Proceedings of International Conference on Problematic Soils, 25-27 May 2005,
Eastern Mediterranean University, Famagusta, N. Cyprus

Stabilization of Expansive Soils of Bursa (Turkey) Region Highway Fills Using Fly Ash

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Abstract

In this study, an experimental investigation is carried out on the stabilization of expansive soil from open-cut excavations in the construction of Bursa Peripheral Highway fills with fly ash from Bursa-Orhaneli thermal power plant. In the course of experimental studies, the chemical, physical and mineralogical properties of the swelling clay to be stabilized and the fly ash are investigated. The percentages of fly ash needed to produce a mixture of clay fill material satisfying the requirements of technical specifications for Turkish General Directorate of Highways, the effects of the properties of the fly ash and the mineralogical content of the clay on the expansion behaviour are examined. It is determined that 35% fly ash treated expansive soil samples provide satisfactory fill material. Furthermore, the strength increases with curing time but liquid limit, plasticity index, swell pressure and thus swell percentage decrease substantially with the increase in fly ash percentage.

Keywords: *stabilization, expansive soil, swell percentage, swell pressure, fly ash*

1 Introduction

Expansive soil is a highly plastic material. It typically contains clay minerals such as montmorillonite, which attracts and absorbs water. Moreover, reaction of an expansive soil to changes in environmental conditions is to swell or exert large pressures against non-yielding structures. Since expansive soils constitute the most vulnerable natural hazard to lightweight structures, in the past decades, many soil engineers have done a lot of research on many aspects (e.g. geological, mineralogical, chemical, geotechnical and microstructure) of expansive soil and numerous reports of expansive soil problems and related damage have been documented in different countries (Johnes and Holtz, 1973; Chen, 1988; Nelson and Miller, 1992; B. Shi et al., 2002).

A great portion of industrial wastes is composed of power plant fly ashes. Therefore, there has been intensive research going on particularly focused on the usability of fly ash as an engineering material in a variety of construction applications, such as fills, concrete, and liners (DiGioia and Nuzzo 1972; Gray and Lin 1972; Leonards and Bailey 1982; Edil et al.

1987; Toth at al.1988; Indraratna at al.1991; Usmen et al. 1992; Rollings and Rollings 1996; Mollamahmutoğlu and Yilmaz 2001; Çokça 2001).

2 Bursa Peripheral Motorway Project

Bursa is one of the most important industrial city located in the west of Turkey. A new peripheral motorway is planned to be built. The amount of open-cut excavation materials is nearly 3 billion m^3 for the project. The site investigation carried out in the region revealed that the local soil is expansive in nature. In order to use soil obtained from open-cut excavations as a fill material in the motorway construction, the requirements of technical specifications of Turkish General Directorate of Highways (Table 1) should be satisfied to avoid unexpected damages of the expansive soil on the highway components. In this context, the results of laboratory experiments on some representative samples taken from open-cut excavations from the route of the Bursa Peripheral Motorway indicate that LL and PI range from 58 % to 80 % and from 32 % - 53 % respectively. It seems that LL and PI of some of the samples exceed the upper limit mentioned in Table 1. According to feasibility report it will not be economical to get rid of all of the open-cut material and find a suitable quarry and therefore it becomes inevitable to treat the local open-cut expensive soil material to be used in the highway fills.

From economical and environmental point of view it is decided that fly ash obtained from the nearest power plant (Orhaneli) is thought be a suitable stabilizing agent for the local expansive clayey soil at the highway construction area.

Table 1. Criteria for highway fill material (Turkish General Directorate of Highways)

Properties	Limit values	Specification #
Liquid Limit (LL), %	<70	AASHTO T-89
Plasticity Index (PI), %	<40	AASHTO T-90
Maximum dry unit weight from standard Proctor compaction test	>14,22 kN/m^3	AASHTO T-99

3 Geotechnical Properties of Fly Ash and Clay Used in This Study

The result of the sieve analysis, natural water content, specific gravity and consistency limits of Orhaneli fly ash is given in Table 2. The fly ash is gray-colored materials that consist of about 93 % silt sized particles (with traces of fine sand), the remainder being clay size fraction <2μ. It has very low specific gravity and classified as non-plastic material according to Unified Soil Classification System (Table 2). Some geotechnical properties obtained from laboratory tests carried out on the clay specimens are shown in Table 3.

