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A Review on Recent Experimental Research on Soil Stabilization

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Abstract. The increasing population results in executing the infrastructure and buildings to be constructed also in weak and soft soil. Therefore, the soil must be strengthened to surrender larger settlements, ground subsidence, etc to resist the collapse of building. In such cases, the necessity of ground improvement has been implemented. The ground improvement techniques is majorly performed for reducing settlement in soft soil, improving the soil bearing capacity, slope stabilization and preventing from earthquake liquefaction. This technique is done for stabilizing the properties of soil and attempted to modify the existing ground. Ground improvement can be done by various techniques i.e., vibro-compaction, dynamic-compaction, ground freezing, Vibro-replacement stone columns, Electro kinetic stabilization, grouting, etc. Recent improvement techniques are introducing Geo cell, Geo-textiles and Geo-membranes has been developed in which the soil is reinforced with materials like aluminum, stainless steel, polyester, fibers, polyamides in the form of strips or grids to stabilize the soil. This paper will give some of the recent techniques adopted in site to improve the soil properties.

Introduction

Due to overpopulation the need for requirement is in peak. In this fast growing world the development of urban areas are playing a major role. This leads to the development of railways, electric power plants, sewage systems and so on. Engineers are in a situation to use both soft and weak soil for construction. Hence construction of bridges, multistory building, transmission towers, etc are unobstructed which can be improved by ground improvement techniques. Also to overcome the ground subsidence in earthquake zones ground improvement techniques are also used.

Ground improvement is a technique in which it improves the engineering properties of soil. It also has various objectives like it improving the bearing capacity of soil, reduces the settlement of soft ground, prevents the liquefaction in the ground, etc. The settlement of soft soil occurs in low land areas, for e.g.: place like Chao Phraya in Thailand. Ground subsidence also occurs in earthquake zones and the main phenomenon for ground subsidence is the liquefaction of granular soils. Geo grid, Vibro compaction, Stone column, grouting, mechanically Stabilized Earth (MSE), etc were the some of the ground improvement techniques. Geo grid is a geo synthetic material which is provided as reinforcement to soft soils. Vibro compaction is done by penetrating the vibrator to the granular soil for compaction, which is then followed by filling with granular soil and the final process is ground level finishing. Stone column is a technique which is as similar to vibro compaction which gives high integrity and interlocks the surrounding soils without ground subsidence. Mechanically Stabilized Earth (MSE)is an artificial reinforcement provided to soil,

which is constructed for abutments, retaining walls etc. Grouting is a process in which soil and rock is derived through the fluid grout. This method helps in improving the physical property of the soil without any subsidence.

Ground improvement techniques

Ground Improvement Technique followed by using Natural Prefabricated Vertical Drains (NPVD)

Asha.S.et.al (2012) studied the ground improvement technique using the natural pre-fabricated vertical drains (NPVD), geo cell and geo foam. Natural prefabricated vertical drains (NPVD) and polymer prefabricated vertical drains (PPVD) were compared on the basis of discharge capacity, compressive stresses and hydraulic gradient. The report suggested that the measure flow rate per unit width of NPVD was lesser than PPVD.NPVD were categorized according to materials, out of which experimental analysis has been carried out in comparison of woven jute and coir strand with non-woven jute. Out of which, woven jute and coir strands showed better flow rate results than the non-woven jute and coir strands. On the other hand, the reinforced soil (with geo cell system) shows better results i.e., 31.35mm than unreinforced soil (without geo cell system) i.e., 133.4 mm in the aspect of vertical displacement. From these results, it has been concluded that, the geo cell reinforced soil can resist the accumulation of shear stresses than in unreinforced geo cell system which also consequently provides stability in cohesion less soil. The study also focuses on geo foam embankments which are most likely preferred over soft soils, because the magnitude of horizontal and vertical displacement is lesser than unreinforced embankment. The factor of safety in geo foam embankment is relatively higher i.e., 2.96. It was found that, the NPVD, geo cell and geo foam are preferable in stabilizing soils in the developing countries [1]. Figure 1a and 1b shows the natural prefabricated vertical drains made from coir strands which is then wrapped with woven and nonwoven jute materials.

