Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 6, No. 2, February, 2020

Behaviour of Soft Clayey Soil Improved by Fly Ash and Geogrid under Cyclic Loading

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Received 27 August 2019; Accepted 16 December 2019

Abstract

The effect of Cyclic loading on the foundation behaviour of many engineering structures presents more important and related to many problems in geotechnical engineering, Especially when construction on soft ground area which represent one of the major concerns in geotechnical engineering. This paper is conducted to investigate the influence of using several improving techniques as (fly ash, Geo-grid, fly ash and Geo-grid) on the behavior of soft clayey soil subjected to cyclic loading. A total of twenty four models have been tested which consists of a wide domain of boundary conditions, such as untreated model, Geo-grid reinforced models, fly ash treated models and models treated with fly ash incorporated with Geo-grid were conducted by varying parameters such as, footing elevations, test velocity and number of geogrid layers. The analysis demonstrates that the settlement behaviour of footing resting on treated models with fly ash and two Geo-grid layers perform better than other improving techniques. Also observed there was an increase in settlement, which corresponds to the increase in test velocity from 6 to 9 mm/sec. Furthermore, it was conducted that the more depth of footing the soil settlement decreases. In general, when other factors remaining constant, the bearing capacity of soil goes on increasing when the depth increased.

Keywords: Soft Soil; Fly Ash; Geogrid; Soil Treatment; Stabilization; Cyclic Loading.

1. Introduction

Many regions in Iraq contain very soft clays especially in south, which have undesirable geotechnical properties such as, low bearing capacity, high compressibility, And because of the rapid economic development and construction of infrastructure particularly transportation infrastructure (e.g., high speed railways, airports, expressways, subways, and ports) in which the load characteristics in most cases as cyclic loading However, there is an increasing demand for studies of the cyclic behavior of clay and methods of improvement. In the absence of a suitable ground improvement, the soft clay deposits clays can sustain excessive settlement, high excess pore-water pressures during cyclic loading. This have negatively effects on the stability of buildings [1]. Reinforcing soft ground by installing geogrid and fly ash well established technique practiced worldwide as well as suitable methods to enhance the geotechnical properties of soil. Settlement of structures built on improved soils with fly ash decreases and the time required for reaching the final settlement is reduced. Fly ash can be used in soil to get improvement in shear strength, cohesion and improvement in the bearing capacity [2]. Also, the inclusion of geogrid leads to increase bearing capacity of shallow foundation by placing one or several layers. Furthermore, it becomes more stable and the factor of safety against bearing capacity

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http://dx.doi.org/10.28991/cej-2020-03091466

failure is improved. The reinforced sand beds perform better than the unreinforced sand beds regardless of the number of reinforcement layers and spacing of the reinforcement under repeated loads [3]. Cyclic loading and its influences towards foundation performance are of the highest importance and associated with many problems in geotechnical engineering, The foundation of structures require the special attention of the civil engineer when subjected cyclic loads in addition to static loads. The response of earth structures to dynamic stress applications, such as those produced by machine loads, wave loads and other low frequency loads are finding increased application in civil engineering practice. There are several sources of cyclic loading, such as traffic (high-speed train), industrial sources (crane rails, machine foundation), wind and waves (on – shore and off – shore wind power plants, coastal structures) or repeated filling and emptying processes (Watergates tanks and silos). In addition, cyclic loading imposes to soil during earthquake events that slipped the adjacent tectonic plates lead to a propagation of shear waves that shear waves induce a cyclic shearing of the soil [4].

The use of fly ash and geogrid reinforcements for improving load-bearing capacity of foundation has been widely studied by many researchers, such as Honnalli and Rakaraddi (2015) studies, which presents the efficacy of multilayer reinforcements in improving the load-bearing capacity when incorporated within the body of fly ash embankment. An increase in load bearing capacity due to the incorporation of reinforcement layers in the model slope were observed in the laboratory tests [5]. Hotti et al. (2014) Conducted laboratory model tests on square footings supported by geogrid reinforced sand bed and subjected to incremental loading and unloading conditions. The results shows that the value of ultimate bearing capacity for reinforced sand are greater than unreinforced sand bed [6]. Also, Saisubramanian et al. (2019) studied the effect of coir geotextile reinforcement on the vertical stress distribution in the sand. The test results showed the inclusion of reinforcement can redistribute the applied footing load to a more uniform pattern, hence reducing the stress concentration which will result reduced settlement [7]. Sridhar and Kumar (2018) reported that with use two layers of Geo-textiles on soft clay led to that the shear strength was enhanced substantially. This study investigates the influence of using improving techniques. on the behavior of soft clayey soil subjected to cyclic loading by achieving a series of model footing tests consists of a wide domain of boundary conditions (untreated and treated with fly ash in addition to the geogrid layers) and varying parameters, such as footing elevations, test velocity and number of geogrid layers [8].

2. Materials and Methods

2.1. Soil

A brown clayey soil was collected from Al-Nahrawan city east of Baghdad. Standard examinations were conducted to decide the properties of the soil used. Details are listed in Table 1. Grain size distribution of the soil used which represent the following percentages: 7.02 % sand, 43.98% silt and 49% clay as illustrated in Figure 1. According to the USCS, the soil is classified as CL.

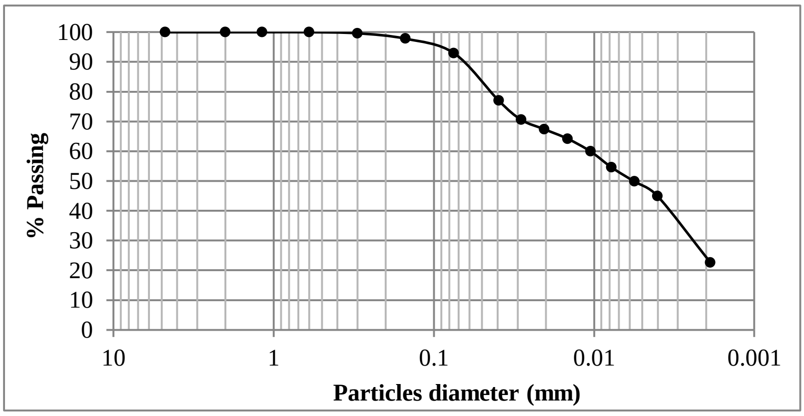


Figure 1. Grain size distribution of the soil used

Table 1. Physical properties of the soil used

Property index	Value index	Standard index
Liquid limit (LL) %	32	ASTM D4318
Plastic limit (PL) %	17	ASTM D4318
Plasticity index (PI) %	15	ASTM D4318
Specific gravity (Gs)	2.69	ASTM D854
Gravel (larger than 2mm) %	0	ASTM D422
Sand (0.06 to 2mm) %	7.02	ASTM D422

Silt (0.005 to 0.06mm) %	43.98	ASTM D422
Clay (less than 0.005mm) %	49	ASTM D422
Maximum dry unit weight (kN/m^3)	16.7	ASTM D1557
Optimum moisture content (%)	21	ASTM D1557
USCS	CL	

2.2. Geogrid

The geogrid used in all tests was manufactured by Al-Latifia Factory for plastic mesh having the engineering properties shown in Table 2 as provided by the manufacturing company [9, 10]. The sheets of geogrid were used from test to test but they were replaced whenever any of the strands become visibly overstressed. Figure 2 illustrate the Geo-grid used.

