CHAPTER-V

GEOTECHNICAL CHARACTERIZATION TEST RESULTS AND DISCUSSION

5.1 INTRODUCTION

The previous chapter deals about the chemical composition of the soil and fly ash whereas this chapter presents the geotechnical properties of both the considered materials. The geotechnical properties help in the classification of soil, determination of its degree of compaction, load resistance capacity, etc. The geotechnical properties of the local soil and fly ash were explained in the subsequent sections. The list of geotechnical tests conducted for the present study are as follows:

a) Specific gravity determination
b) Grain size distribution analysis
c) Consistency limits determination
d) Standard Proctor test
e) Permeability test
f) California Bearing Ratio (CBR) test

The results of these experimental investigations are briefly explained in the following sections and the summary of the present study has been presented at the end of this chapter.

5.2 SPECIFIC GRAVITY

The specific gravity of the Indian origin fly ash is mostly found to be in the range of 1.9–2.2 (Pandian et al. 1998). Also, the specific gravity of coal ash varied from 1.6 to 3.1 (McLaren and Digioia 1987; Behr-Andres and Hutzler 1994). The specific gravity of the present fly ash is 2.35, which is falling in the range of Indian fly ash. The fly ash shows comparable specific gravity when compared with the past studies that are depicted in Fig. 5.1. The specific gravity of the fly ash produced from sub-bituminous and bituminous (high iron) coal are 1.90 and 2.96 respectively (theconstructor.org). The specific gravity of the crushed fly ash (425 m passing) is higher than that of the uncrushed fly ash, indicating that the specific gravity decreases as the particle size increases. When fly ash, bottom ash, and pond ash are all collected from the same place, fly ash shows higher specific gravity than the other two. It decreases with the rise in temperature of the boiler under operation (Moghal 2017). Iron and carbon content has a larger influence on specific gravity, indicated by an increasing & decreasing trend with the increase in iron and carbon content, respectively (Cabrera and Gray 1973). This particularly depends on the particle size distribution, coal type, and shape of the particles. The low specific gravity is attributed due to the presence of light hollow spherical (cenospheres) particles, and it is an advantageous property as it produces low earth pressure, high workability. Table 5.1 indicates that the Indian fly ash has a specific gravity of 2 on an average, which is in accordance with the previous literatures as illustrated in Fig. 5.1. When compared to class C fly ash, the majority of the fly ash produced in India is of the class F kind, which contains a higher percentage of cenospheres. This is the reason why the class C type fly ash has a higher specific gravity than that of the class F fly ash.

The soil has broader range of specific gravity falling between 2.60-2.8. The present local soil has specific gravity close to 2.6 but the average specific gravity is around 2.54. Bowles (2012) divided the various soil based on their specific gravity as sand (2.65-2.67), silty sand (2.67-2.7), inorganic clay (2.7-2.8), soil with mica or iron (2.75-3.00), and organic soil (1.00-2.60). The local soil has a predominance of silt size particles and shows comparable outcomes as sandy soil. The high specific gravity results in the increase in shear strength parameters and other load resistance properties (Roy and Dass (2014)).

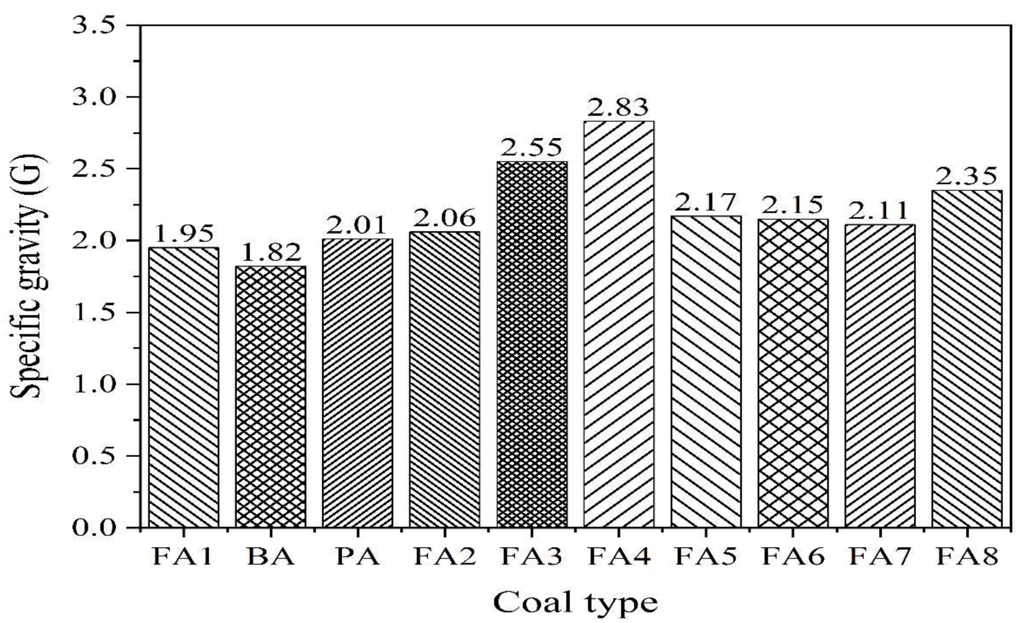


Fig. 5.1. Comparison of specific gravity of fly ash with past studies. (FA1, BA, PA: Sridharan et al. 1998; FA2: Sridharan et al. 2001; FA3: Pandian 2004; FA4, FA5: Moghal and Sivapullaiah 2011; FA6: Kumar et al. 2014; FA7: Rajak et al. 2017; FA8: Present study) (FA: Fly ash, BA: Bottom ash, PA: Pond ash).

