International Journal of Earth Science
2013; 2(3): 88-95
Published online June 30, 2013 (http:// www.sciencepublishinggroup.com/j/earth)
doi: 10.11648/j.earth.20130203.13

Suitability of bentonite clay: an analytical approach

Md. Abdullah Asad*, Shantanu Kar, Mohammad Ahmeduzzaman, Md. Raquibul Hassan

Dept. of Civil Engineering, Stamford University Bangladesh, Dhaka 1217, Bangladesh

Email address:
abdullah.asad03@gmail.com(M. A. Asad), maz060086@gmail.com(M. Ahmeduzzaman)

To cite this article:
Md. Abdullah Asad, Shantanu Kar, Mohammad Ahmeduzzaman, Md. Raquibul Hassan. Suitability of Bentonite Clay: An Analytical Approach. *International Journal of Earth Science.* Vol. 2, No. 3, 2013, pp. 88-95. doi: 10.11648/j.earth.20130203.13

Abstract: Bentonite is a type of clay with a very high proportion of clay mineral montmorillonite, resulting from the decomposition of volcanic ash. With high plasticity, Bentonite is highly water absorbent and has high shrinkage and swelling characteristics. Bentonite slurry is often used to solve problems in the construction of borings or excavating trenches in water- saturated soils. Over time, the uses of bentonite spread into more current applications including papermaking technology, cut-off walls, wastewater purification and even into different aspects of nano-technology because of nano-sizes of bentonite particles. Due to its vast engineering applications, it is of highly research interest. In this present study, an analytical approach has been made to find a suitable bentonite sample from three different types of bentonite samples (China, Pakistan and India) by analyzing their engineering properties and economy as well. Finally, China Bentonite sample is found to be most suitable with good engineering properties and economy than other samples.

Keywords: Bentonite Clay, Suitability of Bentonite, Engineering Properties, Swelling, Economy

1. Introduction

Bentonite clay is sedimentary clay composed of weathered and aged volcanic ash. The largest and most active deposits come from Wyoming and Montana. Bentonite includes any natural material dominantly composed of clay minerals in the smectite group (Hosterman and Patterson, 1992). Wyoming bentonite consists of hydrous silicate of alumina, commonly referred to as montmorillonite clay. Also known as sodium bentonite, Wyoming bentonite is high-swelling sodium montmorillonite clay used in kitty litter (25%), drilling mud (20%), binder in foundry molds (19%), iron ore pelletizing (13%), and other applications (23%) (Virta, 2005). Wyoming Bentonite can sell up to 16 times its original size and absorb up to 10 times its own weight in water. Calcium bentonite, a low or nonswelling variety, is relatively unimportant in Wyoming production. Bentonite, originally known as ‘mineral soap’ or ‘soap clay’, was named ‘bentonite’ in 1898 by Wilbur C. Knight for deposits in the Benton Shale near Rock River, Wyoming. The Benton Shale included Upper and Lower Cretaceous units lying between the Niobrara and Cloverly Formations and their equivalents. Currenty named equivalent stratigraphic units in Wyoming include the Frontier Formation, Carlile Shale, Greenhorn Formation, Belle Fourche Shale, Mowry Shale, Aspen Shale, Muddy Sandstone, Newcastle Sandstone, Thermopolis Shale, Skull Creek Shale, and Bear River Formation. The best Wyoming bentonite is found primarily in the Upper Cretaceous Mowry Shale (Hosterman and Patterson, 1992). Bentonite is usually quarry mined from deposits that can range anywhere from 100 feet to several thousand feet. This depend on the health and vitality of the land, its processed from and how far a producer will go to find the right clay with the proper characteristics and consistency .Bentorite can be used externally as a clay poultice, mud pack or in the bath and, in skin care recipes. Internally, it can be added to water or glazed upon food to help those with sensitive palates. All this evidence provides sufficient information about the usefulness and application of bentonite in practical field. For applicability concern, Suitability of bentonite sample will be judged in this research paper from the engineering point of view.

