

Classification of Expansive Soils and Treatment Methods for Its Stabilization

Aishwarya Sinha

Master of Science

School of Civil Engineering

University of Birmingham,

E-mail: aishwarya28991@gmail.com

Abstract

This paper presents a research conducted to ascertain the feasibility of using different methods for stabilization of expansive soil. The primary focus of the research was concentrated on determination of the effect of different treatment methods on expansive soil, on its swelling pressure and plasticity characteristics and the optimum content of materials, such as marble dust for reduction in swelling potential. The effect of curing period on the swelling characteristics is also ascertained and explained in this paper.

Keywords: Expansive Soil, Swelling Pressure, Soil Treatment, Marble Dust

INTRODUCTION

Expansive soils are those which undergo large volume changes when they interact with water. The large differences in the volumes during dry and wet conditions pose a great danger to the environment. With the growing population and rapid industrialization, a large amount of wastes of different categories are generated all over the world. Handling and disposal of huge amount of wastes is becoming a threat to the environment.

Expansive soils are treated using various methods, the most common being lime, cement and fly ash. Though lime and cement improve the mechanical properties effectively, they are expensive because they need to be procured at cost as industrial products. Utilization of waste products in the treatment of expansive soil provides a viable alternative, since the properties of the soil, if appreciably improved, effectively puts in use the materials which would otherwise be considered as waste.

EXPANSIVE SOIL

Expansive soils are soils which undergo changes in volume with respect to the changes in the water content. They are also referred to as shrink/swell soils due their nature to expand with addition of water and contract with the removal of water, which leads to heaving and settlement of the ground. They are generally found in arid and semi-arid regions of the world. (Al-Rawas & Goosen, 2006).

Identification and Classification

1. Field Identification

Expansive soil behaves differently in various parts of the world and hence poses a problem in identification on the site. Expansive soil can be identified on site by the presence of cracks in the surrounding structures, shrinkage cracks in the ground during dry season and the hummocky terrain of the ground.

Geophysical techniques are used in the identification of the extent of the expansive soil along with Extensometers. The active zone is the top few meters of the ground which experiences heave due to the changes in the groundwater level.

Thus, piezometers are installed to measure the fluctuations in the groundwater level. (Advanced Engineering Geology and Geotechnics, 2004)

2. Laboratory Tests

- **Index Tests**

The Atterberg limit tests are carried out to classify the expansivity of the soil as discussed below. Plastic limit is the difference between the liquid limit and the plastic limit. The increase in the plasticity index of the soil suggests that the volume change potential of the soil has increased.

- **Shrink Swell Tests**

Shrink swell behaviour can be measured by three methods based on Al-Rawas & Goosen(2006) and Jones & Jefferson(2012).

A seating pressure is applied (generally 6.9 kPa) and water is added to the sample. The sample is prevented from swelling by application of incremental loads. Swelling pressure is pressure at which the specimen shows no

inclination to swell, as shown in figure 1.

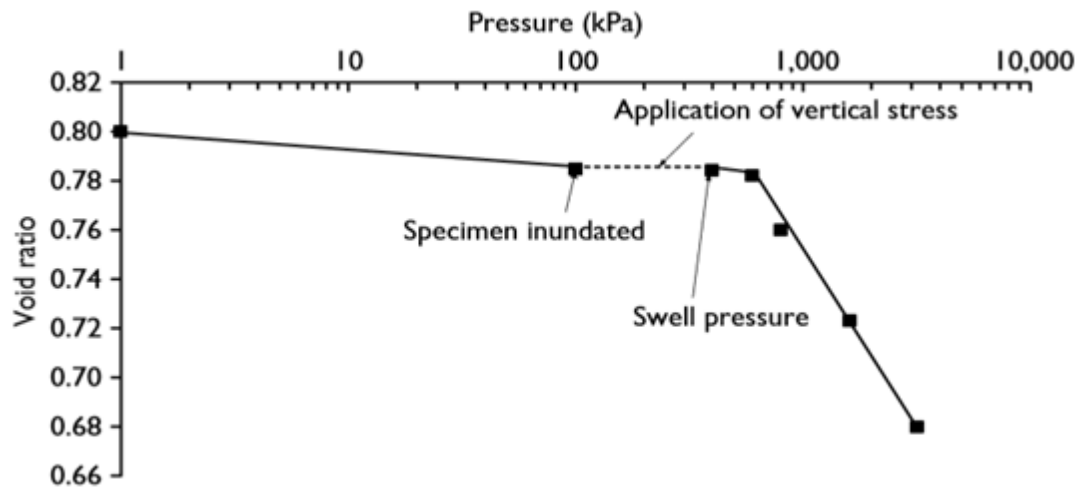


Figure 1 Zero swell test (Al-Rawas & Goosen, 2006)

• **Swell-Consolidation Test**

Water is added to the specimen and it is allowed to swell under a seating pressure. Incremental loads are added

to the specimen in an oedometer until the void ratio of the specimen before swelling is reached. The swelling pressure is depicted in figure 2.