Table 2. Engineering properties of the geogrid used [11] (A) Physical, chemical and biological properties (B) Dimensions properties and technical properties

(A)

Property	Test method	Data
Structure	ASTM D1603	Extruded geogrid
Mesh type		Square
Standard colour		Green
Polymer type		HDPE
Packing		Rolls
Chemical resistance		The product is inert to all chemicals naturally found in soils and water.
Biological resistance		The product is not affected by micro orgenesis.
Sunlight resistance		The addition of suitable stabilizers limits the attack from UV light. The material can be expected to have a life of over 5 years when exposed, without a loose of more than 20% of the product strength in a temperature climate.
Temperature stability		The material is stable within a temperature range of -60 ℃ to 100 ℃, but with a reduced strength at elevated temperature.
UV stabilizer		Added with color

(B)

Property	Test method	Unit	Data
Aperture size	ISO 9864	mm*mm	6*6
Mass per unit area		g/m^2	363
Roll width		m	1
Roll length		m	30
Tensile strength at 2 %		KN/m^2	4.3
Tensile strength at 5 %	ISO 9864	KN/m^2	7.7
Peak tensile strength	ISO 9864	KN/m^2	13.5
Yield point elongation		%	20.0
Aperture size		mm*mm	6*6
Mass per unit area		g/m^2	363

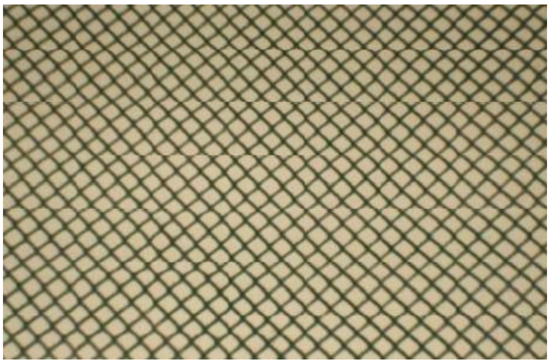


Figure 2. The Geo-grid used

2.2. Fly Ash

The fly ash used is obtained from the south of Baghdad thermal power plant. The chemical compositions are given in Table 3. According to ASTM C 618 [12], this fly ash can be classified as a Class C fly ash.

Table 3. Chemical composition of fly ash used

Composition	Value (%)
SiO_2	32.16
Fe_2O_3	6.13
Al_2O_3	18.37
TiO_2	<0.01
CaO	28.23
MgO	8.16
CO_3	0.34
Na_2O	2.83
K_2O	3.19

3. Loading Machine

The loading machine consists of several parts [13]. As illustrated in Figure 2 which it (Loading jack, Steel Frame, Footing models, steel container).

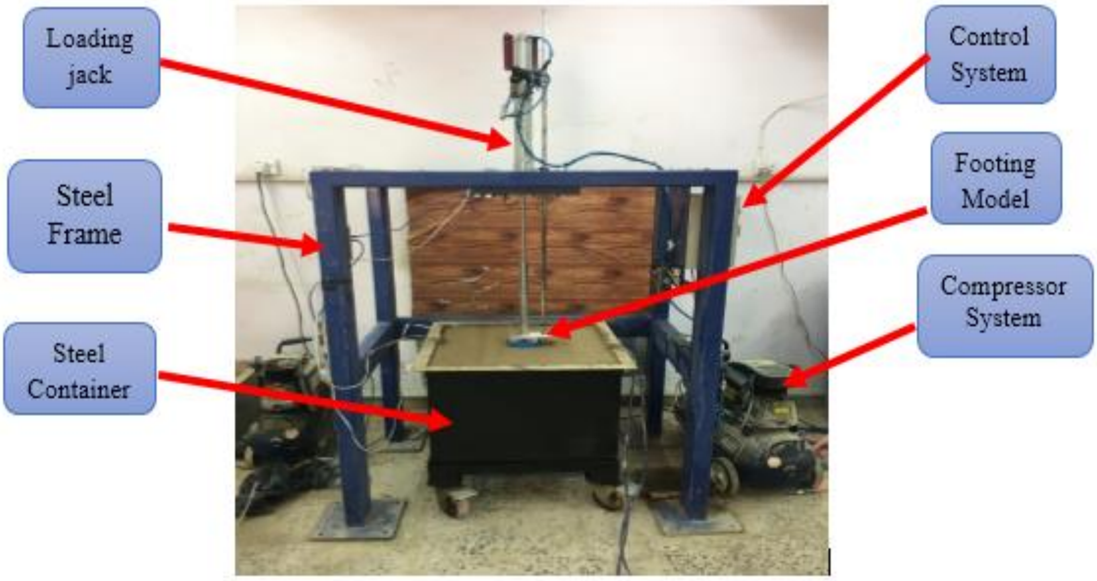


Figure 2. General view of device used

4. Model Footing and Container

Based on the recommendations given by Mohammed (2018) [2], steel ring footing was used in this study with inner diameter of 40 mm and outer diameter of 100 mm and thickness of 20 mm. Steel container is used with inner dimensions of 600×600 mm and depth of 500 mm. The container is made as one piece with a thickness of 6 mm steel plate.

The settlement of the footing during the application of cyclic load was measured by using Laser LVDT. It can measure absolute distances up to 2m. Table 3 listed the specification of the Laser LVDT used. In addition, the system of data acquisition was utilized so that all data could be scanned and recorded automatically by using computer and data logger.

Table 3. Specification of the laser LVDT used

Property	Value
Supply voltage	2.6 to 3.5 V
Global current consumption	15 mA
Ultrasonic frequency	Up to 400 kHz
Maximal range	200cm
Minimal range	3 cm
Resolution	1 cm
Trigger pulse width	10 µs
Outline dimension	4.4 ×2.4 × 1.0 mm

5. Model Preparation

The clayey soil mixed with predetermined amount of water which corresponding to cu = 7 kPa, To get uniform moisture content the wet soil was kept inside tightened polythen bags for a period of four days before use, The mixing operation was conducted using a large mixer (120 L) manufactured for this purpose. After that, the moist soil was placed in five layers inside the container. And pressed gently with a wooden tamper in order to remove entrapped air. Figure 3 illustrates model preparation.

