Laboratory Evaluation of Stabilization of Soft Subgrades by Class C Fly Ash

A. Senol
Assistant Professor, Civil Engineering Faculty, Istanbul Technical University, 34496 Istanbul, Turkey
senol@itu.edu.tr

T.B. Edil
Professor, Department of Civil and Environmental Engineering, University of Wisconsin-Madison, 53706 WI, USA

M.S.B. Shafique
Assistant Professor, Department of Civil and Environmental Engineering, University of Texas-San Antonio, 78249 TX, USA

Abstract: This paper presents the soil property changes after stabilization using self-cementing class C fly ash for two types of soft subgrade soils in Wisconsin, USA. Soft subgrade soils are common problem for highway construction. A well-known approach for the soft subgrade stabilization is to remove the soft soil, and replace with high-bearing capacity materials such as aggregate. One alternative to this common approach is to use fly ash to stabilize the soft subgrade in situ. Mixtures of two types of soils and a class C fly ash were subjected to laboratory tests, i.e., compaction and unconfined compression tests, to assess the properties of the soil-fly ash mixtures and the optimum mix ratios and moisture contents before construction. Sets of stabilized soil specimens were prepared with 10% to 20% fly ash contents and at different water contents using the Harvard miniature compactor. The samples were subjected to unconfined compression tests after 7 days of curing in a 100% relative humidity room. To evaluate the effect of compaction delay that commonly occurs in field construction, groups of samples were compacted either without delay or with two hours of delay after adding water. It is shown that fly ash stabilization improves engineering properties of soft subgrades significantly. Moisture content at which the maximum strength is obtained for any mixture is nearly the optimum compaction moisture content of that mixture when delayed compaction is used.

1 INTRODUCTION

Soft subgrade soils are a common problem for highway construction in many parts of the world including the State of Wisconsin, USA. The usual approach for soft subgrade stabilization is to remove the soft soil, and replace with a high-bearing capacity material such as crushed aggregate. The evaluations of alternative methods of building highways or city streets on soft soils are preferable because of the high costs associated. One alternative method is to use fly ash to stabilize the soft subgrade in-situ. The use of fly ash stabilized subgrade can provides equivalent support to replacement with aggregate with a thinner subbase layer. In this paper, mixtures of two types of soils and a class C fly ash were subjected to laboratory tests, i.e., compaction and unconfined compression tests, to assess the properties of the soil-fly ash mixtures and the optimum mix ratios and moisture contents before construction. The first group of samples was from State trunk Highway 60 (STH60), a rural highway near Lodi, Wisconsin and the second from Scenic Edge, a new residential street development. Both soils were soft soils and required to be stabilized for the pavement construction. Sets of stabilized soil specimens were prepared with 10% to 20% fly ash content and at different water contents using the miniature Harvard compactor (36 mm in diameter and 71 mm long). They were subjected to unconfined compression tests. The unconfined compression tests were performed after 7 days of curing in room temperature and 100% relative humidity. To evaluate the effect of compaction delay that commonly occurs in field construction, one half of the samples were compacted without any delay after mixing with water, while the others after two hours of delay.

2 MATERIALS

2.1. *Engineering Properties of Soils*

The sampling locations of the soils were identified by the Wisconsin Department of Transportation. The STH60 soil samples were collected along the highway shoulder, at a depth of 0.6 m to 0.9 m and the Scenic Edge soil samples were collected 1m below the surface near a city street at Cross Plains (Edil *et al.*, 2000 and 2002).

The index and compaction properties and the classifications of both soils are summarized in Table 1. The natural water content is 26% for STH 60 soil and 24% for Scenic Edge soil. All of the soils are fine-grained materials. The STH60 soil is a low-plasticity silt (ML) according to the unified Soil Classification System (USCS) and A-6 according to the American Association of Highway and Transportation Officials (AASHTO) whereas Scenic Edge soil is a low-plasticity clay (CL) according to the USCS and A-7-6 according to the AASHTO. All of the soils contained at least 93% fines.