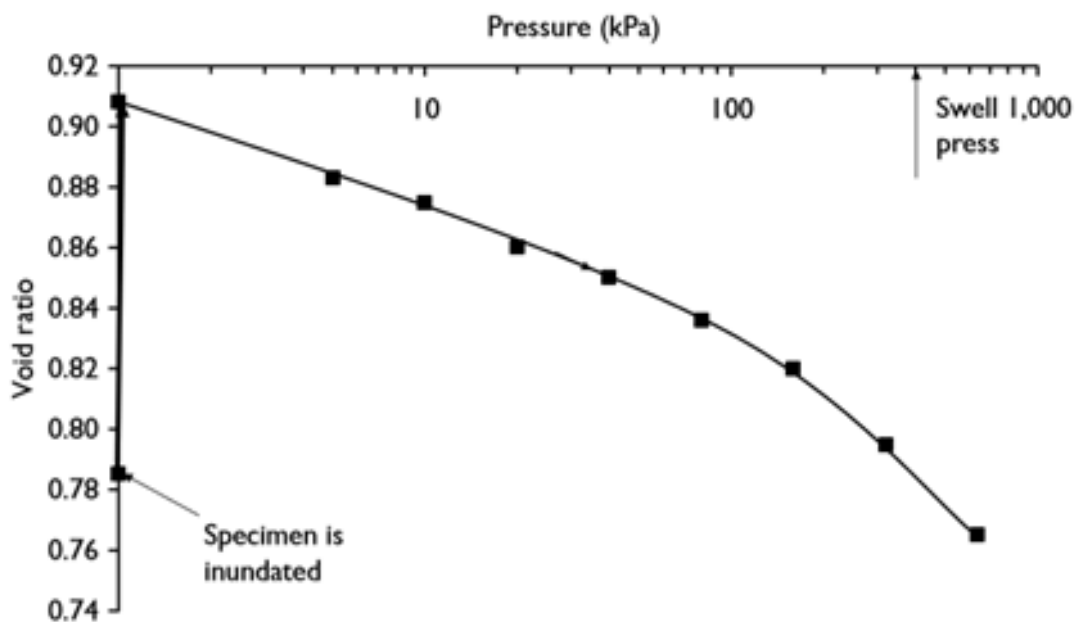


Figure 2 Swell-consolidation test (Al-Rawas & Goosen, 2006)

• **Double-Odometer Swell Test**

Two samples are tested; one under incremental load and water is added to the other sample and allowed to swell. The difference in the change in height of the samples at each stage gives the

swell potential of the soil. Swelling pressure is measured at the point where the swelling potential is zero.

3. Classification Based on Percentage Swell

Table 1 Classification based on percentage swell (book on expansive soils)

Degree of expansion	Holtz and Gibbs (1956) classification of percent swell	Seed et al(1962) classification of percent swell
Low	0-10	0-1.5
Medium	10-20	1.5-5
High	20-35	5-25
Very High	>35	>25

The table 4-1 shows the classification based on percentage swell. The tests carried out by Holtz and Gibbs (1956) were on undisturbed samples whereas

the tests by Seed et al (1962) were on remoulded samples. Thus there is difference in the range provided by the research papers.

4. Classification Based on Plastic Limit and Activity

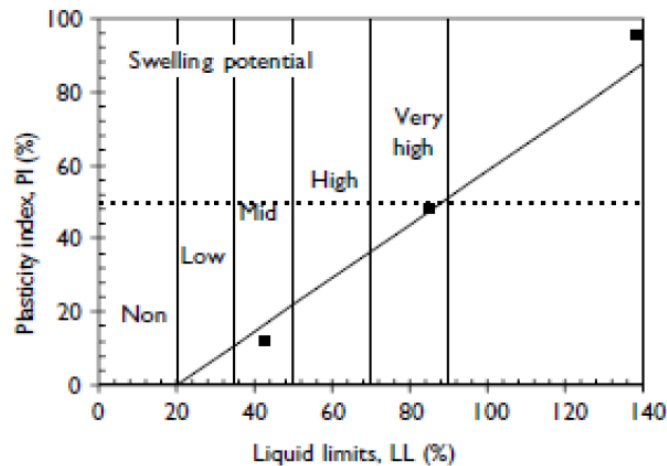


Figure 3 Chart to predict swelling potential (Daksanamurthy & Raman, 1973)

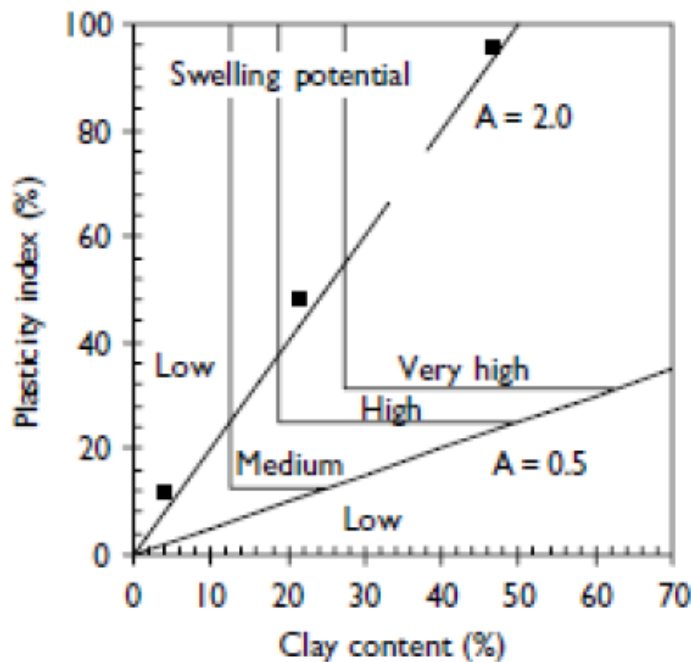


Figure 4 Potential of expansiveness of expansive soil (A.A.B., 1957)

Based on the work by Williams A.A.B(1957) and Dakshanamurthy and Raman (1975), the expansiveness of the soil can be classified in to low, medium, high and very high as shown in the figures 3 and 4. The graph can be used to predict the swelling potential by determining the

plasticity index, liquid limit, clay content and the activity of clay.

