Use of Fly Ash as Weak Cementing Agent to Strengthen Marine Clay

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Abstract. Constructions on problematic soils are inevitable due to the increasing demand for land in the existing scenario. India has a coastline of 7500 Kilometers with large deposits of marine clay. Soft soils like marine clay are considered problematic due to its swelling behavior, low permeability and highly compressibility. Landfill sites and reclamation areas formed due to dumping of dredged soft soils experiences high settlement and poor bearing capacity making it unsuitable as a foundation material. Atterberg limits represent the water holding capacity of soil. It can also contribute to estimation of shear strength, settlement and permeability of soil. Researchers have explored various methods to reduce water holding capacity of marine clay and thereby enhance its engineering properties. Effective additives like fly ash, rice husk ash, marble dust, granite dust etc. are widely mixed with marine soil to stabilize and improve its engineering behavior. Fly ash is a waste material produced in large amount at coal or lignite based thermal power station. It requires large area of land for disposal as ash ponds as well as it causes air and water pollution. To address the adverse impact of dumping of fly ash on environment, wise utilization of fly ash is essential.

In the present study, the effect of addition of Class F fly ash on liquid limit and plastic limit of marine clay and bentonite was studied. Marine clay obtained from Mumbai coast and bentonite from Kutch, Gujarat was used in the tests. The liquid limit of the soil was determined using fall cone apparatus. Initially the tests were performed on virgin clay only. Then the fly ash was added and the percentage of fly ash in the soil was varied. The percentage of fly ash mixed in the soil ranges from 10-70%. The variation in liquid and plastic limit with the addition of fly ash was examined. It was observed that the plasticity index reduced by 60 % in marine soil. Addition of fly ash reduced water absorption capacity of soil which in turn resulted in significant reduction in plasticity of soil. The usage of fly ash in improving clay with active minerals is novel and beneficial for reusing industrial waste products.

Keywords: Atterberg Limits, Fall Cone, Fly ash.

1 Introduction

The stability of structure largely depends upon the performance of soil underlying it. Understanding the behavior of soil under various loading conditions is necessary for appropriate design of foundations. Water present in the soil matrix has a significant effect on the engineering properties of soil. Water holding capacity of any soil generally depends on the mineralogical composition. Soil can be classified in to four types according to water content as solid state, semi-solid, liquid and plastic state. Atterberg limits, namely liquid limit, plastic limit and shrinkage limit gives an idea about soil state transformation from liquid to plastic, plastic to semi-solid and then finally to solid. Atterberg limits indicate how much a soil is likely to settle or consolidate under load. Higher settlement is expected if the field moisture content is close to the liquid limit and vice versa.Behaviour of soil will be different in every state of soil. Hence these tests are conducted at primary stage of soil investigation. Liquid limit can be determined using Casagrande apparatus as well as fall cone. Casagrande method has some limitations such as human error associated with cutting of ideal groove, type of base, etc. This may lead to improper results. In this study fall cone apparatus was preferred as it is comparatively accurate and easy to perform. It can be used to determine shear strength as well. This study follows the method given by Mahajan and Budhu (2009) in which instrumented fall cone penetrometer was used to determine viscosity close to liquid limit.

Fly ash is a residue of coal combustion at power generation and incineration plants. As compared to imported coal, Indian coal is of low grade with 30-45% ash while imported coal contains only 10-15% ash. In India large amount of fly ash is produced yearly which require large area for disposal and is a major cause for water as well as air pollution. Fly ash can be used to lower water content of soils. Fly ash reduces the potential of plastic soil to undergo volumetric expansion by a physical cementing mechanism. Fly ash acts as cementing material to bind soil particles together to control expansion similar to Portland cement bonds between aggregate to form concrete. Polidori (2007) conducted test on six types of soils and their mixtures with silica sand to determine relation between Atterberg limits. Kumar and Wood (1999) conducted test on mixture of kaolin and fine gravel to determine change in liquid limit with respect to clay content in mixture. Linear relation was observed in order to logarithm of cone penetration. Fall in liquid limit value was noted with reduction of clay content. Zainuddin et al. (2018) noted reduction in liquid limit and plastic limit with addition of demolished tile dust in marine clay.

