CETRA[2018]

5th International Conference on Road and Rail Infrastructure

17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

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University of Zagreb

Faculty of Civil Engineering

Department of Transportation

CETRA2018
5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

TITLE
Road and Rail Infrastructure V, Proceedings of the Conference CETRA 2018

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

ISBN
978-953-8168-25-3

DOI
10.5592/CO/CETRA.2018

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2018

COPIES
500

Zagreb, May 2018.

Proceedings of the
5th International Conference on Road and Rail Infrastructures – CETRA 2018
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INFLUENCE OF FLY ASH ON THE ENGINEERING PROPERTIES OF SILTY CLAY AND HEAVY LOAM IN SHANGHAI

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Abstract

To compare the engineering properties of different fly ash modified soil, pH, Atterberg limits and compaction properties were investigated in this study, and several performance indicators were compared, such as liquid limit, plastic limit, maximum dry density and optimum water content of Shanghai silty clay and heavy loam mixed with fly ash. The test results were as follows. The addition of fly ash improved pH of the silty clay and heavy loam. The liquid limit and plastic limit of two types of soil decreased with the increase of fly ash, the maximum reduction rate of silty clay was 7.1 %, 4.9 %, while the heavy loam was 5.8 %, 2.4 %. The influence of fly ash on liquid limit and plastic limit of silty clay was higher than that of heavy loam. The plasticity index and the maximum dry density were reduced, specifically, optimum water content of the silty clay increased with the fly ash added more, while heavy loam was the opposite. The experiment provided a useful reference for modification research of different soil textures and the rational utilization of fly ash.

Keywords: Engineering properties, Fly ash, Soil texture, Modification research

1 Introduction

Located in the southeastern front of the Yangtze River Delta Estuary, Shanghai soil is characterized by loose soil, high water content, large void ratio and high compressibility which make project construction difficulty (Zhou et al., 2005). It's therefore necessary to ameliorate physical properties of soil in Shanghai. Fly ash, one of the coal combustion by-product generated in large quantities from coal thermal power plants around the globe (Blissett et al., 2012), has the features of light weight, loose porous, large specific surface area, more active groups and strong adsorption capacity (Li, F.W. et al., 2002). The total amount of ashes produced worldwide is enormous, which has been estimated to exceed 750 million t/annum, but not all world fly ash production is utilized (Izquierdo and Querol, 2012; Vargas and Halog, 2015). For the power plant production, fly ash is a waste material and thermal power plants are trying to find an econmical and beneficial way to deal with fly ash. For the construction industry, fly ash is used as a cement replacement material in mass and concrete. Besides waste treatment and carbon dioxide storage (Dananjayan et al., 2016; Ukwattage et al., 2015), fly ash can improve workability, reduce heat of hydration and thermal cracking in concrete at early ages and improve mechanical as well as durability characteristics of concrete especially at later ages (Sahmaran et al., 2009). The use of fly ash has made great progress: cement clinkers (Teixeira et al., 2016), concrete production (Malhotra, 1990), waste stabilization or solidification (Pereira et al., 2009) and road basement material (Sobolev et al., 2014).
Utilization of fly ash as an additive for improving soil quality has received a great deal of attention in the nearly three decades, and many studies have been carried out all over the