5.3 GRAIN SIZE DISTRIBUTION

The shape of the fly ash particles is mostly spherical in nature, having a glass content of transparent impression (Davison et al. 1974). Fly ash has a very broad range of particle sizes and for Indian fly ash, it is < 0.1 µm to > 100 µm (Kumar and Upadhyay 1983). The usability of fly ash in concrete has been indicated by two significant factors, Arithmetic mean diameter (AMD) and Span (Sarkar et al. 2012; Duan et al. 2017). Span gives an idea about the gradation whether it is well or poorly graded. A lower Span indicates homogeneous fly ash, which shows a high specific surface area (SSA) (Sarkar et al. 2005). Fly ash having an AMD value of less than 10 µm is good for the use in concrete mortar (Tripathy and Mukherjee 1997). The particle size analysis of the fly ash evident that it has a higher concentration of silt size particles (> 60%), followed by sand (> 25%) and clay (more or less than 5%) (Chang et al. 1977; Fulekar and Dave 1986; Mishra and Shukla 1986a, b). Similarly, for coal ash, the silt size fraction is higher as compared to that of the sand and clay (Rees and Sidrak 1956; Cope 1962).

The specific surface area is inversely proportional to the size of the particles and has ranged from 1.27 to 0.45 m^2/g (Schure et al. 1985). The nomenclature of fly ash has been done using the coefficient of uniformity (C_u) and coefficient of curvature (C_c), which was calculated from the particle size distribution plot. For Indian fly ash, C_u and C_c range from 13.3–10.0 and 2.16–0.73, respectively (Sridharan et al. 1998). In particular, fly ash shows the uniform distribution with a higher value of C_u. The disposal of fly ash in slurry form results in a higher fraction of sand size particles at the near end disposal point as compared to the far end disposal point where silt size particle fractions are predominant. The particle size distribution profile of the fractions passing through 75 microns can be done by hydrometer analysis for low calcium fly ash. On the other hand, XR sedimentation, counting of grain by laser particle, and electrolyte resistivity methods are employed for the high calcium fly ash. The inapplicability of hydrometer analysis for the high calcium fly ash is associated with the reaction between lime and water, which form cementitious compounds. The general classification of fly ash is silty sand or sandy silt. Another form of coal ash, such as pond ash and bottom ash, are usually found in coarser nature in comparison with the fly ash.

The particle size distribution curve of the present fly ash and local soil has been plotted in Fig. 5.2. Also, for better understanding the pictorial representation of different size of particle retained on various sieve of both the soil has been shown in Fig. 5.3. The fly ash contains higher fraction of sand (61.52%) size particles followed by silt (33.19%) and clay (5.29%). Similarly, local soil is composed of maximum silt (81.77%) size particles followed by clay (16.11%) and sand (2.12%). The C_u and C_c of fly ash obtained from the particle size distribution plot is 22 & 0.92 respectively. Similarly, for local soil the C_u and C_c are found to be 10.53 and 1.22 respectively. Since, both the soils are satisfying the desirable condition of well graded soil, hence classified as well graded silty sand (fly ash) and silt of intermediate plasticity (local soil).