SWELL- SHRINK BEHAVIOUR

The observations made by Jones and Jefferson(2012) & Mokhtari & Dehghani (2012) are utilised to explain the shrink swell behaviour.

The presence smectite (montmorillonite) clay mineral in the soil is the main cause of swell shrink behaviour and the increase in concentration of smectite mineral will result in the increase of the expansive potential.

The main aspects of the ground that contribute to the behaviour are the mineralogy of the clay particles and the variation in the water content.

Soil Properties

Montmorillonites and vermiculates are the main source of the volume change but the

extremely fine illites and kaolinites can also contribute to it. The plate like minerals in clay adsorbs water particles in between them. As the soil becomes saturated large amount of water particles in between the clay minerals reduces the inter-clay bond this leads to expansion of the clay. Similarly when the water is discharged, the volume reduces causing settlements and cracks in the soil. The existence of fissures and ground faults in the ground will alter the water content in the soil increasing the swell potential. The behavior of expansive soil on addition of water is shown in figure 5.

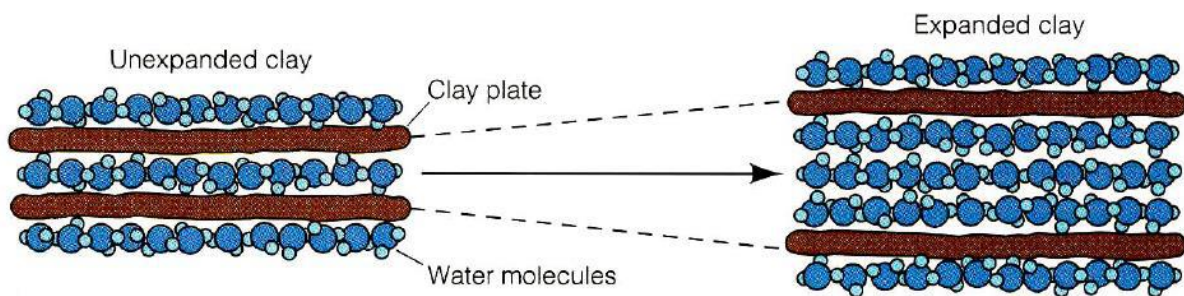


Figure-5 Swell-shrink behaviour

Environmental Factors

The initial water content and the climate are the governing factors to define the volume change. If the soil is dry, it has a higher affinity to attract water and conversely to lose the water if wet. The

vegetation also affects the groundwater thus contributing to the volume change behavior.

Stress Conditions

The state of the stresses in the soil is important as overconsolidated clay is more expansive than normally consolidated clay whereas the external loads on the other hand reduce the swell potential. The ground profile is also an important factor as the depth and location of the expansive layer, whether overlying hard stratum or as the top layer, affects the volume change potential and its effect on the structures.

PROBLEMS ASSOCIATED WITH CONSTRUCTION ON EXPANSIVE SOILS

The swell shrink behaviour exhibited by expansive soil has a great impact on the structures constructed on it. Generally the failures are observed in lightly loaded structures, shallow foundations, retaining structures, roads and reservoirs. (Pritchard, et al., 2013)

A structure on expansive soil may remain stable unless there is a variation in the water content. During the dry months the expansive soil shrinks and develops cracks and the wet season that follows leads to high amount of seepage thus causing swelling. The swelling of the soil causes heave in the structures and the shrinking leads to settlement. The problem mainly arises in areas with variable water content in the soil which leads to differential settlement in the structures.

Foundation

The swelling of the soil causes failure in foundations as it results in uplift of the foundations. Various patterns of heave can be observed in the foundations and the superstructures. Doming heave, based on the rate of evapotranspiration in the area, is the uplift observed in the central portion of the foundation. Edge heave is observed during or post construction that leads to slab movement and cracks in walls, this is a result of removal of vegetation.

Underground Utilities

Water pipes and other utilities develop cracks and are damaged by the ground movement. The leaking pipes further increase the water content and result in swelling of the expansive soil.

Slopes

Structures constructed on a slope consisting of expansive soil can lead to shear failure in foundations due to downhill creep. (Department of the Army, USA, 1983)

Tunnel

The failures observed in tunnels due to expansive soils are in the form of base heave and damage to the invert arch. (Elarabi, n.d.)

TREATMENT METHODS

Mechanical Stabilization

1. Soil Modification

Based on the expansive potential of the soil it can be treated by adding non-expansive soil to reduce the potential of expansion. (Li, et al., 2011) The expansive soil is removed and replaced prior to construction. The removal is generally done for thin layers of expansive soil and is replaced by non-expansive and preferably impermeable soil. (Ardani, 1992)

2. Moisture Content

There are two methods of moisture control either by prewetting or by controlling the moisture content in the soil. The soil may be allowed to expand before construction by addition of water. The moisture content is maintained by adding impermeable layers like plastic, asphalt etc. (Li, et al., 2011). For existing buildings on expansive soils the water should be directed away from the site by sloping the ground or making gutters. (Mokhtari & Dehghani, 2012)

Stone columns and geotextiles are effectively used in reduction of heave potential (K & Muthukkumaran,

2011). Geotextiles are used as reinforcement in the soil and as a result increasing the shear strength of the soil. It also acts as moisture barrier and is used for lining of foundation to prevent heave of soil beneath the foundation. (Shelke & Murty, 2010)

3. Geotextiles and Geogrids

Geotextiles and Geogrids are effectively used in reduction of heave potential, (treatment 2) by reinforcing the soil and as a result increasing the shear strength of the soil (Shelke & Murty, 2010).

