Suitability of Fly Ash as Geotechnical Material

Ghanwat S. B.[1]* Vasatkar A. R.[2]

[1,2] Bhivrabai Sawant College of Engineering and Research, Savitribai Phule Pune University, Pune, India

Abstract* – A key environmental issue is disposal of pozzolonic waste material such as fly ash, pond ash, coal ash, ground granulated blast furnace sag which can be used in civil engineering work such as road embankment, rail embankment, retaining wall, filling structures. This paper presents results of experimental investigation carried out to evaluate effect of fly ash on soft soil and its suitability as material for embankment. In this investigation, stabilized soil samples are prepared at different Class C fly ash content, i.e., 0%, 10%, 15%, 20%, 25%, 30% and optimum proportion of fly ash with partial replacement of soft soil is found out. In experimental study, index properties of soft soil and fly ash stabilized soil samples are determined. The literature review clearly states that more than 30% replacement of soil with fly ash gives lower result in respect to unconfined strength and California Bearing test. As we increase % of fly ash there is reduction in maximum dry density and optimum moisture content but with 20% fly ash gives best suited result of all proportions. The result of this research showed improved soil parameters such as swelling index reduced, specific gravity reduced, and permeability reduced.

***Keywords:* Soft Soil, Fly Ash, Stabilization, Geotechnical Material, Suitability, Expansive Soil, Pozzolonic, Embankment.**

---------------------------------x---------------------------------

1. INTRODUCTION

Many construction work involved work over soft soil. There are most common civil engineering problems associated with use of soft soil which effects on quality of work. Swelling soil creates problems for light loaded structure specially by changing volume or by consolidating under load. Soft soil exhibit low strength with high swelling potential which may impart failure of structure. Soft soil also possess drainage problem. It requires very long dewatering and consolidation period even the thickness of soil is less. Because of drainage problem, use of soft soil for filling or embankment work gets limitations. Therefore there is requirement of soft soil improvement techniques to improve critical parameters of soil such as permeability, swell index etc. Major cost will be saved in pavement design by stabilizing soil in comparison to cutting out and replacing unstable earthen material. Lime and cement have been used successfully for many years and now-a-days fly ash (specially Class C fly ash has been used as economical alternative)

Some conventional methods of soil stabilization are mechanical, cement, lime, bituminous, thermal and electric. Mechanical stabilization is most simple method. In this method, two or more than two types of soil samples mixed together to achieve adequate mix sample which shows better mix design properties as compare to parental soil samples. Cement stabilization gives strong material but it is bit costly method. Therefore, lime stabilization comes into picture. Working of lime stabilization is as same as cement but it is cheaper than cement stabilization technique. In cement method, cement content varies 5 to 13% as per soil characteristics while in lime method, lime content varies 2 to 10%. Bituminous stabilization can be done. Amount of bitumen varies 4 to 7% by weight. Thermal stabilization done for small amount of work in which massive heating followed by excessive cooling is done. In electric stabilization, as current is passed through soil, pore water migrates to the negative electrode. It is mainly used for drainage of cohesive soil. It is most expensive method among all the methods. Some new methods include the addition of NaCl, $MgCl_2$, and $CaCl_2$ in various proportions. which gave positive effects on consistency limits, compaction characteristics, Compressive strength of soil. Recent innovative method uses rise husk ash (RHA), fly ash (FA) for soil stabilization.

Most of the countries, coal is primary fuel in industries. Burning of coal in these plants produces fine residual product is known as Fly Ash. The fly ash is disposed either in dry form or mixed with water and disposed as slurry. In past few years the concerns have been raised about the disposal of fly ash and its impact on environment. India also has a vast coal reserve of 211 billion tones making coal one of the most extensively used fossil fuel for generating power. Around 173 million tonnes of fly ash was produced across India in 2013-14. By 2021-22, the thermal power sector is estimated to produce 300 million tonnes of fly ash a year and with that, utilization of all the fly ash being generated is going to become even tougher. The Ministry of Power, Govt. of India estimates 1800 million tonnes of coal use every year and 600 million tonnes of fly ash generated by 2031-2032.

The Fly-ash mission was commissioned in 1994 with the Department of Science and Technology. The Ministry of Environment and Forests, Govt. of India, Ministry of Power, Thermal Power stations, R&D Institutions and Industry together have launched a Technology Project in Mission Mode (TPMM). Their focus is on the demonstration of coal ash related technologies.