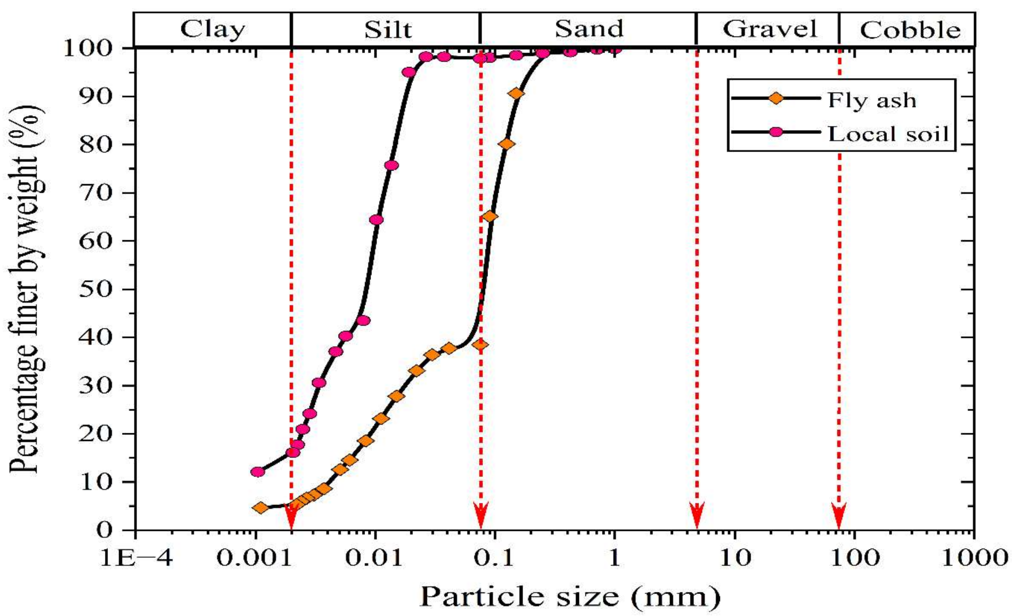
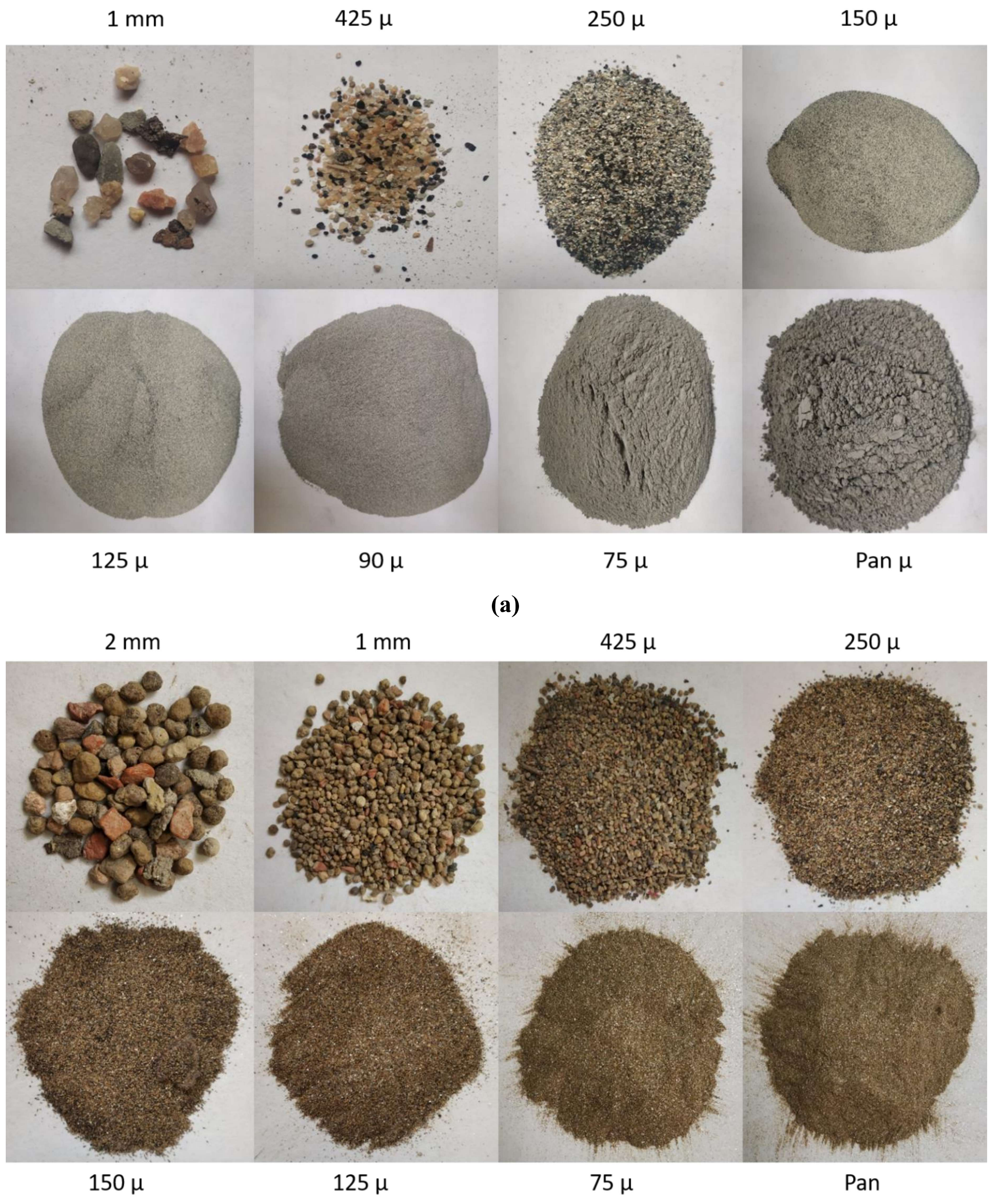


Fig. 5.2. Grain size distribution of local soil and fly ash using sieve and hydrometer analysis.



(b)

Fig. 5.3. Pictorial presentation of different particle size retained on various size of sieve in particle size distribution analysis, (a) fly ash, and (b) local soil.

