

Geosynthetics Stabilizers and Fly Ash for Soil Subgrade Improvement – A State of the Art Review

Prateek Malik, Sudipta k Mishra



Abstract: Soft soil having a low bearing capacity is found in many parts of the world and construction on soft soil is a challenge. To overcome the situation, the soil needs to be stabilized with some external material like geosynthetic, fly ash and rice husk. Geosynthetics materials are tremendous materials used to solve many civil engineering problems. Fly ash is a by-product produced by burning of coal and is available in various thermal power plant as a waste material. Disposal of fly ash is also a problem but in one area where it can be used is soil stabilization. A comprehensive review of published literature on the use of geosynthetic and fly ash to stabilize and enhance the strength of soil was carried out. The effect of using geosynthetic material and fly ash was investigated on the properties of soil like Optimum Moisture Content, Maximum Dry Density, California bearing ratio, unconfined compressive strength and compaction behavior of the soft soil.

Keywords - Bearing Capacity, Soil Stabilization, Geosynthetics, Fly Ash.

I. INTRODUCTION

Soil stabilization is the controlled modification of soil texture, structure and physico-mechanical properties of the soil. The major reasons for performing soil stabilization include:

- Improvement of strength, bearing capacity as well as other engineering properties of soils
- Achieve reasonable dust control for a healthy and safe working environment
- Waterproofing for the conservation of natural or manmade structures
- To promote the use of waste materials in construction

There are three types of soil stabilization:

Biological soil stabilization is achieved through afforestation or planting, and its main purpose is erosion control. This method is suitable for terrain exposed to water and wind influences, which are not meant for building.

Physical stabilization is the modification of soil particle size distribution and plasticity by the addition or subtraction of different soil fractions in order to modify its physical properties. Mechanical stabilization is the modification of soil porosity and inter-particle friction or interlock [1].

Chemical types of soil stabilization can be achieved through the use of traditional and non-traditional agents.

The distinction between the two classes exists as a result of the pre-existing and well-established additives as compared to the most recently developed agents. [2]

Examples of traditional chemical stabilization agents include lime, cement and fly ash and they are usually calcium based. The mechanisms of stabilization for traditional chemical stabilizers include cation exchange, flocculation, agglomeration, pozzolanic reaction and carbonate cementation. Non-traditional agents react chemically with soil in the presence of sufficient moisture to produce physicochemical interactions in the soil. Examples include but are not limited to bitumen emulsions, cement kiln dust, ground granulated blast furnace slag, pulverized coal bottom ash, steel slag, mine tailings, sulphonated soils and polymers are achieved through application of various substances which that act as compaction aids, water repellents and/or binders. The aim of this study is to use geosynthetic material and additives like fly ash to improve the strength properties of soil. The study also focusses on simulation process which is helpful in improving the soft soil and to predict the life span of the modifications done by using geosynthetic material and fly ash.

II. SOIL STABILIZATION MATERIALS

2.1 Geosynthetics

Geosynthetics are planar products that are manufactured from a polymeric material which are used with soil, rock or other geotechnical engineering related material as an integral part of human made product structure or system. The materials used in the manufacture of geosynthetics are primarily synthetic polymers which are generally derived from crude petroleum oil other materials such as rubber fiberglass and vitamin are sometimes also used for the manufacturing of geosynthetics. [3]. Soil stabilization methods are also employed to provide a good subgrade for existing and future roadway construction projects. Geosynthetics are also used in areas other than civil engineering such as mining agricultural and aqua-cultural engineering [4].

Type of Geosynthetic

- **Geotextile** - Geotextile is a planar, permeable product that is available in the form of a flexible sheet. Geotextile is classified into four different categories based on its manufacturing process:-
 - Woven Geotextile - Are geo-textile which are produced by interlacing two or more set of yarns (usually at right angle) by a conventional weaving process.

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* Correspondence Author

Prateek Malik*, Department of Civil Engineering, PhD Scholar, G.D. Goenka University, Gurugram, Haryana, India, Email: prak.malik1@gmail.com

Dr. Sudipta K Mishra, Department of Civil Engineering, Associate Professor, G.D. Goenka University, Gurugram, Haryana, India, Email : Sudipta.mishra@gdgoenka.ac.in

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- Non-Woven Geotextile - A geo-textile produced from directly originated fibers by bonding them with the needle punching method.
- Knitted Geotextile – A geo-textile produced by interlocking one or more yarns together with the help of a knitting machine.
- Stitched Geotextile –A Geotextile in which fibers and yarns or both are interlocked or bonded by stitching or sewing.

