Laboratory Investigation on the Effect of Fly Ash on the Compressibility of Soil

Saeid. Amiralian, Amin. Chegenizadeh, and Hamid. Nikraz

Abstract— One of the key steps in geotechnical construction is study on characteristics of soil for evaluation the deficiency factors of soil properties that lead to some problems such as settlement and heave. Soil stabilization with fly ash as by-product is one of the effective methods that were applied for modifying soil properties. This paper presents a series of laboratory tests for investigation on the adequacy of fly ash on the compressibility and swelling characteristic of soil. In this research the compression index, swelling index, and initial void ratio of one un-stabilized sample and eight stabilized specimens with difference fly ash additives were investigated. Overall, the data reveal that fly ash stabilization could reduce the consolidation property, swelling behaviour. In addition, increment in the amount of fly ash led to reduction in the initial void ratio of stabilized samples.

Keywords— Consolidation, Fly ash, Stabilization.

I. Introduction

ONE of the main and preliminary steps in geotechnical project is study on soil properties and evaluation the requirement parameters for designing structures.

The importance of research on soil properties has been alarmed, since some geotechnical problems such as damage the roads, highways, airports, or destruction of earth structures, dams, buildings, and embankment that are caused by inadequate properties of soil. Settlement and excessive heave are known as two main reasons for these problems that are happened because of unsuitable behaviour of soil. In order to solve these expectable problems were introduced some geotechnical techniques such as replacement, reinforcement, and soil stabilization.

These methods could be modified soil properties by improvement some fundamental characteristics factor of soil such as compactibility, permeability, and compressibility. In this field, soil stabilization is performed for development of mechanical and chemical properties of soil. For civil construction was used chemical stabilization as an environmental friendly and economical method of soil stabilization. In practice, adding the binder such as lime, cement or by-products like fly ash as effective additives lead to development of soil engineering characteristics and reduce the structure damage [1],[2].

Nowadays, the potential of implementation natural resources and industrial mineral in soil stabilization has been found. In this field, fly ash has been applied as an additive in chemical stabilization. Fly ash is systematically arranged into two groups: class C and class F fly ash which separated based on the type of coal burned [3]-[6]. Some benefit of utilization of fly ash is low unit weight and compressibility [7], pozzolanic reactivity properties [7]- [9], economic and environmental friendly, and energy saving benefit[10]. For this reasons, fly ash has explored one of the main plentiful and flexible waste materials that widely implemented for developed the characteristic of poor soil in geotechnical engineering constructions [7], [11], [12].

Compressibility of soil is the key properties of soil in engineering construction, which is necessary for geotechnical structures such as dams projects, foundation and embankment systems. Consolidation as a method, which water particles and void are extruded by application of loads in a definite time was performed for defining the compressibility characteristic of soil. The timing and loading range are depending on the soil permeability and volume of air. Depends on the degree of saturation of soil the settlement will be different. Due to immediately remove of air or water that has reminded among the soil particles, a part of consolidation will occur in the soil that was not saturated completely.

Settlement of soil mass because of deformation of soil particles was calculated the volume changes. The coefficient of consolidation C_v is revealed the amount of settlement in each loading period. However, compression index (C_c) is achieved by the curve of void ratio versus the effective vertical stress is shown the compressibility of soils [13]-[15].

The large number of studies was established about fly ash stabilization effect on compressibility of soil; nevertheless, the necessity of more investigation in this field because of limitation in the achieved results is detected.

Thus, considering to the importance of the consolidation properties of soil for evaluation the final settlement and limited study about the effect of chemical treatment consolidation properties of soil, this study was conducted to evaluate the effect of fly ash on the soil compressibility.