5.4 CONSISTENCY LIMITS

The consistency limits are liquid limit, plastic limit, and shrinkage limit that helps in the determination of the fundamental properties of the soil. The liquid limit is the boundary water content at which the soil behaves like liquid material or water content at which the soil has minimum shear strength. In the same way, the plastic limit is used to determine the plasticity index that represents the range of water content under which it remains as a plastic material. However, the shrinkage limit is the limit beyond which large volume change can occur especially in the case of plastic soil and this is significant only when soil experiences remarkable volume change. There are two apparatus available for the liquid limit determination such as a) Casagrande apparatus, and b) Fall cone apparatus. The Casagrande apparatus is developed for the plastic soil (local soil) whereas Fall cone apparatus is established for the non-plastic soil (fly ash). The plot of water content versus number of blows for the local soil and fly ash has been shown in Fig. 5.4 and 5.5 respectively. The liquid limit of the local soil and fly ash was found to be 35% and 47.5% respectively. Furthermore, the plastic limit of the local soil was found to be 25.45%. These consistency limits are used in the identification of the soil classification.

Fig. 5.4. Flow curve of local soil for the determination of liquid limit.

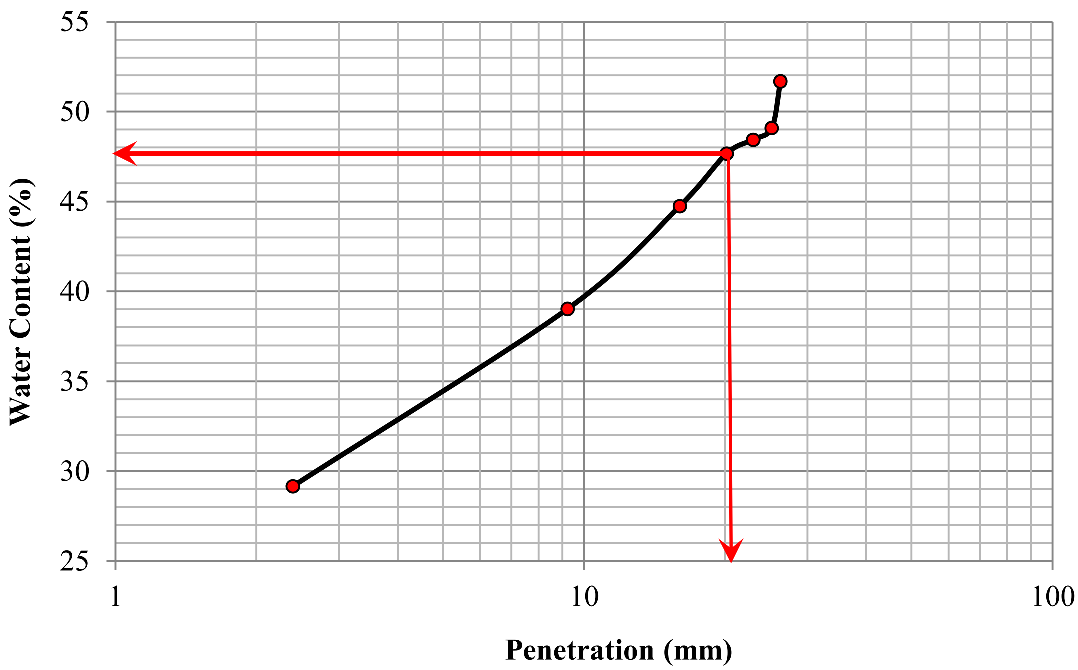


Fig. 5.5. Penetration of cone under different water content for non-plastic soil (fly ash).

5.5 COMPACTION BEHAVIOUR

Compaction is one of the important geotechnical properties of the fly ash because their knowledge facilitates in proper densification of the fly ash in the field. The parameters responsible for the lower dry density are low specific gravity, high content of silt size particle (Raymon 1961), and the presence of cenospheres that has a tendency to absorb appreciable quantities of water (Das and Pakrashi 1990). The shape of the plot between maximum dry density (MDD) and the optimum moisture content (OMC) was found to be the same as that of the cohesive soil (Digioia and Nuzzo 1972; Dayal et al. 1989; Singh 1996). The compaction characteristics of coal ash can be plotted in terms of volumetric basis (void ratio vs. volume water content) instead of weight basis since weight is dependent on specific gravity and coal has a wide range of specific gravity (Prashanth et al. 1998; Sridharan et al. 2001). The high calcium fly ash has shown higher MDD and lower OMC as compared to the low calcium fly ash (Yudhbir and Honjo 1991). The Indian fly ash has a low dry density and high moisture content of the order of 0.9–1.3 g/cc and 18%–38% respectively (C-Farm). It is essential to densify the fly ash within 95%–100% of MDD when used as a fill material of the embankments (ASTM D 698–2000 - 1995). Moreover, it should be compacted below OMC to avoid difficulty in the compaction process. During the compaction, the moisture squeezes out from the compacted surface which in turn reduces the overall moisture below the OMC, indicating lower density. The vibratory smooth drum roller and Pneumatic tired drum roller required more than 8 passes for a thickness of 150 mm to achieve 95% of MDD. Fly ash is a non-plastic material having a flatter compaction plot. The flat shape of the compaction plot is associated with the fact that the change in moisture does not influence the dry density. The typical range of MDD and OMC of fly ash varies in the broad range between 0.92 to 1.71 g/cc and 18 to 38% respectively. The MDD of the present fly ash and local soil were found to be 1.26 g/cc and 1.73 g/cc respectively, whereas the OMC of the fly ash and local soil were found to be 30.5% and 16.4% respectively (Fig. 5.6). The lower dry density of fly ash is due to the light weight nature which is mostly due to the presence of cenospheres and plerospheres. Similarly, higher optimum moisture content is due to the water absorption behaviour of unburned carbon and oxides of calcium (Das and Yudhbir 2006). This absorption nature increase the water required to production lubrication effect during compaction. Furthermore, the fly ash is non-plastic (cohesionless) material which shows bulking characteristics because of the capillary tension. This capillary effect reduces the tendency of closer movement of particles, hence fly ash shows relatively flatter line. Once it gets vanishes results in increase in density of fly ash. Therefore, the usual trend of fly ash's MDD-OMC plot starts little latter than that of local soil. For all further tests, the homogeneous samples were prepared considering the specific relative compaction and their corresponding water content from the Fig. 5.6. Similarly, the stratified samples were prepared by separately considering the particular relative compaction of each soil with their corresponding water content. In the case of soil, the typical range of MDD generally varies in the range of 1.3 to 1.8 g/cc, and the OMC varies in between 12 to 18%. The MDD and OMC of most of the fly ash have been listed in Table 5.1. It can be concluded from the Table 5.1 that the average MDD and OMC of the present fly ash and local soil are within the range of Indian fly ash/local soil. Also, in Fig. 5.7 a similar type of observations have been reported by many researchers. Both the homogeneous and stratified soil samples were prepared in the relative compaction between 95 to 100% of the MDD for all further tests.