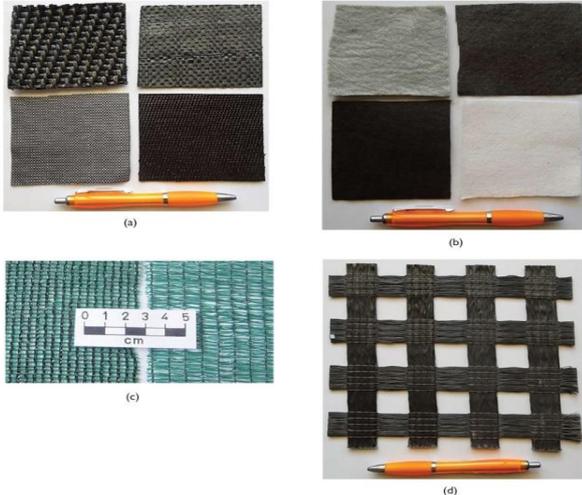


Figure 1. Typical geotextiles: (a) woven geotextile; (b) nonwoven geotextile; (c) knitted geotextile; (d) stitched geotextile.[3]

- **Geogrid** - Geogrid is a planner polymeric product consisting of a mesh or net like regular open network of intersecting tensile resistant elements integrally connected at the junctions[3]. The extruded geogrid are classified into three categories based on the direction of stretching during their manufacturing:-
 - Uniaxial Geogrid - A Geo-grid manufactured by the longitudinal stretching of a polymer sheet therefore it possesses high tensile strength in the longitudinal direction as compared to that of traverse direction[4].
 - Biaxial Geogrid - A Geo-grid manufactured by stretching in both the longitudinal and transverse direction of a polymer sheet therefore it possesses equal tensile strength in both directions.
 - Triaxial Geogrid - A Geo-grid manufactured to haveequal tensile strength in multi-direction which almost has 360 degree and soil properties[5].

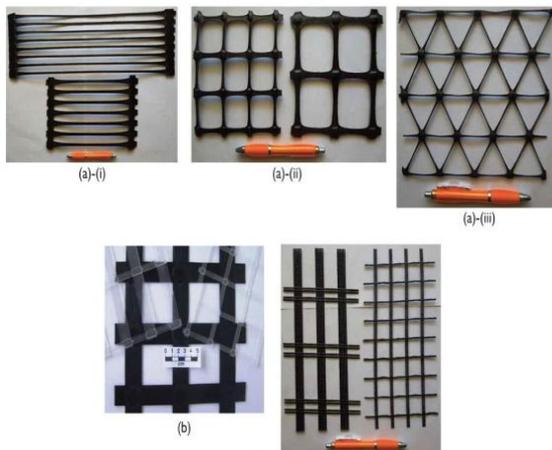


Figure 2. Geogrids: (a) extruded geogrids – (i) uniaxial, (ii) biaxial, (iii) triaxial; (b) bonded geogrids; (c) woven geogrids.[6]

- **Geonets** - are planar or polymeric products consisting of a regular dense network of integrally connected parallel sets of ribs overlying similar sets at various angles. The main function of geo-nets is to perform the in-plane drainage of liquids or gases.

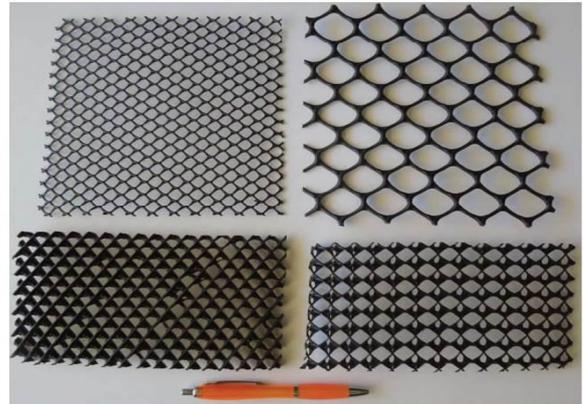


Figure 3. Typical Geonets [7]

Geomembrane- This is a planar, relatively impermeable synthetic sheet manufactured from materials of low permeability to control the fluid migration in a project as a barrier. The materials may be polymeric or asphaltic.