According to a recent study by the Centre for Science and Environment (CSE), fly ash disposal remains a major problem with only about 50-60% of the total fly ash generated by the power sector being utilised. The remaining is dumped into poorly designed and maintained ash ponds. As per estimates, about a billion tonnes of this toxic ash lie dumped in these ponds, polluting land, air and water. It is important to protect environment, conserve the top soil, and prevent dumping of fly ash from Thermal Power Stations on land and to promote utilization of ash in the manufacture of building materials and construction activity. Due to the stringent regulations of ministry of environment and forests (MOEF), government of India (GOI) and increased awareness about the benefits of using fly ash for various purposes has also forced to explore the different possibilities of using waste products instead of landfills. One of the most promising approaches in this area is the large scale utilization of fly ash in geotechnical construction like embankments, road sub bases, structural land fill, as a use of fly ash as replacement to the conventional weak earth material.

This study is concerned with effect of self-cementing Class C fly ash on stabilized soft soil. Its effects are investigated and analysed. Self-cementing Class C Fly ash is added in soft soil with different proportions, i.e., 10%, 15%, 20%, 25%, 30% and its effects on geotechnical properties such as unconfined compression test, California bearing ratio test, proctor test, swelling index test etc. are studied.

2. BACKGROUND

Fly ash is residual after combustion of coal. It has various applications such as concrete production in cement clinker, substitute material brick manufacturing, mineral filter in bituminous concrete, stabilizer in soil stabilization etc. Now-a-dayslarge scale research is going on for developing such optimistic approaches.

Mahvash, Lopez-Querol and Bahadori-Jahromi (2017) carried investigation to evaluate the effect of Class C FA on fine sand compaction and its suitability for embankment. Based on results, it appears that FA sandy soil mix can be suited for sustainable embankment construction. He suggested future scope of his work is that more research should be conducted to evaluate the effect of FA on sand, clayey sand, clayey soil with comparative in Class C and class F FA.

Ozdemir (2016), aimed to determine bearing capacity improvement of soft soil by using Class C FA. He determined modified proctor test, unconfined compression test and soaked C.B.R. test for stabilized soil. Soil samples were stabilized at different FA content, i.e., 0%,3%,5%,7% and 10%. Due to addition of FA, MDD decreases and OMC varies between 8.4 upto 7% FA addition but for 7% and 10% there was remarkable increase in OMC. He concluded that fines % decreases with increasing FA content while fine sample of FA produces better results. He also state that FA doesn't change plasticity of soft soil significantly. He observed that increase in C.B.R. value along with reduction in swelling capacity of soft soil. He gave optimum proportion of FA as 7% or more than 7% FA addition is very effective. Therefore effect of addition of fly ash as stabilizer is very positive. He states that further research needs to be carried out on sand, clayey sand and high plasticity soil to evaluate effect of fly ash on the soil strength.

Binal, Bas and Karamut (2016) studied the changes in geotechnical properties of Ankara clay by mixing highly alkaline FA with soil sample in different proportions, i.e., 5%, 15%, 25%. He got result that C.B.R. values of clay were drastically increase and swelling index were decreased by addition of FA. He also gave conclusion that clay could be stabilized successfully with addition of FA more than 10%.

Hayder, Liet Hadi, Behzad and Segei (2016) did research on soil stabilization with bagasse ash as stabilizing agent. Bagasee ash produced after bagashee which is fibrous material left after crushig of sugarcane after extracting its juice. Bagashee ash contains high percentage of silica (Sio2) similar to fly ash. Bagashee ash is also pozzolonic material but non-reacting in behaviour. He used hydrated lime for cementing property. He prepared soil sample with bagashee ash and hydrated lime (at 1:3 proportion) for different contents, i.e., 0%, 10%, 18%, 25%. He reported that there was increase in U.C.S. and reduction in dry density with significant decrease in swelling capacity. He concluded that such waste material specially having pozzolonic behaviour and cementing property can be effectively used for remediation of expansive soil.

