

# Improvement Of Soil Engineering Characteristics Using Lime And Fly Ash

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## Abstract

A solution available to engineers for facing the problem of unsuitable soils for pavement foundation is the stabilization processes. Among then the use of chemical additives has gained popularity, particularly the last decade. The poor engineering characteristics of soils could be enhanced under the action of various agents and controlling factors, like the pozzolanic activity, the cation exchange and other already recognized reactions taking place in the soil-additive complex. In this research work the findings of laboratory tests for the stabilization of a problematic soil in Xanthi, Northern Greece area are presented. For the testing program a commercial lime and a fly ash from an Electric Power Station have been elected. Various percentages have been used for the preparation of soil-additive mixtures. Based on the findings of the present study, fly ash could be recommended as an effective agent for the improvement of swelling soils, having the benefit of reducing the negative impacts to the environment. The results highlight the need for further investigation of clay soil characteristics after their chemical stabilization with substances freely available or with a low cost, if the intention is to use such soils in highway construction works..

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**Keywords:** Lime, fly ash, soil stabilization, strength

## Introduction

Traffic volumes and the weight of vehicles increase rapidly. In association to the need for aggregate preservation and environmental protection, this fact leads to solutions for the design of new or the reconstruction of existing pavements that will serve as far as possible the above goals. A solution with relatively low cost is the use of materials with moderate or poor engineering and physical characteristics after their enhancement. One of the most commonly employed methods is the treatment of natural soils and aggregates with additives to obtain properties similar to

those set by the relevant standard specifications. This process is called soil stabilization and aims to increase the shear strength of the soil in addressing the effects of frost, shrinkage, etc. The choice of additive is based on the respective intended purpose.

The addition of lime to clayey soils results in immediate reduction of the maximum dry density and increase of the optimum moisture content for the same compaction effort (Miqueleiz et al., 2012; Elsharief et al., 2013). The effect of fly ash on the compaction characteristics is very similar (Deb and Pal, 2014).

Fly ash may be considered as non-plastic, NP, fine silt according to the Unified Soil Classification System (USCS) system. When blended with soil, fly ash can develop cementitious bonds, either due to the pozzolanic reaction (Kenawi and Kamel, 2013; Zumrawi, 2015) or because of an intrinsic property to self harden under favorable moisture and compaction conditions (Mir and Sridharan, 2013). When mixed with soil in various proportions, fly ash reduces the liquid limit and the plasticity index of the soil (Mir and Sridharan, 2014).

The strength of soil mixtures with lime and fly ash depends on many variables such as soil type, the type and content of the additive material, the size of the specimens, the time and method (humidity and temperature) of curing, the water content, specific gravity and time elapsing between the mixing and the compaction of the material (Liu et al., 2012; Jawad et al., 2014). For the needs of the present research work, the values of the additives percentages and the maintenance time have been varied with different effects on the mixture's properties.

Generally, the strength increases with an increase both in lime and fly ash content (Prabakar et al., 2004; Muhmed and Wanatowski, 2013; Zumrawi and Hamza, 2014), as well as with an increase in curing time (Harichane et al., 2011).

For the development of compressive strength, the percentage of fly ash in soil mixtures has been proven to be a more critical factor compared to specimens curing time (Horpibulsuk et al., 2013; Rodriguez, 2007). The exactly opposite effect occurs for the lime mixtures, where the curing time plays an important role for the enhancement of strength (Consoli et al., 2011).

A series of laboratory tests have been conducted in Highway Engineering Laboratory, DUTH University, Thrace, in order to characterize soil-lime and soil-fly ash mixtures for use in road projects running through areas with similar features with those in the area under study on the road-axis Xanthi-Komotini, Northern Greece.

### **The road site and its geological characteristics**

At its 21<sup>st</sup> km the road Xanthi-Komotini (National Road No 2) passes through the village of Nea Kessani. At this location, over a length of approximately 500 meters, reconstruction works and widening of the carriageway had been carried out. The old roadway had been removed because it presented intense cracking problems and differential settlement at the edges of the traffic lanes. These problems have been attributed mainly to the nature of the underlying soil, because it consists of dark colored plastic clays with low strength. The work described in this paper explored the possibilities to improve these clays (underlying soil) with the addition of lime and fly ash.

The area under study belongs to the wider basin of Vistonis Lake, covered in a depth of several meters by recent deposits of nearby streams (gravels, sands, clays, etc.). The material is becoming finer as someone approaches the lake. Thus, around the lake and at its bottom darkened lacustrine deposits consisting of clays, silts and sands prevail. The thickness of these deposits in the lake reaches several tens of meters. The area under study is located at the western limits of the lake where dark colored swelling clays with enough organic material prevail. In this region, the clays have a relatively small thickness and overlie the neogenic sediments (pliocene) which appear in the hilly area SW of Nea Kessani (Figure 1).

