International Journal of Emerging Technologies in Engineering Research (IJETER)
Volume 5, Issue 9, September (2017) www.ijeter.everscience.org

Influence of Geopolymers in the Stabilization of Clay Soil

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Abstract – Soil stabilization means alteration of the soils properties to meet the specified engineering requirements. Searching for the best soil stabilizers to overcome problems occur by the soft soils are still being the main concern, not only to achieve the required soil engineering properties but also by considering the cost and the effect to the environment. Investigation on various materials had been done in order to evaluate their effectiveness as soil stabilizer. Others are causing hazardous effects on the environment and are most harmful to human health. Out of several techniques available for improving the shear strength, our project aims at probing the efficacy of Geopolymer a new eco-friendly binder material in improving the Strength Characteristics of Soft Clay and Sand Mixes. Geopolymer with its high strength, low cost, low energy consumption and CO_2 emissions during synthesis, offers a promising alternative to the above discussed materials. In this study, metakaolin based geopolymer at different concentration (2% & 4%) to examine the feasibility of geopolymer in stabilizing soils. Geopolymer stabilized soil specimens were characterized with Unconfined Compressive Strength test (UCS), Standard Proctors Compaction test. This study illustrated that metakaolin based geopolymer can be an effective soil stabilizer for clayey soil.

Index Terms – Geopolymer, M30-Mix proportion , metakaolin.

1. INTRODUCTION

1.1 GENERAL:

Geotechnical properties of problematic soils such as soft fine-grained and expansive soils are improved by various methods. The problematic soil is removed and replaced by a good quality material or treated using mechanical and/or chemical stabilization. Different methods can be used to improve and treat the geotechnical properties of the problematic soils (such as strength and the stiffness) by treating it in situ. These methods include densifying treatments (such as compaction or preloading), the bonding of soil particles (by ground freezing, grouting, and chemical stabilization). The chemical stabilization of the problematic soils (soft fine-grained and expansive soils) is very important for many of the geotechnical engineering applications such as pavement structures, roadways, building foundations, channel and reservoir linings, irrigation systems, water lines, and sewer lines to avoid the damage due to the settlement of the soft soil or to the swelling action of the expansive soils.Method of stabilisation by mixing clay soil with stabilising agents or binders have been well established to improve engineering properties of the ground which results in improved bearing capacity and reduced settlements under imposed loads.

1.2 SOIL STABILIZATION

Soil stabilization in the broadest sense refers to the procedure employed with a view of altering one or more properties of a soil so as to improve its engineering performance.

It includes both physical stabilization [such as dynamic compaction] and chemical stabilization [such as mixing with cement, fly ash, lime, and lime By-Products, etc]

a).Mechanical Stabilization

Under this category, soil stabilization can be achieved through physical process by altering the physical nature of native soil particles by either induced vibration or compaction or by incorporating other physical properties such as barriers and nailing. Mechanical stabilization is not the main subject of this review and will not be further discussed.

b).Chemical Stabilization

Under this category, soil stabilization depends mainly on chemical reactions between stabilizer (cementitious material) and soil minerals (pozzolanic materials) to achieve the desired effect.

1.3 NEED OF SOIL STABILIZATION

Soil stabilization refers to the process of changing soil properties to improve strength and durability. There are many techniques for soil stabilization, including compaction, dewatering and by adding material to the soil. Mechanical stabilization improves soil properties by mixing other soil materials with the problematic soil to change the gradation and therefore change the engineering properties. Chemical stabilization used the addition of cementitious or pozzolanic materials to improve the soil properties. Chemical stabilization has traditionally relied on Portland cement and lime for chemical stabilization.

The sub-grade is the most important layer in the road pavement which must have minimum strength to construct the pavement. But all the sub-grade soils will not be having minimum strength. So, it must be stabilized with soil stabilizers to gain the strength. The soil must be stabilized otherwise it may not satisfy the requirement as pavement material. This is not only economic solution, but offers a potential use of industrial/domestic waste materials.

Advantages of stabilization are summarized below:

1) Improved stiffness and tensile strength of the material

2) Reduction in pavement thickness

3) Improved durability and resistance to the effect of water

4) Reduction in swelling potential

1.4 SOIL STABILIZERS

1.4.1 Lime stabilization:

Lime stabilization may refer to pozzolanic reaction in which pozzolano materials reacts with lime in presence of water to produce cementitious compounds (Sherwood, 1993, Euro Soil Stab, 2002). The effect can be brought by either quicklime, CaO or hydrated lime, Ca (OH)2. Slurry lime also can be used in dry soils conditions where water may be required to achieve effective compaction.

1.4.2 Cement stabilization:

Cement is the oldest binding agent it may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required. Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil. This can be the reason why cement is used to stabilize a wide range of soils.Numerous types of cement are available in the market; these are ordinary Portland cement, blast furnace cement, sulfate resistant cement and high alumina cement. Usually the choice of cement depends on type of soil to be treated and desired final strength. Calcium silicates, C3S and C2S are the two main cementitious properties of ordinary Portland cement responsible for strength. Calcium hydroxide is another hydration product of Portland cement that further reacts with pozzolanic materials available in stabilized soil to produce further cementitious material (Sherwood, 1993). Normally the amount of cement used is small but sufficient to improve the engineering properties of the soil and further improved cation exchange of clay. Cement stabilized soils have the following improved properties:

- decreased cohesiveness (Plasticity)
- decreased volume expansion or compressibility
- increased strength

1.4.3 Bitumen stabilization:

Bitumen material such as asphalt and tars have been used for soil stabilization This method is better suited to granular soil and dry climates.

1.4.4 Injection stabilization:

Injection of the stabilising agent into the soil is called grouting. This process make it possible to improve the properties of natural soil and rock formations, without excavations, processing and compaction. To improve strength properties or to reduce permeability by filling cracks, fissures and cavities in the rock and the voids in soil with the stabilizers.

1.4.5 Fly ash stabilization:

Fly ash also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. Ash that does not rise is called bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Stabilization can be achieved with a variety of chemical additives including lime, fly ash, and Portland cement. Proper design and testing is an important component of any stabilization project. This allows for the establishment of design criteria, and determination of the proper chemical additive and admixture rate that achieves the desired engineering properties

1.4.6 Rice husk stabilization:

Thus the use of agricultural waste (such as rice husk ash -RHA) will considerably reduce the cost of construction and as well reducing the environmental hazards they causes. Rice husk is an agricultural waste obtained from milling of rice. About 108 tons of rice husk is generated annually in the world. Hence, use of RHA for upgrading of soil should be encouraged

1.5 SELECTION OF SOIL

1.5.1 Introduction:

Soft Clay is a material with low strength and markedly affected by water but it can be relatively strong in dry condition. If water is added to clay, it will behave as plastic or flow like liquid.