Figure 1a and 1b woven jute and nonwoven jute geotextile.

Test results

Compressive stresses and hydraulic gradient were noted for linear flow rate per unit width. According to ASTM D4716, linear flow rate is measured. The tests were performed at the rates of compressive stresses of 0, 10, 30, 50, 70, 100, 150, 200, 250 and 300kPa at different hydraulic gradients of 0.1, 0.15, 0.25, 0.5, 0.75 and 1.0. Figure 2 shows the test setup for flow rate measurement.

Figure 2 Flow rate measurement

A graphical representation is drawn between normal compressive stress (kPa) at x-axis and Flow rate (cubic meter/second) is represented in figure 3.

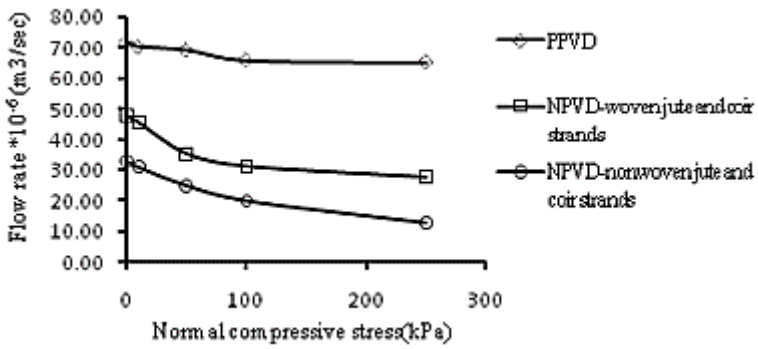

Figure 3 Flow rate versus compressive stress

From the test datas, it showed that NPVD made from woven jute and coir has achieved a better flow rate when compared to nonwoven jute and coir strands. It is found that the flow rates per unit width are comparatively less than PPVD. The reason for less flow rate is due to that compression of core material made of polymer in PPVD is much less than the NPVD coir strands.

Ground Improvement Technique followed by using natural fiber-based Composite-structured geotextiles

Basu.G.et.al (2019) studied the results on Bioengineering of river earth embankment using natural fiber-based Composite-structured geotextiles [2]. Geotextile is made up of jute of HDPE composite structured membrane to hold the soft soils on the river embankments. They have good physical and mechanical properties with a tensile strength of about 10 kN/m. The following are some of the methods involved in the preparation of geotextiles (Jute threads, coconut fibres): Jute threads are prepared using high speed jute spinning machine. Coconut fibers are used to make geotextile net which is done manually by hand knotting method. Testing of geotextile net involves the fiber to place in a humidity of 65+5% and a temperature of 27+2 oc. Tensile strength of geotextile net involves the Instron tensile tester as per BIS 1670 (2002).Mechanical strength of fibre involves the testing of sample in tensile testing machine as per ASTM D4595 (1994). Water

permeability of geotextile sample is tested by flowing water perpendicularly to the geotextile sample with a constant water pressure. From this methodology, hydraulic property of a fiber is known. Table 1 shows the different properties of geotextile polymers

Table 1 shows properties of polymers used as geotextiles.

Type of Fiber	**Specific Gravity (kg/m^3)**	**Modulus of Elasticity (GPa)**	**Tensile Strength (MPa)**	**Elongation at break (%)**
Polypropylene	910	10	780	55
Polyethylene terephthalate	1400	1.5	25	95
Polyamide	1140	6.5	65	45
Polyethylene	940	65	550	72

Area of the geotextile, size of the mesh and thickness of the geotextile sample was referred as per BIS (2002). Experimental study involves digging a toe-trench longitudinally along both sides of the embankments and then the slopes were leveled to provide a point to point contact to the soil and geotextile net. Geotextiles was laid on the surface from toe-trench to other side of embankment. Coconut fiber is also laid over it. Composite geotextile member is fixed by using matured bamboos and metallic U shaped hooks. Geotextile tubes were placed over the geotextile and coconut net. Then they are covered with aggregates and sand to form a filter and this helps in sealing the flow of soil from embankment. Finally the embankment is covered with sandy soil. Bioengineers concluded that it has two major functions like filtration and reinforcement. Effective production in vegetative growth through the geotextiles is the reason for improvement of river-bank condition. The monitoring process has been done for about 8 years. The result shows there isn't any subsidence and migration of slope even after 8 years. The cost of this project is based on three main things like raw materials, cost of machine and transportation.