world. Chang et al. (1997) noted that fly ash increased the water holding capacity of sandy soils and reduced soil surface compaction. Li, G.H. et al. (2002) added different proportions of fly ash into the chestnut soil, and found that fly ash could reduce the bulk density of the chestnut soil, increase the saturated water content and reduce the surface runoff. Campbell et al. (1983) gave a idea that the addition of fly ash usually reduced the soil bulk density, thereby increasing the soil porosity and workability and improving water holding capacity. Zhao et al. (2009) conducted the soil column water infiltration test of sandy soil. It was found that the incorporation of fly ash effectively weakened the infiltration capacity of soil and increased the water holding capacity of sandy soil with the moisture content significantly improved. When the fly ash was mixed with alkaline soil, it neutralized the alkali in the soil and adjusted the water soluble alkaline ion concentration in the sample (Duan et al., 2016). The content of organic matter was improved by adding fly ash into the sand ginger black soil, and the soil moisture permeability and porosity were also improved, which provided a theoretical basis for improving soil infiltration (Wei et al., 2014). Fly ash improved crop yield and had good after- effect on soil improvement (Jia et al., 1992). The study in desert soil indicated that fly ash could improve the ability of the soil to breathe water and permeate, replenish soil nutrients, prevent soil compaction and improve soil physical properties (Li et al., 2005). Through contaminated soil test, Lin et al. (1998) reported that the concentration of cadmium ions in the fly ash imporved soil decreased and the pH could be improved by adding fly ash zeolite in cadmium contaminated soil. The study improving sandy soil with fly ash had shown that fly ash can make an improvement on soil pH and available phosphorus, available boron, and available silicon (Lee et al., 2006). Alkaline fly ash with high Ca can be substituted for lime to reduce soil acidity to a level suitable for agriculture (Parkinson and Coleman, 1991; Matsi and Keramidas, 1999; Pathan et al., 2003). Alkaline fly ash was found chemically equivalent to approximately 20 % reagent-grade CaCO3 for increasing soil pH and supplying Ca to plants (Phung et al., 1979a, b). Direct amendment with fly ash modified the texture of soils from sandy loam to silt loam and sandy clay to loamy, apart from improving their physicochemical properties (Ghodrati et al., 1995; Stout et al., 1999; Lu and Zhu, 2004; Truter et al., 2005).
However, few studies made comparative analysis on the engineering properties of different soil textures after fly ash added. Therefore, this paper uses fly ash as additives of silty clay and heavy loam in Shanghai to analyze the different content of fly ash on its pH, liquid limit, plastic limit, maximum dry density, the optional moisture content, providing a useful reference and reference for the modification research of different soil textures and rational utilization of fly ash.

2 Materials and methods

2.1 Materials

This research was conducted under laboratory conditions with a relative humidity of 65 ± 5 % and an average temperature of 21 ± 2 °C. To investigate the effects of fly ash on engineering properties such as pH and compaction performance on Shanghai soil, two types of silty clay (Soil A) and heavy loam (Soil B) were collected in Shanghai, China (31°14'N, 121°29'E). All these soil samples were collected from the 0 to 15 cm depth of commonly distributed soil great groups in the agricultural fields. The general texture composition and engineering properties of these soils are provided in Tab. 1.
Soil A (Silty clay), which was collected from Changjiang Farm in Chongming Island, belongs to Shanghai coastal solonchak, mainly distributed in the coastal plain of Chongming, Nanhui and Fengxian counties, and the specific sites are presented in Fig. 1. It owns a heavy viscosity, strong water holding and good fertilizer protection performance but poor farming. The surface soil is grayish brown clay with the mass structure and loose soil. Soil B (Heavy loam), sampled from Qianshao Farm in Chongming Island, mainly exists in the coastal areas of Chongming,

Nanhui, Fengxian and other counties of Shanghai, as well as the sand island of Baoshan District. The loam contains high amounts of silty sand with better farming and more working days. Less good is soil hardening, salinization, poor water and nutrient retention capacity. The surface soil is light gray loam and cloddy pulverescent structure. It's therefore necessary to improve soil physical properties and the cohesiveness of soil particles. The fly ash, gray-black powdery solid, was supplied by Yulian Heat-engine Plant in Gongyi, China. The pH value is 9.02, the mass density is 1.9-2.9 g/cm^3, the specific surface area is 800-1950 cm^2/g, and its chemical composition is shown in Tab. 2.