Table 2. Geotechnical properties of the fly ash

Sieve size	% Finer
2,0-0,42 mm	0,9
0,42-0,075 mm	24,1
0,075-0,002 mm	68,1
0,002-0,001 mm	4,0
< 0,001 mm	2,9
Natural moisture content, w_n %	0,1
Specific gravity, Gs	2,104
LL, PL	N.P.

Table 3. Geotechnical properties of the clay

Property	Value
Coarse sand percentage (2-600μm) %	-
Medium sand percentage (600-212μm) %	-
Fine sand percentage (212-75μm) %	0,1
Silt percentage (%>2μm) %	22,2
Clay percentage (%<2μm) %	14,1
Colloid clay percentage (%<1μm)	63,5
Liquid limit, LL %	78-82
Plasticity limit, PL %	26-27
Plasticity Index, PI %	51-55
Linear Shrinkage, LS %	12-18
Natural unit weight, γ_n (kN/m^3)	18,43-18-65
Dry unit weight, γ_d (kN/m^3)	13,92
Natural moisture content, w_n (%)	30-34
Activity, A	0,69
Initial void ratio, e_0	0,977-0,985
Specific gravity, G_s	2,736-2,780

4 Mineralogical Properties of Fly Ash and Clay

Mineralogical study using X-ray diffraction (XRD) was carried out to determine the mineralogical composition of the fly ash. The XRD results indicate that the fly ash has relatively simple crystalline phases; quartz, mullite, hematite and ferrite spinal. Investigation with an ore microscope revealed that cenosphere formation was observed, many of spheres were cracked and also that the irregularly lacy particles seen in Orhaneli fly ash appear to be incompletely carbonaceous material. The fly ash has 100 % amorphous structure.

The clay minerals were specially examined using X-ray diffractometer (XRD) in this research. The minerals in the expansive soils include two types: Original minerals such as quartz, feldspar and mica, which are usually not considered due to their small amounts and low activity; and clay minerals such as montmorillonite, illite and kaolinite, which greatly influence the engineering properties of the expansive soil due to their very active physicochemical properties. The semi-quantitative analysis results showed about 80 % of smectite group in all samples are the major mineral but relatively small quantities of about 20% are illite group. It is therefore understood that the samples tested are likely to swell when they come in contact with water.

5 Chemical Properties of Fly Ash and Clay

Chemical composition analysis of the fly ash was carried out in accordance with ASTM C 311. The results are presented in Table 4. The main constituents of the fly ash are slica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) which together amount to more than 50 % of the total weight. The calcium oxide (CaO) content is about 41 %. The Fe_2O_3 and CaO in the fly ash can improve the particle bonds between clay sheets and restrain the swelling and shrinkage of the soil. It is thus classified as high-calcium fly ash. Since SiO_2+Al_2O_3+Fe_2O_3 fraction of fly ash is greater than 50 % of the total content it may be classified as class C. On the ground that C type fly ashes hardness when in touch with water may compaction process should be carried out in a short time after mixing with water. With reference to ASTM C 618 the fly ash under consideration can be classified as silicocalsic fly ash.

Chemical composition analyses of the clay samples were carried out and the results are presented in comparison with the fly ash in Table 4.