Digioia et al. (1972, 1979) reported that with proper drainage, the fly ash can be used very effectively and economically as a material to construct stable embankments. Dhavan et al. (1988) on the basis of laboratory investigations suggested a typical cross section of road embankment made of fly ash. In order to ensure stability and prevent side erosion of the embankment, they recommended a 45-60cm thick layer of soil/soil-fly ash mix having a plasticity index of 10% on either side of embankment. They further suggested that at the top of embankment 30-50cm thick layer of soil-fly ash mix having plasticity index of about 6% should be provided thus forming a sub-grade of the embankment layer. Ratan Lal and Mandal (2012) based on their study reported that the FA can be used as alternative to conventional back fill material. Nagaarkar (1982) reported that successful use of FA with murum can reduce 50-60% construction cost. Alhassan (2008), Sabat and Nanda (2011) has shown the potential benefits of using rise husk ash (RHA) with the natural soil. It has been seen that with addition of RHA, MDD decreases and OMC increases. Also C.B.R. and U.C.S. values increases substantially. Therefore they concluded that such waste material could e use for improving soil properties.

According to Cetin and Aydilek (2003), effective use of fly ash in embankment construction helps in

- Reducing waste quantity production.
- Providing sustainable construction.
- Minimizing environmental damage.

Also Baykal et. al. (2004) said, reuse of waste materials such as fly ash in highway construction minimizes amount of disposal of waste material. Beghly (2003) explains the main difference between soil modification and soil stabilization. Soil modification is improvement in drying and swelling reduction with use of small quantity of additive such as admixtures, lime, cement etc whereas soil stabilization is higher rates of applications. According to O'Flaherty and Hughes (2016), modification describes use of chemical to improve soil properties without significant changes in strength while stabilization refers utilisation of chemical to achieve improved strength of soil design.

Dockter et. al. (1999), reported that FA has excellent capability for its utilisation n rammed earth construction as sustainable as well as low cost material. Soil stabilization not only improves the compressive strength of soil but also enhances shear parameters and improves drainage system [Bergado et. al. (1996); Prabakar et. al. (2004)], permeability, soil resistance to weathering process [Zlihaet.al. (2013)].

Hossain (2010) states that liquid limit less than 40% and plasticity index withing range of 22-25% is effectively suitable for purpose of stabilisation. Further he reported that investigation on soil to be stabilized using different types and combinations of stabilizers.

Cristelo et al. did extensive research on soil improvement. He compared soil stabilization with both class C and class F fly ash. He reported that with increasing curing period, the unconfined compressive strength improved dramatically. He further suggested that the use of cement along with fly ash would be more effective for stabilization purpose.

3. MATERIALS

A. Soft Soil:

The soil used in this study was obtained locally from pavement sub grade construction in Pune, India. It was dried at room temperature. The basic geotechnical properties of soil including sieve analysis, particle size distribution, consistency limits and the specific gravity were determined. The soil classified as high plasticity clay (CH). Particle size distribution curve on this soil determined based on wet sieving. The index properties of the expansive soil are given below.

SN	Property	
1	Classification of the soil	CH
3	Consistency Limits Liquid Limit Plastic Limit	 66.07 36.75
4	Shrinkage Limit	
5	Plasticity Index (%)	29.32
6	Specific Gravity	2.42
7	Free Swell Index (%)	45
8	M.D.D (g/cc)	1.74
9	O.M.C (%)	17.4
10	U.C.S. (kPa)	200
11	C.B.R. Soaked	7.28 %

Table 1: Index properties of the soft soil

B. Fly Ash:

Fly ash is waste by-product generated after burning of coal in thermal power plant. Fly ash has two types class C and class F. Class F fly ash is pozzolonic in nature, and contains less than 10% lime (CaO). The glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementations compounds on other hand class C Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolonic properties along with self-cementing properties. In the presence of water, Class C fly ash will harden or bonded soil particles together and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator.

Self-cementing Class C fly ash was collected from nearby fly ash brick manufacturer who bought it from Roha, Mumbai, India. Fly ash passing through 425 micron sieve was used for this research. Specific gravity of the fly is 2.20.

4. METHODS

In this study, experimental proctor, U.C.S. and C.B.R. test are conducted in different proportions of fly ash, i.e., 0%, 10%, 15%, 20%, 25%, 30% for determination of optimum proportion of fly ash along with soft soil. Also swelling index and permeability is determined for optimum proportion of fly ash.

