Permeability and Volume Change Behaviour of Soil Stabilized with Fly ash

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Abstract **- Permeability and volume changes play a vital role in soil properties. Volume change in soil result in possible hazardous damage to the footings or to the building they support. Permeability affects the rate of settlement of a saturated soil under load. The settlement rate and pore water pressure dissipation rate are mainly controlled by the permeability of soil. It is known that consolidation process is accompanied by decrease in void ratio which leads to decrease in the coefficient of permeability. In such conditions, stabilization of soil is one good solution. Improvement of geotechnical properties such as coefficient of compressibility and permeability can be done by adding materials like flyash, lime, cement etc to soil. This work mainly investigates the permeability and volume change behaviours of soil stabilized with fly ash. With increase in fly ash content in NIT Agartala soil maximum dry density (MDD) is decreased and optimum moisture content (OMC) is increased. Positive result in consolidation and permeability characteristics are observed by using fly ash in soil.**

Keywords: Coefficient of compressibility, consolidation characteristics, fly ash, permeability, volume change.

1. INTRODUCTION

The behavior of structures depends on the properties of soil on which they are constructed. For the structures to be safe and sound, they should be built on good soils. Soil stabilization is the process in which improving the different type of engineering properties of soil and it is making for stable soil. It can be done by the use of controlled compaction, proportioning and the addition of suitable different types of admixtures and stabilizers. Permeability and volume change are the important geotechnical properties which affect the soil. Improving of such factors is important, considering construction purpose. Adding admixture to improve the geotechnical properties have been widely used giving positive results.

Previous researchers have explained the reason behind variation in MDD and OMC in soil-fly ash mixed samples at various percentage on laboratory experiments as revealed by Ramaiah et al. (1972) Osinubi (1998), Kalkan and Akbulut (2004), Kumar and Sharma (2004), and Kumar (2004).Jyothi and Sastry (1991) investigated the behavior of expansive soils treated with lime. It was observed that, in general, the coefficient of consolidation increases whereas both the compression index and swelling index decrease with increase in lime content. Kumar et al. (2007) presented paper on, by way of comparison, the effect of fly ash on the volume change of two different types of clay, one a highly plastic expansive clay and the other a non-expansive clay, also of high plasticity. Compression index and coefficient of secondary consolidation of both the clays decreased by 40% at 20% fly ash content. Alireza (2013) evaluated the effect of fly ash on the hydraulic properties of the coarse soils reinforced by geotextiles in earth dams. To investigate role of fly ash in flow rate and hydraulics gradients various mixtures of fly ash in reinforced sand have been considered. The results of experiments show with increase in the fly ash ratio in coarse soils, the flow rate decreases significantly and may reach 0.006 of the flow rate in pure sand. Also from the hydraulics view points, the most suitable ratio in the base layer, reinforced by geotextiles, is proposed 20% at most. Rao et al. (2014) studied the compressibility behaviour of black cotton soil admixed with lime and rise husk. It was observed that the coefficient of consolidation increases as the percentage of admixture increases. 1:1 mix is more effective and economical among all the admixtures in reducing compression index.

2. MATERIALS AND EXPERIMENTAL RESULTS

2.1 MATERIALS

Local soils are collected from National Institute of Technology (NIT), Agartala, Tripura,India. Soil sample is reddish brown in colour.

Fly ash is collected from the Kolaghat Thermal Power Station, Kolaghat, West Bengal, India. The fly ash is grey in colour and pozzolanic in nature. The most common chemical compositions of fly ash are SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, organic carbons and others.

The locally available soil, Kolaghat fly ash samples and soil-fly ash mixed samples containing fly ash of 10, 20, 30 and 40% on the basis of dry weight.

2.2 EXPERIMENTAL RESULTS

Following experiments have been carried out as per ASTM standards. The tests were conducted both on local soil and fly ash for determining physical properties and engineering properties

a) Specific Gravity Test (ASTM D854-06)
b) Grain Size Analysis (ASTM D 422- 63(2007))
c) Liquid limit and plastic limit tests (ASTM D 4318- 05)
d) Standard Proctor Compaction Test (ASTM D698 / AASHTO T99)
e) One-Dimensional Consolidation Test (ASTM D2435 - 04)
f) Falling Head Permeability Test (ASTM D5856-95(2007))

i. Specific Gravity

The object of the test is to determine the specific gravity of soil fraction passing 4.75mm IS Sieve. Specific gravity is the ratio of weight in air of a given volume of soil samples to the weight in air of equal volume of distilled water at 4 degree Celsius. It is an important factor which is used in computing other soil properties. It can be determined based on as per ASTM D854-06 for local soil. Density bottle is used for the determination of specific gravity of fine grained soil.

ii. Sieve Analysis

A. Dry sieving

The field soil first dried in oven and all lumps are broken into pieces. A set of sieves are arranged according to IS code and the sieving test has been performed.

