Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Effect of Fly Ash Addition to the viscous Behavior of Bentonite

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Abstract. Bentonite is generally used as mud constituent for oil and water well drilling due to its viscosity and thixotropy behavior. Now a day's demand of drilling mud is increasing for drilling industry. This paper deals with addition of fly ash to bentonite and determination of viscosity using fall cone apparatus. Fall cone apparatus was slightly modified connecting LVDT and data logger. Since decade fall cone apparatus was used to determine viscosity of soil with liquidity index less than 1.5. Viscosity was calculated using the rate at which cone penetrates into bentonite - fly ash mixture. Fly ash is waste produced at thermal power station. Utilization of fly ash is essential to address the adverse impact due to dumping of fly ash. In this experimental study initially tests were conducted on virgin bentonite clay. Then fly ash were mixed to bentonite in various percentage from 10%-70% by weight. The variation in liquid limit, plastic limit and viscosity with respect to fly ash percentage were examined. It was observed that viscosity decreases exponentially with increase in liquidity index. Addition of 20% fly ash was found optimum as it showed higher viscosity. Fly ash can be used as additive to bentonite.

Keywords: Bentonite; Fall cone test; Fly ash; Viscosity.

1 Introduction

Bentonite is generally used as a water-based drilling fluid additive to manage rheology and filtration loss while drilling. In sight of the increased oil-exploration activities globally, the demand for the high-grade drilling mud has been increased significantly. Owing to viscous behavior, bentonite is used as drilling mud. This property of bentonite helps cutting and cleaning operation efficiently, as cutting will settle down if viscosity is less. In present study possibility of use of fly ash as additive to bentonite has been explored. Fly ash is industrial waste produced in large amount it should be utilized at its best, cost effective and environmental friendly. According to Central Electricity Authority (CEA) about 32% of fly ash is unutilized in India. Addition of fly ash in drilling fluid combinations shows better control on filtration properties without changing rheological properties (Mahto and Jain 2013; Gautam , et al 2018). Traditionally fann viscometers were used to determine rheological properties of drilling mud. Recently Kumar R.,et al., (2013) attempted to estimate rheological behavior of bentonite suspension using shear rate of fann viscometer. This study follows the method given by Mahajan and Budhu (2009) in which simple fall cone apparatus was used to determine viscosity close to liquid limit.

2 Materials

2.1 Fly Ash

It is the end product produced by combustion of coal at thermal power station. 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. In this study commercially available fly ash was used having specific gravity 1.34.

2.2 Bentonite

In the present study, Bentonite was used collected from Kutch, Gujarat. This soil had liquid limit (LL) of 192% and plastic limit (PL) of 38%. The specific gravity of clay was 2.51 and it comes under CH group. This soil has 8.6 pH values.

3 Methodology

3.1 Experimental Setup

A fall cone apparatus (BS 1377, British standard Institution, 1990) with 30º smooth cone was used in this study. Potentiometer connected with high speed data logger was used to obtain time versus penetration data as previously done by Budhu (2009). Figure 1 shows experimental setup. The total mass of cone assembly with cone, shaft and LVDT was 0.89N.

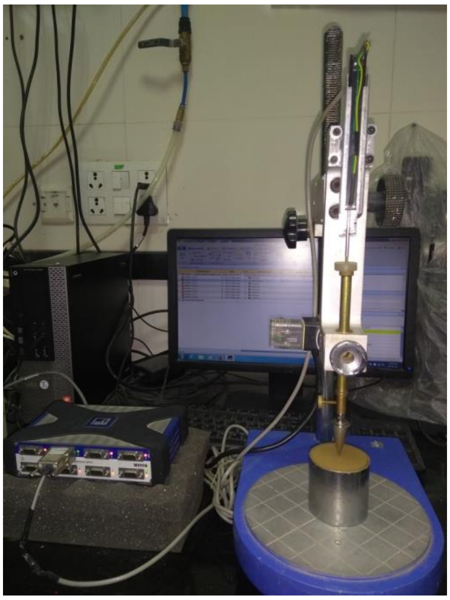

Fig. 1. Modified fall cone apparatus with bentonite-fly ash sample

3.2 Sample Preparation

Prior to use bentonite and fly ash were oven dried. About 150 g of sample passing through 425 micron sieve was used to conduct fall cone test. Fly ash was mixed with dry bentonite 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.

3.3 Test Procedure

About 150g of sample was taken with different percentage of clay-fly ash mixture as mentioned. The mould was then filled with wet sample paste which was kept overnight. Each layer was filed with 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.