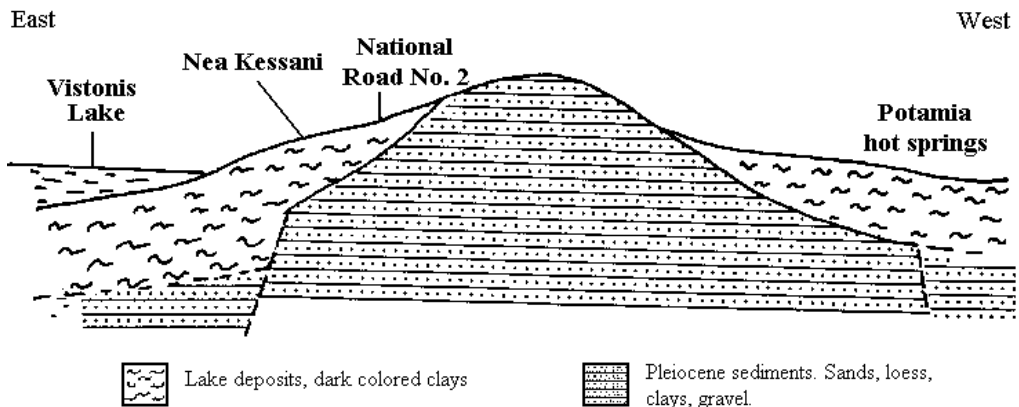


Figure 1: Geological section at Nea Kessani (sketch not in scale).

### Materials and methods

Samples of the clay from the region have been taken from an excavation about 1 m in depth. The Atterberg limit values of the natural soil were: Liquid Limit, LL=62, Plasticity Limit, PL=23, Plasticity Index PI=39. The linear shrinkage of the material was 12.5%. Based on the above results, the soil material is classified in the A-7-6 soil group according to the AASHTO classification system. According to the USCS the sampled

material is characterized as clay CH. Such soil materials are considered unsuitable (moderate to poor) for roadway subgrade construction.

After recognizing the soil's physical state (Atterberg limits, moisture-density relationship, etc.) various percentages of fly ash and lime were added to it. The materials used as admixtures for the preparation of Proctor and strength specimens were a commercial lime traded by limekiln Aimos Co. in Drama, Northern Greece having a high content in calcium oxide and a fly ash obtained at the Megalopolis Power Production Station.

Megalopolis fly ash is characterized by the lack of free lime, while the insoluble residue is large due to high SiO<sub>2</sub> content. According to ASTM C618, the Megalopolis fly ash is designated as Class F. The total amount of oxides of silicon, aluminum and iron is relatively high, assisting the pozzolanic activity of fly ash. The specific weight of fly ash was 2.53 and its particle size distribution consists of very fine particles (about 87% of the particles passing through the No. 200 sieve). The fly ash had a Blaine specific surface 1,530 cm<sup>2</sup>/g.

To find the optimum moisture to be used in each soil sample mix-additive held a series of moisture-density test Proctor (AASHTO T99). The chemical composition of the fly ash and lime is shown in Table 1.

Table 1 Chemical composition of fly ash and lime

Component oxide (%)	Fly Ash	Lime
SiO <sub>2</sub>	48.0	0.01
Al <sub>2</sub> O <sub>3</sub>	18.25	0.01
Fe <sub>2</sub> O <sub>3</sub>	10.3	0.11
CaO	9.0	65.25
MgO	2.1	0.50
SO <sub>3</sub>	3.4	
K <sub>2</sub> O	0.1	0.01
Na <sub>2</sub> O	0.3	0.01
CO <sub>2</sub>	0.1	4.50

Lime and fly ash contents of 3-12% and 5-25% by weight of natural soil, respectively, have been used for the preparation of specimens. Such an amount of water has been added to the dry materials as to reach the optimum Proctor moisture. The specimens were cured in a humidity chamber at room temperature.

## Results and discussion

The results of tests performed for the determination of moisture-density relationship are presented in Table 2 and in Figures 2 and 3. It is shown that the maximum dry density decreases with the additive content, while the optimum moisture increases. As it was expected, adding lime resulted in immediate reduction of the maximum dry density and increase of

the optimum moisture content, while fly ash had a similar effect on the compaction characteristics of the mixtures.