B. Hydrometer test

IS: 2720 (Part 4) - 1985 describes the procedure for determining the silt and clay size content in soils. In this test the soil passed through 75 micron is soaked in dispersing solution and stirred for a period of 15 minutes. After that it is poured into the hydrometer jar and shaken properly. The hydrometer is inserted and test data are collected according to the IS: 2720. Correction is to be made while testing is:

i. Meniscus correction (C_m)
ii. Temperature correction (C_t)
iii. Deflocculating agent correction (C_d)

IS 2720(Part 4)gives the provisions for sieve analysis. Sieve analysis is the method of separation of soils into different fractions based on the particle size. The objective of sieve analysis is to determine the grain size distribution of soil either by sieving or by sedimentation analysis.

iii. Compaction Test

The original Proctor test, ASTM D698 / AASHTO T99, uses a 4-inch-diameter (100 mm) mould which holds 1/30 cubic foot of soil, and calls for compaction of three separate lifts of soil using 25 blows by a 5.5 lb hammer falling 12 inches, for a compactive effort of 12,400 ft-lbf/ft³. The "Modified Proctor" test, ASTM D1557 / AASHTO T180, uses same mould, but uses a 10 lb. hammer falling through 18 inches, with 25 blows on each of five lifts, for a compactive effort of about 25,000 ft-lbf/ft³.

iv. Consolidation Test

The object of the experiment is to determine the consolidation property of the soil by using either fixed ring or floating ring type consolidometer. When a saturated soil mass is subjected to a load increment, the load is initially carried by water in pores of the soil as excess of pore water pressure, because water is incompressible in comparison with soil structure. As the water drains from the soil pores under the pressure gradient so developed, the load increment transfers to soil structure and there is a reduction in the volume of the soil equal to volume of water drained. This process is known as consolidation. ASTM D2435 - 04 gives provision for standard test methods for one-dimensional consolidation properties of soils using incremental loading.

v. Falling head permeability test

The falling head permeability test is conducted in laboratory as per ASTM D5856-95(2007) for local soil. The falling head permeability test involves flow of water through a relatively short soil sample connected to a standpipe which provides the water head and also allows measuring the volume of water passing through the sample. The diameter of the standpipe depends on the permeability of the tested soil. The test can be carried out in a Falling Head permeability cell or in an oedometer cell.

3. RESULT AND DISCUSSIONS

3.1 RESULT

Experimental test data regarding the physical and engineering properties of locally available soil mixed with fly ash at different percentage by dry weight presented .The variation in MDD-OMC, Permeability and consolidation are observed experimentally. Experimental test results on physical and engineering properties of soil and fly ash are shown in table 1 to table 2. The maximum dry density vs. optimum moisture content curve and consolidation parameters of soil and soil mixed fly ash in different percentages are shown in figure-1 to figure-8.

Table 1 Physical and Engineering Properties of Soil

Physical Properties	Test Results
Specific Gravity (G)	2.68
Grain Size:	
Sand (%)	83.0
Silt (%)	10.7
Clay(%)	6.30
Uniformity Coefficient (Cu)	9.3

Coefficient of curvature (Cc)	2.2
Classification of Soil	SW-ML
Name of Soil group	Well graded sand
Liquid limit (%)	23.0
Plastic limit (%)	17.8
Plasticity Index (%)	5.2
Shrinkage Limit (%)	25.08
Plasticity	Low Plastic
Permeability, K (cm/s)	3.43552E-06
Engineering properties	**Test Results**
Light Compaction : Maximum Dry density, MDD (kN/m^3) Optimum Moisture Content, OMC (%)	18.5 14.8
Heavy Compaction : Maximum Dry density, MDD (kN/m^3) Optimum Moisture Content, OMC (%)	19.75 10.8
Compression index C_C	0.118

Table 2 Physical and Engineering Properties of Flyash

Properties	Test Results
Specific Gravity (G)	2.13
Grain Size: Sand Size (%) Silt Size (%) Clay Size (%)	 15.0 77.0 8.0
Plasticity index (%)	Non-Plastic
Maximum Dry density, MDD7 (kN/m^3) Optimum Moisture Content, OMC (%)	11.76 25.6