2 Materials and Experimental Setup

In the present study, Marine clay was used collected from Mumbai coast. This soil had liquid limit (LL) of 75.92% and plastic limit (PL) of 31.74%. The specific gravity of clay was 2.82 and it comes under CH group. This soil has 8.2 pH values. Maximum dry density of 1.42 Mg/m^3 at corresponding optimum moisture content of 22% was observed.

A fall cone apparatus (BS 1377, British standard Institution, 1990) with 30º smooth cone was used in this study. Its dial gauge was replaced by potentiometer (LVDT) and connected to high speed data logger as previously done by Budhu (2009). Figure 1 shows the experimental set up. The total mass of cone assembly with cone, shaft and LVDT was 0.89N

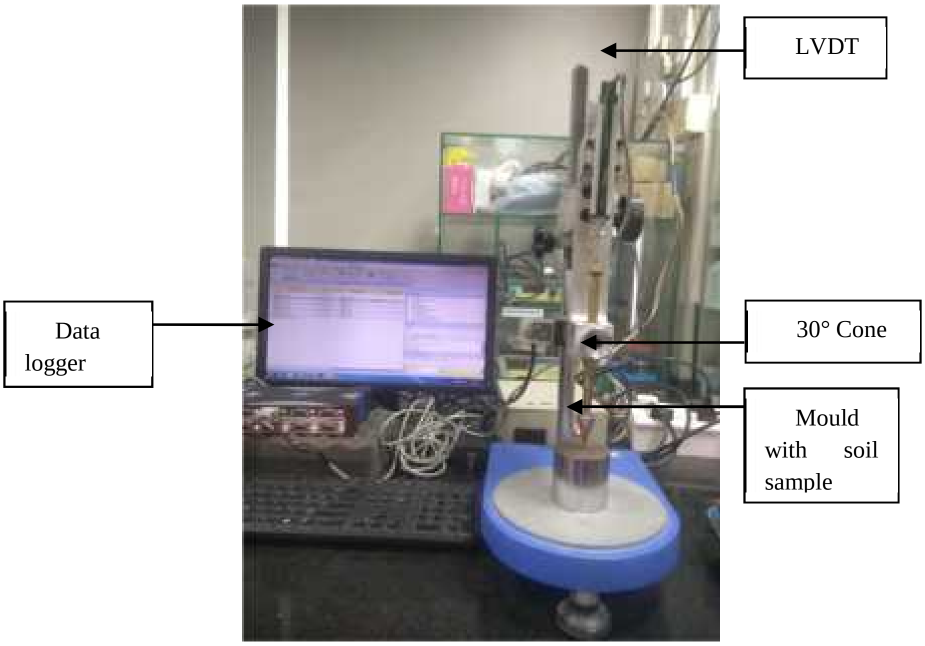

Fig. 1. Modified fall cone apparatus

2.1 Sample Preparation

About 150 g of oven dried soil passing through 425 micron sieve was used to determine the Atterberg limits. Fly ash was mixed with dry marine at varying percentage ranging from 10- 70 % by weight of soil. Distilled water was added to the above mixture and mixed homogenously. The sample was then kept in airtight container and left overnight to ensure proper absorption of moisture.

2.2 Test Procedure

About 150g of sample was taken with different percentage of clay-fly ash mixture as mentioned earlier. The mould was then filled with wet sample paste by tamping to remove the entrapped air. The cone was lowered just to touch the surface of the soil sample and then allowed to penetrate freely for 5s. Depth of penetration of cone was recorded by the data logger at the sampling rate of 0.01s. Same procedure was adopted for every trial by slowly adding water to the soil mixture. Water contents of the sample corresponding to 14-24mm penetration were taken. Relation between the water content and penetration depth was plotted and the liquid limit was obtained by interpolating the results at 20 mm depth of penetration.