Table 4. Chemical compositions of the clay and the fly ash

Properties %	Clay	Fly ash
SiO_2	3,66	43,00
R_2O_3 ($Al_2O_3 + Fe_2O_3$)	10,92	11,96
Al_2O_3	7,42	9,32
Fe_2O_3	3,50	2,64
$SiO_2 + Al_2O_3 + Fe_2O_3$	14,58	54,96
Total CaO	3,94	41,00
Free CaO	0,00	0,00
MgO	4,33	1,90
SO_3	0,00	0,83
Ignition Loss	12,46	1,07

6 Preparation of Samples for Testing

Samples taken from open-cut excavations were initially kept at room temperatures of 20 °C to 25 °C and then broken into small pieces when certain amounts of which passing through ASTM #4 sieve were collected in a pan and mixed along with fly ash and subjected to testing as soon as possible.

7 Standard Proctor Tests

Prior to compaction, dry fly ash and dry clay were mechanically mixed at 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40% (e.g. dry mass of fly ash / dry mass of clay) until homogenous mixtures were obtained and then a certain amount of water was added. It is observed that during preparation of samples for compaction test flocculation takes place as soon as water is added to the mixtures, which prevents homogenous distribution of fly ash into clay matrix. Therefore all mixtures were initially mixed with 7 % of water and then stored in a closed plastic bag for a day. In this way, flocculation was minimized. Thereafter samples were remixed with suitable amount of water and then compaction test was carried out.

Dry densities of the compacted samples were plotted with reference to the corresponding moisture contents to obtain the compaction curves Fig 1.

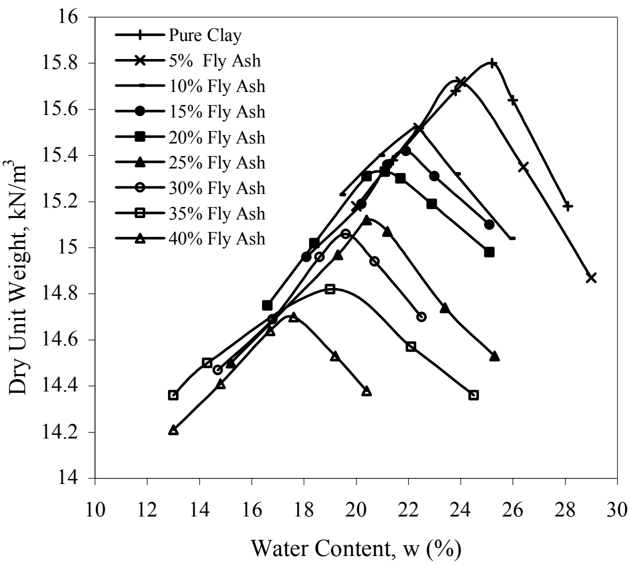

Figure 1. Standard Proctor compaction curves of the mixtures

Variation of maximum dry unit weight and optimum moisture content with fly ash content is shown in Fig 2. It is seen that maximum dry unit weights and optimum moisture contents decrease with the increase in fly ash content. Furthermore LL, PI values decreases with the increase of fly ash content Fig 3. Fig 3 indicates that 35 % fly ash with 65 % clay mixture satisfies the required specification as a fill material (PI=39<40 and LL=67 < 70).

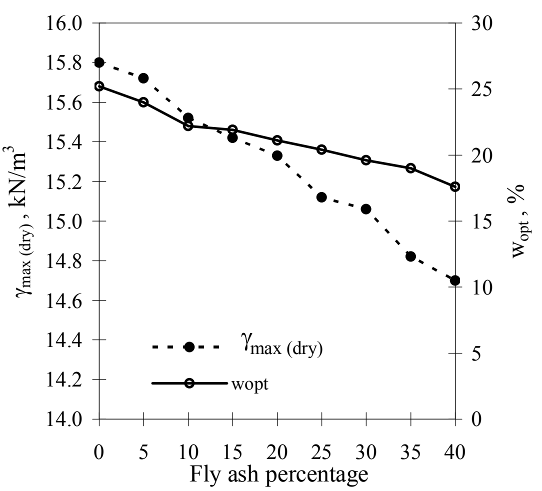

Figure 2. Variation of optimum moisture montent and maximum dry densities with fly ash percentage