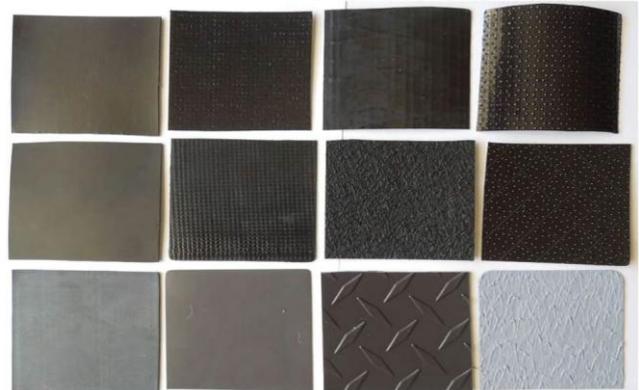


Figure 4. Typical Geomembrane[8]

- **Geo-cell** - Is a three-dimensional, permeable, polymeric honeycomb structure which is produced in the factory using the strips of needle-punched polyester or high density polyethylene.

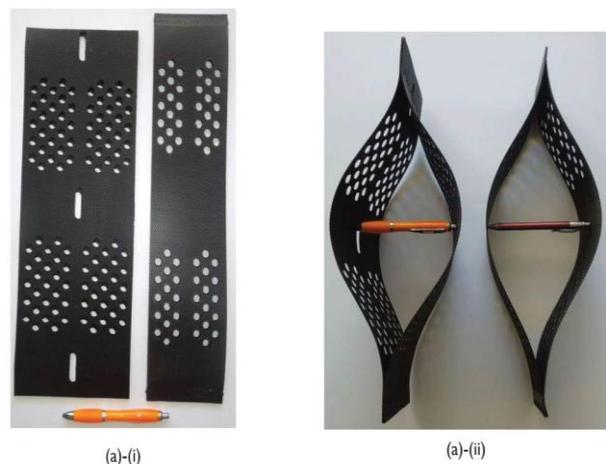


Figure 5. Typical Geo-cell [8]

Geo-foam - Is a lightweight product in slab or blocks form with a high void content, and has applications primarily as lightweight fills, thermal insulators and drainage channels[9].

Geo-composite -Is a product that is manufactured in laminated or composite form by a combination of two or more materials, at least one of which is a geosynthetic (geotextile, geogrid, geo-net, geo-membrane, or any other type), which, in combination, perform a specific function (s) more efficiently than a single geosynthetic material.[10]

Functions of Geosynthetics:-

- **Separation:** The geo-synthetic, placed between two dissimilar materials, maintains the integrity and functionality of the two materials. [11]

- **Filtration:** The geo-synthetic allows liquid flow across its plane, while retaining fine particles on its upstream side[12].
- **Reinforcement:** The geo-synthetic develops tensile forces intended to maintain or improve the stability of the soil geo-synthetic composite[13].
- **Stiffening:** The geo-synthetic develops tensile forces intended to control the deformations in the soil & geo-synthetic composite.
- **Drainage:** The geo-synthetic allows liquid to flow within the plane of its structure[12].