Table 1 Texture composition and engineering properties

Soil	Sand [%]	Silt [%]	Clay [%]	LL [%]	PL [%]	PI	MDD [g/cm^3]	OMC [%]
Soil A	5.98	34.42	54.60	45.9	24.8	21.1	1.73	18.9
Soil B	10.54	74.62	14.79	38.5	23.3	15.2	1.56	22.7

Note:
LL = liquid limit; PI = plasticity index; PL = plastic limit; MDD = maximum dry density; OMC = optional moisture content.

Table 2 Chemical composition of fly ash

SiO_2 [%]	Al_2O_3 [%]	Fe_2O_3 [%]	CaO [%]	MgO [%]	Na_2O [%]	Others [%]
58.0	30.0	4.3	1.5	2.8	3.2	0.2

Figure 1 Location of soil A and soil B

2.2 Sample preparation

The experimental soil samples were air-dried and crumbled to pass a 2 mm sieve. Fly ash passed through a 2 mm sieve was applied with the rates of 0 %(control), 10 %, 20 %, and 30 % on weight/weight (w/w) basis. The dry mixing of soil – fly ash was carried out in a non-porous metal bowl. The mixed soil samples and water were stirred manually for 30 min, spending sufficient time with proper care to get homogeneous mix. Then the uniform samples were put at room temperature (21 ± 2 °C) and humidity (65 ± 5 %) for 24 h.

The fly ash and soils were mechanically mixed according to predefined routines and then transferred into experimental areas carefully and slowly. To avoid all possible mistakes, the control samples (0 %) were also subjected to the same routines as for the other proportions.

2.3 Methods

According to "Soil quality-Determination of pH" (ISO 10390:2005), undisturbed soil was air-dried and crumbled to pass a 2 mm sieve. Fly ash (0 %, 5 %, 10 %, 20 %) was mixed with dried soil and the mixture was put respectively in four 50 ml sample bottles with fastening plugs. The ratio of soil and water added into sample bottles was 1:5. After a 60 minute oscillation and 1 hour static, the pH of soil suspension was tested with the pH meter.
The sample groups with different content of fly ash (0 %, 5 %, 10 %, 20 %) were prepared by the section 2.2. Atterberg limits experiments of each sample group were conducted on the basis of "China Soil Test Regulation for Highway" (JTG E40-2007). With the water content as x-coordinate and the depth of 76 g cone into soil as y-coordinate, the double logarithmic coordinate graphs of Atterberg limits were made. The water content corresponding to the 17 mm depth of cone into soil is the liquid limit, while 2mm depth is the plastic limit. Thereby the liquid limit and plastic limit were calculated through the depth of cone.
The compaction test still chose the Standard Protor Method (ASTM, 1992). Method of sample preparation was same as above. For each mixed soil sample contained a specific amount of fly ash, a 2.5 kg subsample was subjected to spraying treatment to achieve eight water content levels. Soil with the same water content was separately filled into a standard compact chamber in three steps; during each step, the soil layer sustained 25 blows from a 2.5 kg hammer falling from a height of 30 cm. Then, the wet compacted soil was weighed and dried to determine the moisture content and dry bulk density through the difference in weight.

3 Results and discussion

3.1 Effect of fly ash on pH

Shanghai silty clay and heavy loam were mixed with fly ash in different content, the test results werr shown in Fig. 2. As it showed: with the increase of fly ash, the pH of the two types of soil increased gradually. The pH value of Shanghai silty clay and heavy loam were proportional to the fly ash content, and the maximum growth value of pH was obtained when the content was 20 %. The reason is that alkaline substances in alkaline fly ash can react chemically with soil water to quickly release Na^{+}, Al^{3+} and OH^{-}, thereby increasing the pH of the soil (Wong et al., 1990). With the increase of fly ash, the alkaline substances in the soil become more, and the pH value of the silty clay and heavy loam were greatly improved.