These soils cause distress and damage to structures founded on them as they show volumetric changes in response to changes in their moisture content.Due to the changes in climatic conditions on the construction site, structures on the clay will have less durability and requires lot of maintenance cost.Geotechnical problems posed by clay can be handled by various soil stabilization techniques. Here, the improvement of soil is done by adding geopolymer binders in specific proportions

1.5.2 Properties of clay:

a).Physical properties:

The following properties are observed from visual classification in dry condition.

- Colour -- Black colour
- Odour -- Odour of decaying vegetation
- Texture -- Fine grained
- Size -- <2μm
- Dilatancy -- Less Sluggish
- Plasticity --Highly plastic
- Specific Gravity -- 2.45
- Strength -- Very hard when it is dry but loses its strength on wetting

b).Chemical properties:

- PH Value at 25°C – 7 to 8
- Electrical Conductivity -- 21000 mS/cm
- Solvable Salts -- 68250 micro gram/ grams of dry soil
- Carbonates as Co_3 --30 micro gram/ grams of dry soil
- Organic Solids -- 14.54 %
- Chlorides as Cl --27990 micro gram/ grams of dry soil

c).Engineering properties:

- Clay in India have liquid limit values ranging from 50 to 100 %, plasticity index ranging from 20 to 65 % and shrinkage limit from 9 to 14 %.
- Cohesion, C -- 12 .20 t/m2
- Angle of Internal friction, Ø -- 2°
- Optimum Moisture Content -- O.M.C. 21%
- Maximum Dry Density M.D.D. 1.48 -- gm/cc
- It has very low shear strength and high compressibility.
- clay is very sensitive to change the stress system, moisture content and system chemistry of the pore fluid.
- Free swell of clay is around 80%.

1.5.3.Identification of clay soil:

Many methods are presently available that can be used to assess the potential volume change characteristics of a soil. However, it is frequently desirable to know the predominant clay mineralogy of the soil in order to better assess its potential for shrink-swell activity. Simple classification tests can only imply the soil activity whereas more This paper will present the results of a substantial testing program that correlates such soil properties as Atterberg limits, cation

1.5.4 Methods of identification:

The methods commonly used include

X-ray diffraction,

Chemical analysis,

Electron methods of microscope resolution,

Differential thermal analysis,

Gravimetrical analysis,

Infrared analysis.

1.6 Soil stabilization using geopolymer

1.6.1 Geopolymer:

Geopolymers are new materials for fire- and heat resistant coatings and adhesives, medicinal applications, high-temperature ceramics, new binders for fire-resistant fiber composites, toxic and radioactive waste encapsulation and new cements for concrete. The properties and uses of geopolymers are being explored in many scientific and industrial disciplines: modern inorganic chemistry, physical chemistry, colloid chemistry, mineralogy, geology, and in other types of engineering process technologies. Geopolymers are part of polymer science, chemistry and technology that forms one of the major areas of materials science. Polymers are either organic material,i.e. carbon-based, or inorganic polymer, for example silicon-based. The organic polymers comprise the classes of natural polymers (rubber, cellulose), synthetic organic polymers (textile fibers, plastics, films, elastomers, etc.) and natural biopolymers (biology, medicine, pharmacy).Raw materials used in the synthesis of silicon-based polymersare mainly rock-forming minerals of geological origin,hence the name: geopolymer.

1.6.2 Types of geopoymer

- Metakaolin MK-750-based geopolymer binder
- chemical formula (Na,K)-(Si-O-Al-O-Si-O),
- ratio Si:Al=2 (range 1.5 to 2.5)
- Silica-based geopolymer binder
- chemical formula (Na,K)-n(Si-O-)-(SiOAl-),
- ratio Si:Al>20 (range 15 to 40).
- Sol-gel-based geopolymer binder (synthetic MK-750)
- chemical formula (Na,K)-(Si-O-Al-O-Si-O),
- ratio Si:Al=2

1.6.3 Existing applications of geopolymer:

Commercial applications

There exist a wide variety of potential and existing applications. Some of the geopolymer applications are still in development whereas others are already industrialized and commercialized.

Geopolymer resins and binders;

- Fire-resistant materials, thermal insulation, foams;
- Low-energy ceramic tiles, refractory items, thermal shock refractory.
- High-tech resin systems, paints, binders and grouts;
- Bio-technologies (materials for medicinal applications);
- Foundry industry (resins), tooling for the manufacture of organic fiber composites;
- Composites for infrastructures repair and strengthening,
- Fire-resistant and heat-resistant high-tech carbon-fiber composites aircraft interior and automobile;
- Radioactive and toxic waste containment;

Geopolymer cements and concretes

- Low-tech building materials (clay bricks),
- Low-CO2 cements and concretes;Arts and archaeology,Decorative stone artifacts, arts and decoration;Cultural heritage, archaeology and history of sciences

1.6.4 Characteristic Properties Of Geopolymer:

- Geopolymer is essentially temperature dependent.
- It is X-rays amorphous at room temperature
- Microstructure of geopolymer comprises small aluminosilicate clusters. The clusters sizes are between 5 and 10 nanometres.
- It structure seems a highly porous network.
- It is fire-resistant and provides thermal insulation.
- It act as a refractory medium in rotary kilns.
- Geopolymer forms High-tech resin systems, paints, binders and grouts.
- It plays a part Bio-technologies (materials for medicinal applications) and industry (resins), It provides tooling for the manufacture of organic fibre composites for infrastructures repair and strengthening.It influences carbon-fibre composites for aircraft interior, automobile, radioactive and toxic waste containment.

1.6.5 Geopolymer – superior soil stabilizer

Geopolymer composites have three main properties that make them superior than any other stabilizers.
First:
Geopolymers are very easy to make, as they handle easily and do not require high heat and eco-friendly.

Second:
Geopolymeric composites have a higher heat tolerance than organic composites. Tests conducted on Geopolymer carbon - composites showed that they will not burn at all, no matter how many times ignition might be attempted.