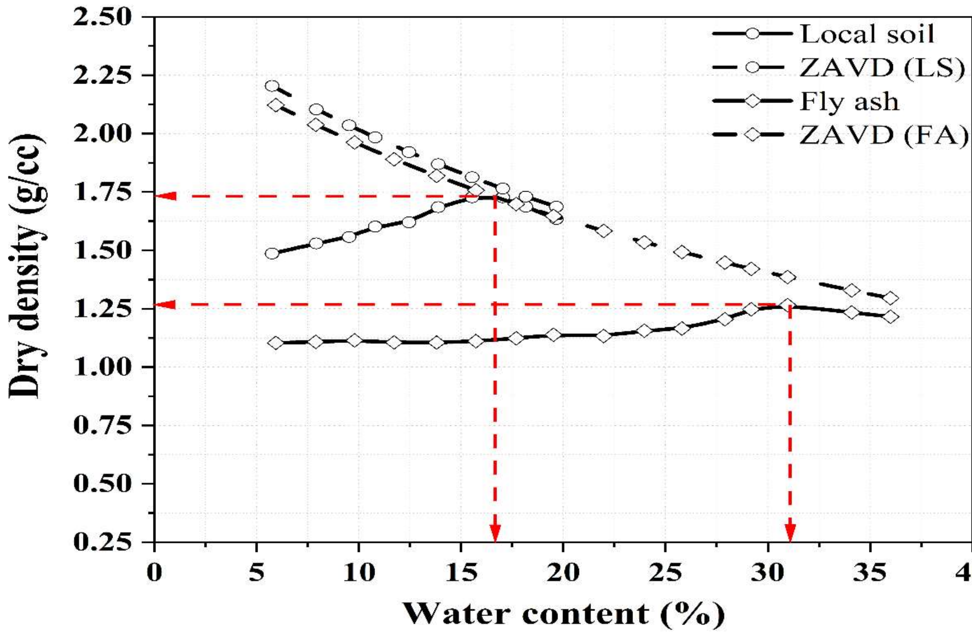


Fig. 5.6. Compaction plot of local soil and fly ash determined by standard Proctor test.