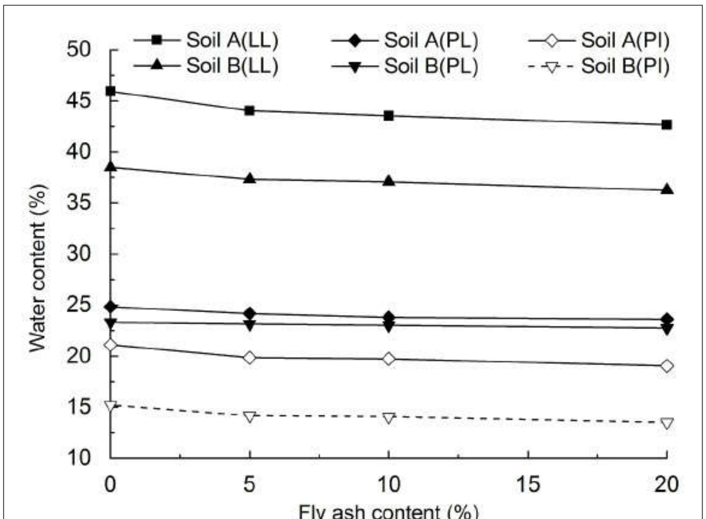

Figure 2 pH of silty clay and heavy loam mixed with fly ash

3.2 Effect of fly ash on the liquid limit, plastic limit

3.2.1 Liquid limit

Liquid limit is the boundary moisture content of soil from the plastic state to a fluid state, fly ash's effect was shown in Fig. 3. When the content of fly ash was 5 %, 10 %, 20 %, the liquid limit of silty clay compared to the control sample decreased by 4.1 %, 5.2 %, 7.1 %, the liquid limit of heavy loam was reduced by 3.1 %, 3.7 % 5.8 %, and the liquid limit of silty clay was higher than that of heavy loam. The incorporation of fly ash made the liquid limit decreased significantly and the liquid limit reached a minimum at the maximum content of 20 %. This is due to fly ash particles carrying some of the high-priced cations on the surface such as Fe^{2+}, Mn^{2+}, Mg^{2+} and the clay particles counter ion Na^{+}, K^{+} and other low-cost cation are equivalently exchanged. Cation exchange makes composite water film arounding clay particles thin, soil particles aggregate increased and coalesced, then smaller soil particles change into a larger aggregate structure. This change makes the water connection through the public joint membrane gradually become stronger, thus soil plastic (liquid limit, plastic limit) decreased (Xu et al., 2001). In addition, less than 10 % of supplemental dosage made a little effect on the liquid limit because the curve was gentle. When the dosage exceeded 10 %, the curve bocome steep with the impact increased, indicating that more fly ash made liquid limit decreased significantly. It can be seen from the comparative tests that the fly ash had a greater influence on the liquid limit of silty clay with a 4.1 % decline. The effect of adding 10 % fly ash into silty clay reached the effect of heavy loam with 20 % fly ash, when the effect of 20 % fly ash added to the silty clay was far more than heavy loam.

3.2.2 Plastic limit

Plastic limit is boundary moisture content of soil from the plastic state to a semi-solid state, the test results were shown in Fig. 3. As it showed, when the fly ash content was 5 %, 10 %, 20 %, the plastic limit of silty clay decreased by 2.6 %, 4.1 %, 4.9 %, respectively, and the plastic limit of heavy loam was reduced by 0.7 %, 1.2 %, 2.4 %. The plastic limit of silty clay was higher than that of heavy loam. Similarly, change of plastic limit was inversely proportional to fly ash content. Differently, plastic limit changes in the curve were flat and the trend was not obvious. Especially, fly ash had little effect on the plastic limit of heavy loam, the influence of small amount of fly ash did not exceed 1 %, and the influence of more fly ash did not even exceed 3 %.