They are generally used in treatment of roads on expansive soils to prevent cracking and have provided better results than chemical stabilization. (Sebesta, 2002)

Chemical Stabilization

The calcium oxide present in the cement and lime is responsible for the stabilization of the expansive soil. The Ca^{2+} ions combine with the negatively charged clay particles and reduces the repulsive forces between them. The OH^- ions of the calcium oxide raises the pH of the soil and induces the pozzolanic reaction between the silicate and aluminium ions of the clay and the Ca^{2+} ions. The compounds like calcium aluminum hydrate and calcium silicate

hydrate are the cementitious compounds formed that are responsible for the flocculated structure formation and thus the reduction in the plasticity index, swelling potential and the improved strength.

1. Lime

Lime is the most widely used method for treatment of the shrink swell behaviour of the expansive soil. (Al-Rawas & Goosen, 2006) The lime content, plasticity index of the soil and curing time play an important role in determining the reduction in swell shrink potential but treatment is generally restricted to shallow depths. (Ardani, 1992)

Quicklime (CaO) and hydrated lime (Ca(OH)₂) are used in practice due to their ability to react with pozzolanic minerals in the clayey soils and formation of cementitious compounds as a result. In addition to this the alkaline nature produces tetracalcium aluminate hydrate and leads to flocculation of the plate like clay particles thereby reducing the volume change potential and increasing the strength over a long period. Bell (1996) stated that the plastic limit and the liquid limit reduce on the addition of lime and thus the plasticity index of the soil reduces considerably. (Bhuvaneshwari, et al., 2013)

2. Cement

Cement is used as a stabilizer to increase the shear strength of soil and the expansive potential. The cement undergoes hydration reaction with the water in the soil and forms a hardened form. (Makusa, 2012) Cement undergoes primary and secondary reactions and increases the strength of the soil. During the primary reaction hydration takes place forming calcium compounds which cause flocculation and secondary reactions form cementitious compounds. (Al-Rawas & Goosen, 2006)

TREATMENT USING WASTE MATERIALS

The work done by Seco, et al. (2011) shows that the presence of silicon and aluminum oxides, sulphates, monovalent and divalent ions facilitate the flocculation of the expansive soil. The waste materials consisting of any one or more of the aforementioned components in order to stabilize the soil.

Flyash

Flyash is generally referred to waste material from coal fired power plants. The two types of flyash are Class C flyash and Class F flyash which comprise of more than 20% of calcium oxide and less than 20% of

calcium oxide respectively. The presence of calcium oxide is responsible for the formation of cementitious compounds as in the case of lime and cement and thus Class C flyash is used in most cases (Khan, 2012). Flyash treatment greatly reduces the plasticity index of expansive soils with a high plasticity i.e. having very high swelling potential but is not effective in soils having a relatively lower plasticity index.

A wide amount of research has been carried out with various types of flyash but the optimum concentration of flyash to be used for stabilization varies based on the mineralogy of the soil and the flyash used. The common point that can be observed is that the addition of flyash beyond the optimum content reduces the strength and the swelling potential increases. (Brooks, 2009) (Rao & Neeraja, 2010)

Rice Husk Ash

Rice husk is the waste material from the rice paddy and it is burnt to obtain rice husk ash (RHA) which is used in the treatment of expansive soil. The silican oxides and aluminium oxides in the RHA causes a pozzolanic reaction to improve the strength of the soil and the volume change potential. Rice husk ash lacks cementing properties and hence additives like gypsum, lime and cement are used. (Singh & Mittal, 2014)

Research conducted by Brooks (2009) and Rao & Neeraja (2010) have shown that addition of RHA to lime or cement stabilized soils greatly improves the mechanical properties such as unconfined compressive strength of the soil and reduces the plasticity index of the soil.

Waste Tyre Rubber

Waste rubber tires are shredded and utilized in the treatment of expansive soils. The research conducted by Tabbaa & Aravinthan (1998) focused on the improvement of the mechanical properties and the swelling potential of the soil by addition of scrap tires shreds. Carraro, et al., n.d and (Subramanian & Jeyapriya (2009) helped establish that the scrap tyre can effectively be used in the treatment of expansive soil. Carraro, et al. (2011) has shown that soil rubber mixture can be used in combination with flyash to improve the stiffness characteristics of the soil but has no impact on swelling potential and strength. Though (Prasad & Raju, 2009) presented results that the addition of tyre to the sub base of pavements has no effect on the heave but only affects the stiffness characteristics, further study is required in order to establish the results.

Sugar Bagasse

Sugar bagasse is the by-product of sugar extraction from sugarcane. The chemical composition of bagasse includes calcium oxide and silica which promote the formation of cementitious compounds. Kharade, et al.(2014) studied the behaviour of expansive soil treated with bagasse and concluded that the strength of the soil improve at the optimum content.

The unconfined compressive strength increases rapidly on the addition of bagasse and addition of lime sludge further improves the results (Sabat, 2012). The addition of bagasse shows a linear decrease in the swelling pressure of black cotton soil tested by Gandhi (2012) but further research is required in order to establish the effect on different expansive soils.