2.2. *Fly Ash Mixtures*

The fly ash-stabilized subbase was prepared by mixing Class C fly ash from the Columbia Power Station in Portage, Wisconsin with subgrade soils. Columbia fly ash is light brown in color indicating higher calcium oxide content. The specific gravity of the fly ash was found as 2.65. It is slightly finer and has particles ranging from fine sand to silt and clay sizes

Table 1. Engineering properties of STH60 Lodi and Scenic Edge soils.

	Soil classification		W	LL	PI	#200	D 698	
							γ_{dmax}	W_{opt}
	USC	ASSHTO		(%)			(kN/m³)	(%)
STH60	ML	A-6	26	39	14	99	14	19
Scenic Edge	CL	A-7-6	24	44	18	93	15	19

The mix designs of test samples were evaluated in the laboratory by preparing specimens in a Harvard miniature compactor following ASTM D4609. Samples were allowed to cure in a 100% relative humidity room for 7 days, and then subjected to unconfined compression test.

3 EVALUATION OF LABORATORY TESTS

The improvement in engineering properties of soft subgrade soils, such as unconfined compressive strength, was investigated. A general trend of increasing unconfined compressive strength by increasing fly ash content is observed. The strength gain generally depends on soil type, fly ash type, and water content but is not strongly correlated with soil index properties. To prepare the compaction specimens, which were also used as the unconfined compression test specimens, the soil samples were first air-dried and all the clods were crushed properly. The fraction passing through #20 standard sieve (0.850 mm opening size) was used. Three different fly ash contents were planned for the mixtures of both types of soils. The fly ash content for the STH60 samples were 10%, 14%, and 18% % (by the total dry weight of soil solids) and the one for the Scenic Edge samples were 12%, 16%, and 20% (by the total dry weight of soil solids and fly ash). After mixing thoroughly, each set of mixture was divided into five groups and different amounts of water were added to each resulting in water contents between 10% and 28% as can be seen Figs. 1 & 2.

3.1. *Compaction Behavior*

The samples were compacted using Harvard Compactor using an effort equivalent to the standard Proctor effort as given in ASTM D698 immediately after introducing water. A total of 15 samples resulted from this procedure and were identified as no-delay samples. The other set of samples, i.e., the 2hr-delay samples, were compacted two hours after the time of mixing of water.

Typical bell-shaped compaction curves were obtained for the STH60 (Fig. 1) and for the Scenic Edge (Fig. 2). For the 2-hour delay samples, the STH60 soil and fly ash mixtures have approximately maximum dry unit weights of 15.8~16.1 kN/m³ and the optimum water contents of 19~20%. Also the Scenic Edge soil and fly ash mixtures have approximately the same maximum dry unit weights (15.5~15.7 kN/m³) and the optimum water contents (20~22%). The no-delay samples resulted in higher dry unit weight values and lower optimum moisture contents than the 2-hour delay samples for both soils.

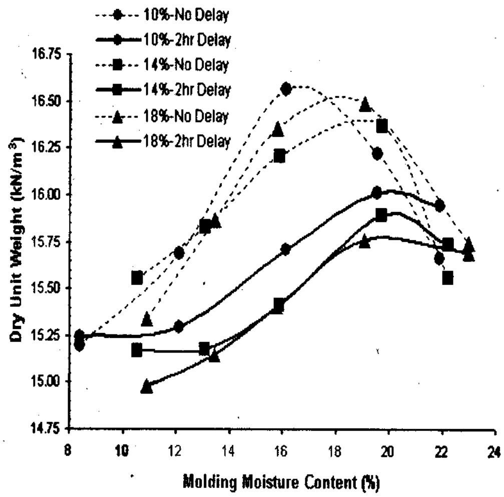

Fig. 1. The compaction curves of STH60 Lodi mixture samples.

3.2. *Unconfined Compression Tests*

After compaction, each specimen was wrapped immediately with polyethylene sheet to prevent any desiccation. They were then sealed using a plastic wrap, and left to cure for 7 days at 25°C and 100% relative humidity prior to curing according to ASTM D1632, (that is, protected from the free moisture in 100% relative humidity room at 21°C). The cured samples were tested for unconfined compressive strength according to ASTM D1633 and ASTM D2166.