3.2.3 Plasticity index

The plasticity index, an important physical state indicator, represents the changeable range of water content of the soil in a plastic state, which comprehensively reflects the particle size and mineral composition. The larger plasticity index indicates the higher combined water content and larger specific surface area. The experimental data was shown in Tab. 3 below. The table showed that when fly ash content was 5 %, 10 %, 20 %, the plasticity index of silty clay decreased by 5.9 %, 6.4 %, 9.7 %, respectively, and the plasticity index of heavy loam was reduced by 6.8 %, 7.4 % and 11.1 % respectively. It can be seen that the fly ash obviously reduced the plasticity of both two soils, and combined water content and the specific surface area decreased. In addition, the plasticity index of silty clay was always higher than that of heavy loam, indicating that the silty clay with a wide range of plasticity moisture content was easlier compacted than the heavy loam.

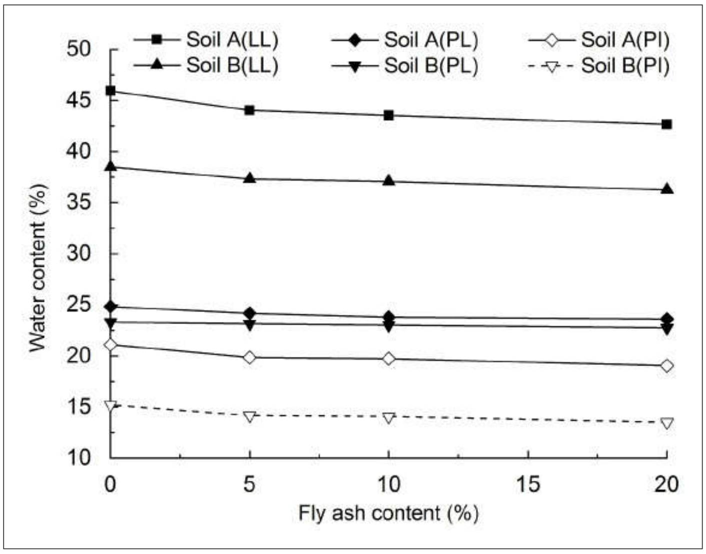

Figure 3 Effect of fly ash on liquid limit, plastic limit and plasticity index

Table 3 Test result of Atterberg limits test

Soil	Fly ash content [%]	LL [%]	PL [%]	PI
Soil A (silty clay)	0	45.93	24.83	21.10
	5	44.03	24.18	19.85
	10	43.54	23.80	19.74
	20	42.66	23.61	19.05
Soil B (heavy loam)	0	38.50	23.30	15.20
	5	37.31	23.14	14.17
	10	37.08	23.01	14.07
	20	36.26	22.75	13.51

Note: LL = liquid limit; PI = plasticity index; PL = plastic limit.

3.3 Effect of fly ash on compaction performance

The maximum dry density and optimum moisture content of silty clay and heavy loam were obtained by the Standard Protor Method. The compaction curve was shown in Fig. 4, and the maximum dry density and optional moisture content data were shown in Tab. 4. With the increase of fly ash, the maximum dry density of silty clay and heavy loam were reduced. This is because the fly ash is porous with small proportion. Soil sample structure become loose and void ratio increase with the incorporation of fly ash, so as to reduce the maximum dry density. It can be seen from Fig. 4 that the solid curve of plain soil was steep, and the curve flattened after fly ash added, and the change was most obvious when the supplemental dosage was 20 %. In other words, the influence of moisture content on soil dry density decreased with the increase of fly ash. And the range of real water content can be widened. The reason is: fly ash has the features of many pores and large pore ratio. Particle pore itself absorbs a large number of moisture in the process of compaction, weakening the sensitivity of soil on water, thus the compaction curve becomes more smooth and the compaction moisture content range widens out.