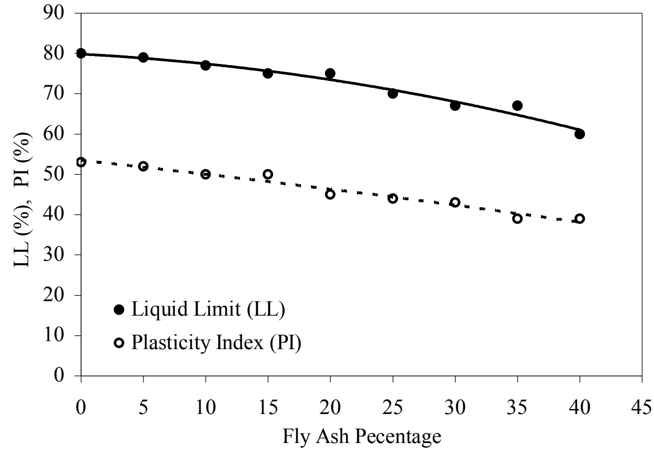

Figure 3. Variation of LL and PI with fly ash percentage

8 Swell Pressure and Swell Percentage from Oedometer Test

Samples compacted at optimum moisture content were subjected to swell pressure and swell percentage tests using oedometer test apparatus having rigs of 75,2 mm in diameter and 20,0 mm in height. 1,0 kPa surcharge pressure was adopted for both swell pressure and swell percentage measurements. When performing swell pressure tests the applied pressure is adjusted such that the maximum settlement of the sample is kept below 0,03-mm.

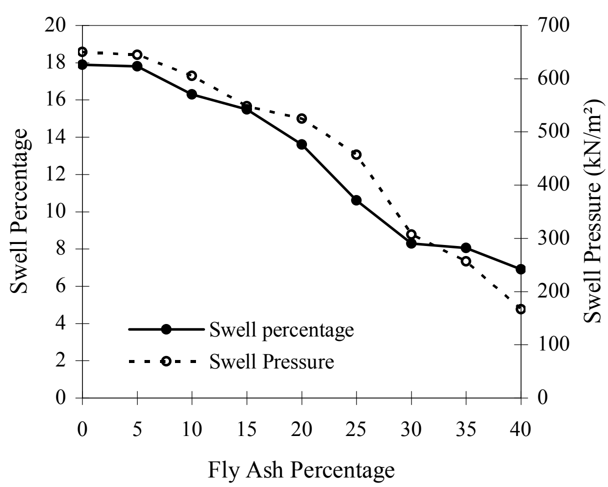

Figure 4. Variation of swell percentage and swell pressure with fly ash content

The relation between the fly ash content with swell percentage and swell pressure were plotted in Fig 4. It may be stated that as the fly ash content increases both swell percentage and swell pressure decrease.

9 Effect of Curing

This part of the experimental program is planned to investigate the effect of curing time on the swell percentage, swell pressure and unconfined strength of pure clay and fly ash-treated samples up to 65 days due to puzzolonic activity.

35% fly ash treated mixture was compacted at optimum moisture content in 6" diameter CBR moulds and then set to cure in a humidity room. Samples extracted from these moulds at the time of experiment are then subjected to unconfined compressive and consistency limit tests.

Swelling percentage and swelling pressure of the samples were obtained at the end of 41st and 65th days and results were given in Table 5.

Table 5. Variation of swell percentage and swell pressure with curing time for 35% fly ash treated samples

Curing period (day)	Swell percentage	Swell pressure (kN/m^2)
0	8,06	257
41	2,62	84
65	2,56	80

It is clear from Table 6 that both swell percent and swell pressure decrease with time. The decrease is abrupt up to 40 days but gentle thereafter.