The fly ash content was 20%, which was optimum percentage depending on previous research, which defined by the ratio of the weight of the fly ash to the dry weight of the natural clayey soil (soft Soil) expressed as a percentage. To achieve that by mixing 25 Kg of dry soil with 5 Kg of fly ash and desired water content. The geogrid layers were placed at desired depth which equal to 5 cm and 7.5 cm (0.5 D, 0.75 D where D = external diameter of footing) Measured from the base of footing.

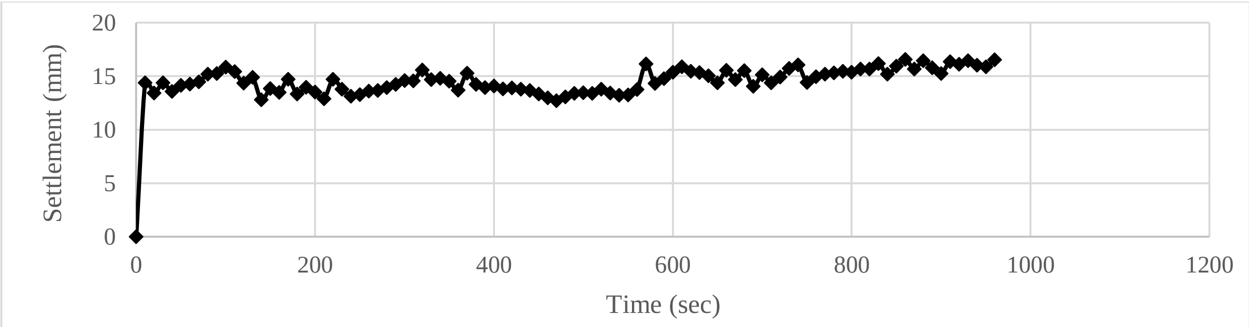
Figure 3. Model preparations

6. Results and Discussion

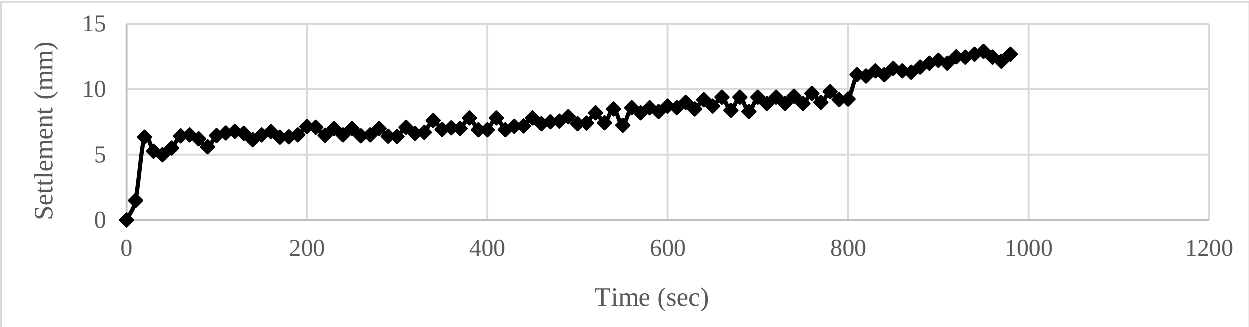
- The number of model tests is 24, which are arranged in four groups as following:
- Four untreated models with ring footing (D_{in}/D_{out}=0.4) (D_{in} is the internal diameter and D_{out} is the external diameter of footing used) placed on soft saturated bed of clay with c_u=7 kPa.
- Four models were prepared and testing with fly ash only with two footing elevations which (D_f=0 and D_f= 100mm) and two velocities that (V_1 = 9 mm/sec and V_2 = 6 mm/sec).
- Eight models were conducted with reinforcement geogrid of variable geogrid depths (0.5 D and 0.75 D; where, D = the diameter of footing) and with two footing elevations (D_f = 0 and 100 mm) and two velocities (V_1 = 9 mm/sec and V_2 = 6 mm/sec).
- Eight models were tested with reinforcement geogrid (with the same depth and velocities mentioned above) and fly ash. For all test models the failure was defined as the load causing a settlement corresponding to 10% of the diameter of footing based on Terzaghi (1943) [14]. In this study, the settlement with time was investigated.

6.1. Model Test on Untreated Soil

Figures 4 and 5 demonstrate the variation of settlement with time for untreated models with variable footing depths (footing at surface and footing at depth) for velocity test equal to 9 and 6 mm/sec respectively. From these figures, it can be seen that the more the depth of footing the soil settlement decrease as presented in figures. In general, when other factors are remaining constant, the bearing capacity of the soil goes on increasing when the depth of the foundation increases. The total settlement of a footing continues to increase during the time reaching a maximum value at the end of test. Moreover, there is an increase in settlement with increasing test velocity which attributed to in case of increase test velocity the soil particles do not have enough time to arrange themselves in denser state. This is in agreement with Fattah et al. (2017) results [4].

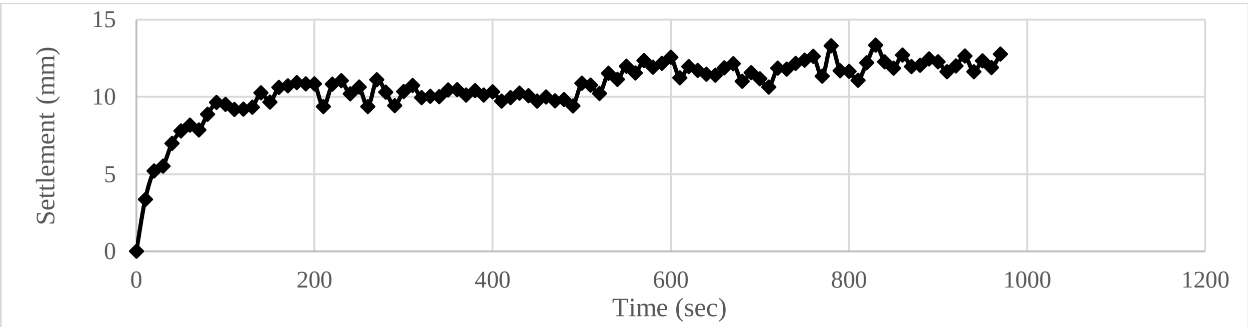


A. Footing at surface

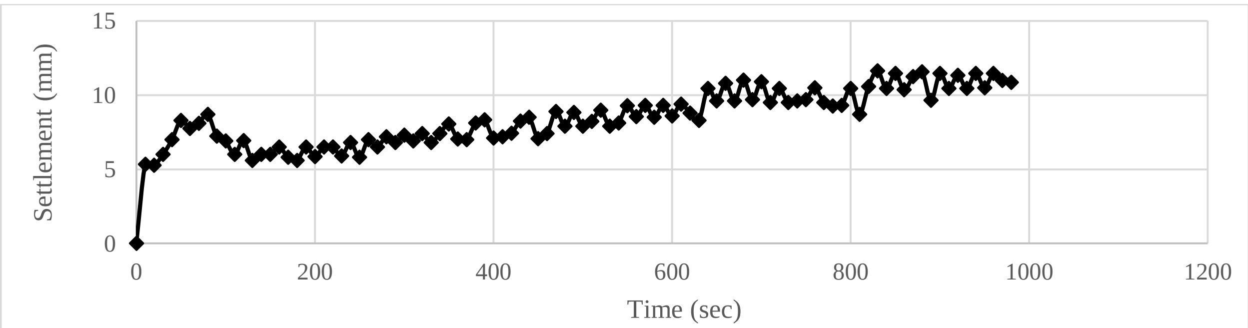


B. Footing at depth

Figure 4. Settlement versus time for untreated models with different footing depth and velocity=9 mm/sec