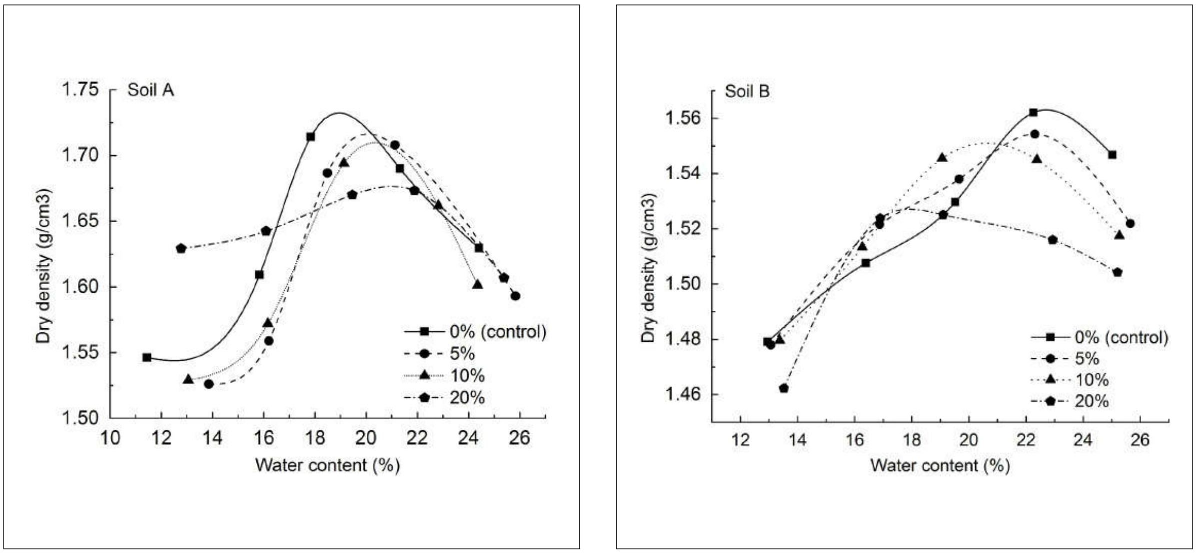

Figure 4 Compaction curves of silty clay and heavy loam in Shanghai

Table 4 Compaction test results of silty clay and heavy loam in Shanghai

Soil	Fly ash content [%]	MDD [g/cm³]	OMC [%]
Soil A (silty clay)	0	1.732	18.9
	5	1.716	20.0
	10	1.710	20.4
	20	1.676	21.1
Soil B (heavy loam)	0	1.563	22.7
	5	1.554	22.3
	10	1.551	20.6
	20	1.527	17.9

Note: MDD = maximum dry density; OMC = optional moisture content.

3.3.1 Maximum dry density

As Fig. 5 showed: when the content of fly ash was 5 %, 10 %, 20 %, the maximum dry density of silty clay decreased by 0.9 %, 1.3 % and 3.2 % respectively, the maximum dry density of heavy loam was reduced by 0.6 %, 0.8 % and 0.6 % respectively. This indicated that fly ash reduced the maximum dry density of soil, but the influence was not obvious, the influence of a small amount of fly ash was less than 1 %, but the impact of much more fly ash was only about 3 %. In addition, the influence of fly ash on silty clay was generally higher than influence on heavy loam, the maximum dry density of silty clay was higher than the heavy loam, this was also why silty clay was easlier compacted than the heavy loam.

Optional moisture content

According to Tab. 6, when the content of fly ash was 5 %, 10 % and 20 %, the optional moisture content of silty clay increased by 5.8 %, 7.9 % and 11.6 % respectively. The optimal moisture content of heavy loam decreased by 1.8 %, 9.3 % and 21.1 %. This indicated that the optimum moisture content of silty clay increased with fly ash added, while the heavy loam decreased. At first, the effect of fly ash on silty clay was higher than that of heavy loam. When the content of the fly ash was more than 5 %, the impact of fly ash on heavy loam was more than that of silty clay, and even the influence value can exceed 20 %. It can be seen that the incorporation of fly ash can greatly change the optimal moisture content of heavy loam, so that it can achieve a stable state in the lower water content (Zha et al., 2007).