2. Statement of the Problem

Bentonite is a clay mineral which is composed of Montmorillonite mineral, with particular properties of swelling and water absorption. A good quality bentonite should be of grey/ cream color; very fine and odorless. Bentonite is a swelling clay .When it becomes mixed with water it rapidly swells and open like a highly porous sponge. Bentonite is used as a bonding material in the preparation of molding sand for the production of iron, steel and non ferrous casting. It is also act as a lubricating agent. At the time of piling, there is a possibility of collapsing of slurry hole if the soil is sandy. Due to the binding properties of bentonite it is used for retaining the soil of slurry hole at the time of piling. However, during practical applications, we often find it difficult to make a right choice to use bentonite from varieties available in the market. Furthermore, cost of bentonite is also a concern. The present study, therefore, has been aimed to investigate the physical properties of clay soil like bentonite. These properties can be used to assess better understanding about the characteristics of Bentonite. Finally, finding a suitable and economical bentonite is a prime objective of the study. This paper will be a good guide to all concerned with application of bentonite in practical field.

3. Materials and Methods

3.1. Sample Collection

Three types of bentonite samples (China, Indian and Pakistan) for conducting this research were collected from Dhaka and Chittagong division of Bangladesh. China bentonite costs 3(three) B.D.T. (Bangladeshi Taka) per kilogram which was the cheapest respective to other types. Indian and Pakistan betonite samples cost 7(seven) and 10(ten) B.D.T. per kilogram respectively.

3.2. Research Methodology

A number of tests were carried out in geotechnical laboratory of Chittagong University of Engineering and Technology (CUET). Specific gravity, liquid limit, plastic limit, shrinkage limit, sieve analysis and hydrometer analysis etc. test were done to find out the suitability and feasibility of using the betonite clay from the mentioned three choices. For the determination of specific gravity, the samples were allowed to undergone through a pycnometer specific gravity determination test.The Atterberg limits like liquid limit plastic limit and shrinkage limit test were implemented to find some special properties like plasticity index, flow curve, linear shrinkage, activity etc. The term activity is used as an index for identifying the swelling potential of clay soils. Flow curve determines liquid limit indicating water absorption capacity and shrinkage limit determines the shrinking capacity of a particular soil. As the bentonite clay possesses high swelling, shrinking and flow characteristics so activity, flow curve and linear shrinkage determination were reliable methods to model a suitable type of bentonite in practical applications. Sieve analysis gives the intermediate dimensions of a particle whereas hydrometer analysis gives the diameter of an equivalent sphere that would settle at the same rate as the soil particle. Both the sieve and hydrometer test were done because of the wide ranges of particle sizes in bentonite. Grain size distribution curve were drawn for the three bentonite samples and parameters like uniformity coefficient and coefficient of curvature were found. Fineness modulus of the respective samples of bentonite was calculated from the standard sieve retain and passing values. Furthermore, grain size distribution curve was useful to find the sand, silt and clay proportions in the bentonite samples during the research period. After finding the test results an analytical approach was made to fix the suitability of different bentonites by comparing the values with the standard values.

3.3. Theoretical Approach

3.3.1. Specific Gravity

The specific gravity of a soil is defined as the ratio of the weight in air of a given volume of soil particles to the weight in air of an equal volume of distilled water at a temperature of 4°C. It is used for determination of void ratio and particle size.

The specific gravity of the bentonite, G_B can be obtained from

$$G_B = W_S * G_T / W_S - W_1 + W_2 \quad (1)$$

Where,
G_B=Specific gravity of bentonite sample
G_T=Specific gravity of distilled water at temperature T
W_S= Dry weight of bentonite
W_1= Weight of pycnometer, bentonite and water
W_2= Weight of pycnometer and water

The specific gravity was determined in the laboratory by pycnometer method. Then it was compared with the standard values. Standard values of specific gravity are presented in table 1.