A. Footing at surface

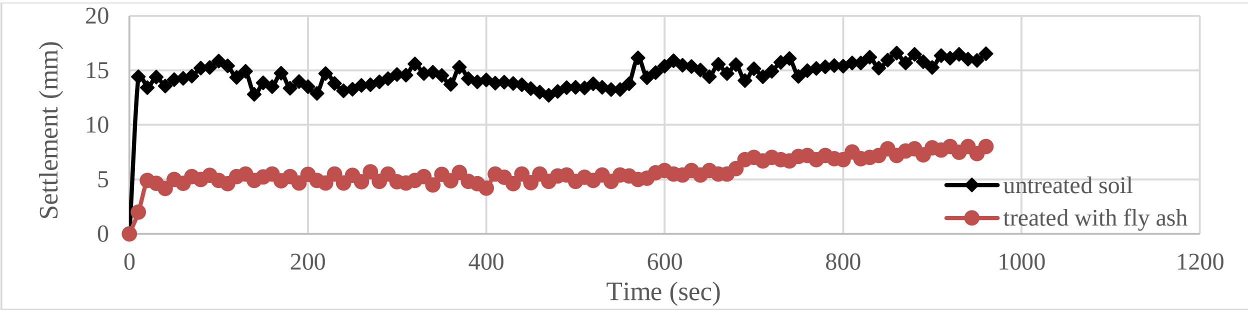


B. Footing at depth

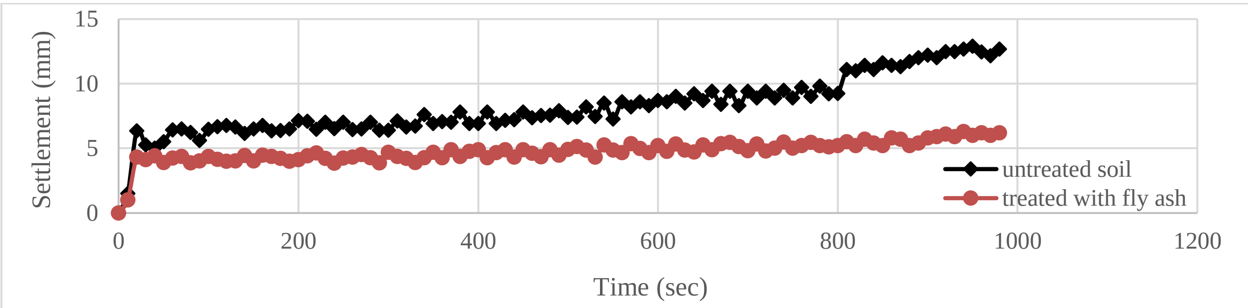
Figure 5. Settlement versus time for untreated models with different footing depth and velocity=6 mm/sec

6.2. Model Test on Treated Soil with Fly Ash

Figures 6 and 7 represent the variation of settlement with time for treated with fly ash and untreated models. From these Figures, it can be noticed with the addition of fly ash there is substantial reduction in settlement of foundation. That is attributed to the pozzolanic reaction between the calcium aluminates within the fly ash and the minerals of soil, which dissolving into water to form calcium-silicate and calcium-aluminate gels, which turn the soil into hardened solid with high strength and stiffness. The improvement in settlement measured at the end of test where more than 50 % when footing placed at surface (D_f = 0 mm), and more than 40% for footing placed at depth (D_f =100 mm) the results are in agreement with Khan et al. (2008) results [15]. Who adopted that "At lower intensity of load and higher number of cycles, The strength of layered system of soil-fly ash matrix increases due to interlocking of fly ash particles and binding effect of interfaces of soil and fly ash layers", Also it can be observed an increase in settlement measured at the end of test from 7.4 mm to 8 mm when footing placed at surface and from 5.8 to 6.2 mm when footing placed at depth. This corresponds to the increase in test velocity from 6 mm/sec to 9 mm/sec.

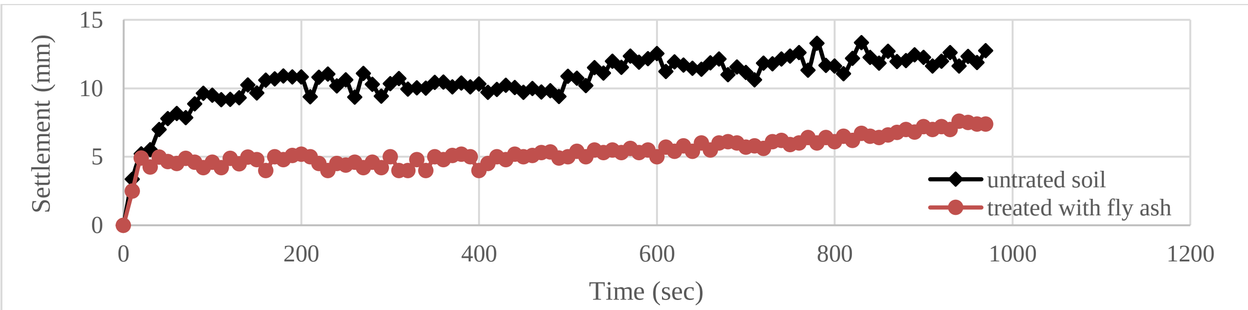


A. Footing at surface

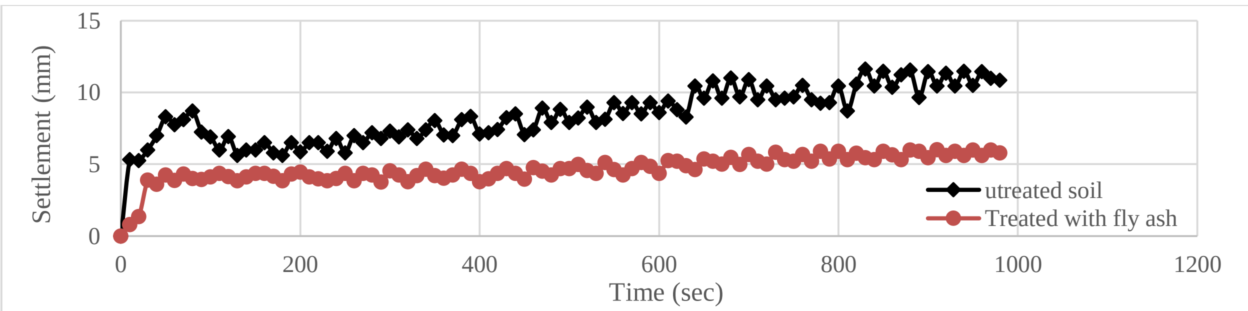


B. Footing at depth

Figure 6. Settlement versus time for untreated and treated with fly ash models with different footing depth and velocity=9 mm/sec