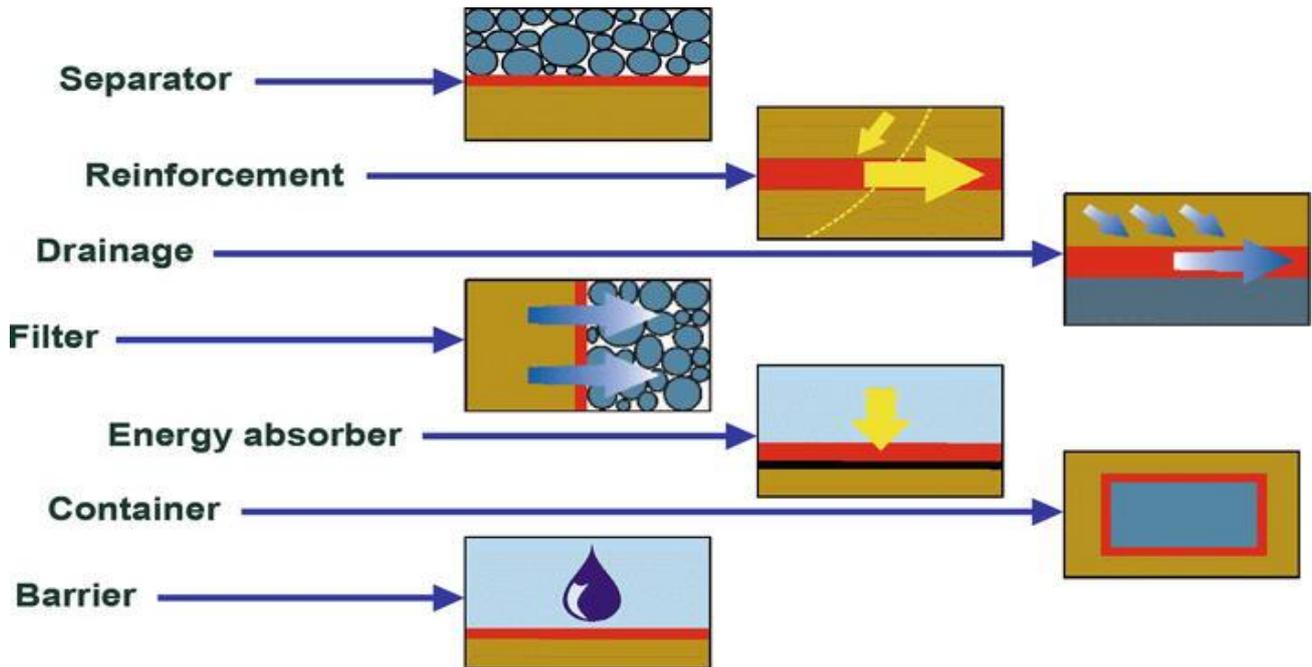


Figure6. Functions of Geosynthetics [9]

Table 1. Functions performed by different type of Geosynthetics [10]

| Geosynthetics Types versus Functions performed | | | | | |
|--|------------|---------------|------------|----------|-------------|
| Type of Geosynthetic | Separation | Reinforcement | Filtration | Drainage | Containment |
| Geotextile | × | × | × | × | |
| Geogrid | | × | | | |
| Geo-net | | | | × | |
| Geomembrane | | | | | × |
| Geosynthetic Clay Liner | | | | | × |
| Geo-pipe | | | | × | |
| Geo-foam | × | | | | |
| Geocomposite | × | × | × | × | × |

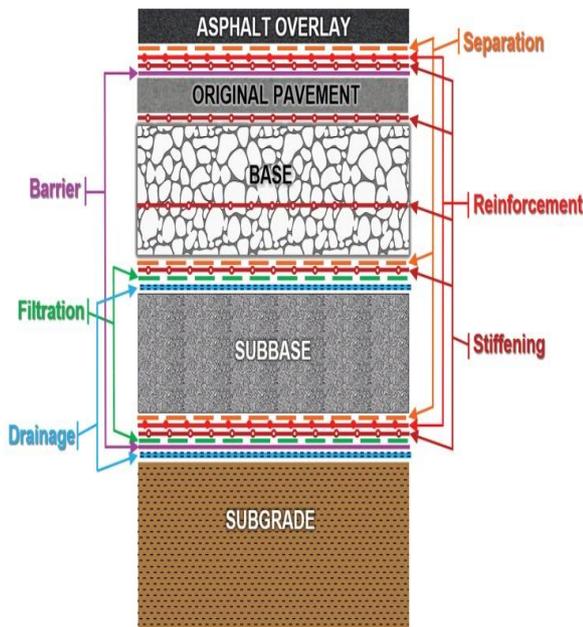


Figure 7. Functions of geosynthetics at different places in road subgrade [7]

2.2 Fly Ash

Is a fine powder that is a by-product of burning pulverized coal in electric generation power plants. Fly ash is a pozzolan, a substance containing aluminous and siliceous material that forms cement in the presence of water. When mixed with lime and water, fly ash forms a compound similar to Portland cement[14].The mechanism of soil stabilization using fly ash is the pozzolanic reaction and the filling of the voids in the mix. It is among the types of soil stabilization suitable for coarse-grained particles with little or no fines.

In India an area of 65000 acres of land is being occupied by ash ponds and its generation is expected to cross 225 million tonnes by the year 2021.

Class C Fly Ash has high cementing abilities and these are formed from the burning of subbituminous coal. This kind of fly ash has lime over of 20% and also does not need an activator based on[15] for the formation of cementitious compounds. Class F Fly Ashes are generated from the combustion of bituminous and anthracite coals. These ashes have less than 10% lime content and need an activator [16].