Eggshell Powder

Eggshell powder has a high concentration of calcium oxide and can be used as a replacement for lime in treatment of expansive soil. Amu, et al., (2005) carried out a research on the treatment using a combination of eggshell and lime and concluded that the combination does improve the strength characteristics of the soil but the optimum lime content for treatment proves to be more effective and

results were also confirmed by eggshell. Though Amu, et al. (2005) and Jassim (2012) both agreed that the addition of eggshell powder effectively reduces the plasticity index of the soil. The swelling index of the soil also considerably reduces with addition of eggshell powder. (Nyankson, et al., 2013)

Olive Waste

Olive oil extraction is mainly carried out in the Mediterranean countries. Olive waste is the by-product obtained after the olives are crushed to extract oil. The wastes deposited in landfills is prone to leaching and results in ground water contamination. Thus disposal of the waste generated is problematic and utilization of the waste is necessary to minimize the environmental impact by using it in a more constructive manner. (Zalihe & Salma, 2006)

Olive waste constitutes of potassium, sodium, phosphorus and calcium ions. The positive ions stabilize the negative charge on the clay particles thereby reducing the repulsive forces between the particles. The olive residue consists of Calcium Carbonate (CaCO_3) which is converted to Carbon dioxide (CO_2) and Calcium Oxide (CaO). Some portion of Calcium Oxide on addition of water converts into Calcium Hydroxide ($\text{Ca}(\text{OH})_2$). These compounds

react with silica in the clay particles to form a cementitious compound, Calcium Silicate Hydrate. This pozzolanic nature of the olive waste is responsible for the modification of the existing soil properties of expansive soils. (Attom & Al-Sharif, 1998)

Based on the research conducted by Attom & Al-Sharif (1998) it can be inferred that plasticity indices of expansive soil can be reduced when treated with olive waste. Four soil samples examined showed reduction in the plasticity index. This reduction in the plasticity index was more for soils which had higher plasticity index compared to the ones which had relatively less plasticity index to start with.

Research by Zalihe & Salma (2006) shows that plasticity index reduces due to addition of olive waste. Incremental addition of olive waste at each stage clearly showed that the liquid limit of the soil sample reduces by a small amount but greatly increases the plastic limit.

When olive waste is added to the soil it fills in the voids increasing the weight of the soil. This increases the maximum dry density. But addition of higher amounts increases the olive waste in the sample as

soil gets replaced by the waste thereby decreasing the maximum dry density.

A small amount of olive waste (2.5% as shown by Zalihe & Salma (2006)) added to the soil samples at their optimum moisture content increased the maximum dry density. However based on Zalihe & Salma (2006) it was also clear that addition of higher amount of olive waste does not appreciably increase it further than the value obtained at 2.5%. Attom & Al-Sharif (1998) and Mutman (2013) show similar results but the percentage of the olive waste varies in each experiment as the soil properties change. Thus a definite comparison cannot be drawn from the results.

Addition of only a small amount (3%) of olive waste considerably reduces the percentage swell (from 9.6% to 4.6%) (Zalihe & Salma, 2006). The further increase in the amount olive waste reduces the percentage swell but the reduction is relatively small. The research by Zalihe & Salma (2006) indicated a decrease in the compression index of the soil instantaneously but after a curing period of 28 days it was found to be increasing for higher percentages (3% or more).

Marble Dust

Marble dust is produced from factories polishing and cutting marble. The oxides silica, aluminum and calcium in the marble dust facilitate the pozzolanic reaction and cause the soil to flocculate. Marble dust improved the swelling pressure and strength characteristics of the soil and was also used in combination with rice husk ash to achieve good results (Akshaya & Radhikesh , 2011).

Though Baser, (2009) stated that limestone dust proves more effective in treatment of expansive soil due to higher content of lime. Marble dust, flyash & sand combination was used by Gupta & Sharma (2014) to achieve a higher degree of improvement in the soil characteristics. The use of marble dust as a stabilizing agent to treat expansive soil is discussed further in detail in section.

TREATMENT USING MARBLE DUST

Marble is a metamorphic rock which is formed when pressure and heat is applied to limestone. It is found in all parts of the

world and quarried at a large scale. It is used in buildings, as aggregates in roadway, sculptures, furnishing, finishing works, flooring and various other industries. Large amount of marble waste is produced in the quarries and other processing industries. The powdered wastes infiltrate the water bodies and form a slurry thus polluting them. The alkaline nature of the marble raises the pH of the soil where it is disposed which poses a problem for growth of vegetation. Marble dust is produced from factories polishing and cutting marble. (Hamza, et al., 2011)

Chemical Composition

Marble primarily composes of calcite and dolomite minerals. The chemical components of marble are given in the table 2 based on Marras, et al.(2010), Pascal (2011) and Sounthararajan & Sivakumar (2013). The figures given correspond to the constituents and their amount found generally, though the values vary based on the location, minerals and other components.

Table 2 Chemical Composition of marble dust

Minerals	Percentage Composition (%)
Lime (CaO)	38-54
Silica (SiO ₂)	3-30
Alumina (Al ₂ O ₃)	0-4
various carbonates	30-32
various oxides	1-2.5

Chemical Stabilization

The chemical stabilization process is due to three factors; cation exchange, pozzolonic reaction and flocculation. The high lime content in marble dust is responsible for the reactions that indicate it can be used as a soil stabilizer.

1. Cation Exchange Reaction

The silica, alumina and carbonates like magnesium carbonate in marble dust contains positive ions that replace the sodium ions attached to the clay minerals, the process is termed as cation exchange. The reaction works towards neutralizing the negatively charged clay particles thus reducing the repulsive forces between them. Figure 6 represents the cation

exchange reaction that takes place in the soil.