Ground Improvement Technique followed by using mechanical stabilization, stabilization by preloading method

Brajesh Mishra (2016) carried out a research in ground improvement techniques and its applications. The analysis which includes mechanical stabilization, stabilization by preloading method, stabilization by sand drain method, physical and chemical modification technique, modification by addition and confinement techniques, sand pile using blasting. Mechanical stabilization is a method of improving the density of granular soils by compaction. The compaction is done by applying a mechanical force which acts on the soil by means of static, vibratory rollers and plate rollers. Stabilization by preloading method provides stability to loose soil, soft soil even to clay and organic silts. This technique involves the compaction and densification of a loose grained soil by the application of loading. The Consolidation process for a compressible layer takes more time as it has to penetrate through the dense layers and reach the surface of the drainage.

This conflict can be solved by introducing sand drains or vertical drains of higher permeability as it helps in reducing the time taken for draining the water present in the soil which easily outreach the drainage surface. Physical and chemical modification technique involves the insertion of waste materials, soils and industrial by-products under the pressure which is also known as grouting. In this modification technique, the soil is compacted by alternate heating and freezing. Modification by addition and confinement techniques involves adding reinforcement to the soil in the form of meshes, fibers and strips. It improves the tensile strength of the soil. The main advantage of this technique is that, it does not involve the migration of soils and keeps the soil as opaque. Sand pile using blasting necessitates the hidden explosions and extracts the soils which then backfill the excavated area. This process enlarges the soil intensity and makes the soil compacted.

Ground Improvement Technique for construction on peat

Duggan A.et.al (2014) performed a study on factors affecting embodied carbon and embodied energy associated with ground improvement techniques for construction on peat. The study focuses on modification or removal of peat and emerging of Embodied Carbon (EC) and Embodied energy (EE) which are taken in consideration in ground improvement techniques. Peat lands were improved as they have high moisture content, low shear strength and creep. This can be achieved by soil-mixing, piling and replacement methods. As it is difficult to predict the settlement in peat type of soil and also the time period for secondary consolidation is excessive, usual ground improvement techniques for soft soil cannot be preferred. Hence, the most reliable method for building roads in peat is considered as Excavate and Replace method. By restoring and rewetting the peat land, CO2 and N2O emission is largely reduced. For stabilizing the peat disposal sites, soft rushes and sphagnum were planted which also helps in binding the peat.

Ground Improvement Technique for construction on peat

Indraratna.B.et.al (2010) studied the system of combined form of vertical drains including vacuum and surcharge preloading and this method is considered as one of the productive methods for the consolidation of soil. Analytical models were used to study the consolidation process and the changes in the properties of the multi layered soil through spectrum method by absorbing vacuum preloading and smear well resistance. The accurate soil behavior was observed when it was exposed to vacuum pressure can be predicted from the demonstration of spectral model. The cylinder specimen were examined containing different percentage of cement and surcharges. The effect of surcharge were compared and is shown in figure 4.

From figure 4, it is evident that, the diffraction intensity of $CaCO_3$ increased to even 4000 a.u, when the carbonation time increased even to about 180days. Due to this, the effect the calcium hydroxide content is slowly diminishing.

Experimental study on Ground improvement using chemical methods.

The recent study shows that Ground improvement plays an vital role in the construction of structures such as, Dams, Petroleum storage yards, large Skyscrapers, Highways and other important structures. The four major polymeric materials used in soil as binders such as Epoxy resins, Polyacrylamide, Polyurethane and Lignosulfonates. The study shows that, hydraulic conductivity decreased from 1.45×10^{-2} to 7.52×10^{-4} cm/s for a Poly Urethane concentration of 4–8%, making the soil type to make stable against water.