Third:
The mechanical properties of Geopolymer composites are as good as those of organic composites. In addition, Geopolymers resist all organic solvents (and are only affected by strong hydrochloric acid).

1.7 Material for soil stabilization

1.7.1 Metakaolin based geopolymer:

Metakaolin MK-750-based geopolymer binder

chemical formula (Na,K)-(Si-O-Al-O-Si-O-),

ratio Si:Al=2 (range 1.5 to 2.5)

Metakaolin MK-750-based resins are used to impregnate fibers and fabrics to obtain geopolymer matrix-based fiber composites. These products are fire-resistant; they release no smoke and no toxic fumes.

1.7.2 Metakaolin source:

Metakaolin is a dehydroxylated form of the clay mineral kaolinite. Stone that are rich in kaolinite are known as china clay orkaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume.

2. LITERATURE REVIEW

2.1 Previous research work on soil stabilization

Stabilization of soft clay soil

Study on stabilization of soft clay soil using stabilizers such as marble dust, rice husk, geopolymers has been described in several articles in technical reports, journals and trade magazines. Most of the authors have used marble dust for stabilizing clay soil.Following literature has been studied and brief reviews of literature on earlier work done in soil stabilization with different types of stabilizers and its composites, properties, its dimensions, experimental methodology conducted by various investigators so far are given below.

1. Mo Zhanga *et al.* (2013) have studied, a lean clay was stabilized with metakaolin based geopolymer at different concentration (ranging from 3 to 15 wt. % of unstabilized soil at its optimum water content) to examine the feasibility of geopolymer in stabilizing soils. Geopolymer stabilized soil specimens were characterized with compressive strength testing, volume measurements during curing, scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and X-ray diffraction (XRD). The testing results indicated that with geopolymer concentrations, compressive strength, failure strain and Young's modulus of the stabilized soil specimens increased, and shrinkage strains during curing decreased. The micro structural analyses confirmed the formation of geopolymer gels in the stabilized soil, and showed the soil tended to form more homogeneous and compact microstructures after stabilization. This study illustrated that metakaolin based geopolymer can be an effective soil stabilizer for clayey soils. In this study, the feasibility of using metakaolin based geopolymer as a soil stabilizer at shallow depth was confirmed. SEM–EDX and XRD results showed that MKG gels effectively developed in the soil, which assist the soil particles to form more compact microstructures and improve its mechanical properties and volume stability. The UCS values of MKG stabilized soils are much higher than the soil, and higher than 5% PC stabilized soil when MKG concentration is higher than 11%. However, the strength increase from 7-day curing to 28-day curing is not appreciable, which might be due to quick reactions of MK-based geopolymer precursor.

2. R. DayakarBabu*et al*. (2013) evolved the new generation of soil stabilizer by introducing geopolymer. It reveals that the inclusion of different percentages of geopolymer to the blends of soft clay and sand had certainly improved the strength parameters and also proved that geopolymer stabilization was effective. From the detailed analysis of the obtained test results and therein its discussions infer the following conclusions, (i) The Cohesion (C) of soft clay and sand blends had been considerably improved with the increase in percentage of geopolymer content. (ii) The angle of internal friction (φ) of soft clay and sand blends had been marginally improved with the increase in percentage of geopolymer. (iii) The inclusion of different percentages of geopolymer to the blends of soft clay and sand proved to be effective in improving the strength parameters i.e. Cohesion and Angle of Internal friction. (iv) The same trend was observed to be very much similar for all the percentages of geopolymer content i.e., 0%, 5%, 10% and 15% for both Cohesion and Angle of Internal friction. (v) Finally, the authors conclude that the waste & weak soft soil can be improved effectively by replacing locally available granular material and further stabilizing it with optimum content of geopolymer.

3.S. Kolias.V, Kasselouri-Rigopoulou, A. Karahalios*et al.* (2004) studied the effectiveness of using high calcium fly ash and cement in stabilizing fine-grained clayey soils (CL,CH). Strength tests in uniaxial compression, indirect (splitting) tension and flexure were carried out on samples to which various percentages of fly ash and cement had been added. Modulus of elasticity was determined at 90 days with different types of load application and 90-day soaked CBR values were also reported. Pavement structures incorporating sub grades improved by in-situ stabilization with fly ash and cement were analysed for construction traffic and for operating traffic. These pavements were compared with conventional flexible pavements without improved sub grades and the results clearly show the technical benefits of stabilizing clayey soils with fly ash and cement. In addition TG–SDTA and XRD tests were carried out on certain samples in order to study the hydraulic compounds, which were formed.

4. NurhayatDegirmenci*et al.* (2007) described the application of phosphogyp sum with cement and fly ash for soil stabilization. Atter berg limits, Standard Proctor compaction and unconfined compressive strength tests were carried out on cement, fly ash and phosphogyp sum stabilized soil samples. Treatment with cement, fly ash and phosphogyp sum generally reduces the plasticity index. The maximum dry unit weights increased as cement and phosphogyp sum contents increased, but decreased as fly ash content increased. Generally optimum moisture contents of the stabilized soil samples decreased with addition of cement, fly ash and phosphogyp sum. Unconfined compressive strengths of untreated soils were in all cases lower than that for treated soils. The cement content had a significantly higher influence than the fly ash content. It was further concluded that the treatment with phosphogyp sum fly ash and cement generally reduces the plasticity index. Principally, a reduction in plasticity is an indicator of improvement. The maximum dry unit weight of the soil increased with the additive content. Fly ash on the other hand decreased the maximum dry unit weight.

5. SeyedAbolhassanNaeini*et al.* (2012) carried out an experimental investigation on the influence of waterborne polymer for unconfined compressive strength of clayey soils. With the use of non-traditional chemical stabilizers in soil improvement daily, a new stabilizing agent was developed to improve the mechanical performance and applicability of clayey soils. He carried out various laboratory tests including sieve analysis, hydrometer, Atterberg Limits, modified compaction and Unconfined compression tests. Three clayey soil specimens with different plasticity indexes were mixed with various amounts of polymer (2, 3 and 5%) and compacted at the optimum water content and maximum dry density. The experiments on these samples concluded that the waterborne polymer significantly improved the strength behaviour of unsaturated clayey soils. Furthermore, an increase in plasticity index caused a reduction in unconfined compression strength. Results showed that with soils stabilized with 4% polymer had higher unconfined compressive strength than other percentages. The stress-strain plots of the tests showed that as the plasticity increased, the soil yielded a higher strain.