Table 1. *Standard values of specific gravity*

Soil type	Specific gravity
Gravel	2.65–2.65
Sand	2.65–2.68
Silty sands	2.66−2.70
Inorganic clays	2.68−2.80
Organic clays	Variable, may fall below 2.00

3.3.2. Liquid Limit

Liquid limit is the water content at which the soil changes from the liquid state to the plastic state. In the other words, liquid limit is defined as the minimum water content at which the soil will flow under the application of very small shearing force. At the liquid limit, the clay is practically like a liquid and possesses a small shearing strength. The liquid limit of soil depends upon the clay minerals present. The stronger the surface charge and the thinner the particle the greater will be the amount of adsorbed water. And therefore, the higher will be the liquid limit.

3.3.3. Plastic Limit

Plastic limit is defined as the minimum water content below which the soil stops behaving as a plastic material. At this water content the soil loses its plasticity and passes to a semi-solid state. The shear strength at the plastic limit is about 100 times than at the liquid limit.

3.3.4. Shrinkage Limit

Shrinkage limit is the smallest water content at which the soil is saturated. It is also defined as the maximum water content at which a reduction of water content will not cause a decrease in the volume of the soil mass.

3.3.5. Shrinkage Index

The shrinkage index is the numerical difference between the plastic limit and the shrinkage limit.

$$I_S=W_P \square W_S \quad (2)$$

Where
W_P= Plastic limit
W_S=Shrinkage limit

3.3.6. Linear Shrinkage

Linear shrinkage is defined as the moisture content, in percent, at which the volume of the soil mass ceases to change.

3.3.7. Plasticity Index

Plasticity index is the range of water content over which the soil remains in the plastic state. It is the numerical difference between liquid limit and plastic limit. It is defined by

$$PI= W_L–P_L \quad (3)$$

Where
W_L=Liquid limit
P_L= Plastic limit

Burmiser classified the plasticity index in a qualitative manner as. This is presented in table 2.

Table 2. *Plasticity range*

Plasticity Index	Nature
0	Non plastic
1–5	Slightly plastic
5–10	Low plasticity
10–20	Medium plasticity
20–40	High plasticity
>40	Very high plasticity

3.3.8. Flow Index

The flow index is the rate at which a soil mass loses its shear strength with an increase in water content. Flow index is the slope of the flow curve obtained between the number of blows and the water content in Casagrande's method of determination of the liquid limit. The greater value of Flow Index has a steeper slope and possesses lower shear strength and vice versa.

3.3.9. Activity of Soils

Activity (A) of a soil is the ratio of the plasticity index and the percentage of clay fraction. The amount of water in a soil mass depends upon the type of clay mineral present. Activity is a measure of the water-holding capacity of clayey soils. The change in the volume of a clayey soil during swelling or shrinkage depends upon the activity. Soil can be classified based on the values of activity. Soil type corresponding to activity is presented in table 3.

Table 3. *Classification of soils based on activity*

Activity	Soil type
A< 0.75	Inactive
A= 0.75 to 1.25	Normal
A> 1.25	Active

The activity can be calculated as

$$A=PI \square \text{ \% of clay-size fraction} \square C \quad (4)$$

Where
A=Activity
PI= Plasticity index
C= is a constant, 9 for bentonite

3.3.10. Grain Size Distribution

The overall average representation of the sizes of particles like big size boulders, grave's, coarse fractions, fine fractions, colloidal clay, drawn on a semi-logarithmic plot of diameter size in mm. on log scale and percent finer on cm. scale, represents the complete grain size distribution of a soil .The distribution of particles of different sizes in a soil mass is called grading. The grain size analysis curve reveals whether a soil is coarse-grained or fine-grained. The distribution of particle sizes larger than 0.075 mm (retained on the N0.200.sieve) is determined by sieving and the distribution of particle sizes smaller than 0.075 mm is determined by a sedimentation process, using a hydrometer to secure the necessary data. A hydrometer is an instrument used for the determination of specific gravity of soil particles. At the time of commencement of sedimentation, specific gravity of suspension is uniform at all depth. When the sedimentation takes place, the larger particles settle deeper than the smaller ones. The lower layer of the suspension has sp. gravity greater than that of upper layer.