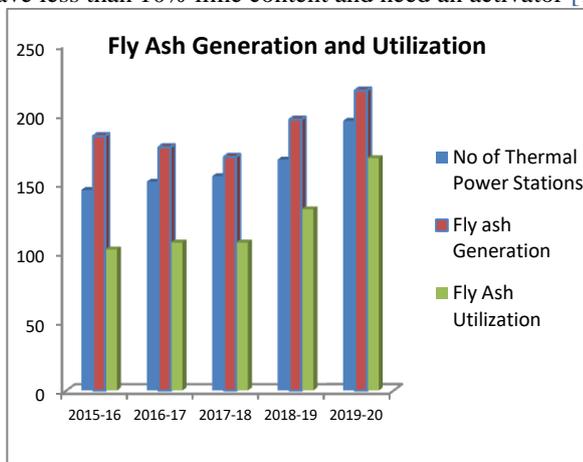


Chart1. Fly ash generation and utilization during the year 2015 to 2020 (Central Electricity Authority)

The behavior engineering and Mechanical properties of soil are difficult to predict. Soft soil has a tendency of sinking and swelling which is not feasible for construction so to make soft soil usable it has to be stabilized with a different type of stabilizers like geosynthetic or fly ash stabilizers[17].

Soil stabilization increases the bearing capacity of the soil and other properties like shear strength and tensile strength penetration strength and bearing ratio.

Fly ash production is increasing day by day and their disposal is also a problem so by using fly ash as a stabilizer it is economical and due to its low cost and its problem of disposal fly ash is an ideal material for soil stabilization fly ash has cementous properties.

III. SOIL STABILIZATION

Atterberg Limit

[18] studied the effectiveness of using stone dust and coarse aggregate for soil stabilization. In the study the author focused on some of the properties of soil like Maximum dry density and Optimum moisture content. [19]Three type of soils were used clay of low plasticity CL silt of low plasticity ML and a mixture of both CL-ML. Stone dust is also used in a proportion of 10% 20% 30% by the mass of dry soil coarse aggregate of 10mm size is used in a proportion of 10% and 20% by mass of soil. Four types of samples were prepared. With the addition of stone dust and coarse aggregate the Maximum dry density value of the soil increased and Optimum moisture content decreased. Similarly,[20]also found that use of Rice Husk Additives and fly ash increase Maximum dry density & reduction in Optimum moisture content values. [21]also evaluated that use of fly ash in soil increase Maximum dry density & reduction in Optimum moisture content values.

California Bearing Ratio

The use of geosynthetics for the treatment of soft soil has been investigated by [22] for the improvement of soil subgrade. The soil used is silty sand. Two type of geosynthetic materials are used (Two geogrid and one Geonet) for reinforcement. Reinforcement is placed at a height of H/2, H/3 and H/4 from the top of the specimen and the double layer is placed at H/4 from top and bottom respectively. California Bearing Ratio test is conducted in unsoaked condition and load is applied at 1.25 mm/min. As the inclusion of a single and double layer of geosynthetics reinforcement at varying depths enhanced the bearing capacity of the soil. The placing of a double layer yield maximum improvement. Geogrid (Tenax 3D) performs better than the other two geosynthetics when geosynthetics is placed in a single layer and Geomat (Tenax Multimat) performs better when geosynthetics is placed in a double layer. The CBR value also increased by 5 to 60 % and 112 to 325% for single and double layers respectively.

[18] studied the effectiveness of using stone dust and coarse aggregate for soil stabilization. Three type of soils were used clay of low plasticity CL silt of low plasticity ML and a mixture of both CL-ML.

Addition of stone dust and coarse aggregate individually or with the combination of one other increase the CBR value with all type of soil it has been observed that with the addition of stabilizer CBR increases from 2.4 to 4.7 % addition of 20% coarse aggregate which soil proved to be the most economical approach.[20]also found that use of Rice Husk Ash & fly ash improved CBR values. [23]investigated the use of reinforced fly ash overlying the soft soil to improve the subgrade layer of road payment. Eleven types of fly ash samples were taken from different thermal power plants in East India. Multifilament and polypropylene woven type of geo-textile is used. In this study geotextile is used at different depths in the soil sample. It is observed that the bearing ratio values for a reinforced and reinforced with single layer are 37.7 % and 55% respectively. Inclusion of a single layer of geotextile reinforcement increases the bearing ratio by about 45% and inclusion of geotextile near about the subgrade prevent contamination of base layers underline soft soil the maximum bearing ratio value is obtained when geotextile reinforcement is placed at 1 by 3 depth of the compacted fly ash layer from the top of the specimen. With the increase in the number of geotextiles layers the bearing ratio of the compacted fly ash has been increased.

[24]investigated the use of geogrid in soil samples and conducted CBR test on soil sample reinforced with geogrid and a reinforced sample with varying proportions and place of placement like 3L/4, L/2 and L/4 and concluded that use of geogrid increases the CBR value up to 40% and can cause reduction in the thickness of the pavement.