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II. Background

In order to reduce the roads settlement or differential settlements between constructions the compressibility of embankment or a structural backfill material has to be the minimum amount [16]. On the other hand, regarding to lack of suitable resources for construction and effectiveness of by-product materials such as fly ash, utilization of fly ash in soil treatment is advanced. Compressibility properties of fly ashes associated with initial density, degree of saturation, self-hardening property, and pozzolanic activity [16]. Some studies reported that the amount of settlement that achieved by laboratory test on fly ash was more than real settlement under actual field condition [16]. The result of settlement is calculated by the compressibility that is the volume change behaviour of soil. Compression index as a parameter for measuring the compressibility of soil is achieved by consolidation curve [13]-[15]. In the previous literature review, scholars attempted to find a relationship between the compression index and the liquid limit, the moisture content, and initial void ratio. Some researches could find a correlation between soil properties and the compression index through laboratory research [13]. In most of them, the initial void ratio and liquid limit are defined as two main factors for evaluation the C_c [13]. In order to find the accurate and reliable correlation some experimental research was done on natural soil. Comparison between compression index of natural soil and theoretical compression index off the correlation show, due to undefined initial moisture content of soil the estimated result was not reliable [13].

Thus, the importance of consolidation properties of soil as a critical factor, definition the final and range of settlement of soil is a necessary factor in geotechnical engineering. However, the research regarding to this topic is very limited and need to be more investigation. For this reason, this research was conducted by study on compressibility of one un-stabilized sample and eight different combinations of fly ash specimens.

III. L Materials and Experimental Details

A. Material Characteristic

Due to extensive availability of sand in Western of Australia, the applied soil samples in this study were Baldivis Yellow Concrete Sand. The local sand used in this study has been collected from the Baldivis, 50 $_{km}$ south of Perth (Western of Australia) and known as quartz sand. Baldivis sand is widely implemented as a suitable material for mixing, footings, making concrete and mortar in geotechnical construction of Western of Australia. Regarding to, unacceptably of utilization consolidation test for sand settlement, “kaolin clay” was applied for mixing with sand. However, it can be seen some problems about utilization of yellow sand that lead to the necessity of more investigation about sand in Western of Australia.

Kaolin an industrialized mineral with a chemical formal $Al_2Si_2O_5(OH)_4$ is known as mineral clay. The utilized kaolin clay for this study is simply discrete in water, and are ideal for bulging to slurries. It is generally consisting of; $_{\%}$ 46.1Silicon Dioxide (Sio_2), $_{\%}$ 36.5Aluminium Oxide (Al_2O_3) and other martials such as, Iron Oxide, Calcium Oxide, Potassium Oxide, and etc.

The Fly ash was utilized for this study, collie fly ash, which usually used for concrete additive, bulk filler, fine filler in asphalt and other products, mine paste fill, soil amendment and stabilisation, stabilising agent for liquid wastes, road base. Roughly $_{\%}$40 of particles size of fly ash is less than 10 micrometers. The fly ash ingredient is between $_{\%}$10-30 Mullite, $_{\%}$ 9crystalline silica, and $_{\%}$30-60 amorphous silica.

B. Sample Preparation

In sample preparation step, for removing the natural moister of Baldivis Yellow Concrete Sand that was dried in the oven temperature (100±1 ºc) for 24 hours and was passed through US Number 4 sieve (4.76$_{mm}$ aperture). The applied optimum moisture content and maximum dry density, for adding to sample was achieved by standard proctor compaction test specifically for each sample. Specimens were prepared and kept on the laboratory room with 22.5 ºc for one-hour curing time. In order to achieve the necessary dry unit weight, the combination was compacted in the consolidometer ring, which had a diameter 63.5$_{mm}$ and height 25.4$_{mm}$. In this study, 50-percent kaolin clay and 50-percent sand for non-stabilized specimen was applied and, other eight samples were mixed by diverse percent of the fly ash (i.e., $_{\%}$2.5-$_{\%}$20) combination based on dry weight of non-stabilized specimen.