3.3.11. Fineness Modulus

Fineness modulus is an empirical formula obtained by taking the sum of the cumulative percentages of sand retain on the following standard sieves 3inch, 1.5 inch, ¾ inch, 3□8 inch, no. 8, no. 16, no. 30, no. 50 and no. 100 and dividing the sum by 100. It is generally denoted by F. A smaller value of fineness modulus indicates the presence of larger proportions of finer particles and vice versa.

3.3.12. Uniformity Coefficient

This parameter is defined as

$$C_{U}= D_{60}/D_{10} \quad (5)$$

Where
C_U= Uniformity coefficient
D_{60}=Diameter corresponding to 60 % finer
D_{10}= Effective size, a good measure to estimate the hydraulic conductivity and drainage through soil
The standard values for C_U is given in table 4.

Table 4. *Standard values for* C_U

Type of soil	Uniformity coefficient
Uniform	<2
Well graded gravel	≥ 4
Well graded sand	≥ 6

3.3.13. Coefficient of Curvature

This parameter is defined as

$$C_C= (D_{30})^2 /D_{60}* D_{10} \quad (6)$$

Where
C_C =Coefficient of curvature
D_{30}=Diameter corresponding to 30% finer.

3.3.14. Density of Bentonite Compared To Water

Due to the density of bentonite slurry being higher than that of water, Bentonite slurry protects a trench from water inflow from outside sources. “Water-soil-bentonite” mixtures inside the trench form “clay–lock. Moreover, the walls of the trench dry out over time, and develop a Bentonite clay crust which improves the stability of the trench. Due to thixotropic properties of Bentonite slurry, it could keep its slurry state for nearly unlimited amount of time, and as result trenches are able to keep their shape. Another technological advantage of Bentonite slurry is reversible viscosity. Contractors can place any structural element required within Bentonite slurry.

3.3.15. Mechanism of Swelling

Bolt (1956) suggests that osmotic pressure indeed develops in the soil—water system is responsible for the swelling mechanism. Bolt (1956) concluded that swelling of both illite and montmorillonite clays is caused by the excess osmotic pressure in the adsorbed layer of ions. Based on the theory, osmotic pressure is the only internal pressure acting between particles. If the soil is subjected to external pressure, the distance between particles will decrease and water will be squeezed out. As a result, the ion concentration between the particles will increase and the osmotic pressure in turn increases. Equilibrium is finally reached when the osmotic pressure equals the external pressure. The reverse process involves the decrease of external pressure and the suction of liquid by osmotic pressure between the particles to dilute the concentration of ions. The distance between the particles would increase, resulting in volume increase and a reduction of osmotic pressure. The process continues until a new equilibrium is established. The imbibitions of water are the most important cause of swelling. Moisture heave sometimes takes place in heavily consolidated clays with high plasticity index. In many cases this is a matter of the reswelling of montmorillonite which has been reduced to relatively low moisture content by consolidation stress. However, there seem to be cases in which such moisture heave takes place in soils which do not have any expandable clay minerals. Such soils seem too composed essentially of illite and chlorite with very little non-clay mineral material. Apparently such soils may have a texture which does not come to equilibrium under consolidation pressure so that it re-swells when the pressure is removed and additional water becomes available. The added moisture does not expand the lattice of the clay minerals but perhaps serves as a lubricant between the particles so that strains may be relieved. From experience it is found that no swelling will take place if the environment of expansive soil is not changed. Environmental change can consist of volume increase due to increase of moisture pressure release due to excavation desiccation caused by temperature increase. The effect of water on expansive soils is the most important element and of most concern to the practicing engineer.

4. Analysis and Test Results

The test results represent a bird’s eye view of the whole project focusing on the engineering properties of bentonite.

The results are shown by tabular and graphical form. The summary of the test results are briefly described in table 5.