3. Results and discussion

The procedure followed for conducting the fall cone test is as per IS 2720(Part 5). Conventional cone was modified by attaching a potentiometer to the apparatus. Table 1 shows one of the trial result obtained by fall cone penetration which represents all the tests. Shear viscosity was determined using the equation proposed by Budhu (2009)

$$\mu_p = 2.94KW\sqrt{h_f}\left(\frac{0.67}{h_{eq}} - \frac{1}{h_f}\right)^2 \qquad (1)$$

Where μ is the shear viscosity, h_f is the final depth of penetration, h_{eq} is equilibrium depth of penetration at which velocity reaches to its maximum as shown in fig. 4, K is modified cone factor (Koumoto and Houlsby, 2001) and W is weight of cone assembly.

As well the shear strength of the soil as shown in Eq (2)(Mahajan and Budhu,2007) was determined using equilibrium depth.

$$\tau = \frac{W}{Fh_{eq}^2} \qquad (2)$$

Where W is the weight of the cone assembly (cone and shaft)

τ is the maximum shear strength of the soil sample
h_{eq} is the dynamic equilibrium height
F is the non-dimensional cone resistance factor define by (Koumoto and Houlsby, 2001)

$$F = \pi N_{ch} tan^2\theta$$

Where N_{ch} is the modified bearing capacity factor for a 30° semi rough cone
θ is the half angle of cone.

Table 1. Determination of shear strength and shear viscosity

Sr. No	h_f mm	heq mm	Water Content %	LI	Weight N	τ_{cs} (kPa)	τ (kPa)	Ÿ / s	μ (pa s)
1	13.94	4.28	70.65	0.88	0.89	6.09	28.89	2.88	2955
2	14.5	4.73	71.81	0.91	0.89	5.63	23.65	2.82	2214
3	15.6	6.3	73.07	0.94	0.89	4.86	13.33	2.72	776

4	16.88	6.75	74.52	0.97	0.89	4.15	11.61	2.62	724
5	18.73	7.52	77.3	1.03	0.89	3.37	9.36	2.48	607
6	19.34	8.17	78.32	1.05	0.89	3.16	7.93	2.44	444
7	21.47	9.58	81.92	1.14	0.89	2.57	5.77	2.32	278
8	22.2	9.75	82.36	1.15	0.89	2.40	5.57	2.28	291
9	23	10.3	84.01	1.18	0.89	2.24	4.99	2.24	246
10	24.47	11.25	86.79	1.25	0.89	1.98	4.18	2.17	190

Sample time penetration data recorded by the data logger is shown in Fig 2. Velocity of the cone was obtained by differentiating the polynomial conforming to the time penetration data and plotted with respect to penetration depth in Fig 3.