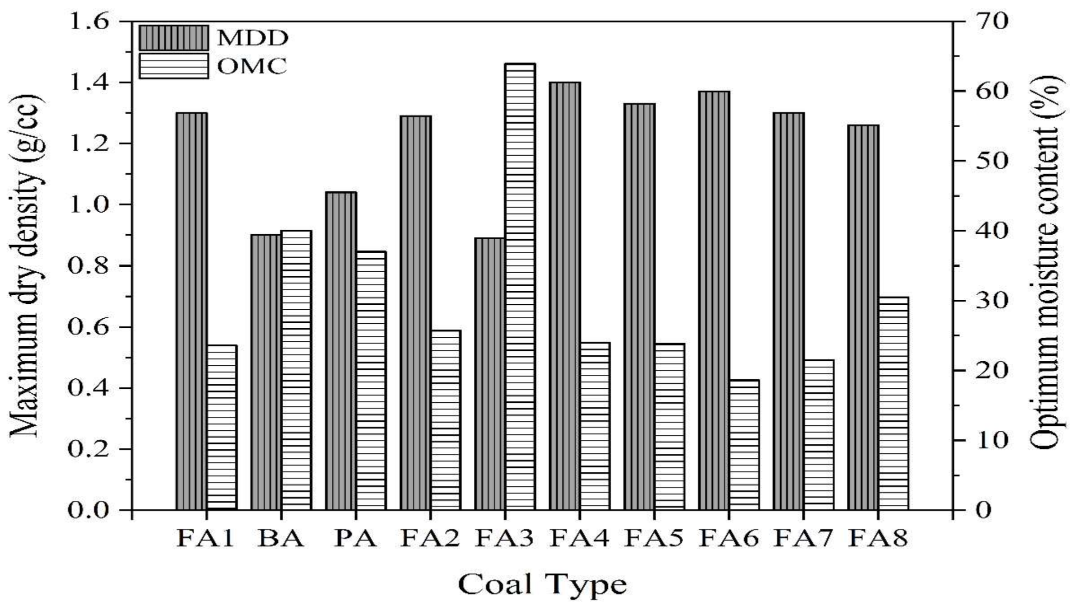


Fig. 5.7. Demonstration of MDD and OMC of fly ash with past studies. (FA1, BA, PA: Sridharan et al. 1998; FA2: Sridharan et al. 2001; FA3: Pandian 2004; FA4, FA5: Moghal and Sivapullaiah 2011; FA6: Kumar et al. 2014; FA7: Rajak et al. 2017; FA8: Present study) (FA: Fly ash, BA: Bottom ash, PA: Pond ash).

Table 5.1 Basic geotechnical properties of fly ash from various power plants in India

Thermal Station	G	Sand (%)	Silt (%)	Clay (%)	C_u	C_c	MDD (g/cc)	OMC (%)	C (kg/cm^2)	ϕ (°)	References
Dahanu (M)	2.1	31	66	3	7.2	1	1.22	23	0.245	29.66	Kumar and Mandal 2016
Koradi (M)	2.15	15	78	7	NA	NA	1.21	24	NA	NA	Padade and Mandal 2014
Kolaghat (WB)	2.06	14.96	83.42	1.62	2.42[a]	0.85[a]	1.24	24.50	NA	NA	Saha and Pal 2013; Pal and Ghosh 2010[a]
Anpara (UP)	2.15	38	59.5	2.50	4.66	0.72	1.370	18.60	0.205	25.8	Kumar et al. 2014a, b
Budge (WB)	1.99	24.050	69.94	6.01	3.33	1.124	-	-	NA	NA	Pal and Ghosh 2010
Dadri (UP)	2.19	NA	NA	NA	5.60	0.72	1.18	22	0.35	23	Hasan et al. 2014
Panki (UP)	1.98	NA	NA	NA	5.3	1.7	1.08	34.5	NA	NA	Sachan and Rao 2010
Suratgarh (R)	2.18	NA	NA	NA	5.5	0.80	1.12	31	NA	NA	Tiwari and Ghiya 2013
Neyveli (TN)	2.55	27	70	10	3.16	1.04	0.89	62.3	0.16-0.96	26-39	Pandian 2004
Bhilai (C)	1.90-2.55	NA	NA	NA	3.1-10.7	0.05-0.4	0.9-1.6	18-38	Negligible	30-40	Chacko et al. 2013
Raebareli (UP)	2.05	34[a]	65[a]	1[a]	NA	NA	1.30	23.0	0.23	34	Sridharan et al. 1998; Pandian 2004[a]
Raichur (K)	1.98	81[a]	13[a]	1[a]	9.0[a]	1.25[a]	1.04	36	NA	29	Sridharan et al. 1998; Pandian 2004[a]
Korba (C)	1.98	34[a]	21[a]	3[a]	6[a]	1.14[a]	1.134	33.0	0.22	34	Sridharan et al. 1998; Pandian 2004[a]
Badarpur (D)	1.97	NA	NA	NA	13.3-10	2.16-0.73	1.038	37.4	0.26	32	Sridharan et al. 1998
Vijayawada (AP)	1.95	NA	NA	NA	13.3-10	2.16-0.73	1.30	23.6	0.16	37	Sridharan et al. 1998
Ramagundam (T)	2.18	NA	NA	NA	13.3-10	2.16-0.73	1.240	27.6	0.23	33	Sridharan et al. 1998
Fly ash (UP)	2.35	61.52	33.19	5.29	22	0.92	1.26	30.5	0.5	43.8	Present study
Indian Fly ash range	1.66-2.55[a]	7-90[b]	8-85[b]	1-10[b]	1.59-6.0[c]	0.61-2.47[c]	0.92-1.71[a]	18-38[d]	Negligible	20-41[a]	Prakash and Sridharan 2009[a]; C-Farm[b]; Pandian 2004[c]; Mehta et al. 2013[d]
Local soil (UP)	2.52	2.12	81.77	16.11	10.53	1.22	1.73	16.4	0.82	33.4	Present study
Indian Soil range	2.55-2.75	40-80	20-40	5-40	1-20	-	1.3-1.8	12-18	0.20-1.50	25-35	C-Farm