Table 2 Moisture-density test results for various additive contents (24 hours curing period)

Additive (%)	Optimum Moisture (%)	Maximum Dry Density (kg/m <sup>3</sup> )
0	21.4	1,602
Fly Ash		
5	23.1	1,552
10	23.6	1,513
15	24.3	1,487
20	25.4	1,463
25	26.6	1,433
Lime		
3	25.0	1,479
6	25.7	1,444
9	26.3	1,431
12	27.6	1,413

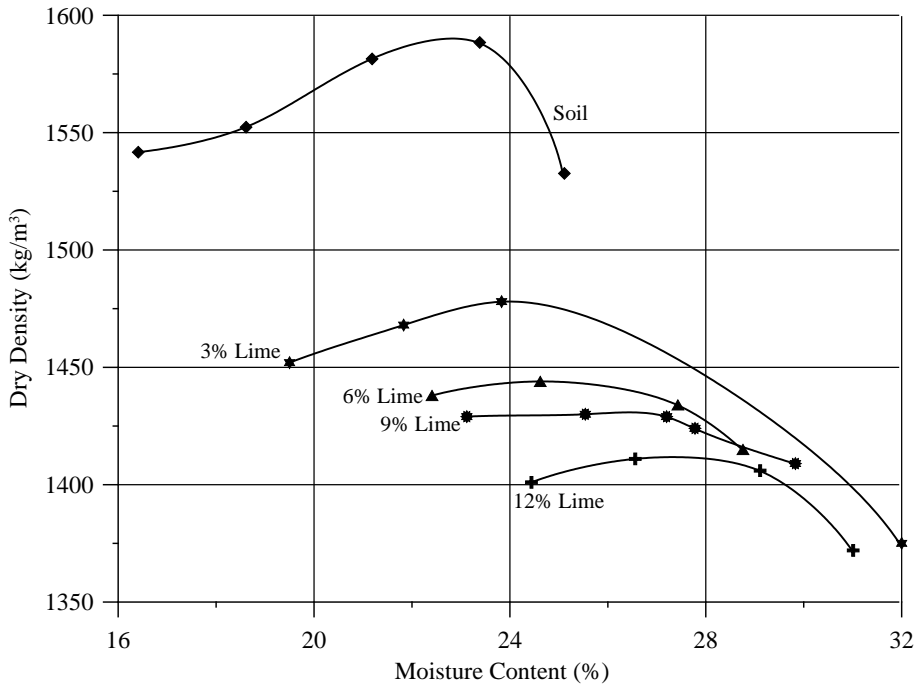


Figure 2 Moisture-density relationship as a function of lime content

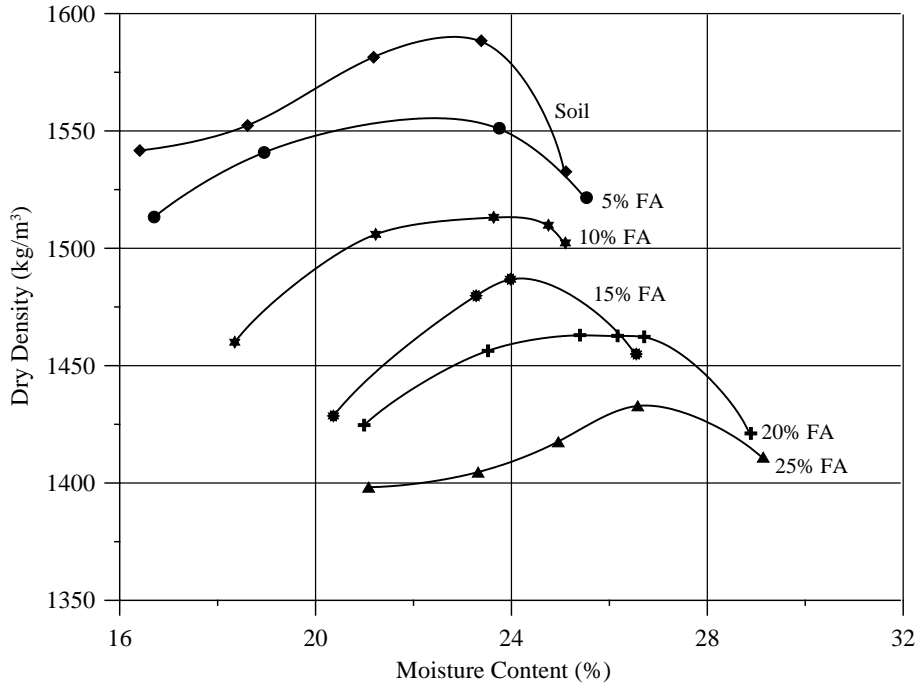


Figure 3 Moisture-density relationship as a function of fly ash content

The compaction of the mixtures of the soil with the additives yielded moisture-density curves common feature of which is that they are in areas of lower densities and higher moistures than those of the untreated soil (Figures 2 and 3). Particularly, with the addition of fly ash, the curves are smooth and they have a form comparable to that of the soil sample and, as the additive content increases, they show a denser space between each other. Thus, after some additive percentage, the compaction characteristics will only slightly change. The curves of soil-lime mixtures are very offset relatively to the curve of the untreated soil, already with small additive percentages, but they have small distances between them, which are constantly decreasing.