A. Footing at surface

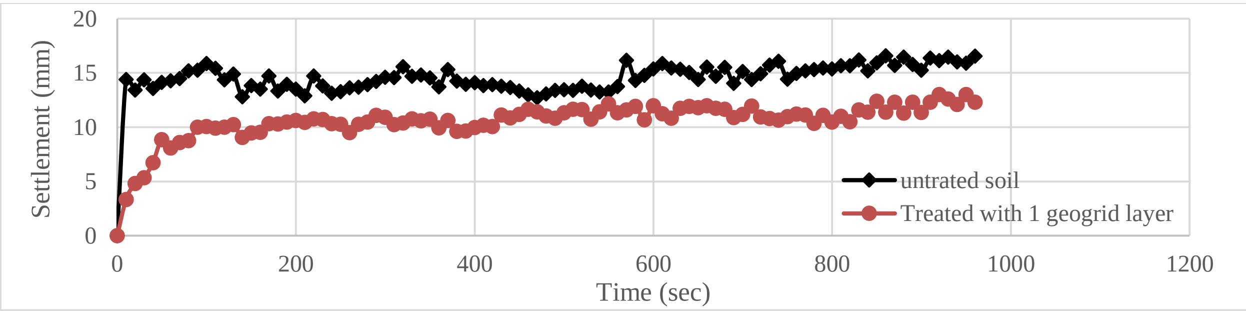


B. Footing at depth

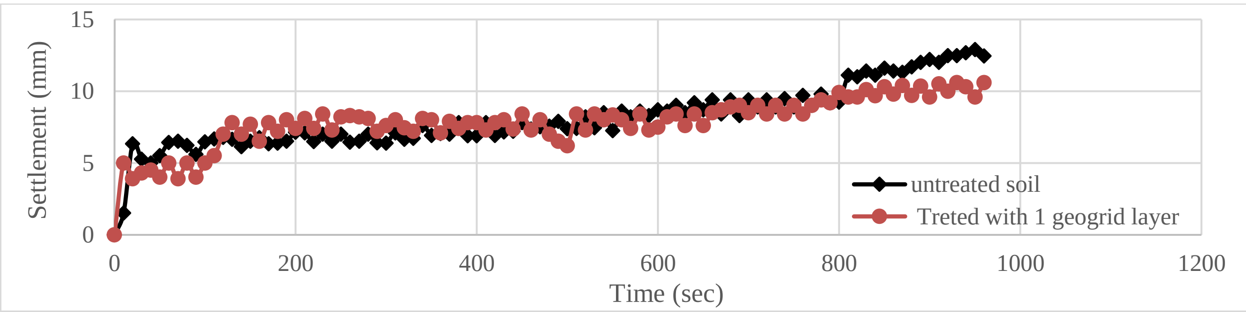
Figure 7. Settlement versus time for untreated and treated with fly ash models with different depth and velocity=6 mm/sec

6.3. Model Test on Treated Soil with Geogrid

Figures 8 to 11 present the relationship between time and settlement for untreated and treated with 1 and 2 geogrid layer models. Obviously as seen in these figures, the amount of settlement increased with time progress, the settlement was slightly lower for the case of reinforced clay with one geogrid layer than unreinforced clay. In contrast, it can be observed that in case of using double geogrid layers, there is an improving in the settlement measured at the end of the test, which was about 16.58 – 10 mm and 12.89 – 8.1 mm. For models footings placed at the surface (D_f = 0) and at the depth (D_f =100 mm) respectively with test velocity = 9 mm/sec. This reduction is likely to happen because of, interlocking between the clay and geogrid, when the soil interlocks in the geogrid and stress is applied. The stress is transmitted to the rib of geogrid more precisely the stress transmitted to the longitudinal ribs through the junction leading to increase bearing capacity subsequently and enhance settlement performance. This is consistent with Hotti et al. (2014) findings who noted that there was further increases in the load carrying capacity with the inclusion of geo-grid reinforcement [6]. In addition, the use of the geogrid reinforcement leads to better performance from the point of view of Cu improvement as well as settlement reduction. This also observed by Das and Shin (1994) [16], who studied the permanent settlement of a surface strip foundation supported by geogrid-reinforced saturated clay and subjected to a low-frequency cyclic load. The results present that "Full depth geogrid reinforcement may reduce the permanent settlement of a foundation by about 20% to 30% compared to one without reinforcement". Sudhakar and Sandeep (2016) studied the effect of geocell reinforcement on bearing capacity of ring footing and circular footing under vertical loading and cyclic loading using experimental approach. The results showed that "footing performance due to cyclic loading is better for geocell reinforced soil than that of unreinforced soil" [17]. Also for the same condition, the improvement in ultimate bearing capacity increases with increase of reinforcement layers that conducted by Zidan (2012) [18], who discussed the behavior of a circular footing constructed on reinforced sand under the influence of some factors including number of geogrid layers under static and repeated loading. It is worth noting that less settlement observed when the other variables, such as footing depth, geogrid layers depth were remaining constant but the test velocity drop to 6 mm/sec.