NA : Not available

5.6 PERMEABILITY BEHAVIOUR

The present fly ash and local soil particles are found to be lower than that of the sand. Thus, the falling head permeability test is preferred for the determination of the permeability of fly ash and local soil. The permeability is a critical parameter in the following cases: settlement of foundations, the time required for consolidation, and for the dissipation of pore pressure (Shil and Pal 2015). It is dependent on many factors such as degree of densification, void ratio, grain size distribution, internal structure, soil type, etc. (Wang and Huang 1984; Rajasekhar 1995). The permeability of present fly ash and local soil are found to be 4.23×10^{-5} cm/sec and 2.11×10^{-8} cm/sec respectively. The local soil exhibits very low permeability as compared to that of the fly ash due to the presence of high concentration of clay particles. The permeability of soil usually varies from 1 to $< 10^{-6}$ cm/sec for the wide particle size between gravel to clay (Evirgen et al. 2015). Similarly, the permeability of fly ash varies in the narrow range of 1.87×10^{-4} to 8×10^{-6} cm/sec and the permeability of bottom ash & pond ash also falls in this range (Pandian 2004). The permeability of fly ash resembles the permeability of non-plastic silts, on the other hand, compacted fly ash is defined as moderately permeable (Kaniraj and Gayathri 2004). The permeability of fly ash shows a decreasing trend when used as a stabilizing agent in soil (Parker et al. 1977). The combination of fly ash and bentonite is very popular in the application of landfill liner. It is observed that a mixture of fly ash and bentonite in percentage of 95% + 5% and 80% + 20% shows superior results when used as a liner (Sankar and Niranjan 2015; Mollamahmutoğlu and Yilmaz 2001; Hasan et al. 2014). The permeability is highly interconnected with the effective size (D_{50}) and size of the aggregate (Chen et al. 1977; Hauser 1978). The increment of both classes of fly ash leads to the decrement in permeability of concrete, with a certain amount of cement. Comparing class C and class F fly ash, the former one has not shown a satisfactory reduction in the permeability than that of the later one (Eliss et al. 1991). Meyers et al. (1976) specified that higher content of fines fills the interconnected voids in concrete. This results in lower permeability attributed to the high pozzolanic activity, which increases the amount of SiO_2, Al_2O_3, and CaO. The permeability of fly ash is low followed by pond ash and bottom ash. Pond ash is showing intermediate permeability because it is disposed of directly by blending fly ash and bottom ash. In field applications like road subgrade, it is applied and compacted in an alternate layer form, leading to the generation of an interface. This results in the variation of field permeability in comparison to the laboratory.

5.7 CALIFORNIA BEARING RATIO (CBR)

The California Bearing Ratio (CBR) of homogeneous (fly ash & local soil) and stratified soil-ash deposit (combination of fly ash & local soil) has been evaluated in the present study. The pressure resistance of soil versus penetration of plunger plots of all the soil combination subjected to unsoaked and soaked conditions has been shown in Fig 5.8 & 5.9. The CBR value of all soil combination was checked at 2.5 mm and 5 mm penetration. As per Indian Standard IS: 2720 (Part 16) (1987), the CBR at 2.5 mm penetration is usually higher than that of the CBR at 5 mm penetration. If the CBR at 5 mm is higher as compared to 2.5 mm, then the test should be repeated and adopt the higher CBR after repetition. In the present study, the unsoaked condition shows higher CBR at 5 mm penetration whereas the 2.5 mm penetration exhibits higher CBR under soaked conditions. The unsoaked CBR value of local soil, fly ash, and stratified soil-ash deposit are found to be 12.05%, 22.13%, and 13.22% respectively. Upon soaking of the sample for 96 hours, the CBR value was reduced drastically to 1.22%, 1.77%, and 1.57% in the case of local soil, fly ash, and stratified soil-ash deposit respectively. Similar type of observation has been witnessed by Baditala and Sreedhar (2016) for the local soil having an equivalent maximum dry density. The unsoaked CBR of fly ash and murrum were found to be 6.91% and 38.43% respectively, and that was reduced to 3.5% and 19.02% after soaking (Pandian and Krishna 2001). The present fly ash shows higher CBR value under the unsoaked condition and lower value under soaked condition as compared to the past studies. The soil having soaked CBR value less than 2 is usually considered as poor subgrade that needs improvements using stabilization or reinforcement (Praveen et al. 2021). Bowles (1992) has been given the soil classification based on CBR as very poor (0-3%), poor (3-7%), fair (7-20%), good (20-50%), excellent (>50%).