Table 3 Specific Gravity (G) of soil, flyash and soil-flyash mix

Soil Properties	Soil	Fly-Ash	Soil +10% Fly ash	Soil +20% Fly ash	Soil +30% Fly ash	Soil +40% Fly ash
G	2.68	2.13	2.53	2.49	2.43	2.40

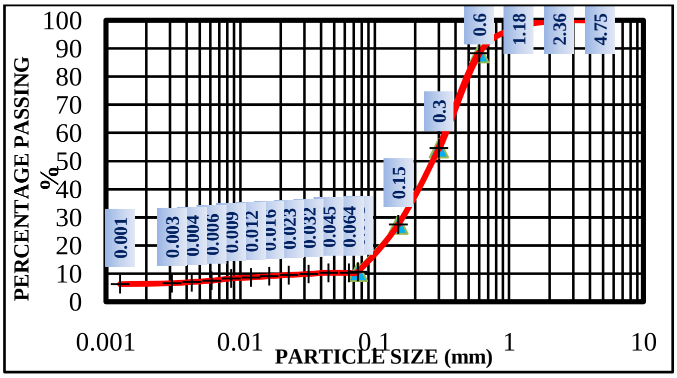

Fig. 1. Grain Size Distribution of soil

3.2 DISCUSSIONS

Discussions have been made in this section based on the laboratory test conducted on different geotechnical parameters. Effects of fly-ash on specific gravity of soil, compaction characteristics of soil, coefficient of compressibility (a_v) of soil, coefficient of volume change (m_v) of soil, on dial gauge reading of the soil, on compression index (C_c) of soil, on coefficient of consolidation (C_v) of soil, on settlement of soil and coefficient of permeability (k) of soil due to soil fly-ash mix (% by weight) have been discussed herein.

3.2.1 Effect Of Fly Ash On Specific Gravity (G) Of Soil

In the presence of fly ash, the specific gravity values of soil mixed with fly ash decrease from 2.68 for 0% to 2.40 for 40% of fly ash. Fly ash particles are hollow, thin walled cenosphere, having low weight than conventional soil, so in mixed samples the overall weight become less. Similar progression was observed for soil-flyash mixed (Mohammed Hussein Al-Dahlaki 2007).

3.2.2 Effect Of Flyash On Compaction Characteristics Of Soil

The results of dry unit weight and optimum moisture content of soil and soil-fly ash mix at various percentages are shown in Fig. 1. Table 3 summarizes the maximum dry densities and optimum moisture contents. The soil has a maximum dry density of 18.5 kN/m³at optimum moisture content 14 %. Flyash exhibit maximum dry density of 11.76 kN/m³at optimum moisture content 25.4 %. The 10, 20, 30, 40 % flyash-soil mixture exhibit a decrease of maximum dry density with increasing optimum moisture content. The result s show that as the flyash content increases, the maximum dry density decrease and the optimum moisture content increase, it is due to lower specific gravity of ash particles. Fabio Santos et al. 2011 illustrated that the decrease in maximum dry density with increase in flyash is associated with the notion that flyash is light compared to soil only. The higher optimum moisture content associated with higher flyash content follows from the need of hydration reaction for cementitious flyash, and to release the capillary tension from the greater exposed surface of the finer flyash particles. The maximum dry density and the optimum moisture content show a significant dependence upon the flyash content. The maximum dry density values of flyash-soil mixture are lower than those of soil, which is typically range from 14.25 to 18.5kN/m^3.