C. Consolidation Test

A series of consolidation test is implemented for investigation on the fly ash composite settlement. Consolidation test given in the *AS1289.6.6.1* is used for the saturated and partially saturated samples. This test will be performed in order to the determine magnitude and rate of volume reduction of soil sample, which is laterally limited and suffers the different vertical pressures. By the obtained void ratio-effective stress curves and settlement- log time, the results will be calculated. For achieving the reliable result, the automatic consolidation device was applied for this research. The data (i.e., Load, displacement, elapsed time) were recorded at each second by the program. Specimens were set between two porous stone and filter paper that were located on top and bottom of sample. Samples were positioned under an initial seating load of 50$_{kpa,}$ and the next incremental load was doubled until 800$_{kpa}$. The period of each loading was taken between minimum (i.e., 3 hours) and maximum (i.e., 24 hours) depend on the initial data and software calculation. The program was calculated the minimum require time that the displacement would be fixed in each loading, and then was computed $_{\%}$100 primary consolidation. Moreover, based on the consolidation tests with different timing period of load increments on fly ash, primary consolidation in most of fly ashes was completed very quicker than the predicted time [16].

IV. Result And Discussion

With regard to the rate and amount of consolidation settlement, and void ratio of samples, the consolidation characteristic of soil was investigated in this research. Furthermore, in order to evaluate the swelling behaviour of stabilized soil, the swelling behaviour of specimens was studied. Figures 1-9 contain the graphs that achieved by the void ratio and effective vertical stress in log scale (e₋σ′p) for sand and fly ash combination with a different amount of fly ash i.e., %2.5, %5, %7.5, %10, %12.5, %15, %17.5, and %20). The data are revealed that fly ash stabilization could be improved the consolidation properties and swelling behaviour of compressibility of non-stabilizer sample. The compression index (C_c) and swell index (C_s) present the compressibility of soil is illustrated in Table I.

TABLE I
Compression index and swelling index data(FA: Fly ash)

Sample	C_c	C_s	e_0
% 0 FA	$4.98*10e^{-2}$	$3.98*10e^{-2}$	0.523
% 2.5 FA	$4.89*10e^{-2}$	$2.12*10e^{-2}$	0.490
% 5 FA	$3.98*10e^{-2}$	$2.05*10e^{-2}$	0.465
% 7.5 FA	$3.65*10e^{-2}$	$1.92*10e^{-2}$	0.439
% 10 FA	$3.57*10e^{-2}$	$1.86*10e^{-2}$	0.416
% 12.5 FA	$3.40*10e^{-2}$	$1.72*10e^{-2}$	0.389
% 15 FA	$2.82*10e^{-2}$	$1.46*10e^{-2}$	0.361
% 17.5 FA	$2.65*10e^{-2}$	$1.19*10e^{-2}$	0.340
% 20 FA	$2.65*10e^{-2}$	$1.39*10e^{-2}$	0.319

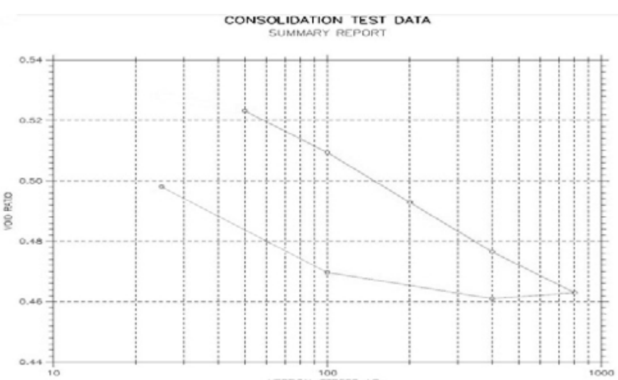

Fig. 1 Consolidation curve of %0 Fly ash

Figure 1 shows the compression curve of pure sample that had not any fly ash. The initial void ratio in zero percentage of lime sample is around 0.523, compression index is $4.98*10e^{-2}$, and swell index is $3.98*10e^{-2}$. The level and quality of fly ash treatment on sand will evaluate by compared between results of fly ash mixtures and sand sample.