[25] Investigated the stabilization potential of geo-polymer determined by conducting the unconfined compressive test, free swell ratio and shrinkage limit test on stabilized specimens. The quantity of fly ash & rice husk ash (FARHA) taken is (5, 10, 15 & 20%). X-ray diffraction (XRD), Scanning electron microscopy (SEM) was conducted to analyse the micro-level changes in geopolymer. The result shows that geopolymerisation significantly improves the strength and at the same time makes it less prone to swelling and shrinking.

Shear Strength

[26] Investigated the use of geosynthetics encased granular columns (EGC) to increase the bearing capacity of soil against vertical loading or high shear resistance. Three types of geosynthetics materials were used in the study are woven geotextile, cotton socks and paper towel. Two types of granular columns were used and case granular columns (EGC) and open granular columns (OGC). Direct shear test was conducted based on three types of arrangement with the granular column at the centre with triangular (three EGC) in shape and with square arrangement with four EGC. From the result it is concluded that there is an improvement of lateral load capacity with encased granular columns (EGC) due to mobilization of tensile force for open granular column (OGC) there is a marginal increase in shear strength. For EGC there is a sustainable increase. After rupture of the encased granular column (EGC) the strength is reduced to the level of Open granular columns (OGC). A group arrangement mobilizes higher shear strength as compared to Single in case of encased granular columns (EGC). Similarly, [27]use plastic waste bottles and fly ash as a filler material conducted a compressive strength test and concluded that the use of plastic water bottles and fly ash as

a filler material increases the compressive strength by 30 to 40% similarly [21]also concluded that internal friction is increased between the particles with the addition of fly ash. Scanning electroprobe method shows that fly ash particles cover the surface of soil with an impervious clay and cause reduction in shrinkage and swelling. [28] used four types of geo-synthetic material that is uniaxial, biaxial, woven and non-woven they also suggested that particle size affects the friction angle and interlocking in the soil but shear strength test conducted shows that particle size has no significant effect on shear strength. The inclusion of geo-grid layer increases the shear strength as compared to other types of geosynthetic materials similarly [29]Investigated the shear strength interface between fly ash and high-density polyethylene geomembrane of various textures. Direct shear test was conducted for fly ash, cement and high-density polyethylene geomembranes. The results indicate that greater interface friction angle was obtained for textured geomembrane as compared to smooth geomembrane and adhesion is greater in smooth geomembrane. Textured geomembrane has peak and residual strength twice that of smooth geomembrane.[30]also suggested that use of geogrids improve the aggregate interlocking. Finite element modelling shows that the use of geogrid improved the pavement performance in low volume roads. [31]also supported the investigation that by using polymer there is an increase in shear properties. [32]also supported that by using geogrids interface interaction between particles increased and justified the fact by scanning electroprobe method.

Pull out Characteristics

[33] investigated the suitability of geosynthetic material for subgrade soil treatment. Cohesion less soil is used and three types of geosynthetic materials are used that i.e. Woven, non-woven and geogrid respectively. They conducted the pull-out test and found that both geosynthetics materials show similar Behaviour for large soil particles whereas for smaller soil particles non-woven geotextile exhibit more friction angle. [34]Investigated the interaction parameters with the help of pull-out test. The pull-out test is conducted in multilayer to find out the correlation between the reinforcement and the soil particles. The size of the pull-out box is H x L x B of 40 x 90 x 100 cm respectively. Test is repeated three times with different confining loads. The soil sample is divided into three different boxes i.e., upper, centre and bottom respectively. The test start from top and goes to the bottom. Two type of geogrids are used as reinforcement (type A soft geogrid) and (Type B Stiff geogrid) When confining stress is 90 KPA in the single layer pull out test the breaking occurred when pull-out displacement was approximately 18 mm and for multilayer the breaking occurred when pull-out displacement was approximately 20 mm. The angle of friction for a single layer is 0.86° and for multilayer is 1.30° which suggests that multi-layer reinforcement is better than single layer but there is an only slight difference.

[35]Investigated the pull-out resistance of geogrid in mechanical stabilized Earth walls MSE. The author used an innovative idea and added a steel Traverse element to an ordinary polyester geogrid using a nut and bolt called anchored geogrid.

With the arrangement the system is capable of increasing the pull-out resistance of ordinary polyester geogrid by up to 65%.