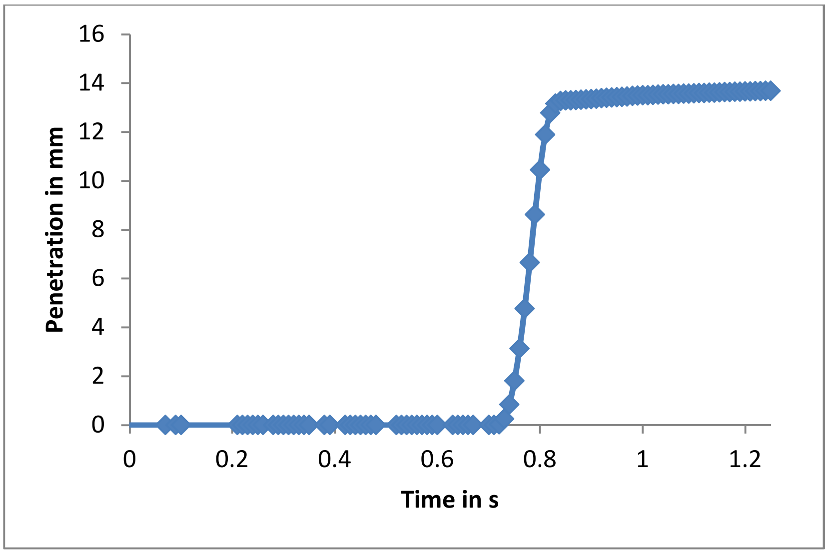

Fig. 2 Time penetration data obtained by data logger

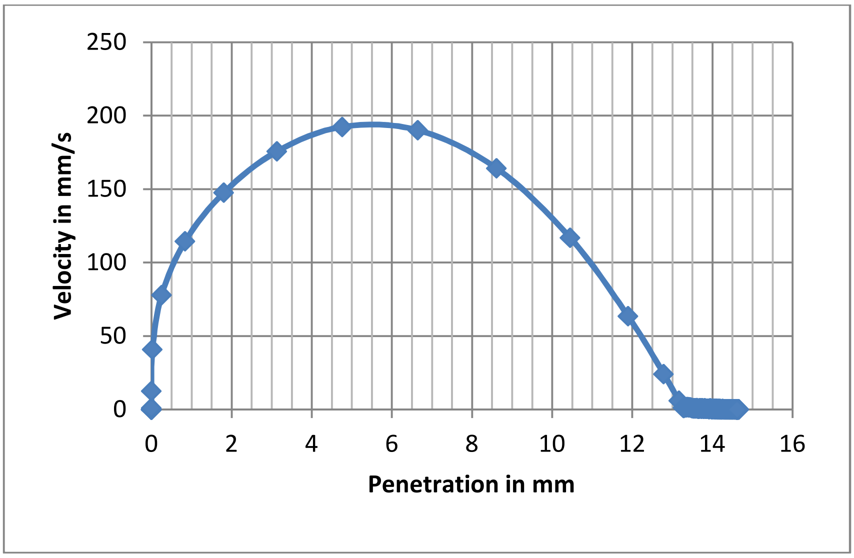

Fig. 3. Velocity versus penetration plot

Figure 3 shows plot of velocity versus penetration depth. Velocity is obtained by differentiating polynomial. When velocity of cone increases up to its maximum value at equilibrium depth and starts decreasing. In this case equilibrium height of 4.76mm was obtained at maximum cone velocity of 191mm/s.

4 Results and Discussion

The water holding capacity of marine clay mixed with varying percentage of fly ash was determined using fall cone test. Shear viscosity and shear strength were also interpreted from the fall cone test results using the equations given by previous researchers (Hansbo (1957), Koumoto and Houlsby (2001), Mahajan and Budhu (2009).

Figure 4 shows the variation in Liquid limit and plastic with addition of fly ash in marine clay. Clear decrease in the Plasticity index of about 60 % was observed for soil mixtures. The workability of the soil –fly ash mixture improved with rise in fly ash percentage, besides drop in volume of soil sample at similar water content. The probable reason for this change can be attributed to the replacement of montmorillonite mineral with fly ash.