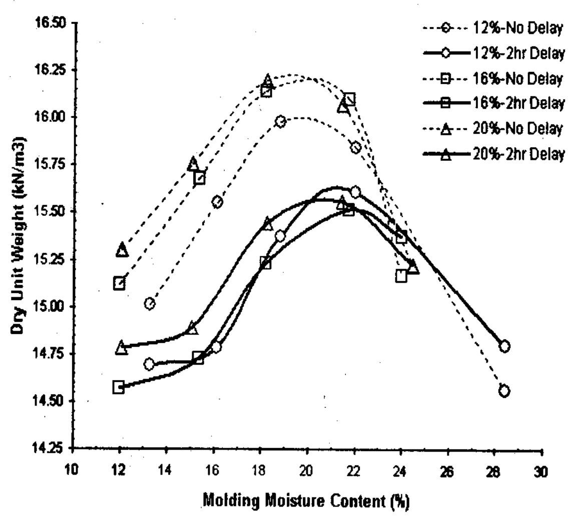

Fig. 2. The compaction curves of Scenic Edge mixture samples.

The average value of unconfined strength of the unstabilized STH60 subgrade soils at its original in-situ condition with the water content 24% was about 125kN/m². The average value of unconfined strength of the unstabilized Scenic Edge subgrade soils at its original in-situ condition with the water content 25% was about 105kN/m². Both water contents represent approximately the original field conditions and they are on the wet side of their optimum moisture contents. The unconfined compression strength of the mixtures are higher by a factor of about 3~10. The Figs. 3 & 4 show the unconfined compression curves for the compacted no-delay and 2-hr delay samples for both soils at varying fly ash contents.

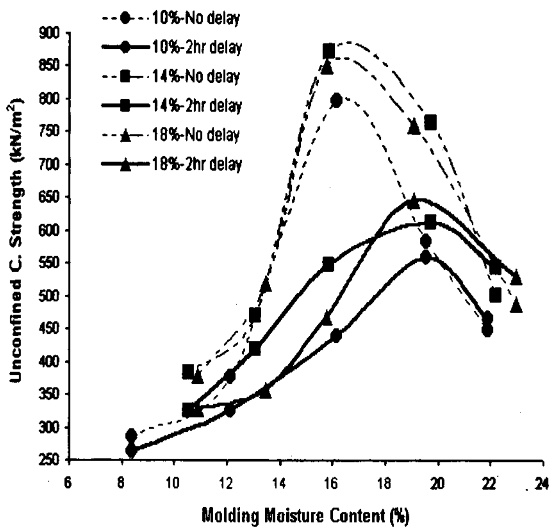

Fig. 3. The unconfined compression curves of Scenic Edge mixture samples.

Table 2 summarizes the moisture contents for the maximum dry density and the maximum unconfined compressive strength from all of the tests. For both soils, the optimum compaction moisture content and the moisture content for achieving the maximum strength are nearly the same for the 2hr-delay samples (i.e., $w_{opt} \approx w_{qumax}$). Drier or wetter mixtures than w_{qumax} result in lower strength. The maximum strength of the no-delay samples is greater than the 2hr-delay samples; however, the molding water content corresponding to the peak strength values for the no-delay condition for both soils is about 1~3% lower than the corresponding original compaction optimum water content.

Table 2. The comparisons between the optimum water contents and the water contents of maximum unconfined compression strength values of STH60 and Scenic Edge soils for no delay and 2-hr delay conditions.

		FA (%)	γ_{dmax} (kN/m³)	w_{opt} (%)	q_{umax} (kN/m²)	w_{qumax} (%)
STH60	No delay samples	10	16.60	16	800	16
		14	16.55	18	880	16
		18	16.40	20	860	16
	2-hour delay samples	10	16.00	20	560	20
		14	15.90	20	620	20
		18	15.75	20	650	19
Scenic Edge	No delay samples	12	16.00	19	975	19
		16	16.20	20	1200	18
		20	16.25	19	1060	18
	2-hour delay samples	12	15.65	21	790	21
		16	15.50	22	900	19
		20	15.55	20	820	20