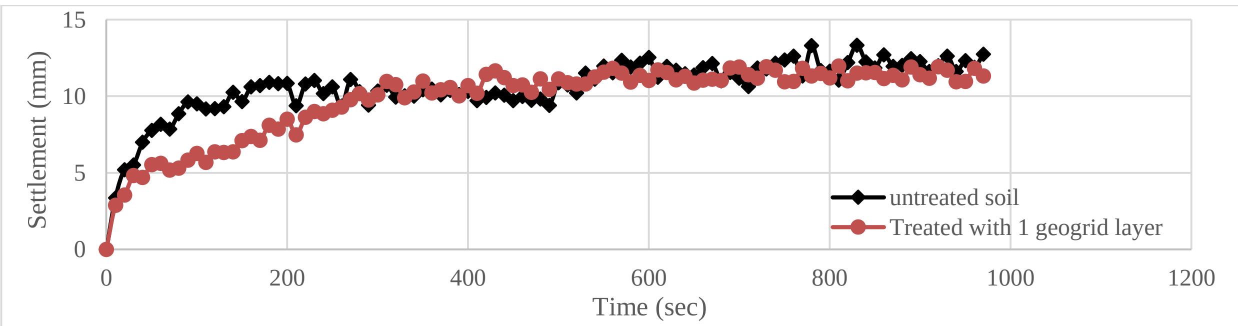


A. Footing at surface

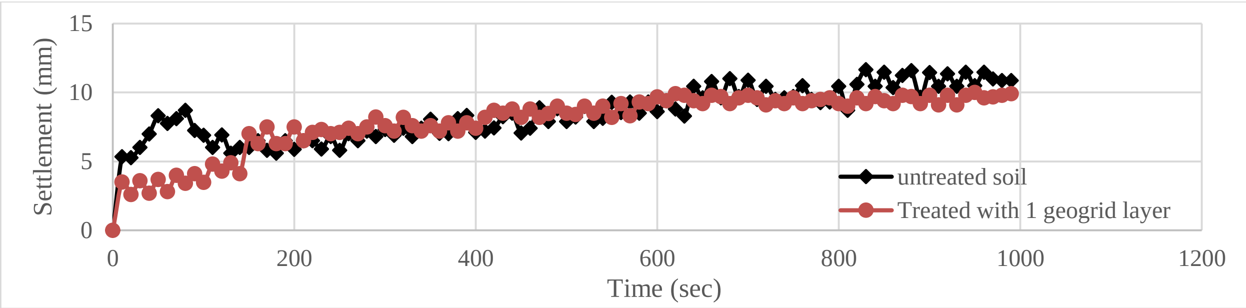


B. Footing at depth

Figure 8. Settlement versus time for untreated and treated with 1 geogrid layer model with different depths and velocity=9 mm/sec

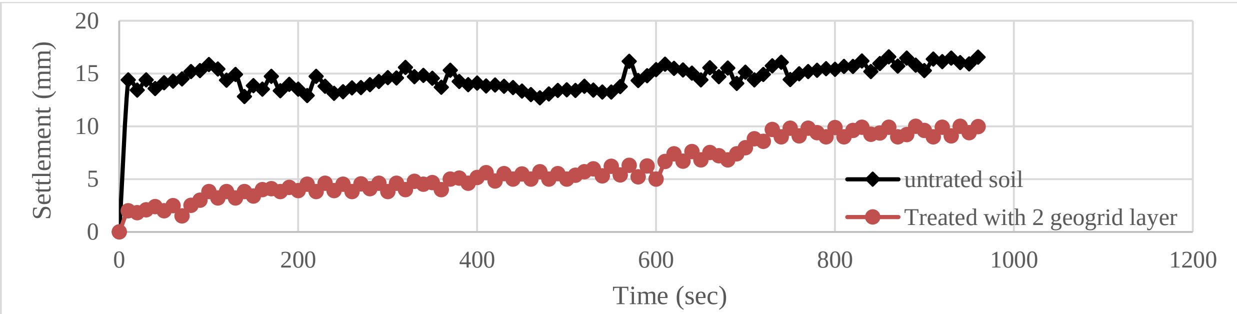


A. Footing at surface

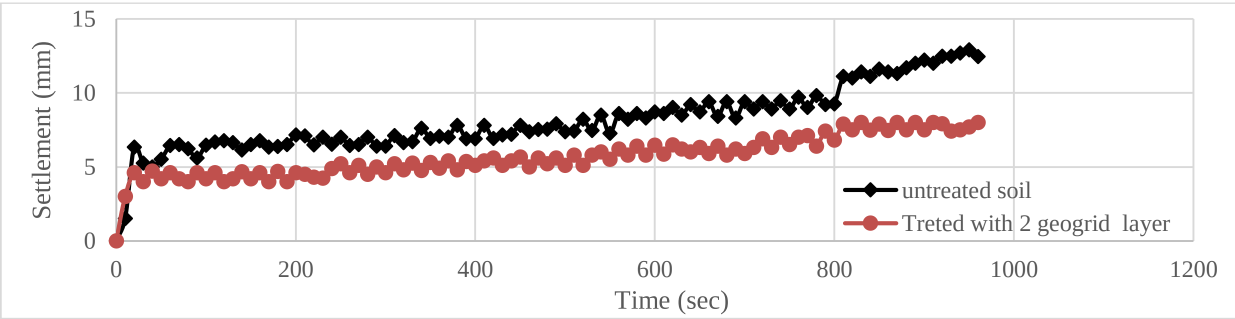


B. Footing at depth

Figure 9. Settlement versus time for untreated and treated with 1 geogrid layer models with different depths and velocity=6 mm/sec

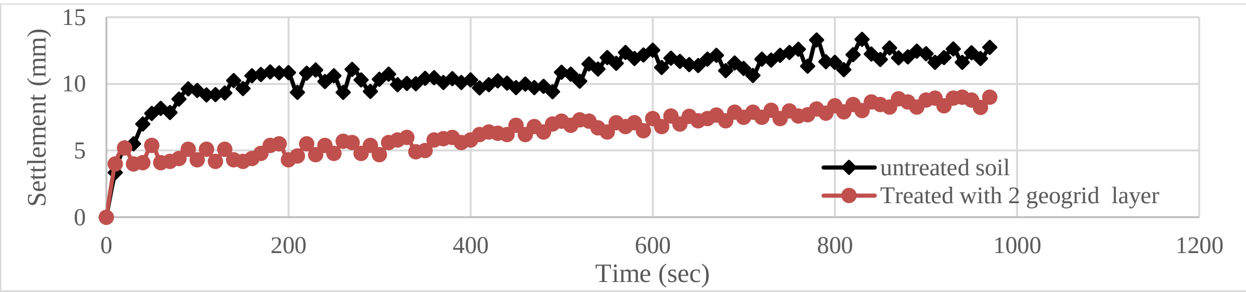


A. Footing at surface

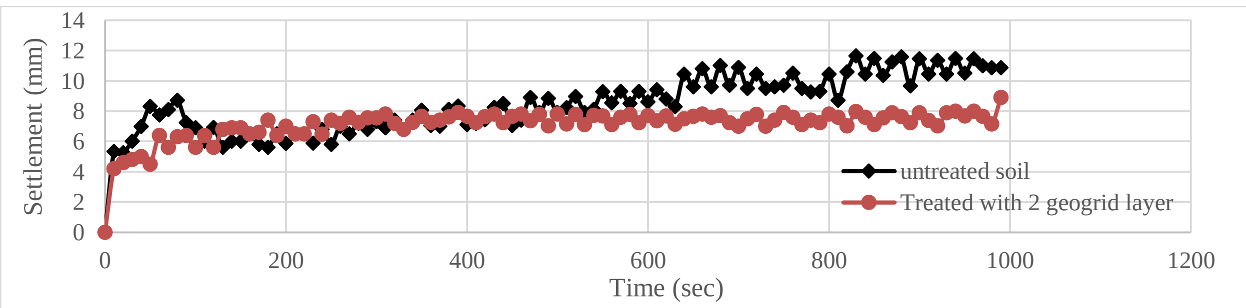


B. Footing at depth

Figure 10. Settlement versus time for untreated and treated with 2 geogrid layer models with different depths and velocity = 9 mm/sec