4 Result and Discussion

The conduct fall cone test procedure was adopted as per IS 2720(Part 5). Conventional cone was modified by attaching a potentiometer to the apparatus. Table 1 represents results of one trial obtained by fall cone penetration. Shear viscosity was determined using the equation proposed by Mahajan and Budhu (2009).

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

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.

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

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 viscosity

Sr. No	h_f mm	heq mm	Water Content %	LI	Weight N	τ_{cs} (kPa)	τ (kPa)	Ÿ / s	μ (pa s)
1	11.39	4.08	118.866	0.53	0.89	9.12	31.79	3.19	2169
2	15.29	5.75	151.996	0.74	0.89	5.06	16.00	2.75	1125
3	16.35	5.82	163.623	0.82	0.89	4.43	15.62	2.66	1296
4	17.58	6.64	179.829	0.92	0.89	3.83	12.00	2.56	894
5	18.58	8.01	187.878	0.98	0.89	3.43	8.25	2.49	422
6	21.54	8.9	202.979	1.07	0.89	2.55	6.68	2.32	425
7	22.22	10.5	211.257	1.13	0.89	2.40	4.80	2.28	183
8	23.96	11.25	221.252	1.19	0.89	2.06	4.18	2.20	171
9	24.17	11.51	230.614	1.25	0.89	2.03	3.99	2.19	153
10	26.74	12.5	237.292	1.30	0.89	1.66	3.39	2.08	149

Sample time penetration data recorded by the data logger is plotted 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. It shows highest velocity at depth of 6.64mm i.e. equilibrium depth of penetration.

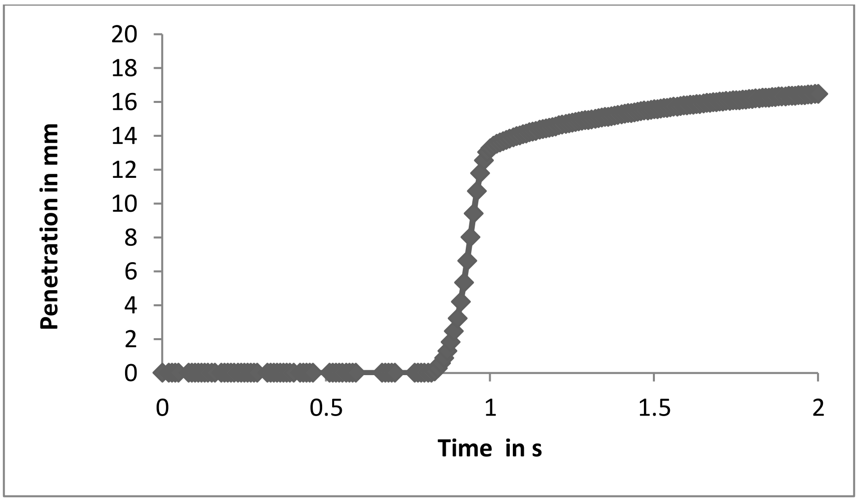

Fig. 2 Time penetration data obtained by data logger

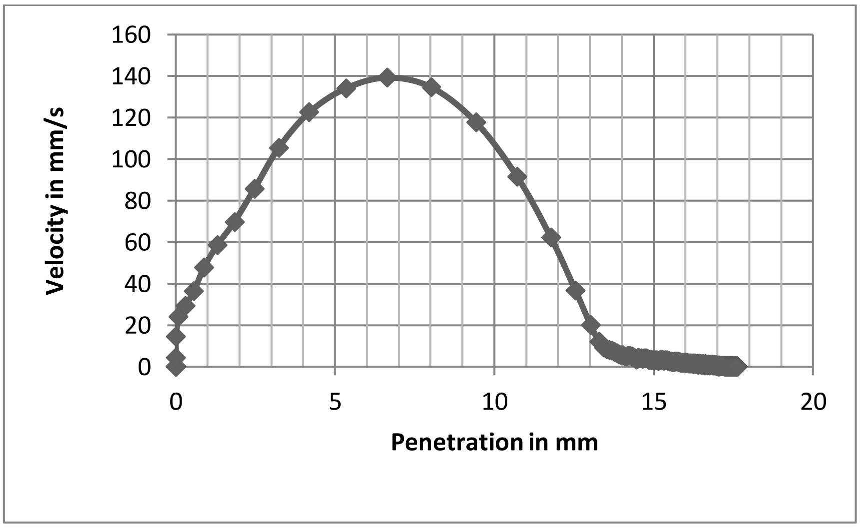

Fig. 3. Velocity versus penetration plot

Figure 4 represents relationship between shear viscosity and liquidity index. As liquidity index increases viscosity decreases exponentially.