Standard proctor test performed to determine maximum dry density and optimum water content for different fly ash content. Plot water content vs. dry density graph for individual samples and then plot comparative graph for same samples for better understanding. The results obtained from proctor test used for unconfined compression tests and California bearing tests.

For U.C.S. test, predetermined fly ash contents used and the soaking was not performed. The required bulk density required for compacting samples were determined by maximum dry density and corresponding water content from standard proctor tests for each sample. For stability of slope soil, shear parameter should be improved. U.C.S. gives unconfined compressive strength with corresponding shear strength. U.C.S. test performed on unconsolidated undrained soil mix samples.

From literature review, unsoaked C.B.R. values are always shows satisfactory results in deign point of view but the problem arises due to drainage condition. Effect of drainage on C.B.R. value can be analysed by performing soaked C.B.R. test on soil samples. For soaked C.B.R. tests, each sample was compacted to corresponding maximum dry density at optimum moisture content. samples were cured for period of 4 days. After curing period, settlement of test sample measured.

5. RESULTS AND DISCUSSION

A. Specific Gravity:

Specific gravity of soft soil and fly ash is determined according to IS: 2720 (Part. 3) 1980
Sect/2. Specific gravity of soft soil is 2.33 which is greater than specific gravity of fly ash that is 2.20. Therefore by addition of fly ash in partial replacement of soft soil reduces overall weight of construction. Therefore overburden pressure on foundation gets reduced.

B. Consistency Limits:

Liquid Limit and plastic limit test was carried according to IS:2720 (Part 5) 1985 and shrinkage limit test carried according to IS:2720 (Part 7) on uncured (0 day cured) samples. The plasticity index is determined with help of liquid limit and plastic limit.

Liquid limit and plastic limit found out 65.80% and 36.61% respective which shows plasticity index is 29.19%. Shrinkage limit obtained as 18.35% which shows marginal degree of severity.

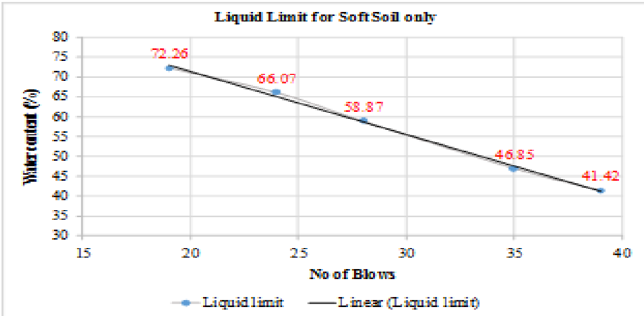

Figure 1: No of Blows vs. Water Content

Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit (%)	Degree of severity
20-35	<12	<15	Non critical
35-50	12-23	12-30	Marginal
50-70	23-32	30-60	Critical
70-90	>32	>60	Severe

Table 2: Classification system as per (IS: 1498)

Plasticity Index	Swelling Potential
0-15	Low
15-35	Medium
20-55	High
55 and greater	Very High

Table 3: Relationship between swelling potential with plasticity index as per terzaghi & peck (1967), bowel (1988)

A. Free Swell Index:

Tests were conducted for stabilized and unsterilized soil with different soil-FA content as shown in Table 4. The mineral responsible for swelling of soil is montmorillonite. Clay shows highest content of this mineral. Therefore clay has highest swelling index. From Table 4, its clearly shows as we increase fly ash from 0% to 30% free swell index gets effectively reduced. This is because fly ash provides divalent and trivalent Cations (Ca^{2+}, Al^{3+}, Fe^{3+} etc) that reduces effect of montmorillonite mineral.

This reduction will continue upto some extend then again mix will show increase in free swell index. The void spaces between soil grains gets clogged due to very fine grained fly ash material but when it exceeds saturation limit then excess fly ash will show swelling behaviour but in small manner. As per literature survey, above 40% fly ash replacement shows little increase in free swell index.

In this research we tested samples for 0 days of curing period. Literature review states that this reduction in swelling potential also increases with increasing curing period. For example, 7 and 28 days of curing samples will have much less swelling potential. This happens because of hydration and pozzolonic behaviour of fly ash.