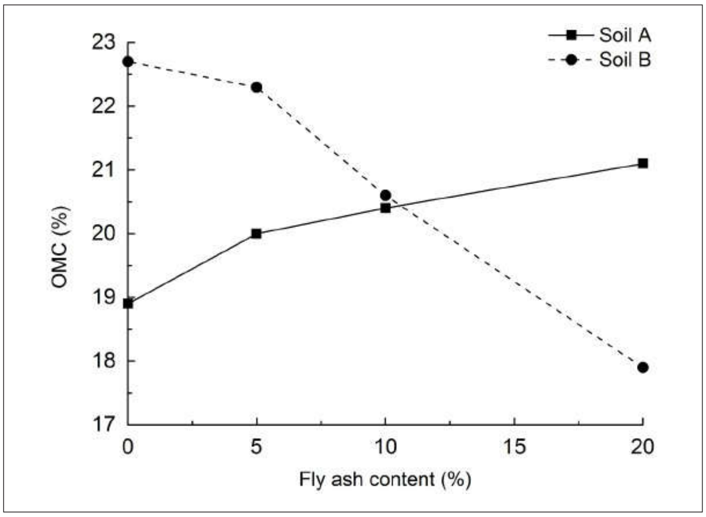

Figure 5 The effect of fly ash content on OMC

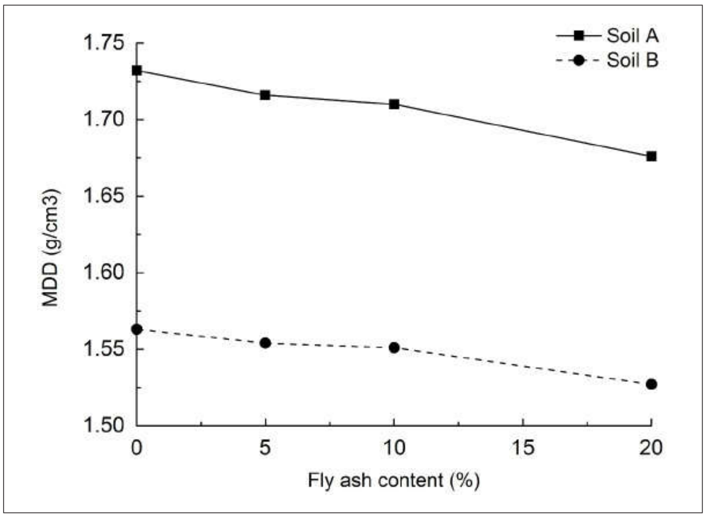

Figure 6 The effect of fly ash content on MDD

4 Conclusion

Taking the industrial waste fly ash as the modified material, the following conclusions were drawn through the research and analysis on the change of engineering properties of Shanghai silty clay and heavy loam:

1) The pH change of silty clay and heavy loam were proportional to the fly ash content. When the content is 20 %, the increase of pH is the largest.
2) After the fly ash was added, the liquid limit obviously decreased, and the influence on the liquid limit of the silty clay was more obvious. The maximum reduction rate can reach 7.1 %. The plastic limit had a slight decrease, especially for heavy loam, plastic limit reduction was not even more than 3 %. The plasticity index of both two soil were obviously reduced.
3) With the increase of fly ash, the maximum dry density decreased, but unobvious. The maximum dry density of silty clay was always greater than that of heavy loam, and the influence of fly ash on the maximum dry density of silty clay was also higher than that of heavy loam. The optional moisture content of silty clay increased with the increase of fly ash, but the optimum moisture content of heavy loam decreased with fly ash added. When fly ash content exceeded 5 %, the influence on the optional moisture content of heavy loam was much higher than the silty clay, and the reduction rate can even exceed 20 %.

Acknowledgements

Many thanks to Changjiang Farm and Qianshao Farm in Chongming Island, giving us great priority to collect soil experimental samples. Meanwhile, thanks to School of Environment and Architecture for the great support.

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