6. Joseph Davidovits and Michel Davidovics*et al*. (1991) have studied geopolymer as a ultra-high temperature tooling material for the manufacture of advanced composites. Although geopolymers are more expensive than the most other castable mineral compounds, their superior performances often makes them ultimately more economical. Since they are adaptable, geopolymer resins can be formulated for a multiplicity of processes, such as castable compounds, filament winding, wet lay-up composite or dry lay-up with prepregs. The material and process will yield the most accurate dimensions in the tool as the tool is being copied directly from PFP masters. As part of the impregnation process, the interface is important in obtaining high translation of fiber properties in the Geopolyceram composite. The interface problem, along with other problems should be studied. It seems clear that the sizings used on carbon fibres and silicon carbide fibres for organic thermosetting prepreg would not be appropriate for geopolymer prepregs. Geopolymers of the Poly(silicate-disiloxo) type (-Si-O-Al-Si-O-Si-O-), very-low viscosity inorganic resins, harden like thermosetting organic resins, but have use-temperature range up to 1000°C (1830°F) and geopolymers provide faithful reproduction of mould or die surface and allow for precision and fineness.

7. Francesco Colangelo*et al.* (2013) prepared reports for the first time the preparation and characterization of geopolymeric mortars containing epoxy resins. The composites are produced by the addition of polymerizable commercially available epoxy monomers in liquid form to the geopolymeric mortar suspension during mixing. Epoxy-modified systems harden by the simultaneous progress of geopolymerization and epoxy polymerization. The hardened epoxy resins form spherical particles (whose diameter ranges from 1 to 50 μm) homogenously dispersed into the inorganic matrix. As a result, a co-matrix phase is formed that binds aggregates strongly. In respect to the neat geopolymeric mortars, the geopolymeric hybrid mortars prepared present: (i) Improved strength: the polymer-modified mortars have improved compressive strength in comparison with unmodified ones. Furthermore, the polymer in the mortar helps restrain micro-crack propagation, which improves the overall toughness of the mortar. (ii)The total porosity decreases with the addition of the organic polymer. This may contribute to improve gas and water impermeability and consequently the durability. These improved properties allow the use of polymer-modified geopolymeric mortars in several applications that would otherwise be difficult or impossible, including concrete reinforcement and repair, decorative cement overlays, and many others. For these reasons polymer-modified geopolymeric mortars are promising construction materials for the future because of the good balance between their performance and cost compared to other mortar-polymer composites.

8.Raghavendra S.R &Girisha Y.A *et al.* (2012) have studied stabilization of black cotton soil using fly ash and geopolymer. They concluded that the experimental results on Black Cotton Soil stabilized with Fly ash and Geopolymer and got the following results. (i)The specific Gravity of the soil for construction purpose should be 2.6 to 2.8, whereas the Black Cotton soil of this project had a specific gravity of 2.45. Through experiments by addition of stabilizing agents like Fly ash and Geopolymer in quantities like 2%, 4% and 6% has showed the increase in specific gravity of the soil to 2.51, 2.58, and 2.72 respectively. (ii) The liquid limit of the soil should be less for construction purpose. Black Cotton Soil of this project had a liquid limit of 84% initially. Further by addition of stabilizing agents like Fly ash and geopolymer in percentages like 2%, 4% and 6% the liquid limit was reduced to 70%, 65% and 53% respectively. (iii) The shrinkage limit is the main factor responsible for volume changes in soil. The Black Cotton soil exhibits drastic changes in its volume when exposed to water. The shrinkage limit of the Black cotton soil of this project was 13.16% further by addition of stabilising agents like Fly ash and geopolymer in percentages like 2%, 4% and 6% the shrinkage limit of the soil was reduced to 13.05%, 12.78 and 12.07 respectively. (iv)The Black Cotton soil was subjected to compaction test by Jodhpur mini compacting mould where the Maximum Dry Density (MDD) and Optimum Moisture Content obtained is 1.48 g/cc and 21%. (v)The soil for construction purpose should have good load bearing characteristics. This load baring capacities was determined by Unconfined Compression Strength test. The soil of this project had strength of 0.056 N/mm2. By addition of stabilising agents like Fly ash and Geopolymer in percentages like 2%, 4% and 6% the results obtained are 0.04 N/mm2, 0.095 N/mm2 and 0.083 N/mm2 respectively. (vi)Here it can be observed that the compressive strength was increasing up to addition of stabilizing agent till 4% on further addition there will be decrease in the soil strength. (vii) Finally it can be concluded that the stabilising agents like Fly ash and geopolymer will help in increasing the engineering properties of the Black Cotton soil. (viii) Oil like specific gravity, liquid limit, shrinkage limit, compaction characteristics and unconfined compressive strength.

2.2 Observations from literature review

The above review of literatures on the field of soil stabilization using geopolymer with its high strength, low cost, low energy consumption and CO2 emissions during synthesis plays a vital role as a soil stabilizer in future. So, further investigation has to be done in order to evaluate the potential of metakaolin based geopolymer in field application rather than focusing in term of experimental studies. And also from literatures we found the feasibility of using geopolymer as the next-generation soil stabilizer has been confirmed by this experimental study. The strength, stiffness, and ductility of the soil were improved after the stabilization with metakaolin based geopolymer. The shrinkage of the soil was reduced after the stabilization with metakaolin based geopolymer.

3. STABILIZATION METHODS

3.1.1 In–situ stabilization

The method involves on site soil improvement by applying stabilizing agent without removing the bulk soil. This technology offer benefit of improving soils for deep foundations, shallow foundations and contaminated sites. Planning of the design mix involves the selection and assessment of engineering properties of stabilized soil and improved ground. The purpose is to determine the dimensions of improved ground on the basis of appropriate stability and settlement analyses to satisfy the functional requirements of the supported structure. The technology can be accomplished by injection into soils a cementitious material such cement and lime in dry or wet forms. The choice to either use dry or wet deep mixing methods depend among other things; the in-situ soil conditions, in situ moisture contents, effectiveness of binders to be used, and the nature of construction to be founded. Depending on the depth of treatment, the in it stabilization may be regarded as either deep mixing.