	Free Swelling Index (%age)	Free Swell Ratio
Only Soft soil	45	1.45
Soft soil + 10% FA	42.11	1.42
Soft soil + 15% FA	36.84	1.37
Soft soil + 20% FA	33.33	1.33
Soft soil + 25% FA	29.41	1.29
Soft soil + 30% FA	29.41	1.29

Table 4: Free Swell Index

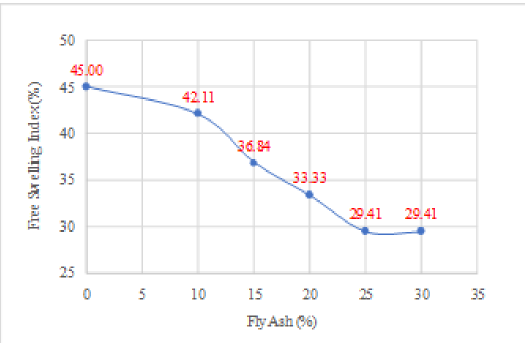

Figure 2: Fly Ash (%) vs. Free Swell Index (%)

Free Swell Index (%age)	Degree of expansion	Degree of severity
<50	Low	Non critical
50-100	Medium	Marginal
100-200	High	Critical
>200	Very High	Severe

Table 5: Classification system as per (IS: 1498)

A. Proctor Test:

The standard proctor tests were performed on samples according to IS: 2720 (Part 7) 1980. Results obtained after the tests are shown in table 6.

Mix Design	MDD (g/cc)	OMC (%)
Only Soft Soil	1.740	17.40
Soil + 10% FA	1.582	25.81
Soil + 15% FA	1.587	26.18
Soil + 20% FA	**1.668**	**24.74**
Soil + 25% FA	1.537	26.58
Soil + 30% FA	1.493	28.30

Table 6: Compaction Characteristics of Samples

Specific gravity of fly ash is less as compared to soil grains and so the fly ash grains are lighter in weight than soil grains. Therefore when we replace soil with fly ash, its MDD gets reduced while OMC increases. But for soil with 20% replacement shows exceptional result. MDD varies 1.668 to 1.493 along with OMC from 24.74 to 28.69 for fly ash 10-30%. Among all mix design, soil with 20% fly ash replacement shows excellent results in terms of MDD and OMC. Soil with 20% FA shows maximum MDD, i.e., 1.668 with minimum OMC, i.e. 24.74 among all mix design.

These compaction characteristics were used for unconfined compression tests and C.B.R. tests.

A. Unconfined Compression Strength Test:

Unconfined compression strength test is performed under undrained and uncosolidation condition for determining unconfined compressive strength of soil. In this test there is only deviator stress and no lateral confining stress. This test is special case of triaxial test. U.C.S. is stress at the time of failure of sample.

Diameter of test sample was taken 38 mm and height was 76 mm so that the height-to-diameter ratio obtained as 2. Shear strength is half of compressive stress at failure.

Mix Design	U.C.S. (kPa)	Shear Strength (kPa)
Only Soft Soil	180	90
Soil + 10% FA	130	65
Soil + 15% FA	160	80
Soil + 20% FA	170	85
Soil + 25% FA	140	70
Soil + 30% FA	140	70

Table 7: Unconfined Compressive Strength of Samples

With increasing percentage of fly ash, firstly for 10-20%, U.CS increases and then it starts decreasing. As expected the best suited result gives by soil with 20% of fly ash. This already known to us because the MDD of 20% fly ash was the highest among all mix design. The strength is due to soil grains and not due to fly ash. When we are replacing soil with fly ash, it is obvious that there is reduction in strength. The state of saturation is that state of soil where max pores between soil grains are filled or replaced with fly ash grains. At saturation level, maximum compactness will be obtained by the corresponding fly ash mix. At this state, the strength will get maximum in all mix design but still it will be lower than the strength obtained from only soil.

A. California Bearing Test:

For C.B.R. test, soil samples were kept in soaked condition. After period of 4 days, testing was done on soil samples. From literature, soaked condition is always critical condition for subgrade strength. Therefore in this study, soaked C.B.R tests are done only on soil mix samples.