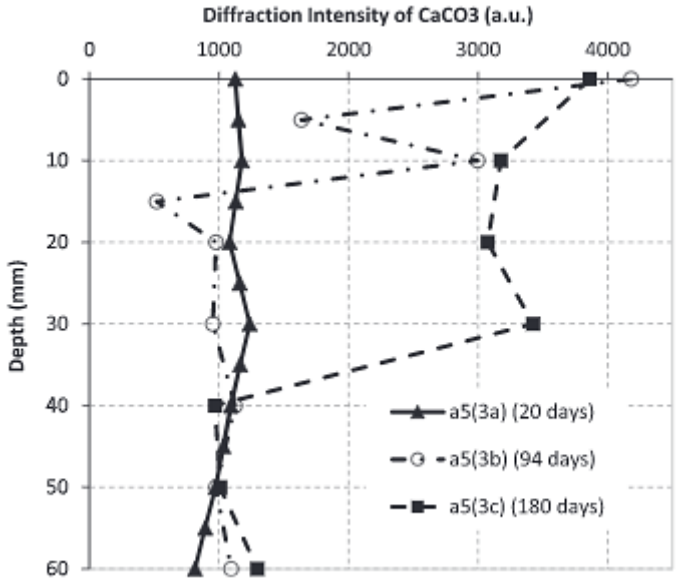

Figure 4 Proportions of CaO diffraction intensity for varying depths and duration.

Another chemical, named, lesser quantity of Lignosulfonate have a greater potential against the soil erosion by improving the tensile strength.

Figure 5 & 6 shows SCM of the kaolinite sample for various percentage of cement. Initially, cement were added in the proportions of 5%, 10%, inaddition, the combination of epoxy resin + kaolinite and 10% cement + kaolinite + epoxy resin is taken as samples.

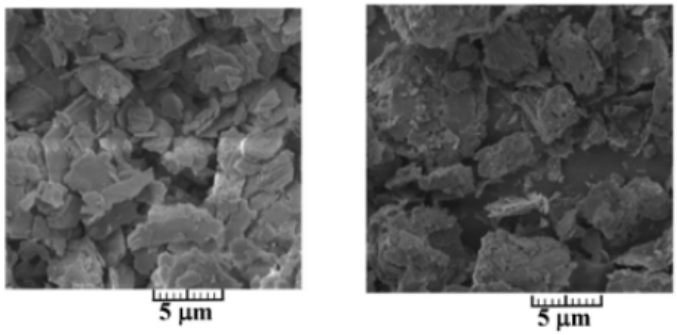

Figure 5a Kaolinite and Figure 5b kaolinite + 10% cement

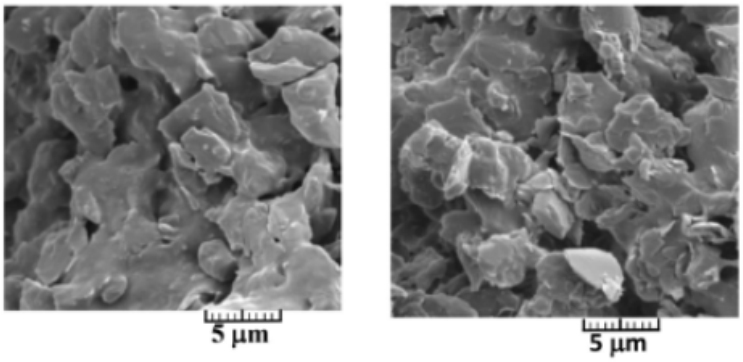

Figure 6a Epoxy resin and Kaolinite, Figure 6b Kaolinite +10% cement + Epoxy resin

It is seen that, by adding these admixtures, it reduces the development of high intensity of pore pressure. Also the dispersion of particles are gives the better flow capability. From the study, it is observed that, kaolinite is more effective than illite.