A. Footing at surface

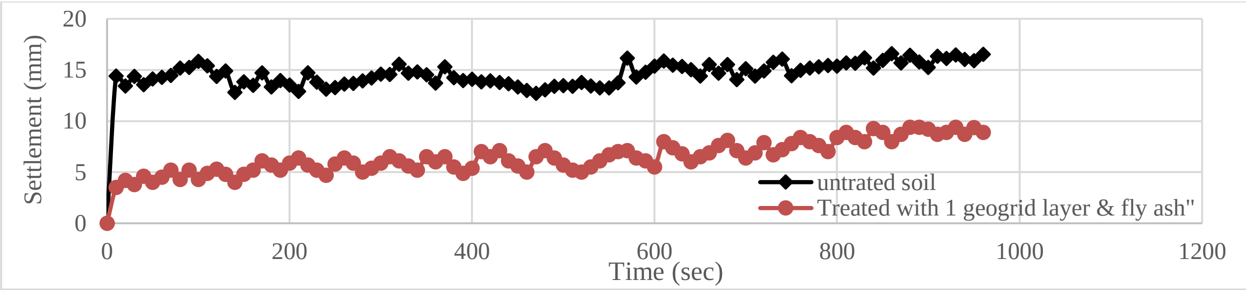


B. Footing at depth

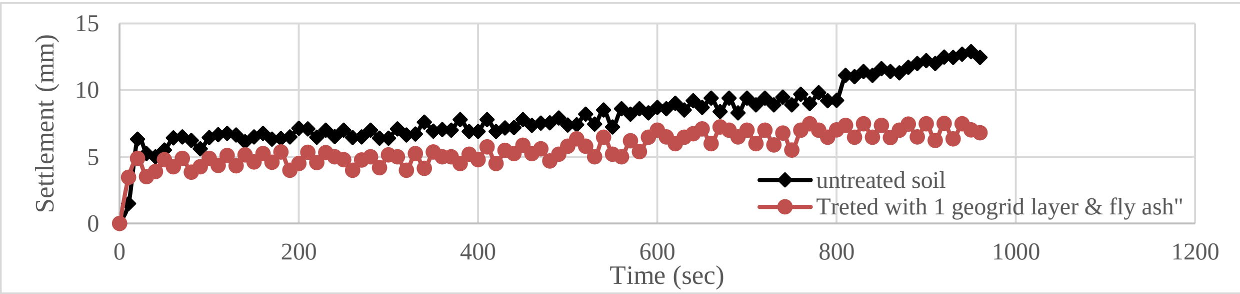
Figure 11. Settlement versus time for untreated and treated with 2 geogrid layer models with different depths and velocity = 6 mm/sec

6.4. Model Test on Treated Soil with Geogrid and Fly Ash

Figures 12 to 15 present the typical relationship of settlements versus time for soil bed improvement with geogrid-fly ash layer. In general, the figures depict that the addition of fly ash in the presence of geogrid reduces the settlement compared to models without treatment. Even though models treated with geogrid or fly ash only. That is compatible with Tejaswini et al. (2014), who studied the performance of circular footing resting in reinforced fly ash beds under repeated loads [19]. Based on the results of experiments, the circular footing resting on reinforced fly ash beds performs better than its counterpart resting on unreinforced fly ash beds. Moreover, from these figures it can be noticed that the total settlement of a footing continues to increase during the time of the load and reaches a maximum value in most figures at the end of test. Also, it can be seen for models treated with 1 geogrid layer and fly ash that there is an improving in the settlement measured at the end of the test more than 40% for models footings placed at the surface (D_f =0) and at the depth D_f =100 mm with test velocity =9 mm/sec. In addition, a significant reduction in settlement value measured at the end of test for models treated with 2 geogrid layers and fly ash compared to untreated models. That is equal to 6.89 mm and 5.87mm for footing at D_f=0 with velocity equal to 9 and 6 mm/sec respectively. A better performance occurs with inclusion of geogrid reinforcement that agrees with Choudhary et al. (2010) and Hotti et al. (2014) results [3, 6].

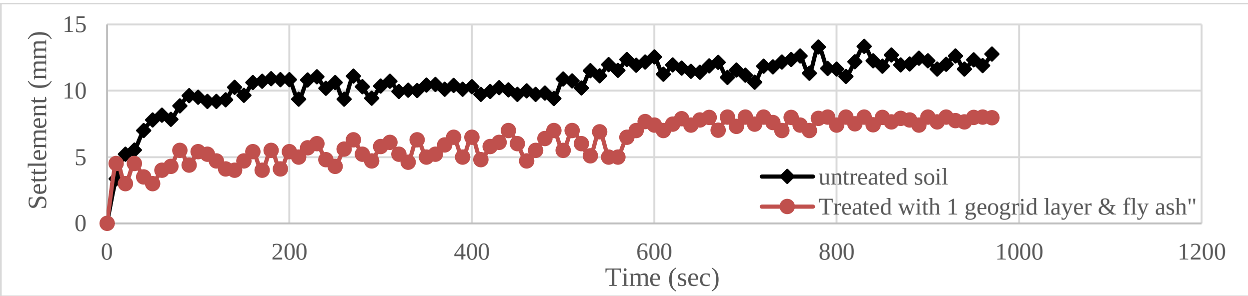


A. Footing at surface

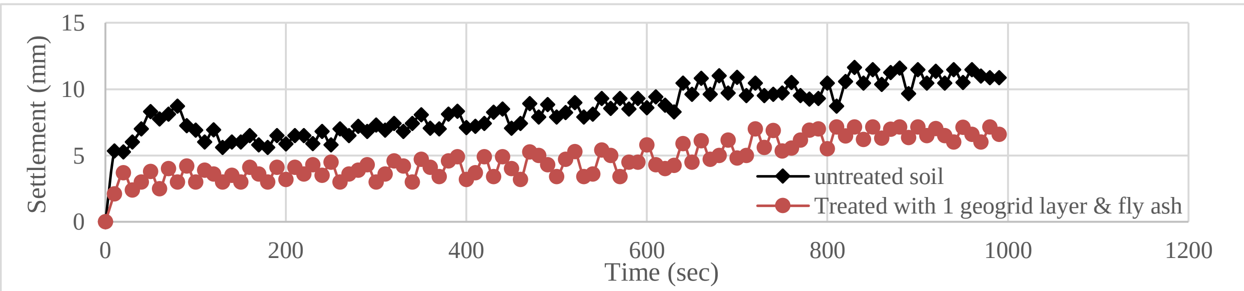


B. Footing at depth

Figure 12. Settlement versus time for untreated and treated with 1 geogrid layer and fly ash models with different depths and velocity = 9 mm/sec