3.1.2 Deep mixing method

The deep mixing method involves the stabilization of soils at large depth. It is an in situ ground modification technology in which a wet or dry binder is injected into the ground and blended with in situ soft soils (clay, peat or organic soils) by mechanical or rotary mixing tool (Porbaha et al, 2005; EuroSoilStab, 2002). Depending on applications, the following patterns may be produced single patterns, block patterns, panel pattern or stabilized grid pattern (EuroSoilStab, 2002). Note that, the aim is to produce the stabilized soil mass which may interact with natural soil and not, to produce too stiffly stabilized soil mass like a rigid pile which may independently carry out the design load. The increased strength and stiffness of stabilized soil should not, therefore, prevent an effective interaction and load distribution between the stabilized soil and natural soil (EuroSoilStab, 2002). Thus the design load should be distributed and carried out partly by natural soil and partly by stabilized soil mass (column).

3.1.3 Wet mixing method

Applications of wet deep mixing involve binder turned into slurry form, which is then injected into the soil through the nozzles located at the end of the soil auger (Massarsch and Topolnicki, 2005). The mixing tool comprise of drilling rod, transverse beams and a drill end with head. There are some modifications to suit the need and applications. For instance, the Trench cutting Re-mixing deep method (TRD) developed by circa Japan, in 1993 provides an effective tool for construction of continuous cutoff wall without the need for open trench. The method uses a crawler-mounted, chainsaw-like mixing tool to blend in-situ soil with cementitious binder to create the soil-cement wall. It further consists of a fixed post on which cutting, scratching teeth ride on a rotating chain and injection ports deliver grout into treatment zone. Wall depths up to 45 m having width between 0.5 m and 0.9 m are achievable. The wall quality for groundwater barrier is high with permeability between 1 x 10-6 and 1 x 10-8 cm/s (www.HaywardBaker.com). Similar to TRD, in 1994, Germany developed the FMI (Misch-Injektionsverfahren) machine. The FMI machine has a special cutting arm (trencher), along which cutting blades are rotated by two chain system. The cutting arm can be inclined up to 80 degrees and is dragged through the soil behind the power unit (Stocker and Seidel, 2005). Like TRD, the soil is not excavated, but mixed with binder which is supplied in slurry form through injection pipes and outlets mounted along the cutting arm

3.1.4 Dry mixing method

Dry mixing (DM) method is clean, quiet with very low vibration and produces no spoil for disposal (Hayward Baker Inc). It has for many years extensively used in Northern Europe and Japan. The method involves the use of dry binders injected into the soil and thoroughly mixed with moist soil. The soil is premixed using specialized tool during downward penetration, until it reaches the desired depth. During withdrawal of the mixing tool, dry binder are then injected and mixed with premixed soil leaving behind a moist soil mix column. In Scandinavians countries and Sweden in particular, this method is referred to as Lime Cement Column (LCC), whereas, in Italy, the method is termed as Trevimix and in Japan, the same technology is called dry jet mixing (DJM) (Bruce et al, 1996; Yasui and Yokozawa, 2005). A typical DM machine consists of track mounted installation rig and a drill motor. Binder is fed into compressed air through the hose into mixing shaft to the outlet of mixing shaft into the ground. Powdery binders under compressed air are injected into soft ground without processing into slurry form. Blade rotates creating a cavity in the soil in which air and binders fill in during withdrawal. During construction, the most efficient sequence is to work the stabilizing machine within its operational radius as much as possible (EuroSoilStab, 2002).

3.1.5 DEEP INJECTION METHOD

Geopolymer is allowed to blend with soft clay by the method of 'deep injection'.

Deep Injection Process: It is the process of injecting our expanding, high density geopolymer at subsurface depths. The Deep Injection Process allows for injection at the depth of voids or weak and unconsolidated soils, providing up to a 200% increase in ground bearing capacity.

3.1.6 Mass stabilization method

Mass stabilization is a shallow to deep stabilization method in which the entire volume of soft soil can be stabilized to a prescribed depth. The technique is relatively new and is highly suited for the stabilization of high moisture content such as clay, silty, organic soils and contaminated sediments (Euro Soil Stab, 2002; Hayward Baker Inc). Mass stabilization offers a cost effective solution to ground improvement in site remediation especially with a huge amount of contaminants and high water content. Remediation of most deposits of contaminated dredged sediments, organic soils and waste sludge usually make use mass stabilization method (Keller, 32-01E). The method provides an alternative to traditional method of soil improvement such as removal and replaces techniques.

D_{10} = 0From Eq. (I), $C_u = 2.85 < 4$........ silt soil is considered

3.1.7 Ex-situ stabilization

The technology involves dislodging of the soils and or sediments from the original position and moves to other place for the purpose of amendment. These can be encountered in dredging of river channel and Ports. The main objectives of dredging can be either for amending the contaminated sediments to reduce toxicity and mobility or to maintain or deepen navigation channels for the safe passage of ships and boats (US EPA, 2004). Offsite treatment of the sediment can be done in confined disposal facilities (CDF) and then be used or disposed at designated site.

3.2 TESTING OF SOIL STABILIZATION

3.2.1 Test to be done on un-stabilized soft clay

3.2.1.1 Sieve analysis :

Determination of percentage of different grainsizes in soil passing through 4.75 is sieve and retained on 75-micron is sieve

A grain size distribution curve is also used to determine the coefficient of uniformity (C_u) and coefficient of curvature (C_c).

Co-efficient of Uniformity (C_u) = D_{60}/D_{10}………………………………..... (I)

Co-efficient of curvature (C_c) =$(D_{30})^2$ / **(** D_{10} x D_{60}**)**………………………….. (II)

Where,

D_{60} = diameter of particles corresponding to 60% fines;

D_{10} = diameter of particles corresponding to 10% fines, also known as effective size; D_{30} = diameter of particles corresponding to 30 % fines;

PROCEDURE:

1. Take 500gm oven dried sample passing through IS sieve 4.75mm. Clean the different sizes of sieve with brushes and weigh all sieves separately in balance.
2. Assemble sieve in ascending order of sizes i.e. 4.75mm, 2.36mm, 1.18mm, 600µ, 300µ, 150µ, 75µ and pan. Carefully pour the soil sample into top sieve and place lid on top.
3. Place the sieve stack in the mechanical shaker and shake for 10 minutes.
4. Remove the stack from the shaker and carefully weigh and record the