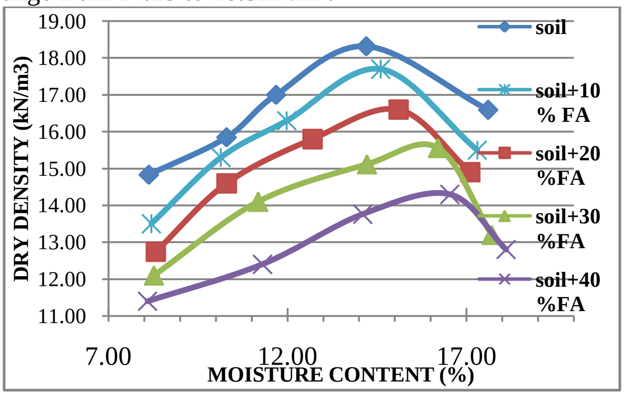

Fig. 2. Dry density vs. Moisture content curve of soil

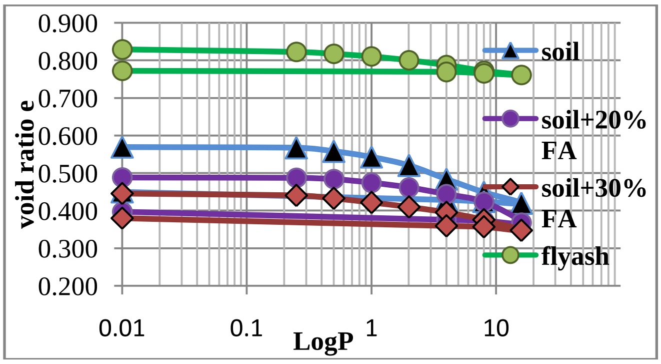

Fig. 3. e vs. logp curve for soil, fly ash and soil- fly ash mix

3.2.3 Effect of fly ash on coefficient of compressibility (a_v) of soil

The coefficient of compressibility (a_v) vs. logarithmic pressure (log p) relationship of soil and soil-flyash mix (30% by weight) is shown in Fig.4. Coefficient of compressibility (a_v) decreases as load increases. The value of Coefficient compressibility of soil ranges from 0.0406 to 0.0036 and that of flyash ranges from0.0249 to 0.0014. Flyash is less compressible than soil. When soil is mixed with 30%flyash by weight a_v ranges form 0.029-0.0035 and that for 20% ranges from 0.034-0.0032.The results indicate that fly ash treatment decreases the compressibility of the soil. This reduction in the compressibility of the soil is due to pozzolanic character of fly ash. As flyash is mixed with soil, clay percent decreases and percent of silt size particle increases. Indraratna (1996) illustrated that, because of pozzolanic properties of fly ash due to the presence of free-lime content, the compressibility of fly ash reduces. The structural arrangement of the soil and flyash particles plays a vital role in the compressibility of soil.

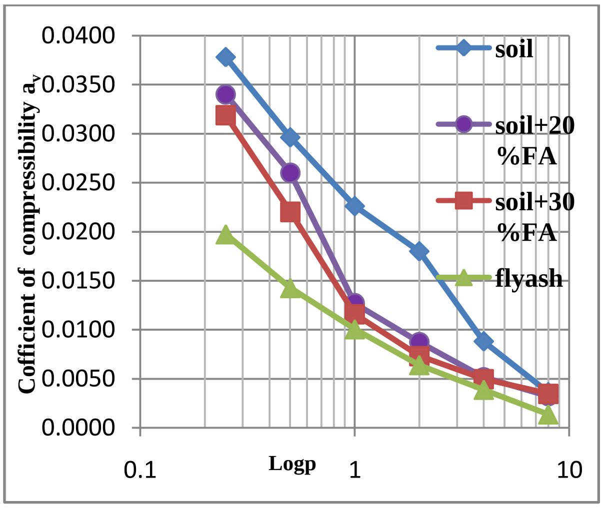

Fig. 4. Coefficient of Compressibility (a_v) vs. log p curve for soil fly ash and soil- fly ash mix

3.2.4 Effect of fly ash on coefficient of volume change (m_v) of soil

Fig. 5 shows the relationship between coefficient of volume change (m_v) and applied pressure. Coefficient of volume change (m_v) decreases as the applied pressure increases but mv is directly proportional to the thickness of the specimen and the void ratio. The greater percentage of silt content and lesser plasticity of the fly ash result in lesser volume change of the soil. The higher silt content and lesser plasticity of non-expansive clay resulted in lesser volume change on addition of non-plastic fly ash (Kumar and Sharma 2007).

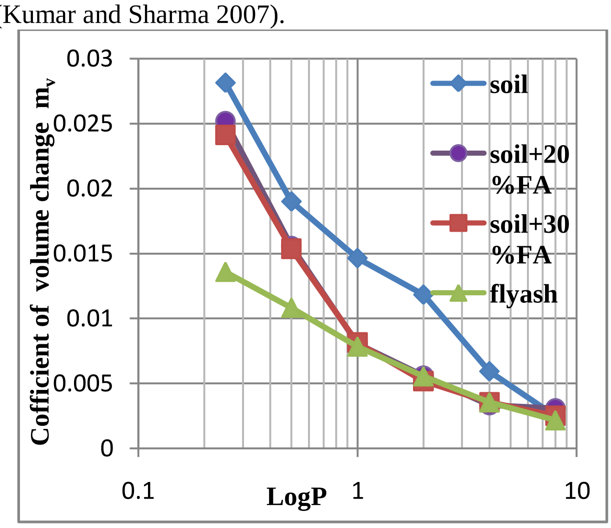

Fig. 5. Coefficient of volume change (m_v) vs. log p curve for soil fly ash and soil- fly ash mix