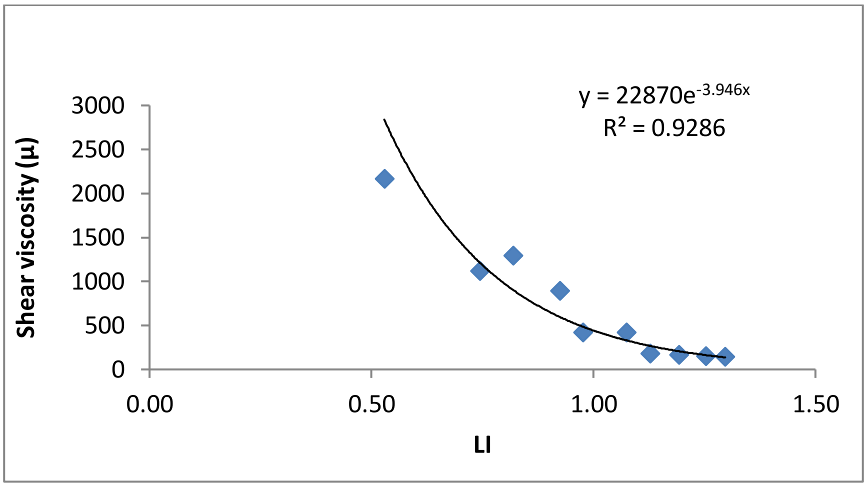

Fig. 4. Viscosity versus LI plot

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 5 shows the variation in Liquid limit and plastic with addition of fly ash in marine clay. The workability of the soil –fly ash mixture enhanced with addition of fly ash percentage, moreover drop in volume of soil sample at similar water content was observed. The probable replacement of montmorillonite mineral with fly ash showed this change in Atterberg limits.

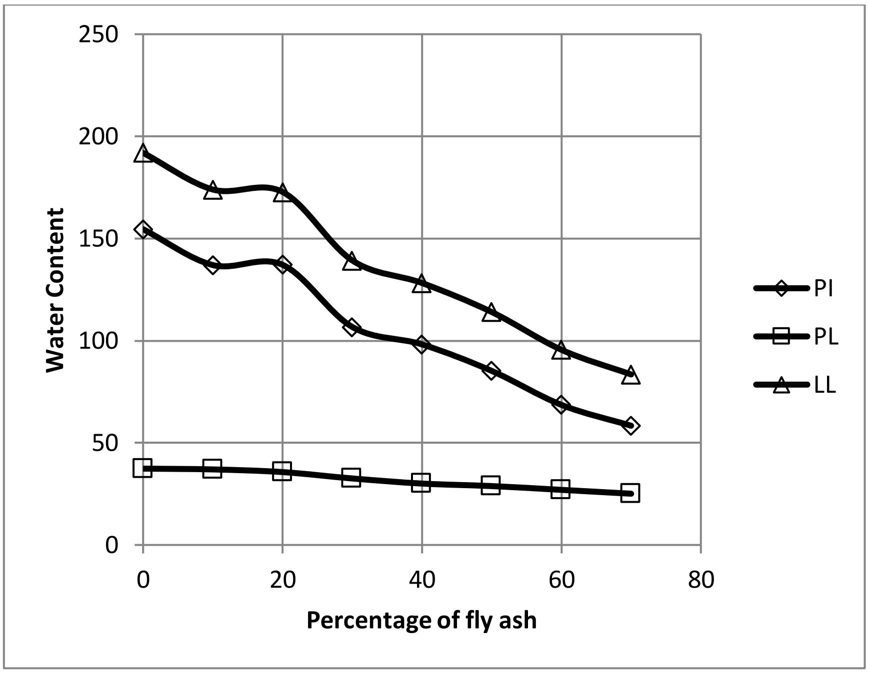

Fig. 5. Atterberg limits with different fly-ash content

The variation of water content with depth for different combination of bentonite-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.

