Clay Columns Stabilized with Fly Ash in Soft Soils

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Abstract. Geotechnical design and execution of civil engineering structures on soft to very soft soils are usually associated with substantial difficulties. These soils are sensitive to deformations and possess low shear strength values. Geotechnical properties of such soil stabilization are improved by various methods. Admixtures improve soil properties in order to form strong foundation capable of bearing loads of such structure. Clay soils cause cracking and fracture of pavement, railways, highways, embankment, foundations... etc. The main objective of this study is to discuss and evaluate the effect of addition of fly ash on shear strength of soft soil and bearing capacity of these soils by adding clay columns stabilized with fly ash in soft soils. The essential idea represents in investigation of possibility of using fly ash to reduce compressibility to find solution for some problems of failure in soft soils in Iraq. This will encourage the use of fly ash as stabilizer especially as it is an economic material and for its local availability. Soil used in the study was obtained from Al-Nahrawan City 35 km east of Baghdad. According to the Unified Soil Classification System, it is classified as (CL) soil. The soil consists of 3% sand, 35% silt, and 62% clay. The tests were carried out using a steel container with internal dimension of (400x350x300 mm). The steel container is made of steel plates that are 4mm in thickness. The thickness of the bed of clay was 300 mm, and 400 mm for (L/D) 4 and 6, respectively. The depth of the column was 200 mm and 300 mm for (L/D) 4 and 6, respectively, at 50mm diameter of column (D). Square steel foundation of 4mm thickness and width 60 mm was used in all the tests. The length to diameter ratio (L/D) which was used in this study was 4 and 6. The results of curing days in 14 days and 28 days are close to each other. The incensement ratio is about 5% between 14 and 28 days for the two (L/D) 4 and 6. (L/D) 6 has shown more improvement than L/D 4, the improvement in bearing ratio failure is about 30%.

1. Introduction
The soft clay soils are late alluvial deposits presumably formed through the 10,000 years covered by their featureless and flat sold ground surface. Such clay are identified by their low un-drained shear strength (Cu<40 Mpa) and high compressibility (Cc between 0.19 and 0.44). They are found in soil with high natural moisture content typically (40-60 %) with plasticity index (45-65 %).

Geotechnical properties of such soil stabilization are improved by various methods. This is called “soil stabilization” which means alteration of soil properties to specify engineering requirements. Method of stabilization may be divided into two methods: Mechanical and Chemical stabilization.
using admixtures. These admixtures are cement, lime, rubber wests, fly ash ... etc.; add to the natural soil samples, to use them as chemical admixture. Admixtures improve soil properties in order to form strong foundations capable of bearing loads of such structure.

Good improvement in engineering properties of soft clay has been noticed by using fly ash. Fly ash is a coal combustion product that is composed of the particulates (fine particles of burned fuel) that are driven out of coal-fired boilers together with the flue gases. The components of fly ash vary considerably, depending upon the source and composition of the coal being burned.

The main objective of this study is to discuss and evaluate the effect of addition of fly ash on shear strength of soft soil and bearing capacity of these soils by carrying out physical and consolidation settlement test.

The essential idea represents investigation of possibility of using fly ash to reduce compressibility and decrease dry unit weight to find solution for some problems of failure of roads in Iraq. This will encourage using fly ash as stabilizer especially as it is an economic material and for its local availability.

2. Materials

2.1 Soil

The used soil is brought from Al-Nahrawan city 35 km east of Baghdad city. Table (1) illustrates the properties of the soil. According to the unified soil classification system the soil is clay of low plasticity with 3% sand, 35% silt and 62% clay, the particle size distribution is illustrated in Figure (1).

| Test                  | Value | Specifications       |
|-----------------------|-------|----------------------|
| Liquid Limit (L.L)    | 43    | ASTM D 4318-(2002)  |
| Plastic Limit (P.L)   | 19    | ASTM D 4318-(2002)  |
| Plasticity Index (P.I)| 24    | ASTM D 4318-(2002)  |
| Specific Gravity (Gs) | 2.67  | ASTM D 854-(2002)   |
| Gravel (%), > 4.75mm  | 0     | ASTM D 422-(2002)   |
| Sand (%), 0.075 - 4.75mm | 3   | ASTM D 422-(2002)   |
| Silt (%), 0.005 - 0.075mm | 35 | ASTM D 422-(2002)   |
| Clay (%), <0.005mm    | 62    | ASTM D 422-(2002)   |
| Activity              | 0.36  | Skempton formula     |

Figure 1. Particle size distribution of soft soil.
2.2: Fly Ash

The fly ash used in this study can be considered as a waste material from the burning of coal in thermal power in Al-Doura power station. Table (2) illustrates the chemical properties of fly ash.