A. Characteristics of Compression and Swelling Curves

Compression curve and swelling curve of soil-stabilized samples with stabilizer are revealed that soil characteristics of treated samples have a diverse behaviour in each mixture of additives (Figuer2-9). In general, by the amount of compression index was reduced in fly ash treated samples. This decreasing has a continuously trend until sample with %17.5 of fly ash. After that, the data were shown adding more fly ash to the combination was not effective on C_c of sample. The compression index of sample with %20 of fly ash was fixed in comparison with sample with previous combination (i.e., %17.5).

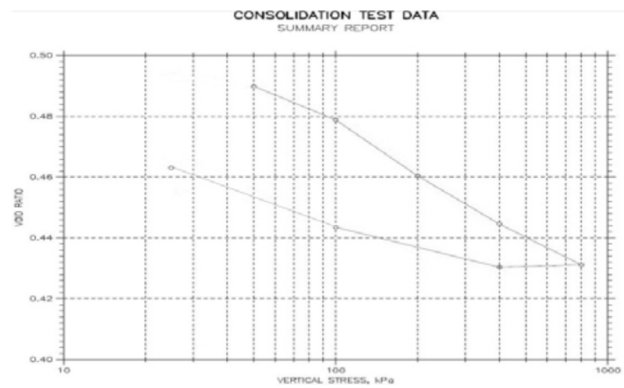

Fig. 2 Consolidation curve of %2.5 Fly ash

As are shown by Fig 8 and 9, the lowest settlement related to fly ash treated sample with 17.5 percent and 20 percent of fly ash. It can be seen from the Table I the compression index in the sample with 17.5 percentage of fly ash is $2.65*10e^{-2}$, whilst the reduction of settlement was not change after adding more than 17.5 percentage of fly ash to sand. The Figure 9 is shown that C_c by adding 20 percent of fly ash was $2.65*10e^{-2}$ again, which it is the same as compression index that was obtained in the prior mixture. It seems that, utilization of 20percent fly ash had not more effect on reduction of compression index. Moreover, the achieved results on TABLE I are illustrated that an association between initial void ratio and amount of additives. For instance, as is represented by the Table I the sample with 20 percent of fly ash had the minimum amount of initial void ratio, whilst, soil treatment by 2.5 percent of fly ash had a maximum e_0 among other stabilized samples. Due to the same result in compression index of two last samples, could not be extended this correlation for establishing a relationship between the amount of additive, e_0 and C_c. Nevertheless, could confirm the effective role of fly ash on reduction in compression index of soil. Thus, it seems that stabilization with 17.5 percentage of fly ash and 20 percentage of fly ash had the same and optimum effect on compression index of soil.

On the other hand, in the field of swell characteristic of sand the obtained data about swelling behaviour of fly ash treatment specimens were illustrated that fly ash was effective on the reduction of swelling index of sand.