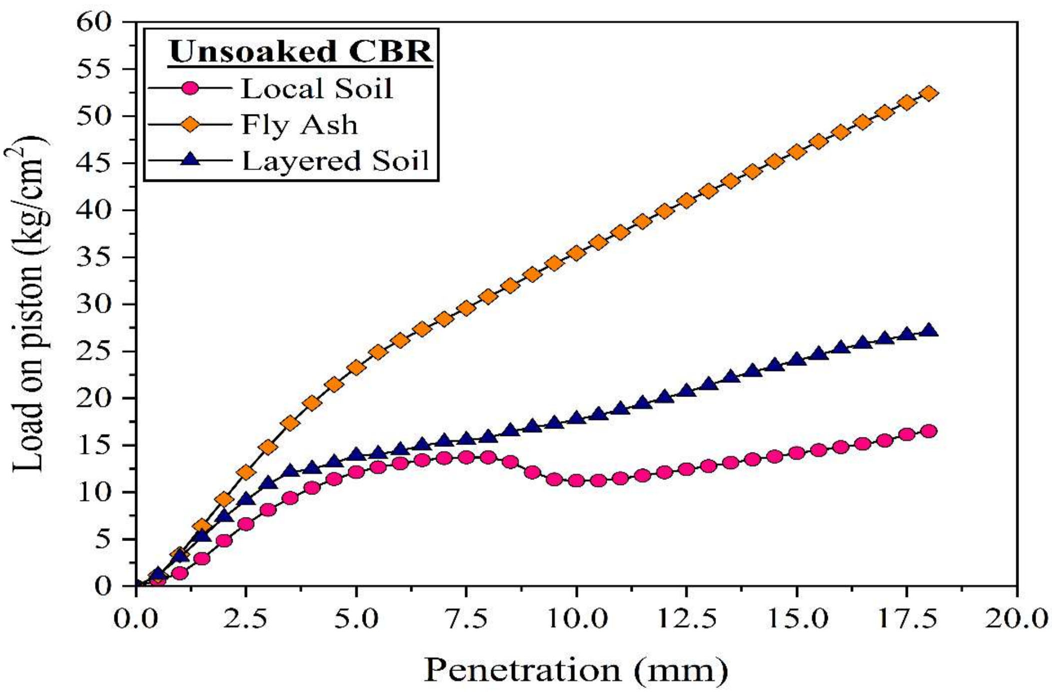


Fig. 5.8. Graphical representation of the unsoaked CBR of homogeneous and stratified soil-ash deposit.

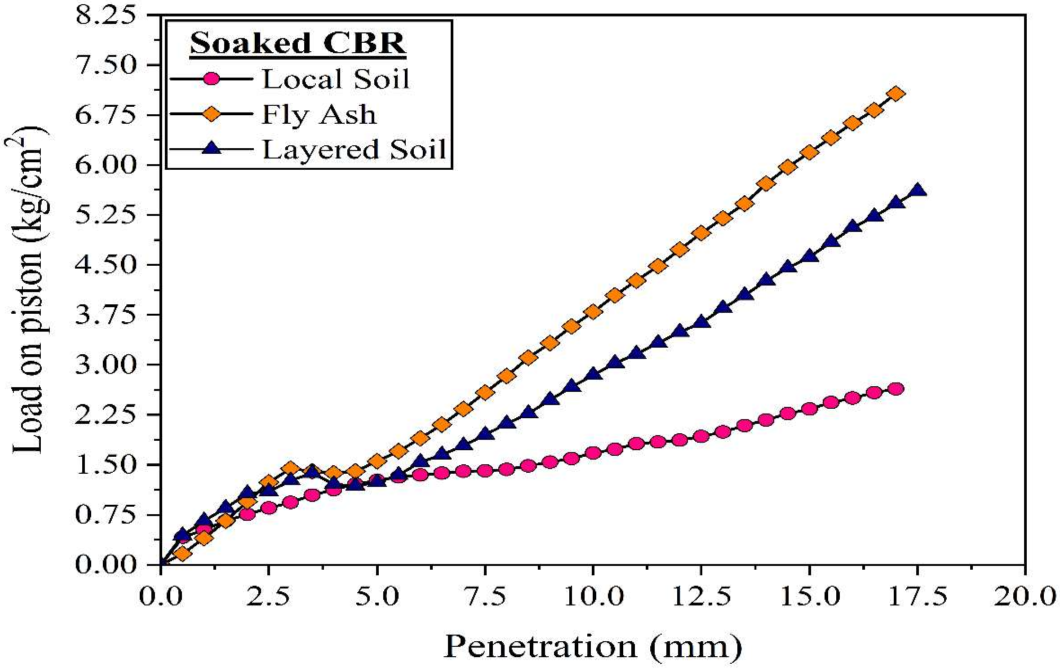


Fig. 5.9. Graphical representation of soaked CBR of homogeneous and stratified soil-ash deposit.

5.8 SUMMARY

The geotechnical properties of the fly ash and local soil has been determined as per the Indian standard and explored to carry out the advanced static and cyclic triaxial experiment of the considered arrangements. From the above discussion, the following conclusion can be drawn. The comparison between fly ash and local soil reveals several key differences. The fly ash is composed of a higher fraction of sand particles (61.52%), followed by silt (33.19%) and clay (5.29%), while the local soil primarily consists of silt particles (81.77%), followed by clay (16.11%) and a smaller proportion of sand (2.12%). In terms of soil classification, fly ash is categorized as well-graded silty sand according to the Unified Soil Classification System, whereas the local soil is classified as silt of intermediate plasticity. One notable distinction is that fly ash requires a higher percentage of water to exhibit liquid-like behavior compared to the local soil. Additionally, the local soil exhibits a higher degree of compactness at lower water content, whereas the fly ash necessitates a greater amount of water to achieve the maximum compaction. The local soil also has a higher maximum dry density compared to the fly ash. Due to the presence of a higher percentage of clay particles, the local soil demonstrates very low permeability, making it suitable for trapping harmful leachates from fly ash. Lastly, when considering the California Bearing Ratio (CBR), the fly ash shows a higher value, followed by stratified soil-ash and the local soil for both the unsoaked and soaked conditions. This indicates that the fly ash has a better load-bearing capacity than that of the local soil. In summary, the comparison highlights differences in particle size distribution, soil classification, water requirements, compaction characteristics, permeability, and load-bearing capacity between fly ash and local soil.