| Parameter                  | Value     |
|----------------------------|-----------|
| Type                       | Class C or high |
| Loss on Ignition           | lime fly ash |
| Fineness > 0.045 mm        | 2.2       |
| Free Lime (Caofrei)        | 6.3       |
| Sulfate (SO₃)              | 33        |
| SiO₂ (S)                   | 14.60     |
| Fe₂O₃ (F)                  | 4.3       |
| S+A+F                      | 51.2      |
| CaO                        | 35.14     |
| MgO                        | 1.16      |

The chemical composition and properties of fly ash vary substantially depending on the nature of the coal burned (i.e., anthracite, bituminous, and lignite) and the characteristics of the power plant. Fly ash particles are commonly spherical in shape consisting of often hollow spheres of silicon, aluminium and iron; and oxides, and unoxidized carbon. It can be considered as non-plastic fine silt according to the Unified Soil Classification System (USCS). It produces spherical glassy particles finer than Portland cement. Fly ash particles consist mostly of silicon dioxide (SiO₂), aluminium oxide (Al₂O₃) and iron oxide (Fe₂O₃).

3. Experimental work

3.1 Steel container

The tests were carried out using a steel container with internal dimension of (400x350x300 mm). The steel container is made of steel plates that are 4mm in thickness. Figure (2) shows the steel container and loading assembly. The thickness of the bed of clay was 300 mm for end bearing model, and 200 mm for floating models, and the depth of the column (L) was 200 mm for floating, at 50mm diameter of column (D).

3.2 Steel footing

Square steel foundation of 4mm in thickness, width 60mm were used in all test.

3.3 Loading assembly

A loading frame was designed and manufactured to apply static vertical loads on the model footing. The details of the main features of the loading assembly are illustrated in Figure (2).
4. Presentation and discussion of test results
According to many previous researches, the optimum fly ash present was 5% which is used in all tests of this study.

Figure (3) illustrates the bearing ratio of the clay without treatment, and according to Terzaghi theory the failure of the soil is at $S/B = 10\%$ which reaches to 4.7.

Eight models are used to illustrate the relationship between different time curing for the clay columns stabilized with 5% fly ash 1, 7, 14 and 28 days for $(L/D)$ 4 and 6.

Figure (4) illustrates the bearing ratio versus settlement ratio for $(L/D)$ 4 and 6 and both in curing 1 day and the failure are 6.2 and 8 for the $L/D = 4$ and 6, respectively.

Figure (5) illustrates the bearing ratio versus settlement ratio for $(L/D)$ 4 and 6 and both in curing 7 days and the failure are 8.2 and 10.1 for the $L/D$ 4 and 6, respectively.
Figure 4. Load-settlement curve for the 1 day curing.

Figure 5. Load-settlement curve for the 7 days curing.

Figure (6) illustrates the bearing ratio versus settlement ratio for (L/D) 4 and 6 and both in curing 14 days and the failure are 9 and 11.1 for the L/D 4 and 6, respectively.

Figure (7) illustrates the bearing ratio versus settlement ratio for (L/D) 4 and 6 and both in curing 28 days and the failure are 9.5 and 11.7 for the L/D 4 and 6, respectively.
**Figure 6.** Load-settlement curve for the 14 days curing.

**Figure 7.** Load-settlement curve for the 28 days curing.

The summary of the tests results, improvement ratio and settlement reduction ratio for (L/D) 4 and 6 are illustrated in Figures (8 – 13) and the summary results are illustrated in Table (3).
Figure 9. Bearing improvement ratio for (L/D) 4.

Figure 10. Settlement reduction ratio for (L/D) 4.

Figure 11. Load-settlement curve for (L/D) 6.
There are two types of fly ashes presented depending on the type of coal that was burned: class C and class F, the main difference between them is the presence of content of iron, calcium, alumina and silica in the ash. Fly ash- Class C is produced from the burning of younger lignite or sub bituminous
coal. This type has both pozzolanic and cementitious properties that hardens and gains strength over time. It generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulphate (SO$_4$) contents are generally higher in Class C fly ashes. Class F fly ash has pozzolanic properties produced from burning of harder, older anthracite and bituminous coal. This fly ash contains less than 10% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Class C fly ashes are used in this study as the waste material came from burning of coal in thermal power in Al-Doura power station.

5. Conclusions
Based on the test results, it is concluded that:

- For (L/D) 4 the failure bearing ratio is increased about 54% when the curing days were increased from 1 day till 28 days.
- For (L/D) 6 the failure bearing ratio is increased about 47% when the curing days were increased from 1 day till 28 days.
- The results of curing days in 14 days and 28 days are close to each other with the incensement ratio of about 5% between 14 and 28 days for the two (L/D) 4 and 6.
- (L/D) 6 has shown more improvement than (L/D) 4, the improvement in bearing ratio failure is about 30%.

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