Results and Conclusion

Based on the findings, the following conclusions can be drawn:

1. The clay encountered in open-cut excavation of Bursa Peripheral Motorway area can be classified as CH according to USCS and has high colloid content with normal activity.
2. X-RAY diffraction test results show that the main mineralogical composition of the clay is smectite one thus indicating capability of swelling potential.
3. Orhaneli fly ash obtained from Orhaneli Power Plant can be classified as C type fly ash according to ASTM C 618 and X-RAY diffraction results display that the fly ash is completely amorphous structure and has puzzolonic property.
4. The untreated clay's swell percentage and swell pressure values are 17,9% and 650 kN/m^2 respectively but swell percentage and swell pressure of 35 % fly ash treated clay mixtures are reduced to 8,06 % and 257 kN/m^2 respectively, which is acceptable for a fill of highway material.
5. Swell percentage and swell pressure of 35% fly ash treated clay samples decreases up to 40th day and then stabilizes. The time-dependent behaviour may be attributed to the puzzolonic activity of fly ash.

As a general conclusion, utilization of Orhaneli fly ash as a stabilizing agent for the local expansive clay to be used as a fill in Bursa peripheral motorway has the advantages of utilizing an industrial waste eliminating the risk of environmental pollution or potential land use and is economically attractive due to fact that it is close to the motorway region

Acknowledgment

The authors would like to express their gratitude to Turkish General Directorate of Highways and Turkish General Directorate of Electricity for providing Bursa region expansive clay and Orhaneli Thermal Power plant fly ash respectively.

References

Chen, F.H., 1988. Foundations on Expansive Soils. Developments in Soil Geotechnical Engineering, Vol 54. Elsevier Science, New York, p.467.

Çokça, E. 2001. Use of Class C Fly Ashes for the Stabilization of an Expansive Soil. J. Geotech. and Geoenviron. Engrg., ASCE, 127 (7), 568-573.

DiGioia, A.M., and Nuzzo, W.C. 1972. Fly Ash as Structural Fill. ASCE, J. Power Div., ASCE, 98, 72-92.

Edil, T.B., Berthoueux, P.M., and Vesperman, K.D. 1987. Fly Ash as a Potential Waste Liner. Proc., Geotech. Pract. For Waste Disposal'87, R.D. Woods, ed., ASCE, New York, 447-461.

Gray, D.H., and Lin, Y.K. 1972. Engineering Properties of Compacted Fly Ash. J. Soil Mech. and Found. Engrg. Div., ASCE, 98, 361-380.

Indraratna, B., Nutalaya, P., Koo, K.S., and Kuganenthira, N. 1991. Engineering Behaviour of a Low Carbon, Puzzolonic Fly Ash and its Potential as a Construction Fill. Can. Geotech. J., 28, 542-555.

Johnes, D.E., and Holtz, W.G. 1973. Expansive Soils-The Hidden Disaster. Civil Engineering, ASCE 43(8), 49.

Leonards, G.A., and Bailey, B. 1982. Pulverized Coal Ash as Structural Fill. J. Geotech. Engrg. Div., ASCE, 108, 517-531.

Mollamahmutoglu, M., and Yilmaz, Y. 2001. Potential Use of Fly Ash and Bentonite Mixture as Liner or Cover at Waste Disposal Areas. Engineering Geology,

Nelson, J.D., and Miller, D.J. 1992. Expansive Soils-Problems and Practice in Foundation and Pavement Engineering, Wiley, New York.

Rollings, M.P., and Rollings, R.S. 1996. Geotechnical Materials in Construction, McGraw-Hill, New York.

Shi, B., Jiang, H., and Fang, H.Y. 2002. Engineering Geological Characteristics of Expansive Soils in China. Engineering Geology, 67, 63-71.

Toth, P.S., Chan, H.T., and Crag, C.B. 1988. Coal Ash as Structural Fill with Special Reference to Ontario Experience. Can. Geotech. J., 25, 694-704.

Usmen, M. A., Baradan, B., and Yazici, S. 1992. Geotechnical and Geoenvironmental Properties of Stabilized Lignite Fly Ash. Proc., Mediterranean Conf. on Environ. Geotechnology, M.A. Usmen and Y.B. Acar, eds., Balkema, Rotterdam, The Netherlands, 419-427.