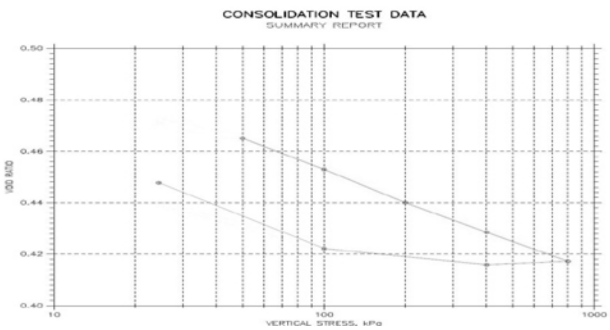

Fig. 3 Consolidation curve of %5 Fly ash

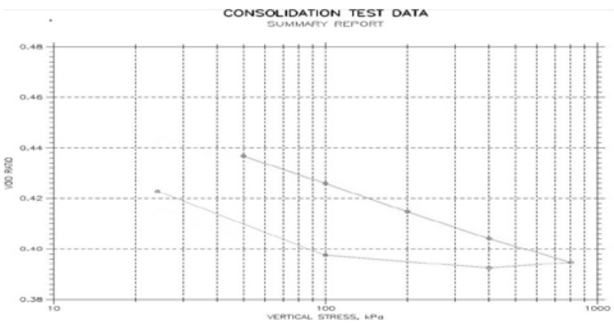

Fig. 4 Consolidation curve of %7.5 Fly ash

At the first glance, the tendency of reduction of swelling index was continued until the last mixture, which was stabilized with 20 percent of fly ash. As is shown by TABLE I C_s in sand specimen is $3.98*10e\text{-}^2$ that is more than the amount of swelling index in sand treatment with fly ash

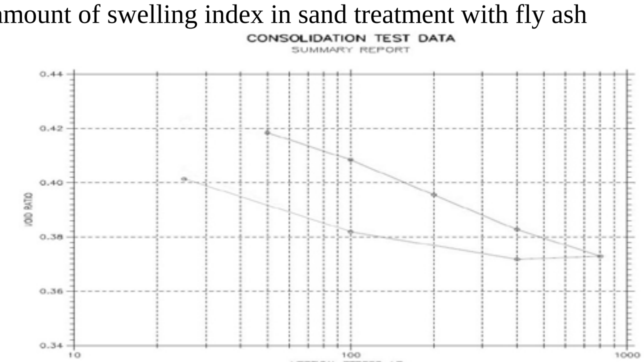

Fig. 5 Consolidation curve of %10 Fly ash

As in shown by the slope of unloading period graphs, which are illustrated the swelling properties of soil was reduced by increment in the dosage of fly ash. This reaction was similar with the settlement behaviour of stabilized soil after adding 20 percent.

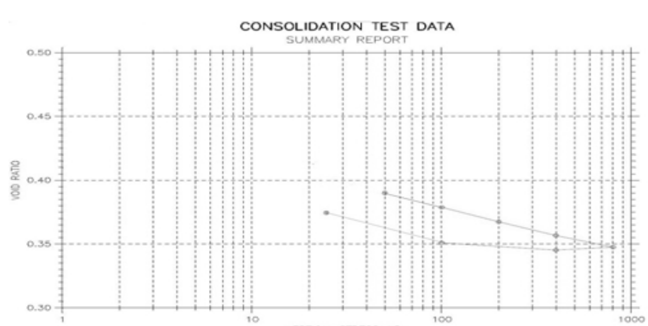

Fig. 6 Consolidation curve of %12.5 Fly ash

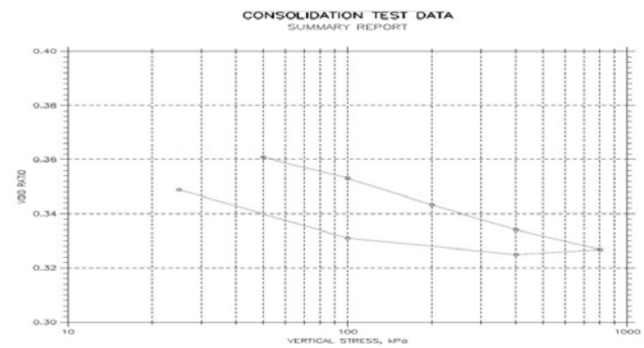

Fig. 7 Consolidation curve of %15 Fly ash

It seems that by adding more fly ash up to 17.5percent, the C_s was $1.19*10e\text{-}^2$, which had the most significance effect on swelling index of sand treatment with fly ash. Nonetheless, sand stabilization with more than 17.5 percentage of fly ash lead to increment in swelling index that was increased to $1.39*10e\text{-}^2$.