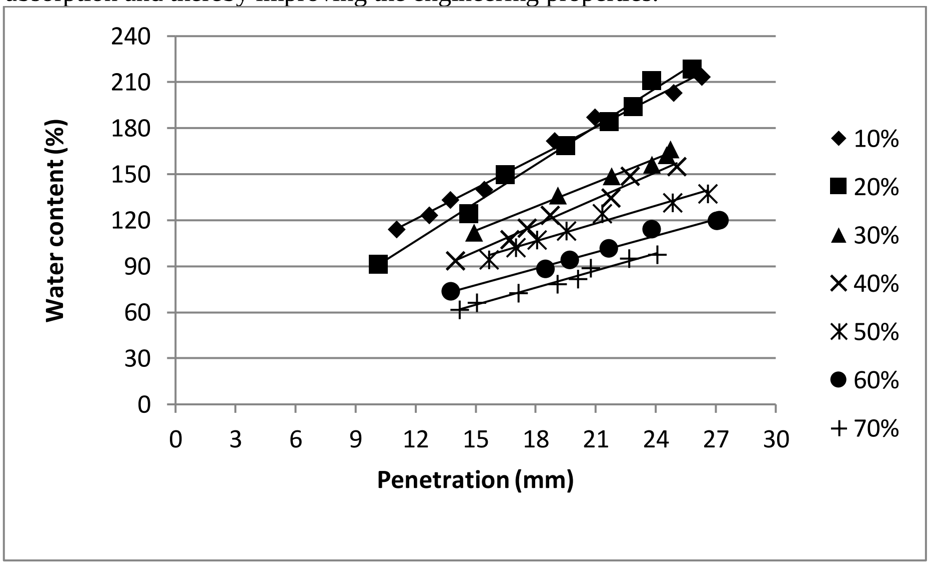

Fig. 6. Water content with respect to penetration

Figure 7 represents relationship between shear viscosity and water content for bentonite respectively. Plotted results are in approximately similar pattern with sand and clay mixture studied by Cabalar and Mustafa, (2015). Mixing fly ash with bentonite regulates its water holding capacity and improves its shear viscosity. Water content reduced linearly with increase in fly ash percentage, However shear strength reached peak value at 20 % and then dropped on further addition of fly ash. Therefore optimum fly ash content can be considered as 20 %.

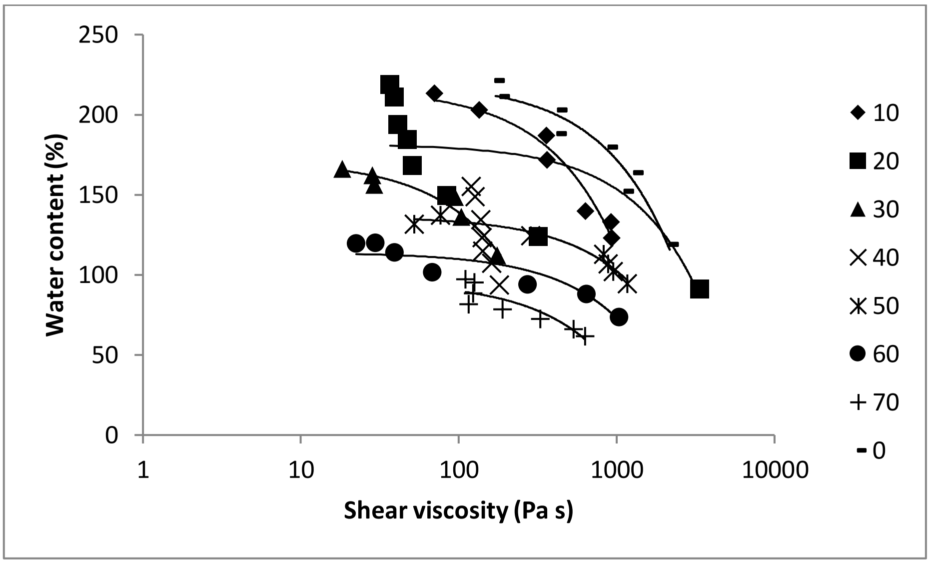

Fig.7 Relationship between water content and shear viscosity with respect to fly ash

5 Conclusions

Shear strength and shear viscosity decreased exponentially with increase in Liquidity index. Bentonite exhibited maximum shear strength and viscosity with 20 % fly ash. Replacement of cohesive clay with nonplastic fly-Ash might be the reason for reduction in viscosity on further addition of fly-ash in the soils. In addition notable reduction in plasticity index was observed. About 60 % reduction in plasticity index was observed in soil mixtures. Clay content in the soil mixture predominantly affects the liquid limit. Clay content varies linearly with Liquid limit and Plastic limit. Up to 20% fly ash can be used with bentonite without altering rheological properties of drilling fluid.

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