Pressure filtration and vane shear

[36] studied the use of geotextile and fly ash on the hydraulic properties of soil and what is the effect of polymer conditioning on strength improvement. Seven types of different woven geotextile were used depending on their physical properties size and hydraulic properties. All geotextiles are made of polypropylene. Pressure filtration & vane shear test are performed to evaluate the shear strength. Geotextile tubes are successful in retaining the solid strength of filter cake is increased by polymer condition. Chemical analysis of the effluent showed that filter cake properties and polymer conditioning do not affect reducing the concentration of elements is old in the effluent hydraulic properties of textile do not play a significant role in fly ash devoting performance.

[37] Investigated the factors in which three geo-textiles were used in the study and factors like TSS removal, hydraulic conductivity and filtration aspect were studied and the result indicated that after a short period the geotextile material with an apparent opening size of 150 μm can effectively remove suspended solids. [38] also investigated types of failure in different MSE walls and found that proper drainage, improper compaction and fine soil is the main reason for MSE walls failure. [39] Also analysed the dynamic behavior of reinforced walls and concluded that use of geosynthetics can solve many engineering problems and its use can increase the strength of retaining walls.

Compression Characteristics

[40] Invested that suitability of the different types of geosynthetics to improve the strength of soil the different types of geosynthetics used are woven geotextile geo-grid and polyester film. The type of reinforcement provided is in the form of a horizontal layer, circular geo-cell and randomly distributed fibers (having 11 mm length and 2mm width). A series of triaxial compression tests were conducted on the unreinforced and reinforced sample. All reinforced samples exhibit improvement in stress & strain as compared to unreinforced sample. The strength improvement depends on the type of geosynthetics. Cellular reinforcement is considered most effective in improving strength. Polyester geocells proved to be highly efficient in improving the strength as compared to the textile because of their formation. [41] conducted model test on bearing capacity of soil reinforced using geo-synthetic material and corresponding numerical analysis and found that the effectiveness of reinforcement primarily depends on the position of reinforcement and its skin friction. No extra effect of reinforcement occurs when it is placed deeper than half of its height. When reinforcement ends fixed with the ground it results in maximum effect. The maximum reinforcement effect occurs when the enforcement is placed at half the depth and its end fixed with the ground.

[42] Present a numerical investigation using 3D finite element modelling (FEM) to analyse the improvement of unpaved road system reinforced by geogrid under repeated traffic load. In this study geogrid is used as reinforcement. Numerical analysis using finite element software was conducted to investigate the performance of geogrid reinforcement over soft subgrade. Triaxial test was conducted. Drucker - prepper model was used. Cyclic load

up to 2000 KN was applied. ABAQUS contact feature was used to study the model of geogrid soil interface. The presence of geogrid gives approximately 25% improvement in terms of displacement reduction. The inclusion of reinforcement influences the behavior of pavement in terms of reduction of peak values of stress. 3D finite element analysis was carried out by ABAQUS software that reinforced configuration works better than unreinforced configuration further [43] investigated the subgrade reinforcement with geosynthetics in road pavement with numerical analysis. An analysis was carried out within the infinite element program ADINA using 2D modelling with different pavement material, structure, and traffic conditions and subgrade soil. Rutting design and fatigue criteria were evaluated. The result of numerical modelling confirms that reinforcement influences most of the factors and increases the capacity of the soil also [44] evaluated the effectiveness of coir mats on the pavement surface. wheel tracking test is used to investigate the varying contact pressure on payment layer with and without coir mats placed between subgrade and sub base layer and concluded that use of coir Mats in the subgrade helps in decreasing the base layer thickness of pavement. [45] investigated the use of geogrid in granular piles and conducted finite element studies with the help of PLAXIS. Geogrids are placed in vertical, horizontal and a combination of both and concluded that use of geogrid enhances the load bearing capacity.

Bearing Capacity

Similarly, [46] Conducted a series of cycling plate loading tests to evaluate the benefits of using geogrid and high strength geotextile in reinforcing base aggregate layer or stabilizing a weak subgrade in flexible pavement. Two types of geosynthetics were used in this research a triaxial geogrid (GG) and high strength geotextile (GT). In section 1 a 305mm geotextile wrapped sand layer is placed above the subgrade. In section two a non-woven geotextile layer is placed above the subgrade and a layer of triaxial geogrid is placed above it and another layer of triaxial geogrid is placed at a height of 1/3 from the top layer. In section 3 a layer of Non-woven geotextile is placed above the subgrade and a layer of triaxial geogrid is placed above it. In Section four only a non-woven geotextile layer is present between the base course and subgrade. In Section five a high strength woven geotextile layer is placed between subgrade and base course and in section six the height of base course decreased and the height of subgrade is increased with a layer of high strength woven geotextile placed between them. Based on the test results of the cyclic plate loading test with and without geosynthetic reinforcement It is concluded that both geosynthetics improve the performance of the pavement section. The inclusion of geosynthetics reinforcement results in redistributing the applied load to a wider area and reducing stress distribution. Among all six sections tested the best performance was observed for the payment section having double geosynthetics reinforcement. Similarly, [47] also suggested the use of geosynthetic material between subgrade and sub base layer increase the stability and strength of pavement.