Sample (Soaked)	C.B.R. (%)	Swell (%)
Clay	7.28	45.00
Clay + 10% FA	5.94	42.11
Clay + 15% FA	6.02	36.84
Clay + 20% FA	6.39	33.33
Clay + 25% FA	6.32	29.41
Clay + 30.% FA	6.09	29.41

Table 8: Soaked C.B.R. Test

Sample (Unsoaked)	C.B.R. (%)	Swell (%)
Clay	13.08	45.00
Clay + 20% FA	19.62	42.11

Table 9: Unsoaked C.B.R. Test

A. Consistency Limit for Soil with 20% Fly Ash

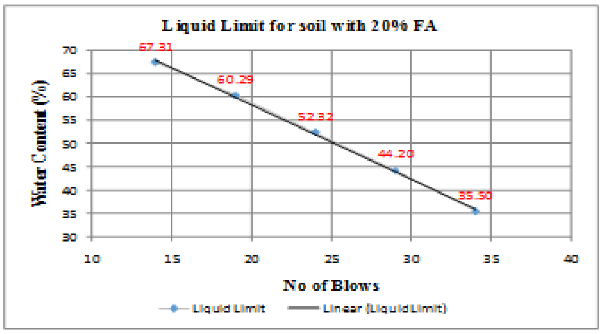

Figure 3: Liquid Limit for Soil with 20% Fly Ash

This clearly indicates that there is changes in inconsistency limit after addition of fly ash. Liquid limit decreased to 52.13% whereas plastic limit doesn't changed significantly. Plastic limit reduced to 32.57% after adding 20% fly ash. Overall plasticity index decreased from 29.19% to 19.56% due addition of fly ash.

6. CONCLUSIONS

1. Due to lower specific gravity of fly ash than the soft soil, it reduces overall weight on foundation. Therefore stress acting on foundation gets reduced.

2. With addition of fly ash, consistency limits get improvised. Due to fly ash addition, liquid limit decreased rapidly but plastic limit does not change significantly. Therefore overall plasticity index gets reduced.

3. Free swell index for soft soil is 45% and for soil with 20% fly ash is 33.33%. Free swell index reduced due to fly ash addition from 10% to 30% but as per literature it will get again increased by more than 40% fly ash addition.

4. The permeability of fly ash is lower than the permeability of soft soil due to its fineness. The void spaces between soil grains occupied by the very fine grained fly ash. Therefore, permeability decreased in soil with fly ash mix.

5. By the addition of fly ash, there is reduction in M.D.D. whereas elevation in O.M.C. At saturation limit, i.e., soil+20% FA, mix design shows the highest 1.668 M.D.D with lowest 24.74% OMC among all mix design.

6. The maximum U.C.S. of 170 kPa is obtained for soil with 20% fly ash mix. From proctor compaction test, its already been expected. The U.C.S. test was performed for 0 days cured sample and from literature, it's expected that there is increase in U.C.S. with increasing curing period because of hydration and pozzolanic behaviour of fly ash material.

7. C.B.R value of soaked sample tested at O.M.C. with 20% fly ash content is found to be maximum (6.39 %) in all mix design. Therefore for comparison, unsoaked test was performed on soft soil and soil with 20% fly ash. The result obtained was very satisfactory. C.B.R value of unsoaked sample tested at O.M.C. without fly ash content found out as 13.08% whereas with 20% fly ash gives 19.62%.

Hence for the maximum C.B.R. value, the optimum value of fly-ash mix is 20 percent.

7. RECOMMENDATIONS

In this study soil is stabilized with class C fly ash only. The soil stabilization could e done with class C and class C fly ash along with additional stabilizers such as cement, lime, RHA with different proportions. Also further investigation should be done on fine aggregate to reduce effect of sand boiling or quick sand condition.

8. ACKNOWLEGEMENT

This paper would not have been completed without the help and support of my advisor. I would like to express my gratitude to Prof. Vasatkar A. R. Assistant Professor, Civil Engineering Department, BSCOER, Pune for his guidance and encouragement for this paper.

REFFERENCES

Achmad Fauzia, Wan Mohd Nazmi Wan Abdul Rahmanb, Zuraidah Jauharic (2012). Utilization Waste Material as Stabilizer on Kuantan Clayey Soil Stabilization. *Malaysian Technical Universities Conference.* Volume 53 (2013), pp. 42-47.

Adil Binal, Bertan Bas, Orkun Rustu Karamut (2016). Improvement of the Strength of Ankara Clay with Self-Cementing High Alkaline Fly Ash. *World Multidisciplinary Civil Engineering-Architecture-Urban Planning symposium.* Volume 161, pp. 374-379.