Experimental study on bearing capacity of geo cell reinforcement in embankments.
Ling Zhang.et.al (2009) discussed about the experimental study on bearing capacity of geo cell reinforcement in embankments. Geo cell is a three dimensional geo synthetic cellular network formed from thin polymer strips. The beneficial use of geo cell is that it provides a working platform for construction, reduces migration of soil, reduction of ground subsidence and it has high bearing capacity. The study focuses about the comparison of ultimate bearing loads by constructing the embankment with and without geo cell. In first method, concrete tank was installed under a loading frame and it was filled with clayey sand. Then three layers of sub grade soil were filled. Two soil pressure cells were fixed in a clay bed for measuring the vertical soil pressure. Then the embankment is constructed over the soft soils which are then compacted using wooden rod. With the use of hydraulic jack, a surcharge load is applied to the embankment. The load is gradually increased until the surface reaches the settlement of above 55 mm. Second method is as same as first method, but it involves the installation of geo cell between soft soil and the embankment. After leveling the soft clay bed, a layer of crushed stones was filled and geo cell is placed over that. The hollow region of geo cell was in-filled with crushed stones and leveling was done using wooden rod. After that the embankment is constructed and the load is applied over the embankment. The ultimate bearing load carrying capacity was increased by 78.22% when using geo cells are used.

Experimental study on shear strength of recycled construction materials intended for use in vibro ground improvement.
Mckelvey.D.et.al (2002) investigated the shear strength of recycled construction materials intended for use in vibro ground improvement. This paper aims on the replacement of granular materials. They made a comparative study between crushed concrete, building debris, quarry waste. Crushed concrete and building debris were tested by using a shear box of suitable dimension. In this test different vertical pressures were applied and each layer of the respective material was compacted using proctor hammer. To systemize the energy provided to the setup they have used a metal plate of suitable dimension for crushed concrete and building debris. The same procedure was followed for quarry waste with a replacement of wooden block placed over it during the supply of load. As a result it is concluded that the usage of recycled materials instead of naturally available resources has a good impact. Especially high grade recycled concrete wastes possess better strength and are a good refilling material. Usage of these materials does not affect the overall performance in construction. It was also observed that addition of such materials in the construction should be careful as there are possibilities for the materials to get smudged (contamination).

Experimental study on soil improvement using additives.
Mohammad Bilal.et.al (2016) gives a brief study on soil improvement using additives, by mechanical method, soil improvement without using admixtures, preloading and thermal methods. Soil improvement using additives involves the usage of additives like lime, cement and fly ash. Research study shows the improvement in load bearing capacity, workability, stiffness and stability of the soil sample. Soil improvement by mechanical method deals with the compaction of soil by rollers, vibrators, etc. This method is followed by Stone column, Vibro Floatation, Micro Piles and Soil Nailing. Stone column method involves the process of extraction and backfilling the

excavated area by stone filling. Vibro compaction is same as stone column and the granulated soil is used as the backfill material. Micro pile is a process of inserting the steel piles which effectively resist the compressive, tensile or lateral loads. Soil Replacement involves the replacement of soft soil with well compacted suitable materials which involves techniques like Soil Replacement, Vertical Drains, Sand Drains, Pre-Fabricated Vertical Drains (PVDs). Soil improvement using thermal involves heating and freezing. Strength of the soil can be improved by heating and freezing involves the reduction in temperature which causes the water to freeze and it acts as cementing agent.

Experimental study on ground improvement techniques involving vibro-compaction, vibro-flotation.

NimishaKachra.et.al (2016) discussed about the experimental study on ground improvement techniques involving vibro-compaction, vibro-flotation, back-fill material, vibro-displacement, soil-nailing and grouting. Vibro-compaction is mostly suitable for loose soil, which compacts and densifies the soil using vibrator. Vibro-flotation is mainly implemented for the soil which does not have optimum relative density. In this method, oscillator vibrator is used to achieve a densely packed soil particle thereby reducing the displacement. Backfill material is used to refill the same dug out or excavated area of a particular region. Vibro -displacement method carries the process of displacing the soil. Soil nailing is a remedial construction technique which involves the reinforcement bars to treat the unstable soil structures. Grouting is the method of filling the holes of excavated area with closely compacted material i.e., denser material in the place of reinforcement.