For all additive contents, the maximum dry density of the mixtures with fly ash is greater than the corresponding of mixtures with lime. This is attributed to the smaller apparent specific weight of lime. From the curves, it appears that lime contents greater than 10% have little effect on the maximum dry density.

The changes in the engineering properties of the soil, when mixed with lime and fly ash, are attributed to mechanisms such as cation exchange, flocculation of clay, carbonation and pozzolanic reactions (Jawad et al., 2014; Zumrawi and Hamza, 2014). The first two reactions occur rapidly and cause direct changes in plasticity, workability and swelling properties. The pozzolanic reaction is time-dependent and contributes to plasticity enhancement and to strength increase.

After curing periods of 7, 28, and 90 days, the strength of the samples were determined. The unconfined compression test has been used for the determination of the strength of soil mixtures with fly ash and lime.

The unconfined compressive strength values of the soil sample were quite low, typical of clay soils, and they do not meet the suitability criteria for road subgrades. When various lime and fly ash percentages were added, the stress-strain characteristics improved. Particular role to strength increase has been played by the curing time of the compacted samples.

The strength was increased with the addition of fly ash at a 5% content. This increase continued, with an even more intense rate, at the subsequent additive contents in the soil-fly ash mixture.

In Figures 4 and 5, the curves depicting the variation of the strength of the soil samples as a function of the percentage of fly ash and lime used to prepare the unconfined compression test specimens respectively, are presented. Each strength value represents the average of three compression specimens with 5x10 cm (diameter x height) dimensions. In each of these figures, three curves relating to the time intervals (i.e. seven, twenty-eight and ninety days) of specimen curing are drawn.