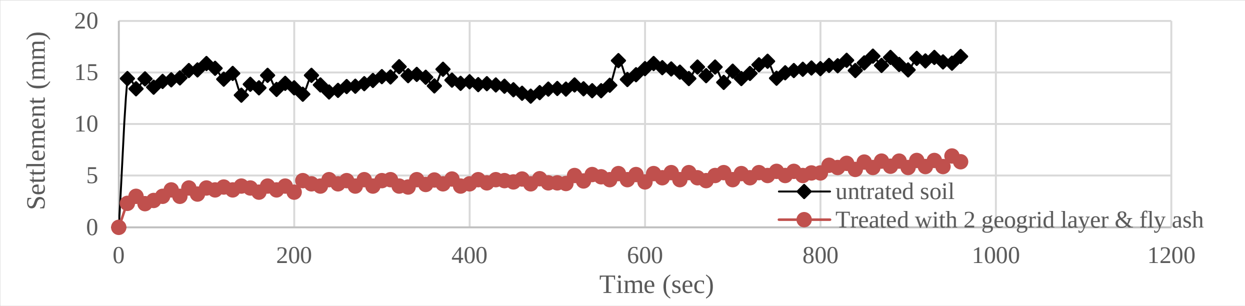


A. Footing at surface

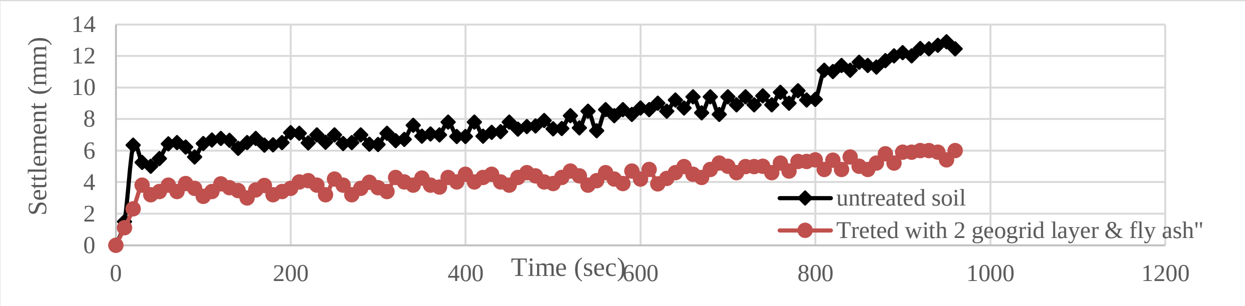


B. Footing at depth

Figure 13. Settlement versus time for untreated and treated with 1 geogrid layer and fly ash models with different depths and velocity = 6 mm/sec

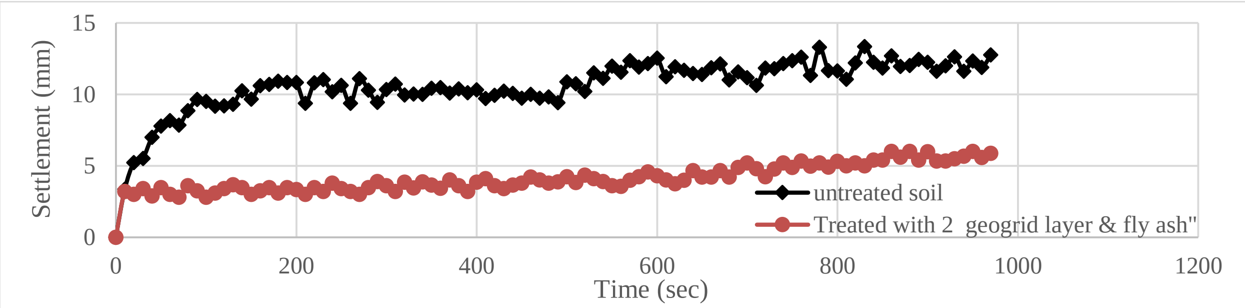


A. Footing at surface

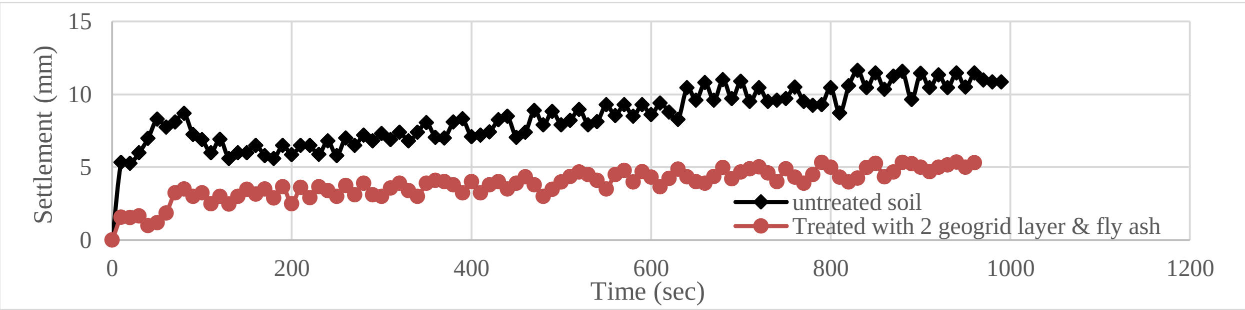


B. Footing at depth

Fig. 14: Settlement versus time for untreated and treated with 2 geogrid layers and fly ash models with different depths and velocity = 9 mm/sec



A. Footing at surface



B. Footing at depth

Figure 15. Settlement versus time for untreated and treated with 2 geogrid layers and fly ash models with different depths and velocity = 6 mm/sec

7. Conclusions

Depending on comprehensive laboratory tests performed on models soil with varying improvement techniques and untreated one, the following conclusions are drawn.

- In most models, an increase in settlement was measured at the end of test, which corresponds to the increase in test velocity from 6 to 9 mm/sec.
- In general, the settlement decreases with the increase in the footing depth for both test velocities and thus the bearing capacity increases with depth.

- The addition of fly ash causes a reduction in settlement of about more than 40 to 50% for footing at the surface and depth respectively.
- The settlement decreases slightly with reinforcing clay with 1 geogrid layer. While the settlement decreases remarkably with 2 geogrid layers for both footing placed at the surface or at depth.
- The addition of fly ash with geogrid (1 or 2 layers) reduces the settlement to about 50% for both velocities compared to those models treated with either geogrid only or fly ash only.
- The maximum settlement value is less for model treated with fly ash and two geogrid layers, which is equal to 5.87 mm at rate of velocity = 6 mm /sec, and equal to 6.89 mm at rate of velocity = 9 mm /sec compared with the other models.

8. Conflicts of Interest

The authors declare no conflict of interest.

9. References

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