Experimental study on bearing capacity of embedded strip foundation on geo grid-reinforced sand.

Patraa.C.R.et.al (2005) studied the bearing capacity of embedded strip foundation on geo grid-reinforced sand. Geo grids are polymeric products which come under geo synthetic materials used to reinforce the soft soil structures. This is considered to be an emerging technology which can be used as an alternative of geotextile. These grids are used to overcome the tension force which pulls the soil aside. The foundation used for this experiment was made out of mild steel plate. The base of the foundation was made rough by applying glue and rolling it on sand. The inner surface walls of mild steel plate were polished to decrease its friction rate. The foundation and the geo grid were placed beneath the soil surface at a desired height. Different loads were applied on this setup and the results were recorded until the setup reached its failure point. These types of experiments can be conducted on weak cohesive soil which is useful for the determination of bearing capacity of the soil, the efficiency of reinforcement.

Experimental study on development of ground improvement techniques being introduced in the recent time and old days.

Dr. Tiwari S.K.et.al (2014) investigated the development of ground improvement techniques being introduced in the recent time and the methods which were used in olden times. The techniques were Mechanical improvement technique, Hydraulic modification, Physical and chemical modification. Mechanical improvement technique involves the application of mechanical force, in which the density of the soil is increased. Static or fixed type vibrators are used in such cases. In Hydraulic modification, the refinements of soil properties are attained by pressurizing the pore water out from the soil by means of wells or drains. The water level is reduced in case of coarse grained soil by laying bores or trenches. For fine grained soil, external or artificial loads are applied. While dealing with Physical and chemical modification methodology, adhesive materials

are mixed physically which are used to hold up the constituents together. Natural soil wastes or cementing materials can also be used. In some instances, the adhesives are inserted through grouting.

Experimental study on Ground improvement techniques by compaction piling

Zoltan V.Solymar.et.al (1986) discussed Ground improvement techniques by compaction piling. This experiment is done on loose silty fine sand which is prone to liquefaction caused by seismic disturbances. To prevent liquefaction in such loose soils and to reduce the settlement, following tests were conducted and results were recorded. Cone Penetration Test (CPT) shows the relation between relative density and the volume of soil sample taken. Standard Penetration Test (SPT) gives that resistance against penetration in loose silty fine sand is uniform after compaction. After performing the tests, it showed slight increment in the results. It was also studied that, this type of sand does not liquefy much during seismic occurrence. Buckling or horizontal movement or failure of steel piles may happen due to liquefaction in loose silty fine sand and results in decreasing the lateral support of steel piles. Compaction piling is done to get rid of these difficulties and also stabilize the soil. Compaction piling involves the process of drilling of holes and back filing the hole with layered sand. The usage of compaction pile increases the permeability, densifies the soil against earthquake, and increases the firmness of the soil.

Conclusion

Due to population increase and rapid urbanization there is a high demand for stable and firm sand for construction of buildings as well as highways. Improving the properties of loose soil and soft clay by ground implement techniques prevents the settlement and collapse of the structures built on it. The stability and bearing capacity of the soil has been raised by controlled compaction method or by addition of admixture or stabilizer. The most effective method of stabilization of fine-grained soil is Terra Zyme. On the other hand, high permeable soils are stabilized by grouting. Electrical and chemical stabilization also involves improving the soil properties which are expensive compared to other modes of stabilization. A system of Prefabricated vertical drains (PVDs) combined with vacuum preloading is an effective method of for accelerating soil consolidation. From the test results, it is evident that, Natural vertical drains are comparatively less than polymer prefabricated drains. But, still further more studies are required on Natural polymer vertical drain.

The unstable slopes of soils were economically remediated by soil nailing. Geo-textile and Geo-membrane are widely used nowadays for improving soil characteristics. Although variety of improvement techniques have developed, the suitable method has been adopted based on the economy needed and structure to be constructed. A combination of suitable techniques based on the type of soil, type of project may provide a most sustainable solution for ground improvement solution.

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