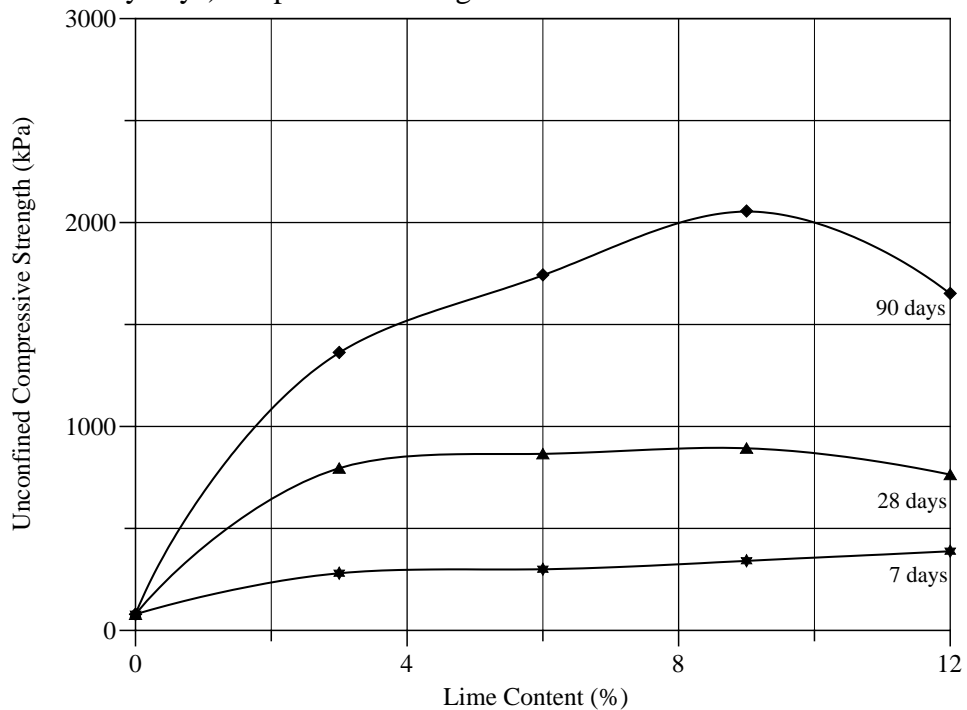


Figure 4 Unconfined compressive strength as a function of lime content

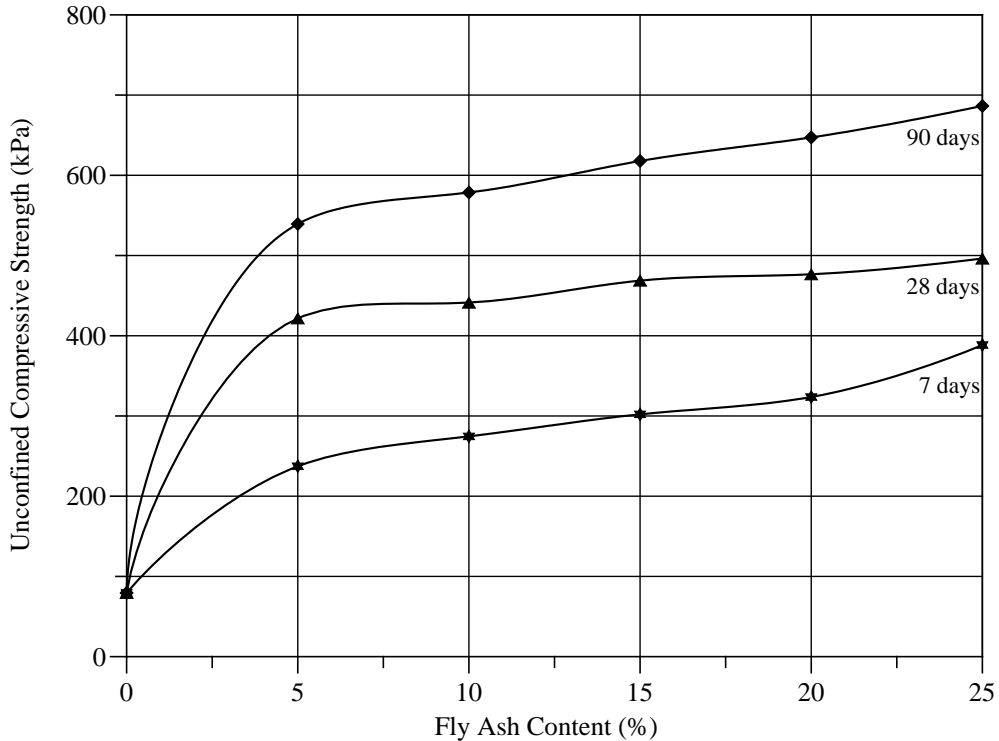


Figure 5 Unconfined compressive strength as a function of fly ash content

The admixture of lime to the clayey soil led to improved unconfined compressive strength. The optimal lime content ranged from 8% to 10% by weight of natural soil. By further increasing the percentage of lime in the mixture, the strength values decreased.

From the developing strength point of view, the optimum lime content in the mixtures is 6% after 28 days of curing. For the specimens cured for 90 days, an optimum 9% lime has been recorded. Moreover, for the 7 days curing period, the lime content beyond 3% had little effect on unrestricted compressive strength values of the samples.

For the development of compressive strength, the percentage of fly ash in all the soil mixtures has been a more critical factor compared to specimens curing time. The exactly opposite effect occurred after the addition of lime, where the curing time played an important role for the enhancement of strength. In the first stage of curing, i.e. after 7 days of storage under controlled conditions of humidity and temperature, the strength of all soil-lime mixtures was greater than that of the untreated sample. The largest increase occurred in the specimen containing lime 9% by weight of soil. The addition of lime contents greater than 9% by weight caused a reduction of the 7-days strength compared to the strength at this content.



Probably, better results in terms of strength will be brought by soil mixtures with a combination of the two additive materials in various ratios between them. The compaction method -modified instead of the used standard Proctor- would have a significant impact on the strength values (Ghosh 2013).

## Conclusion

The admixture of lime or fly ash to soils results in a gradual reduction of the maximum dry density, indicative of the increased resistance offered by the flocculated structure to the compaction effort, as well as in an increase of the optimum moisture content which is derived from the excess water hold in the open structural units of the flocculated structure.

The highest strength values obtained for the soil tested are directly associated to the moisture content and the concentration of lime. Both the maximum compressive strength and the maximum dry density could be achieved if the specimens are compacted with the optimum moisture content.

Based on the present study, fly ash could be recommended as an effective agent for the improvement of swelling soils. Using fly ash in such a manner it would also have the benefit of depositing an industrial by-product without negatively affecting the environment.

The laboratory testing findings point out the need for a thorough study of clay soils' characteristics, if these soils are intended to be used in highway construction works. The stabilization process is proved to be a fiscally effective and environmentally successful solution for construction works of such an extent and importance.

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