Note: FA=Fly ash content, w_{qumax} =The water content of maximum q_u value

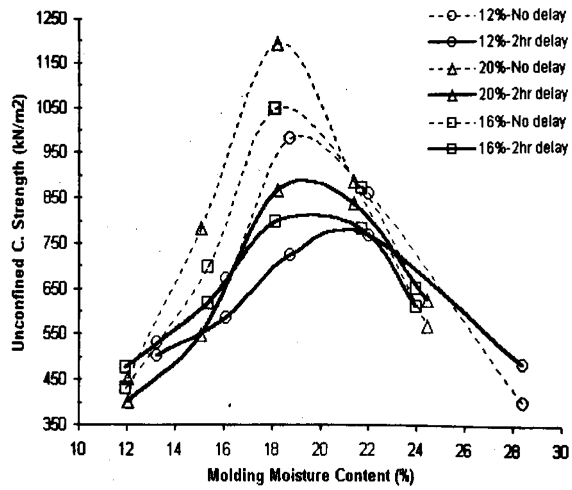

Fig. 4. The unconfined compression curves of STH60, Lodi mixture samples.

4 CONCLUSIONS

The objective of this part of the research was to quantify the effect of mixing Class C Columbia fly ash on two different soft subgrade soils.

Specimens of soil-fly ash mixture were prepared at different fly ash contents (10-20%) with the specimens compacted at varying water contents using the standard Proctor effort. Subsequent to 7 days of curing unconfined compression tests were performed on these specimens. In summary, the results from the laboratory tests on these specific soil-fly ash mixtures are as follows:

- Two-hour compaction delay after mixing water resulted in considerably lower dry unit weights and higher optimum water contents compared to no-delay compaction.
- 2hr-hour delay samples consistently resulted in lower unconfined compressive strengths compared to no-delay samples. It is considered that 2-hr delay samples represent the field conditions more closely than no-delay ones.
- Moisture content at which maximum strength is obtained is comparable to optimum compaction moisture content for the 2hr-hour delay samples but drier than the optimum moisture content for the no-delay samples.
- Fly ash stabilization increases unconfined compressive strength significantly and offers an alternative method of generating a working platform for pavement construction over soft subgrades.
- Stabilizing at the specified water content and minimizing compaction delay in the field could maximize the strength of fly ash-stabilized soils.
- A compaction delay simulating field conditions, such as 2 hours, is recommended in all laboratory tests in order to simulate the field conditions. Optimum compaction moisture content can be used as the approximate optimum strength gain moisture content for delayed compaction.

ACKNOWLEDGMENTS

The financial support for the study was provided by the U.S. Department of Energy through the Combustion Byproducts Recycling Consortium, Wisconsin Department of Transportation and the University of Wisconsin-Madison Consortium for Fly Ash Use in Geotechnical Applications. The Istanbul Technical University rectory provided additional financial support for the research.

REFERENCES

ASTM Designation: D698-00a, *Standard Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600kN-m/m³).*

ASTM D1632-96 *Standard Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory.*

ASTM D1633-00 *Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders.*

ASTM D2166-00 *Standard Test Method for Unconfined Compressive Strength of Cohesive Soil.*

ASTM D4609-01 *Standard Guide for Evaluating Effectiveness of Chemicals for Soil Stabilization.*

Edil, T.B., Bin-Shafique, M.S. & Şenol, A. 2000. Properties of fly ash stabilized soil from Cross Plains, Technical Report, University of Wisconsin-Madison, USA.

Edil, T.B., Benson, C.H., Bin-Shafique, M. S., Kim, W., Tanyu, B.F. & Şenol, A. 2002. Field evaluation of construction alternatives for roadway over soft subgrade, *Journal of Transportation Research Record 1786:* 36-48. National Research Council, Washington D.C., USA.

Meyers, J.F., Pichumani, R., Kapples B.S., & US Department of Transportation, 1976. Fly ash as a construction material for highways, Report No. FHWA-IP 76-16, Washington, D.C., USA.

Şenol, A., Bin-Shafique, M.S., Edil, T.B. & Benson, C.H., 2003, Use of Class C Fly Ash for the stabilization of soft soil as subbase, *The Bulletin of the Istanbul Technical University* 53: 89-95, Istanbul Technical University, Istanbul, Turkey.

Proceedings of the

FIFTEENTH SOUTHEAST ASIAN GEOTECHNICAL CONFERENCE (15th SEAGC)

Bangkok, Thailand
22 to 26 November 2004

Volume 1

editors

S. Sambhandharaksa
D.T. Bergado
T. Boonyatee