3.2.5 Effect of fly ash on dial gauge reading of the soil and soil-flyash mix

Fig. 5 shows the layout of dial gauge reading vs. square root of time (t). It shows that dial gauge reading for fly ash is more than the soil. i.e., rate of consolidation for fly ash is quicker than the soil. Addition of flyash in soil result in increase in dial gauge reading than that of soil. Due to increase in silt size particle of soil rate of consolidation is increasing which will result in settlement in quicker time (Moghal and Sivapullaiah 2011).

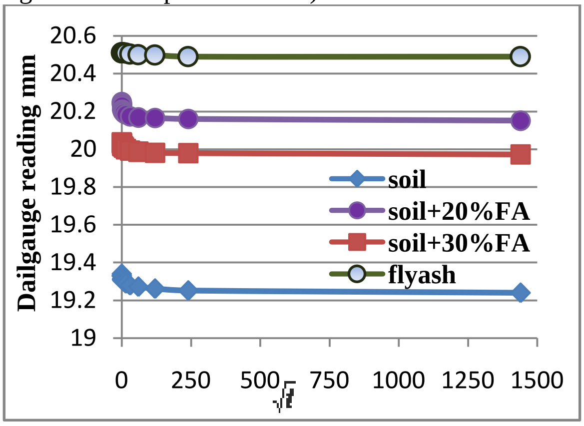

Fig. 6. Dial gauge reading versus $\sqrt{t}$ for soil, fly ash and soil- fly ash mix

3.2.6 Effect of fly ash on compression index (C_c) of soil and soil-flyash mix

In the present study, C_c value for fly ash is 0.048 and for soil is 0.118. The use of 30% fly ash in soil the value of C_c is reduced to 0.056 from 0.118 of soil. The value of Cc for 20% fly ash by weight in soil is 0.0631. The value of C_c decreased with addition of fly ash. The result indicates that with addition of flyash settlement will be less. The reduction in C_c with percentage fly ash was steeper in the case of expansive clay, which was more plastic and compressible, than in the case of non-expansive clay having greater silt content (Kumar and Sharma 2007). Due to addition of fly ash in soil, the soil can withstand the compressive loading better and hence shows lesser compressibility. When fly ash mixed with soil, it develops cementation bonds due to the pozzolanic reaction or an inherent self-hardening property under favorable conditions of moisture and compaction.

3.2.7 Effect of fly ash on coefficient of consolidation (C_v) of soil and soil-flyash mix

It is observed that the coefficient of consolidation of soil is 9.069E-03 cm^2/sec and that of flyash is 5.07E-04 cm^2/sec. The result indicated that rate of consolidation of flyash is more compared to soil i.e. permeability is more for flyash. After adding flyash in soil the coefficient of consolidation is 13.42E-03 and 11.41E-03cm^2/sec for 30% and 20% respectively. It is mainly due to increase in rate of permeability. It appears that the fineness of fly ash caused the coefficient of consolidation of soil-flyash mix to increase. The coefficient of permeability is primarily influenced by the nature of the voids in between the particles. Fine fly ash particles have voids much smaller than the soil particles. Larger specific surfaces of fly ash would cause more resistance to the flow of water through the voids (Saeid et.al. 2012).

3.2.8 Effect of fly ash on settlement of soil and soil-flyash mix

Fig. 7 established the relationship between settlement and log p for the soil, fly ash, soil-flyash mix. From the laboratory oedometer test it is observed that the maximum settlement for the soil sample is 0.45 mm and for fly ash it is 0.17 mm where sample height is 20 mm. Due to addition of flyash (30% by weight) maximum settlement is 0.27mm and 0.28mm for 20% Fly ash by weight. The test result shows that with addition of flyash settlement will be less. For non-plastic fines such as fly ashes and for cohesionless soils, the settlement occurs immediately upon the application of load and settlement is less due to mix of flyash (Moghal and Sivapullaiah 2011).