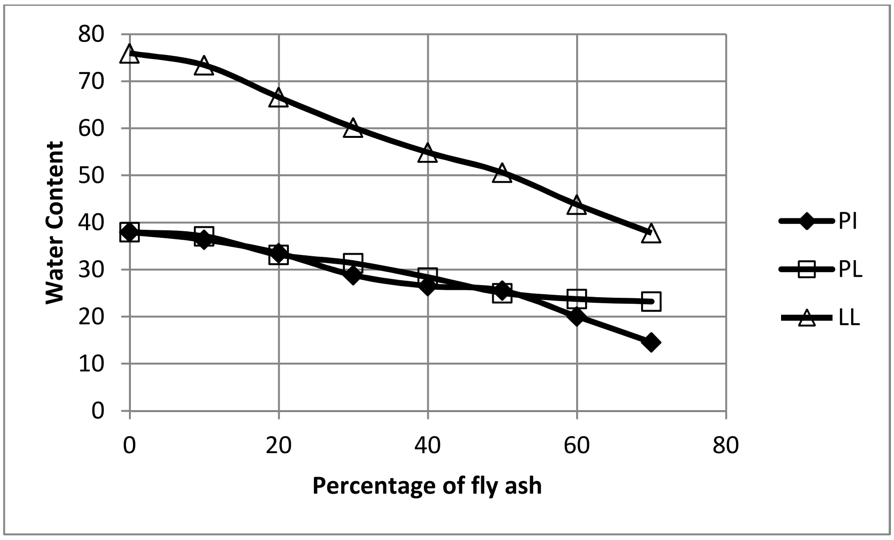

Fig. 4. Atterberg limits with different fly-ash content

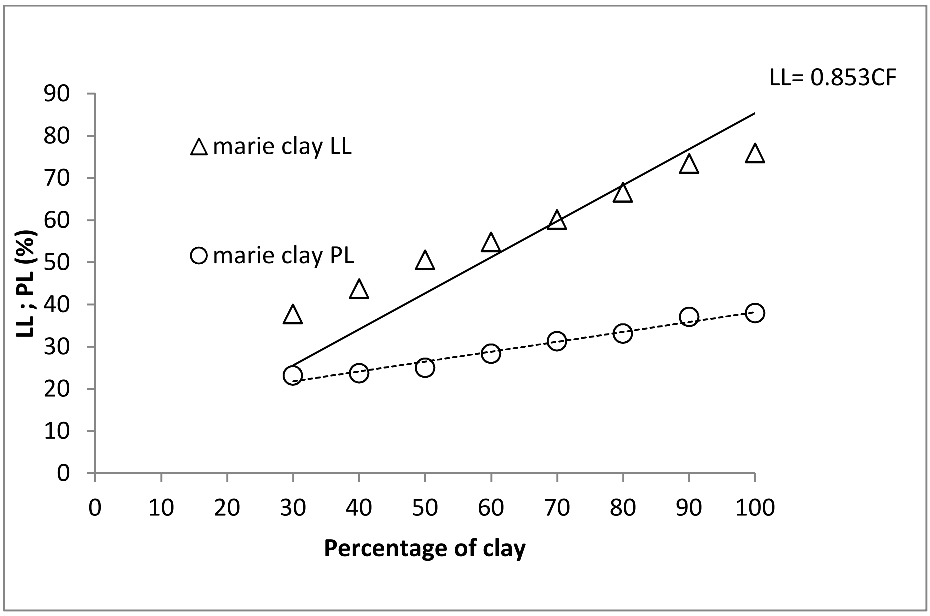

Fig. 5. Relationship between clay fraction and liquid limit; plastic limit of soil

Liquid limit and plastic limit were plotted against the varying clay fractions for the soil mixtures as shown in Figure 5. The Atterberg limits varied linearly with clay fraction.

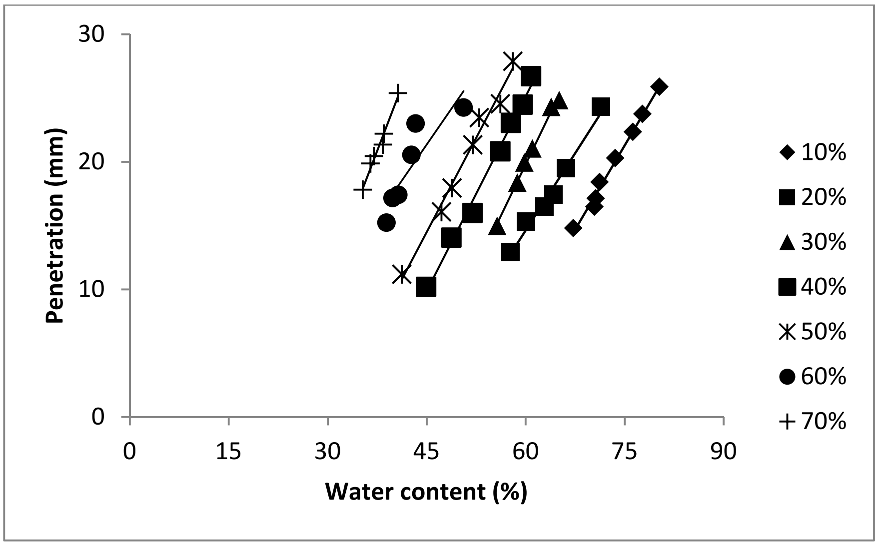

Fig. 6. Water content with respect to penetration for marine clay

The variation of water content with depth for different combination of Marine clay-fly ash plotted in Fig 6. Significant reduction in the water content was observed at identical penetration depth for higher fly ash content. This indicates reduction in water absorption and thereby improving the engineering properties.