2. Pozzolonic Reaction

The lime present in marble dust raises the pH of the soil that promotes the pozzolonic reaction. The silica tetrahedral and aluminate octahedral in the clay is removed and replaced by the calcium ions. These positive ions undergo the pozzolonic reaction and form compounds like calcium silicate hydrate (CSH) and calcium aluminum hydrate (CAH). These gel like compounds tend to bind the soil particles together. This process is takes a long period of time and is temperature dependent. (Al-Mukhtar, et al., 2010) Figure 7 depicts the pozzolonic reaction that takes place on

addition of marble dust to the expansive soil.

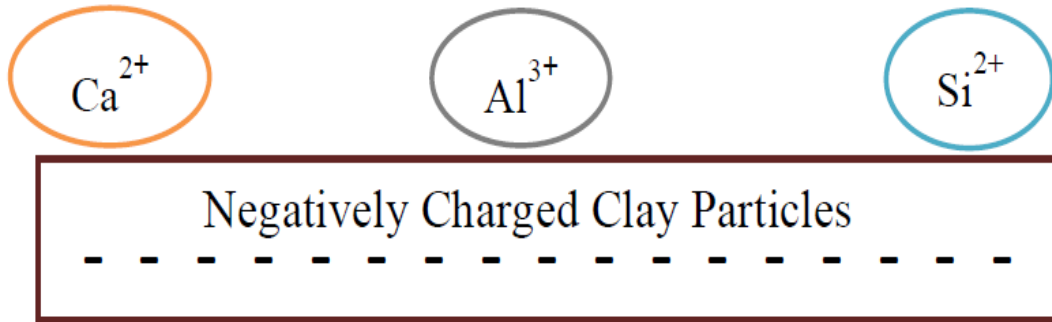


Figure 6 Cation exchange reaction

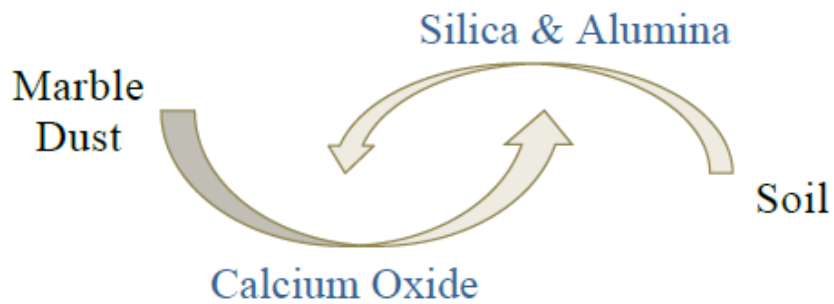


Figure 7 Pozzolonic reaction

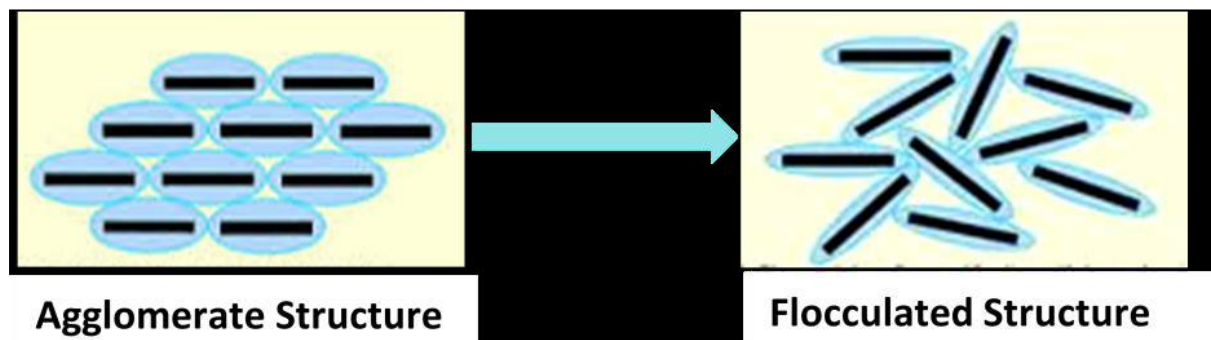


Figure 8 Flocculation Process

3. Flocculation

The cation exchange and pozzolonic reaction results in formation of a flocculated structure that combines the soil and reduces the surface area. The agglomerate structure has the tendency to move along the surface thus reducing the strength of the soil. On the other hand the flocculated structure binds the soil and increases the strength and expansive properties of the soil.

These reactions are responsible for the soil stabilization that takes place due to addition of marble dust to expansive soil.

Effect on Soil Properties

1. Plasticity Index

The plasticity index is an indicator of the swelling potential of the soil as shown by Daksanamurthy & Raman (1973) thus the decrease in the plasticity index predicts the reduction in the swelling potential.

The Plasticity Index of the sample reduces on addition of marble dust. According to Sivrikaya, et al. (2013) stone dust increased the plastic limit and reduced the liquid limit of the soil. The plasticity index of the soil reduces by 3% and 28% on addition of 5% and 50% of stone dust, respectively.

Bhavsar, et al. (2014) also verified the results by stating that the plasticity index of black cotton soil reduces by 30% on addition of 50% of marble dust.

2. Maximum Dry Density

When marble dust is added to the soil it fills in the voids increasing the weight of the soil. This increases the maximum dry density. But addition of higher amounts increases the marble dust in the sample as soil gets replaced by the waste thereby decreasing the maximum dry density

Gupta & Sharma (2014) discussed the usage of beas sand, flyash and marble dust and concluded that the highest value of maximum dry density was noted when marble dust was added to the black cotton soil, flyash and sand mixture. The maximum dry density increased when 12% marble dust was added but reduced on further addition.