From Eq. (II), $C_c = 0.986 \approx 1$.....well graded soil

OBSERVATIONS AND CALCULATIONS:

TABLE NO 1: SIEVE ANALYSIS

<u>Sieve Analysis of Fraction Passing 4.75mm IS</u>

Sieve Designation	Mass of soil Retained and Mass of Container	Mass of Container	Mass of Soil Retained	Cumulative Mass Retained	Soil Retained as % of Partial Soil Taken	Soil Passing as Percentage of Partial Soil Sample Taken for Analysis
mm I		gm III	Gm IV=II-III	gm V	% VI=V/500 .22%	% VII=100-VI
4.75	506.62	506.62	0	0	0.000	100.000
2.36	430.6	427	3.6	3.6	2.718	97.282
1.18	344.62	334.62	10.0	13.6	5.013	94.783
0.6	449.38	428.11	21.27	34.87	12.78	87.962
0.3	427.61	376.97	50.64	85.51	30.08	69.746
0.15	436.86	344.32	92.54	178.05	64.67	36.135
0.075	499.35	356.8	142.55	320.6	78.16	21.622
Pan	541.78	363.48	178.3	499.67	_	_

but Retained on 75-Micron

weigh the soil retained in pan. From graph, $D_{60} = 0.8$, $D_{30} = 0.47$ and

MASS = 500gms

Chart no 1: Grain size analysis

3.2.1.2 Specific gravity

The specific gravity of soil is the ratio between the weight of the soil solids and weight of equal volume of water. It is measured by the help of a volumetric flask in a very simple experimental setup where the volume of the soil is found out and its weight is divided by the weight of equal volume of water.

Specific Gravity G =(W2−W1) / (W4−W1) –(W3−W2)

W1- Weight of bottle in gms

W2- Weight of bottle + Dry soil in gms

W3- Weight of bottle + Soil + Water

W4- Weight of bottle + Water

Specific gravity is always measured in room temperature and reported to the nearest 0.1

Table no 2: Specific gravity

sample number	1	2	3
mass of empty bottle (M1) in gms.	112.45	114.93	115.27
mass of bottle+ dry soil (M2) in gms.	162.45	164.93	165.27
mass of bottle + dry soil + water (M3) in gms.	390.088	395.38	398.16
mass of bottle + water (M4) in gms.	359.448	364.07	367.87
specific gravity	2.58	2.50	2.48
Avg. specific gravity	2.52		

3.2.1.3 Atterberg limits

Transitions of soil from one state to another state according to increase and decrease in water content are termed as Atterberg Limits. So this test is also called Atterberg limit test

a).Determination of liquid limit (by mechanical method) and plastic limit of soils.

The liquid limit is the water content at which soil changes from liquid state to plastic state. At this stage all soil behaves practically like a liquid and posses certain small shear strength. It flow close the groove in just 25 blows in Casagrande liquid limit device. As it is difficult to get exactly 25 blows in the test 3 to 4 tests are conducted, and the number of blows (N) required in ach test determined. A semi-log plot is drawn between log N and the water content (W). The liquid limit is the water content corresponding to N=25.The plastic limit is the water content at which soil changes from plastic state to semi-solid state. The soil in this stage behaves like plastic. It begins crumble when rolled in to threads 3mm diameter.

The Casagrande tool cuts a groove of size 2mm wide at the bottom and 11 mm wide at the top and 8 mm high. The number of blows used for the two soil samples to come in contact is noted down. Graph is plotted taking number of blows on a logarithmic scale on the abscissa and water content on the ordinate. Liquid limit corresponds to 25 blows from the graph.Moisture content in % = 100 x weight of water (gms) / weight of dry soil (gms)

Table no 3 Liquid limit

Sample No.	1	2	3
Mass of empty can	156.00	156.00	156.00
Mass of can + wet soil in gms.	206.00	221.56	216.48
Mass of can + dry soil in gms.	167.87	172.12	178.32
Mass of soil solids	25.13	27.46	23.32
Mass of pore water	15.86	15.99	12.83
Water content (%)	55.5	31.78	28
No. of blows	19	32	44

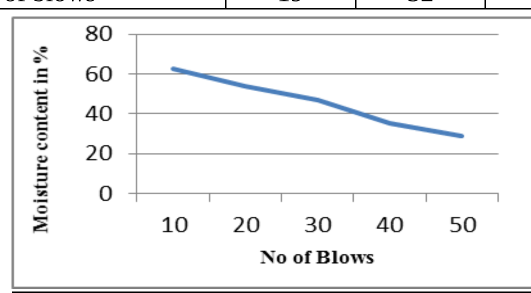


chart no 2: Liquid limit of soft clay

Plasticity index is the difference between its liquid limit and plastic limit.

Plasticity Index (I_p) = liquid limit (W_L) – plastic limit (W_P) …….. (1)

If the plastic limit is equal or greater than liquid limit, the plasticity index is reported as zero.

Non-Plastic–will not form a 6 mm dia, 4 cm long wire, or if formed, cannot support itself if held on end

Slightly Plastic–6 mm dia, 4 cm long wire wire supports itself, 4 mm dia, 4 cm long wire wire does not

Moderately Plastic–4 mm dia, 4 cm long wire wire supports itself, 2 mm dia, 4 cm long wire wire does not

Very Plastic–2 mm dia, 4 cm long wire wire

Table No 4 Plastic Limit

Sample No.	1	2
Mass of empty can	156.00	156.00
Mass of can + wet soil in gms.	176.00	176.56
Mass of can + dry soil in gms.	168.87	167.12
Mass of soil solids	11.13	10.46
Mass of pore water	8.86	9.63
Water content (%)	46.5	45.78
Average Plastic limit	46.14	

Plasticity index:

Ip = WL – WP = 55-46.14 = 8.86 low plasticity soil.

b).Determination Of Shrinkage Limit

Shrinkage limit can be determined for both undisturbed and remoulded soil. It is used to find out the structure of soil. The greater shrinkage, more the disperse structure. Because any soil that undergoes a volume change Volume expansion and contraction depend on period of time and both on soil type and its mineral and change in water content.Soil shrinkage (or contraction) is produced by soil suction. Suction is the phenomenon which produces a capillary rise of water in soil pores above water table.The aggregate which is retained over IS sieve 4.75mm is termed as coarse aggregate. The coarse aggregate may be of following types:

1.Crushed graves or stone obtained by crushing of gravel or hard stone.