Arora, K. R. (2008). Soil Mechanics and Foundation Engineering, Seventh Edition, Standard Publishers Distributors, Delhi, India.

B.C. Punmia. Soil Mechanics and Foundations 13th edition.

Baykal, G., Edincliler, A., Saygili, A. (2004). Highway Embankment Construction using Fly Ash in Cold Regions. Resour, Conserv. Recycl. Volume 42, pp. 209–222.

Beeghly, J.H. (2003). Recent Experiences with Lime–Fly Ash Stabilization of Pavement Subgrade Soils, Base, and Recycled Asphalt. *International Ash Utilization Symposium, Center for Applied Energy Research, University of Kentucky.*

Bergado, D., AndersIn, L., Miura, N., Balasubramaniam, A. (1996). Soft Ground Improvement: In Lowland and other Environment. *American Society of Civil Engineers, New York.*

Bumjoo, K., Prezzi, M., Salgado, R. (2005). Geotechnical Properties of Fly and Bottom Ash Mixtures for Use in Highway Embankments. *ASCE: J. Geotech. Geoenviron*. Volume 137 (7), pp. 914–924.

Cetin, B., Aydilek, A.H. (2013). pH and Fly Ash Type Effect on Trace Metal Leaching from Embankment Soils. Resour. Conserv. Recycl. Volume 80, pp. 107–117.

Dhavan, P.K., Goswami, N.K. and Bhasin, N.K. (1988). Utilization of fly ash in road construction. *Proc. National Workshop on Utilization of Fly Ash, C.B.R.I, Roorkee.*

DiGioia, A. M. Jr., and William, L.N. (1972). Fly ash as structural fill. *ASCE Journal of Power Division*. Volume 98, No. 101, pp. 77-92.

Dockter, B.A., Eylands, K.E., Hamre, L.L. (1999). Use of Bottom Ash and Fly Ash in Rammed-Earth Construction. *International Ash Utilization Symposium*. Center for Applied Energy Research, University of Kentucky.

Hayder Hasan, Liet Dang, Hadi Khabbaz, Behzad Fatahi, Sergei Terzaghi (2016). Remediation of Expansive Soils Using Agricultural Waste Bagasse Ash. *The 3rd International*

Conference on Transportation Geotechics. Volume 143, pp. 1368-1375.

Jyoti S. Trivedi, Sandeep Nair, Chakradhar Iyyunni (2013). Optimum Utilization of Fly Ash for stabilization of Subgrade Soil using Genetic Algorithms. *Chemical, Civil and Mechanical Engineering Tracks of 3rd Nirma University Interational Conference.* Volume 51, pp. 250-258.

Leema Peter, P K Jayasree, K balan, Alaka Raj S. (2014). Laboratory Investigation In The Improvement Of Subgrade Characteristics Of Expansive Soil Stabilised With Coir Waste. *11th Transportation Planning and Implementation Methodologies for Developing Countrie.* Volume 17, pp. 558-566.

Leonards, G.A. and Baily B. (1982). Pulverized coal ash as structural fill. *Journal, Geotechnical Engg. Div., ASCE*. Volume 108, No.4, pp. 617-697.

Murat Aziz Ozdemir (2016). Improvement in Bearing Capacity of a Soft Soil by Addition of Fly Ash. *The 3rd International Conference on Transportation Geotechics.* Volume143, pp. 498-505.

Nagarkar, P.K., Kulkarni, M.K. and Kalamkar, P.G. (1982). Use of fly ash in embankment construction for storing the fly ash at Ekalahare thermal power station. *Proc. of the Conference on Construction Practices and Instrumentation in Geotechnical Engineering, Surat*. pp. 57-60.

Science Direct.

Siavash Mahvash, Susana Lopez-Querol, Ali Bahadoei-Jahromi (2017). Effect of Class F Fly Ash on Fine Sand Compaction through Soil Stabilization.

Zaliha, S.Z.S., Kamarudin, H., Al Bakri, A.M., Binhussain, M., Salwa, M.S.S. (2013). Review on Soil Stabilization Techniques. *Australian Journal of Basic and Applied Sciences.* Volume 7 (5), pp. 258–265.

Corresponding Author

Ghanwat S. B.*

Bhivrabai Sawant College of Engineering and Research, Savitribai Phule Pune University, Pune, India

E-Mail – swapnilghanwat1@gmail.com