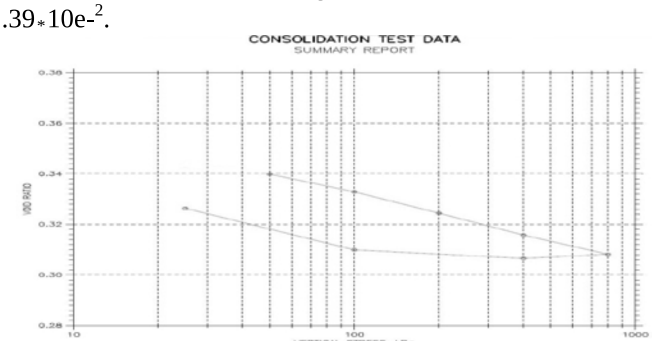

Fig. 8 Consolidation curve of %17.5 Fly ash

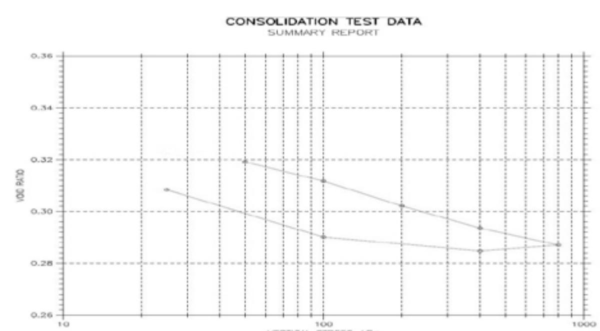

Fig. 9 Consolidation curve of %20 Fly ash

Although some factors such as curing time, duration and amount of loading and unloading pressure that were applied in this test, can effect on compressibility and swelling properties of soil, the achieved results were suggested the efficiently of fly ash stabilization on soil. Hence, that application of fly ash as an additive led to reduction in the amount of compression index and swelling index in sand stabilization.

V.CONCLUSION

Application of stabilization method in improvement of characteristic of poor soils is known as an effectual method in geotechnical engineering projects. This research was conducted in order to investigation on the effect of fly ash additions on compressibility and swelling behaviour of sand. Based on experimental research on nine samples, which are divided to un-stabilized specimen and fly ash stabilized combination (i.e., %2.5, %5, %7.5, %10, %12.5, %15, %17.5 and %20) this paper represents the laboratory investigation data of consolidation and swelling properties of sand.

The results indicate that, in contrast with pure sand, the compressibility of treated specimens were developed. In all stabilized samples were observed that fly ash play a pivotal role in reduction the compression index of each sample, which could be occurred due to pozzolanic reaction between fly ash and soil particles.

It can be seen that increase in the dosage of fly ash related with decrement in compression index of stabilized sample. However, it seems that utilization more than 17.5 percent fly ash on stabilized sample had not a remarkable effect on compression index, which it was the same as compression index of the pervious mixture (i.e., %17.5).

Study on the swelling properties of fly ash stabilized samples was indicated that the variation results for swelling index characteristic of sand treatment with flay ash. In overall, the results reported that a downward tendency in swelling index data of fly ash specimens. Nevertheless, the lowest amount related to sample with 17.5 percent fly ash and utilization of 20 percent fly ash led to increment in C_s of specimen.

The initial void ratio of each combination was reduced with increased in the amount of fly ash percentage. It was also observed a relationship among reductions in compression index of samples, increment dosage of additive, and reduction of initial void ratio, although this correlation was changed for soil stabilization with 20 percent fly ash.

Therefore, the data suggested that application of fly ash could effect on the improvement of compressibility behaviour and swelling properties of soil. In spite of various results of C_c and C_s in fly ash stabilized samples, can draw a relationship between the proportion of increment the amount of stabilizer and decrement of soil compression index and swelling index. However, regarding to the environmental friendly, cost-effectively, and engineering properties aspects, comparison between the results of fly ash specimens shows that, soil stabilization with 17.5 percent of fly ash was more efficient than other dosage of additives that was tested in this research.

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