2.Uncrushed graves or stone resulting from the natural disintegration of rocks.

3.Partially crushed gravel obtained of product of blending of above two types.

Table No 5 Plasticity Index

Sl.no	**DESCRIPTION**	SOIL SAMPLE
1	Determination No.	1
2	Shrinkage Dish No.	S-1
3	Weight of Shrinkage Dish in gm	35.82
4	Weight of Shrinkage Dish + wet soil pat in gm	79.53
5	Weight of shrinkage dish + dry soil pat in gm	67.80
6	Weight of oven dry soil pat (**W_0**) in gm.	31.68
7	Weight of water in gm	11.73
8	Moisture content (**w**) of soil pat in %	36.68
9	Density of Mercury (gm/ml)	13.53
10	Weight of mercury filling + weight of Glass cup	744.53
11	Weight of mercury filling shrinkage dish in gm	364.06
12	Weight of Glass Cup in gm	64.22
13	Weight of mercury after displaced by the dry soil pat + Weight of Glass cup in gm	479.03
14	Volume of wet soil pat (**V**) in ml	26.91
15	Weight of Mercury displaced by dry soil pat in gm	265.50
16	Volume of dry soil pat (**V_0**) in ml	19.62
17	$W_s = (V-V_0)/W_0 \times 100$	22.78
18	Shrinkage Limit from equation (2)	.90
19	Shrinkage Limit (**Ws**), %	13.90

$W_S = W-((V-V_O) / W_O) \times 100$.....................(1)

$I_S = I_P - W_S$ .... (2)

Good soil = $W_s < 5\%$

Medium soil = Ws 5-10%

Poor soil = Ws 10-15%

Very poor soil = Ws>15%

Ws= 13.90 a poor soil is considered

Table no 6 proctor compaction test

Sl no	Soil sample	1	2	3
1	Weight of empty mould(Wm) gms	2062	2062	2062
2	Internal diameter of mould (d) cm	10	10	10
3	Height of mould (h) cm	13	13	13
4	Volume of mould (V)=(π/4) d2h cc	1000	1000	1000
5	Weight of Base plate (Wb) gms	2071	2071	2071
6	Weight of empty mould + base plate (W') gms	4133	4133	4133
7	Weight of mould + compacted soil + Base plate (W1) gms	6234	6348	6347
8	Weight of Compacted Soil (W1-W') gms	2101	2215	2214
9	Weight of Container (X1) gms	19.49	21.55	20.15
10	Weight of Container + Wet Soil (X2) gms	130.21	119.28	125.00
11	Weight of Container + dry soil (X3) gms	106.51	102.32	108.94
12	Weight of dry soil (X3-X1) gms	87.02	80.77	788.75
13	Weight of water (X2-X3) gms	20.7	16.96	16.06
14	Water content W%= X2-X3/X3-X1	21.18	25	18.1
15	Dry density ϒd= ϒt/(1 + (W/100)) gm/cc	1.47	1.54	1.63

Optimum Moisture Content (OMC) = 21.18% , Maximum Dry Density (MDD) = 1.47 g/c

c).Determination Of Unconfined Compressive Strength

Water content = 21%

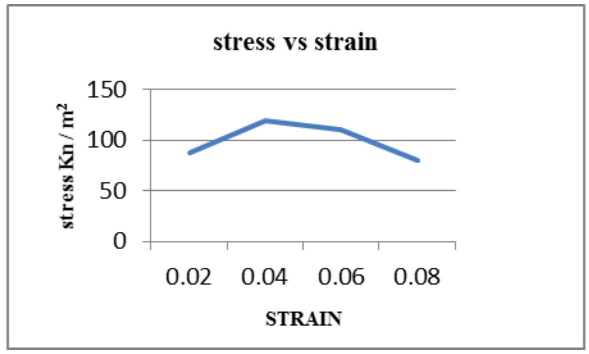
Volume of soil sample taken = $8.61 * 10^5\ m^3$ (dia 38 mm length 76 mm)

Mass of soil sample (M_s) = 173.26 gm

Initial Length (L_o), mm = 76

Initial Area (Ao), $mm^2 = 1133 mm^2$

Chart No 3: Stress Strain Curve



$E_S = 100 / 0.0229 = 4366.81\ Kn/m^2$

$C_U = q_u / 2 = 119 / 2 = 59.5\ Kn / m^2$

3.2.2.2 Atterberg Limits

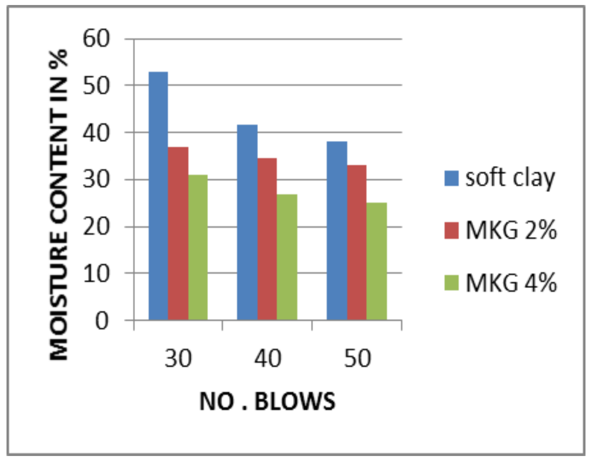


Chart No 5: Liquid Limit

PLASTICITY INDEX:

Ip = WL – WP = 28- 18 = 10 medium stiff

Ip = WL – WP = 27.76 – 12.7 = 15.76 slightly high

DETERMINATION OF SHRINKAGE LIMIT

$W_S = W-((V-V_O) / W_O) X 100$ ....(1)

$I_S = I_P - W_S$ .... (2)

Good soil = $W_s < 5\%$

Medium soil = Ws 5-10%

W_S = 7.8 shows medium soil

3.2.2.3. Proctor Compaction Test

a)Determination of water content-dry density relation using light compaction.