Based on Khan (n.d.) it can be concluded that the maximum drydensity increases with the addition of marble dust and the

optimum moisture content decreases.

Ali & Koranne (2011) show similar results but the percentage of the marble dust varies in each experiment as the soil properties change. Thus a definite comparison cannot be drawn from the results.

3. Unconfined Compressive Strength

Unconfined compressive strength has a direct correlation with the maximum dry density of the soil. Ali & Koranne (2011) concluded that the maximum compressive strength of the soil with different amount of marble dust (incremental addition for different samples) is achieved at the percentage which gives the maximum dry density. These results comply with the fact that the maximum strength is achieved when the voids ratio in the soil is minimum, which is at the maximum dry density. Though it was also observed that the increase in strength was minor (15%) even on addition of 50% of stone dust and flyash. Though Baser, (2009)

stated that limestone dust proves more effective in treatment of expansive soil due to higher content of lime.

4. Swelling Pressure

Gandhi (2013) conducted a comparative study between using rice husk ash and marble dust as soil stabilizing agents. It was concluded that the reduction in swelling pressure was more when marble dust was added to black cotton soil as compared to the reduction observed with rice husk ash. Marble dust demonstrated a linear decrease in swelling pressure when 0 to 30% of marble dust was added and correspondingly the swelling pressure decreased from 196 kN/m² to 147 kN/m².

Sabat & Nanda (2011) conducted a study which was based on addition of marble dust to soil already treated with rice husk ash to analyze if there is further improvement in the mechanical and swelling characteristics of the soil. The expansive soil was initially stabilized with the optimum content (10%) of rice husk ash and marble dust ranging

from 0 to 25% was used for testing. According to the results the swelling pressure reduced from 112 kN/m² to 0 on addition of 25% marble dust. The research on decrease in swelling potential using marble waste is not well documented, hence the complete elimination of swelling pressure on addition of 25% marble dust cannot be fully justified.

Further research is required in order to determine the degree of improvement in the expansive soils using marble dust so that a comparison can be drawn from the conventional additives like flyash, lime and cement; which are widely used.

CONCLUSION

Further research is required in order to determine the degree of improvement in the expansive soils using marble dust so that a comparison can be drawn from the conventional additives like fly ash, lime and cement; which are widely used.

REFERENCES

1. A.A.B., W., 1957. Discussion on prediction of total heave from double oedometer test. s.l.:s.n.
2. Abdullah, W. S. & Alsharqi, A. S., 2011. Rehabilitation of Medium Expansive Soil Using Cement Treatment. *Jordan Journal of Civil Engineering*, 5(3), pp. 343-356.
3. Advanced Engineering Geology and Geotechnics, 2004. Various Aspects of Expansive Soils Relevant to Geoengineering Practices. *Advanced Engineering Geology and Geotechnics*, Issue Spring 204.
4. Akshaya, . & Radhikesh , N., 2011. Effect of marble dust on strength and durability of Rice husk ash stabilised expansive soil . *International Journal of Civil and Structural Engineering*, 1(4), pp. 939-948.
5. Al-Mukhtar, M., Lasledj, A. & Alcover, J.-F., 2010. Behaviour and mineralogy changes in lime-treated expansive soil at 20 °C. *Applied Clay Science*, Volume 50, pp. 191-198.
6. Al-Rawas, A. A. & Goosen, M. F., 2006. *Expansive Soil*. London: Taylor and Francis Group.

7. Ardani, A., 1992. Expansive soil treatment methods in Colorado. Colorado: Federal Highway Administration.
8. Bell, F., 1996. Lime stabilization of clay minerals and soils. *Engineering Geology*, Volume 42, pp. 223-237.
9. Bhavsar, S. N., Joshi, H. B., Shrof, P. K. & J., P. A., 2014. Impact of Marble Powder on Engineering Properties of Black Cotton Soil. *International Journal for Scientific Research & Development*, 2(2), pp. 136-139.
10. Bhuvaneshwari, S., Robinson, R. G. & Gandhi, S. R., 2013. Behaviour of Lime Treated Cured Expansive Soil Composites. *Indian Geotechnical Society*, Volume 3.
11. Brooks, D. R. M., 2009. Soil stabilization with flyash and rice husk ash. *International Journal of Research and Reviews in Applied Sciences*, 1(3).
12. Carraro, D. J. A. H., Dunham-Friel, J. & Smidt, M., n.d. Beneficial use of scrap tire rubber in low volume road and bridge construction with expansive soils, Colorado: Colorado State University.
13. Daksanamurthy, V. & Raman, V., 1973. A simple method of identifying an expansive soil. *Japanese Society of Soil Mechanics and Foundation Engineering*, 13(1), pp. 97-104.
14. Department of the Army, USA, 1983. *Foundation in expansive soils*. s.l.:s.n.
15. Elarabi, H., n.d. damage mechanism of expansive soil. s.l.:University of Khartoum.
16. Gandhi, K. S., 2011. Expansive Soil Stabilization Using Bagasse Ash.. *International Journal of Engineering Research & Technology*, 1(5), pp. 1-3.
17. geotechdata, 2013. *geotechinfodata.info*. [Online] Available at: <http://www.geotechdata.info/parameter/soil-dry-unit-weight.html> [Accessed 13 march 2014].
18. Hamza, R. A., El-Haggar, S. & Khedr, S., 2011. Marble and Granite Waste: Characterization and Utilization in Concrete Bricks. *International Journal of Bioscience, Biochemistry and Bioinformatics*, 1(4), pp. 286-291.
19. Hasan, H. A., 2012. Effect of Flyash on Geotechnical Properties of Expansive