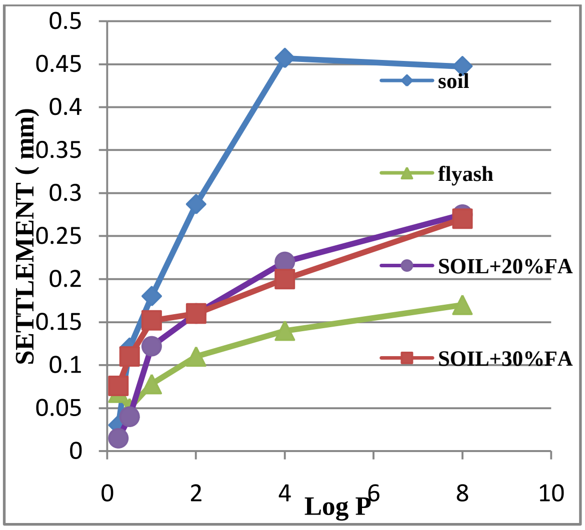

Fig. 7. Settlement versus log p curve for soil, fly ash and soil- fly ash mix

3.2.9 Effect of Fly Ash on Hydraulic Conductivity (k) of Soil, Fly ash and Soil-Fly Ash Mix

The hydraulic conductivity (k) values for seven days in soil samples, fly ash and soil-fly ash mixed samples are presented in Fig 8. The hydraulic conductivity for the local silty- soil is 3.38×10-6 cm/sec. With the increase of fly ash contents in mixed samples, the rate of permeability increasing. The hydraulic conductivity values are within the range of 3.43−2 .21×10-6 and 2.93−1 .58×10-6 with percentages of fly ash 20 and 30% respectively. Increase in silt size particles in soil due to addition of fly ash make the mixed samples comparatively coarser and increases permeability. Researchers like, Ghosh and Subbarao (1998) in stabilization of a low lime fly ash with lime and gypsum, Osinubi (1998) in Hekinan and Matsushima fly ash for direct falling head permeability, and Porbaha et al. (2000) in conducting indirect calculation from consolidation observed similar trend. Similar trend was also observed in compacted fly and bottom ash mixtures with increasing fly ash content by Show et al. (2003), Kim et al. (2005) in high volume fly ash cement paste composite formed of various combinations of fly ash, cement, lime, silica fume, and chemical admixtures, Kalkan and Akbulut (2004) in application of silica fume for natural clay liners, and Pal and Ghosh (2011) in nine numbers of class F Indian fly ash.

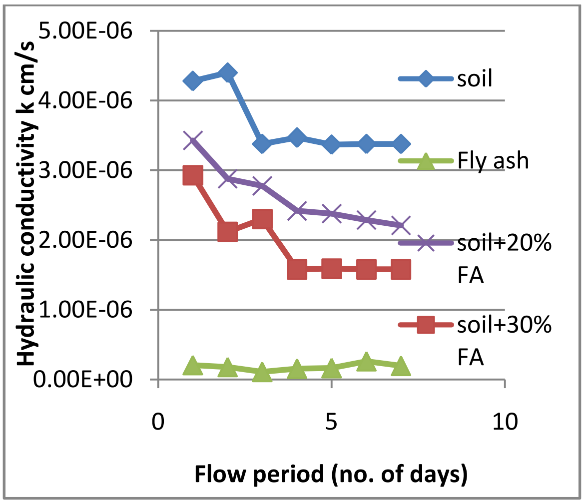

Fig. 8. Hydraulic conductivity vs. flow period for soil and soil fly ash mix

4. CONCLUSIONS

Following conclusions may be made based on the above test results and discussions:

- Soil-fly ash mixtures exhibit well-defined moisture-density relationship, varying the mixture percentage. As the fly ash content increases optimum moisture content increases and maximum dry density decreases. The dry unit weight for soil-fly ash is lesser than those of typically compacted soil.
- Soil-lime mixture too exhibit well defined moisture-density relationship with increment of percentage. As the lime content increases optimum moisture content increases and maximum dry density decreases.
- Due to addition of fly ash in soil, the soil can resist the compressive loading better and consequently shows lesser compressibility.
- The higher silt content and lesser plasticity of the fly ash result in lesser volume change of the soil.
- The test result shows that with addition of flyash settlement will be less.
- The value of Cc decreased with addition of fly ash.
- It appears that the fineness of fly ash causes the coefficient of consolidation of soil-flyash mix to increase.
- The rate of permeability increases with increase of fly ash in soil.

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- Fly ash with high percentage content can be mixed in local sandy silt soil, this material may be used as land filling and embankments in the field of geotechnical engineering construction.

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