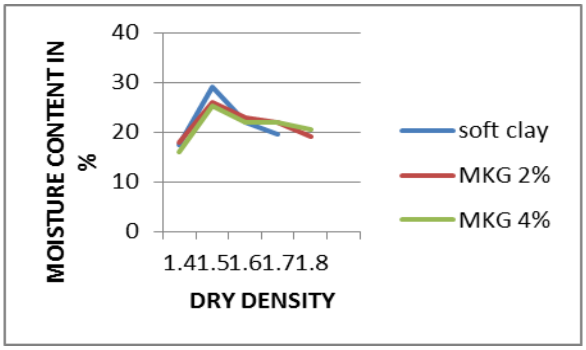


Chart No 6: Omc & Mmd

3.2.2.4 UNCONFINED COMPRESSION TEST

a).Determine Unconfined Compressive Strength Of Remoulded Soil

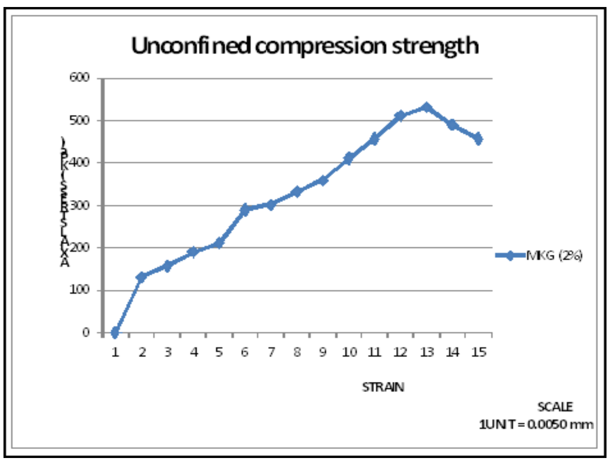


Chart N0 7 : MKG 2%

Metakaolin 4% test sample

b).Unconfined compressive strength test :

Metakaolin 4% test sample

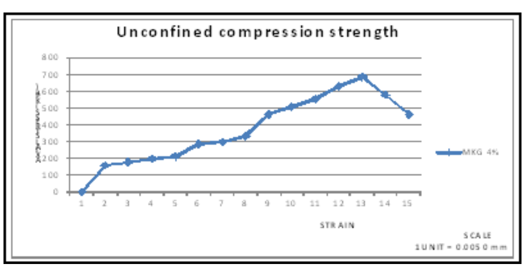


Chart N0 8 : MKG 4%

c).Comparison between (mkg 2% vs mkg 4%)

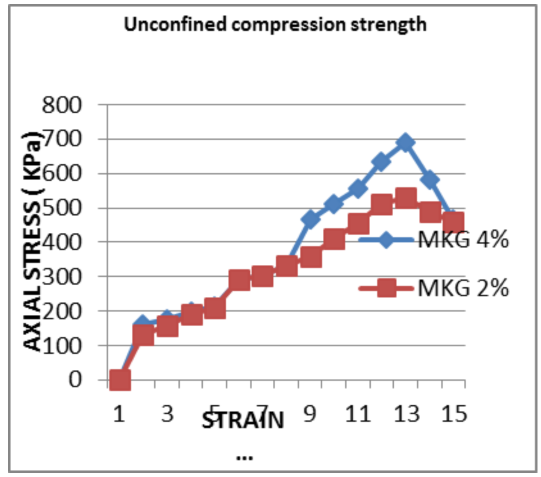


Chart N0 9 : Mkg 2% Vs Mkg 4% Of Ucs

c).COMPARISON BETWEEN (SOFT CLAY VS MKG 4%)

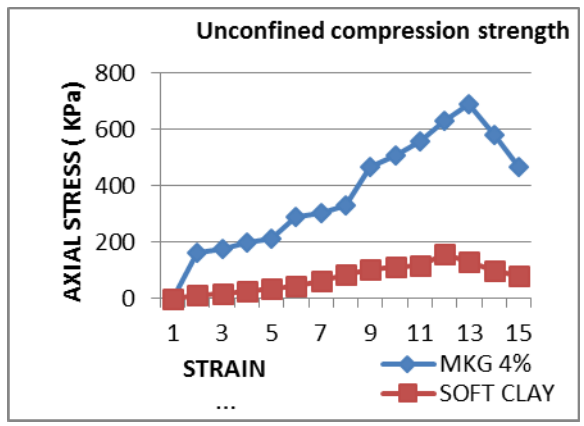


Chart No 10: Mkg 4% Vs Soft Clay Of Ucs

Comparison between the compressive strength of soils. (soft clay, mkg 2% & mkg 4%)

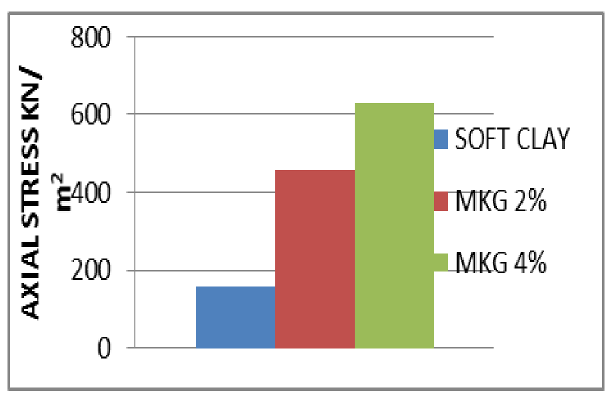


Chart No 11:Ucs Comparison Of Soft Clay & Mkg

4. RESULT AND DISCUSSION

Under the unconfined compression strength results shows that soft clay having 120 KN/m^2 . After applying metakaolin with the same soft clay taken shows that 4 times the normal soft clay sample.When comparing a soft clay with metakaolin 4% sample the strength increased and attains 6 times the softclay.

5. CONCLUSION

From the observations it is clear that when the metakaolin content increased, the compressive strength is increasing. Compared to metakaolin with 2% with clay soil 4 % of metakaolin proportion is good. The cost of metakaolin based geopolymer is economical. Further exploration can be done by using other by-products. From the detailed analysis of the obtained results and therein its discussions infer the below said conclusions.

1) The Cohesion (C) of soft clay with metakaolin had been considerably improved with the increase in percentage of geopolymer content.

2) The inclusion of different percentages of geopolymer to the blends of soft clay with metakaolin proved to be effective in improving the strength parameters

3) The same trend was observed to be very much similar for all the percentages of geopolymer content i.e., 0%, 2% and 4% for both Cohesion and compression strength.

4) Finally, we conclude that the waste & weak soft soil can be improved effectively by replacing locally available granular material and further stabilizing it with optimum content of metakaolin based geopolymer.

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