- soil. Journal of Engineering and Development, 16(2), pp. 306-316.
20. Jassim, N. W., 2012. Influences of Fly-Ash and Eggshell Powder on Some of Engineering Properties of Al-Umara Soil. Journal of Engineering and Development, 16(2), pp. 211-219.
21. Jones, L. D. & Jefferson, I., 2012. Expansive Soils. ICE Manuals, Volume 1.
22. Khan, M. A., 2012. A CBR based study evaluating subgrade strength of flexible pavements having soil flyash interface. International Journal of Civil Engineering, 11(1).
23. Khan, S. A., n.d. Physical characteristics of fine soil stabilized with marble industry waste. Taxila: University of Engineering and Technology.
24. K, H. & Muthukkumaran, K., 2011. Study on swelling soil behaviour and its improvements. International Journal of Earth Sciences and Engineering, 4(6), pp. 19-25.
25. Kharade, A. S., Suryavanshi, V. V., Gujar, B. S. & Deshmukh, R. R., 2014. Waste product bagasse ash from sugar industry can be used as stabilizing material for expansive soils. International Journal of Research in Engineering and Technology, 3(3), pp. 506-512.
26. Li, X., Wang, M. & Liang, Y., 2011. Study on Treatment Theory and Expansive Soil Geological Disasters. s.l.:enan Science and Technology Department.
27. Makusa, G. P., 2012. Soil stabilization methods and materials. Lulea, Sweden: Luleå University of Technology.
28. Marras, G., Careddu, N., Internicola, C. & Siotto, G., 2010. Recovery and reuse of marble powder by-product, Cagliari: Global Stone Congress.
29. Mokhtari, M. & Dehghani, M., 2012. Swell-Shrink behaviour of expansive soil, damage and control. EJGE, Volume 17, pp. 2673-2682.
30. Mollamahmutoglu, M., Yilmaz, Y. & Güngör, A. G., 2009. Effect of a Class C Flyash on the Geotechnical Properties of an Expansive Soil. Turkey: s.n.
31. Nyankson, E. et al., 2013. Characteristics of stabilized shrink swell deposits using eggshell powder. Global Journal of Engineering Design and Technology, 2(3), pp. 1-7.

32. Pascal, B., 2011. The Chemical Composition of Marble. [Online] Available at: <http://www.sciences360.com/index.php/the-chemical-composition-of-marble-5059/> [Accessed 20 July 2014].
33. Prasad, D. S. V. & Raju, G. V. R. P., 2009. Performance of waste tyre rubber on model flexible pavement. *ARPN Journal of Engineering and Applied Sciences* , 4(6), pp. 89-92.
34. Pritchard, O. G., Hallett, S. H. & Farewell, T. S., 2013. Soil movement in the UK - Impacts on critical infrastructure, s.l.: Cranfield University.
35. Rao, A. & Neeraja, D., 2010. Use of certain admixtures in the construction of pavement on expansive clayey subgrades. *International Journal of Science Engineering and Technology*, 2(11).
36. Sabat, A. K., 2012. Utilization of Bagasse Ash and Lime Sludge for Construction of Flexible Pavements in Expansive Soil Areas. *EJGE*, Volume 17, pp. 1037-1046.
37. Sabat, A. K. & Nanda, R. P., 2011. Effect of marble dust on strength and durability of Rice husk ash stabilised expansive soil. *International Journal of Civil and Structural Engineering*, 1(4), pp. 939-948.
38. Sada, H. & Eberemu, E., 2013. COMPRESSIBILITY CHARACTERISTICS OF COMPACTED BLACK COTTON SOIL TREATED WITH RICE HUSK ASH. *Nigerian Journal of Technology* , 32(3), pp. 507-521.
39. Sebesta, S., 2002. Investigation of Maintenance base repairs over expansive soils, Texas: Texas Transportation Institute.
40. Seco, A., Ramírez, F., Miqueleiz, L. & B.García, 2011. Stabilization of expansive soils for use in construction. *Applied Clay Science*, Volume 51, pp. 348-352.
41. Shelke, A. & Murty, D., 2010. Reduction of swelling pressure of expansive soil using EPS Geofoam. Mumbai, Indian Institute of Technology, Bombay.
42. Singh, M. & Mittal, A., 2014. A Review On The Soil Stabilization With Waste Materials. *International Journal of Engineering Research and Applications*, Volume 1, pp. 11-16.

43. Sivrikaya, O., Kiyıldı, K. R. & Karaca, Z., 2013. Recycling waste from natural stone processing plants to stabilise. Nigde, Turkey: Environment Earth Science.
44. Sounthararajan, V. M. & Sivakumar, A., 2013. Effect of lime content in marble powder for producing high strength concrete. Journal of Engineering and Applied Sciences, 8(4), p. 262.
45. Subramanian, R. M. & Jeyapriya, S. P., 2009. Study on Effect of Waste Tyres in Flexible Pavement System , Coimbatore: Government College of Technology.
46. Tabbaa, A. A.-. & Aravinthan, T., 1998. Natural clay-shredded tire mixtures as landfill barrier materials. Waste Management , Volume 18, pp. 9-16.
47. Urena, C. et al., 2012. Improving the geotechnical properties of expansive soils by mixture with olive mill wastewater. Geophysical Research Abstracts, Volume 14, p. 1.
48. Zalihe, N. & Salma, T., 2006. Evaluation of the effectiveness of olive cake residue as an expansive soil stabilizer. Environmental Geology, Volume 50, pp. 803-807.