[48] addresses the effectiveness of geo-cell mattresses prepared with fly ash as a filler material overlaying the soft clay soil. The material used in this study is plastic bottle in the place of synthetic material, fly ash clay soil, Jute geotextile and bamboo geogrid. The study attempts for sustainable development with the use of plastic water bottles in place of your synthetic material which will solve the problem of decomposition of disposal of plastic waste. With the increase in the height of fly is paid directly placed over soft clay the footing performance gets improved. The inclusion of jute geotextile as separator underneath the fly ash belt enhances the footing performance resulting in high improvement factor. [9] also concluded that reinforcing fly ash bed with geo-cell mattress along with a Basal geogrid and jute geotextile separator can enhance the footing capacity around seven times that of reinforced fly ash.

[49] Focus on investigating the development of tensile strain along geogrids that are placed in in asphaltic layer. The testing program includes cyclic wheel loading on unreinforced asphaltic layer, geogrid reinforced asphalt overlay, geogrid reinforced asphalt overlay with less base thickness. Extensometers are used for measuring tensile strain of geogrid. The results indicate that strain developed in the under reinforced model were higher than reinforced model and are continuously increasing. Presence of geogrid in asphaltic layer decreases the thickness of base course to half as compared to unreinforced model.

IV. RECOMMENDATIONS

Although the current published work deals with using geosynthetic material and fly ash or other additive materials to stabilize the soft soil for Highway construction and various civil engineering problems.

The following are recommendations for future work

- A combination of different types of geosynthetics material with additives like fly-ash and Rice husk should be utilized for soil stabilization.
- Use of finite element modelling (FEM) should be used as it helps in predicting the performance of payment and it gives a life cycle Cost Analysis which is beneficial.
- Placement of geosynthetics plays a vital role in the performance of geosynthetic material.

V. CONCLUSIONS

The type of geosynthetics material and amount of fly ash or additives has a great influence on strength index and compaction properties of soft soil the published paper shows that the use of geosynthetics material search different functions like filtration drainage separation etc. and fly ash or other additives can act as filler material and enhance the strength of the soil and act as a binder due to their cementous properties. Hands from the review done above for the treatment of soft soil with geosynthetics material and fly ash following conclusions can be drawn: -

- Geosynthetics material alone or with the combination of fly ash can be used to treat soft soil. The result of published papers proves that the use of geosynthetics material alone or with the combination of fly ash significantly improves the strength liquid limit and plastic limit compaction factor, shear strength and CBR value of soft soil. Utilization of fly ash in soil stabilization can reduce the waste from the environment. The conventional methods used for

stabilization with the help of chemical cause environmental problems such as groundwater contamination. Hence fly ash can be used in a controlled way to save the environment and to stabilize the soil.

- The different types of geosynthetics materials can be used to treat soft soil because a different type of geosynthetic has different properties. However, geogrid can only serve as reinforcement and the main function of geo-net is drainage. Classy fly ash can be used as a filler material due to its cement as property which helps in the reinforcement and contamination.
- The use of fly ash in the treatment of soil could reduce the negative impact of these materials on the Environment by reducing the amount of area to be used for disposal.

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AUTHORS PROFILE



Prateek Malik a PhD Scholar in G.D. Goenka University Gurugram Haryana India completed his MTech from Guru Jhambeshwar University Hisar and BTech from Kurukshetra University. Presently working as Lecturer in C.M.R.A Government Polytechnic Sanghi, Rohtak, Haryana INDIA
Link of Google Scholar Profile –

<https://scholar.google.com/citations?user=UjX0M9UAAA&hl=en&oi=a>



Dr. Sudipta K Mishra presently working as assistant professor in Civil Engg. Deptt. In G.D. Goenka University Gurugram .Sudipta holds a PhD from the University of Iowa (USA); MTech (Water Resources) from Indian Institute of Technology, Guwahati; and B.E. (Construction Engineering) from Jadavpur University.