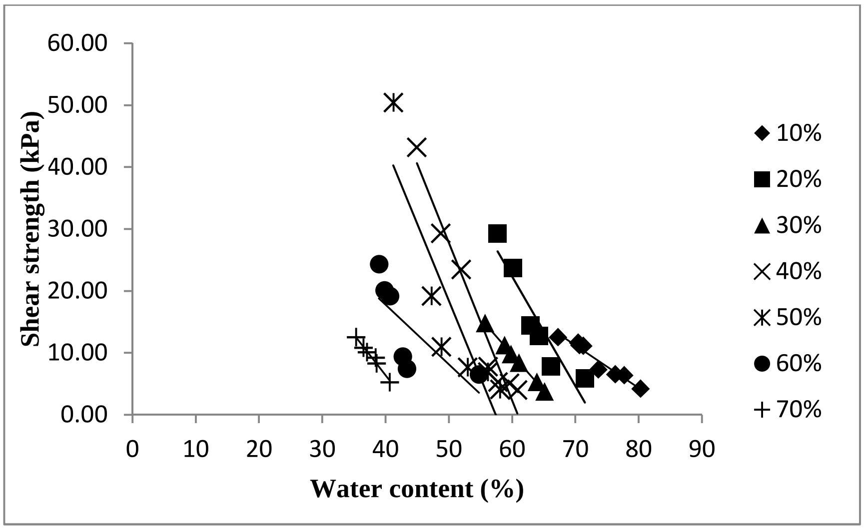

Fig. 7. Shear strength versus water content relationship of soil

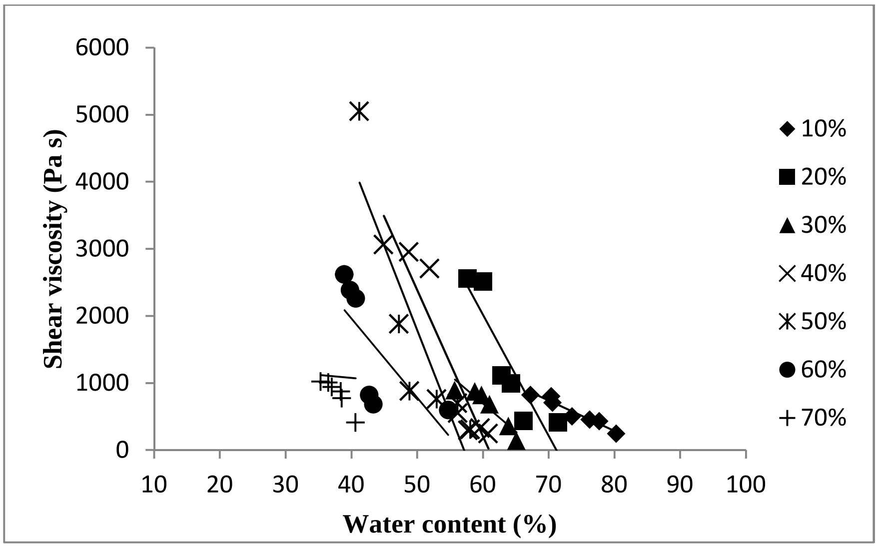

Fig.8 Relationship between water content and shear viscosity

Figure 7 and 8 represents relationship between shear strength; shear viscosity and water content for marine clay respectively. Figure shows approximately similar pattern with sand and clay mixture studied by Cabalar and Mustafa, (2015). Mixing fly ash with marine clay regulates its water holding capacity and improves its shear strength and shear viscosity. Water content reduced linearly with increase in fly ash percentage, However shear strength reached peak value at 50 % and then dropped on further addition of fly ash. Therefore optimum fly ash content can be considered as 50 %.

5 Conclusions

Fall cone tests were performed using marine clay in the study. Dredged marine soil is problematic due to its high water absorption capacity. Fly ash was added to soil in varying percentage to reduce its water holding capacity and improve its engineering properties. Following conclusions were drawn from the present study:

- Mixing of fly ash to marine clay results in notable reduction in plasticity index. About 60 % reduction in plasticity index was observed in the soil mixtures.
- Clay content in the soil mixture predominantly affects the liquid limit. Clay content varies linearly with Liquid limit and Plastic limit.
- Shear strength and shear viscosity decreased exponentially with increase in Liquidity index. Addition of 50 % fly ash with marine clay exhibited maximum shear strength and viscosity. Replacement of cohesive clay with non plastic fly-Ash might be the reason for reduction in strength on further addition of fly-ash in soil.

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