreading of the column. This method known as Geosynthetic encased stone column. The installation is usually performed in several steps so as not to damage the geotextile. First, a hole is created with the vibrator to the required depth and the vibrator is extracted. In the next step, the geotextile is mounted over the vibrator above the ground surface and, subsequently, the penetration is repeated with the geotextile to the same depth as before. On the way up, stones are filled and densified inside the geotextile like in the usual dry bottom feed process [22].

8. Conclusions

Geosynthetics, now days are broadly using in Civil Engineering fields. It is used in soil improvement due to its reliable applications in the field of Geotechnical Engineering. It is used in reducing lateral earth pressure in retaining structures, embankment stability, providing well defined drainage paths, water proofing and in controlling soil erosion and soil conservation. Stone columns are case of soil improvement using soil reinforcement with or without using Geosynthetic casing. It is ecofriendly in nature.

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