Table 5. *Tables may span across both columns*

Properties	China	Pakistan	Indian
Specific gravity	2.87	2.75	2.76
Liquid limit	140%	84.5%	82.5%
Plastic limit	75.17%	46.41%	51.39%
Plasticity index	75.33%	38.08%	31.11%
Linear shrinkage	22.76%	10.5%	14.3%
Activity	2.6	2.4	1.25
Uniformity coefficient	26	54	55
Coefficient of curvature	3.76	2.15	7.36
% finer 200# sieve	58.37	49.29	51.29
Result of hydrometer analysis			
Sand	5%	9%	12%
Silt	20%	28%	20%
Clay	75%	63%	65%
Color	light white		

The bentonite sample of China origin has the highest specific gravity of 2.87. Specific gravity of Indian sample is slightly greater than the Pakistan sample. These are 2.76 and 2.75 respectively. This is shown graphically in Fig. 1.

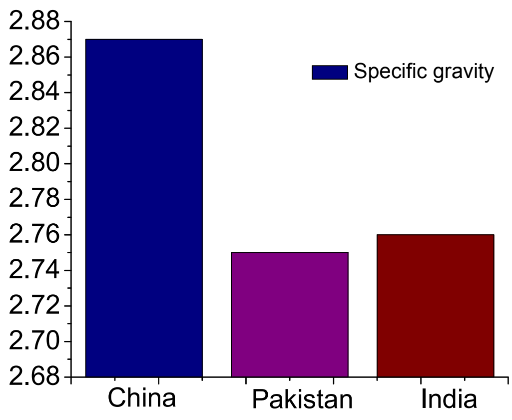

Figure 1. *Specific gravity of different bentonite samples*

The liquid limit of china sample is the highest among the three samples and it is 140 %. But, the liquid limit of Pakistan bentonite sample is slightly larger than that of Indian sample and they are 84.5% and 82.5% respectively. This is shown graphically in Fig. 2.

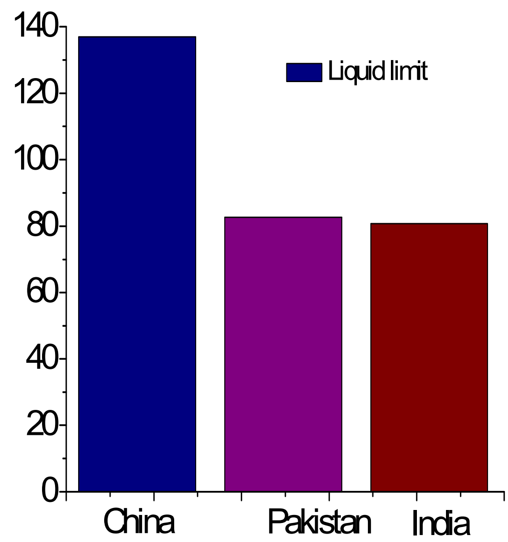

Figure 2. *Liquid limits of different bentonite samples*

The flow curves for China, Pakistan and Indian samples are drawn by plotting moisture content in a normal scale versus number of blows in a log scale. From the flow curves the liquid limit for the respective samples are calculated corresponding to 25 blows. The flow curve for china sample is presented in Fig. 3.

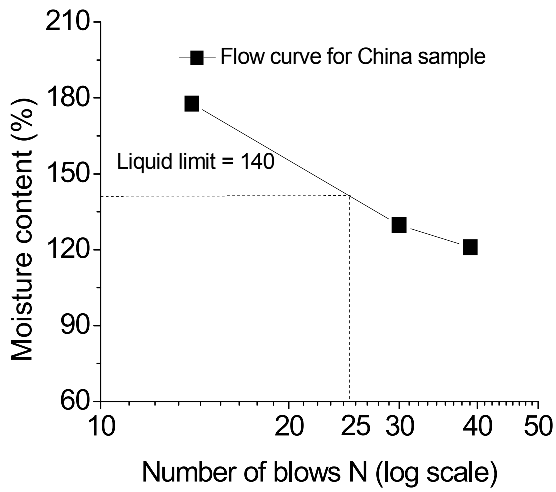

Figure 3. *Flow curve for China bentonite sample*

The plastic limit of the China sample is the highest and it is 75.17%. However, Indian sample shows high value of plastic limit than that of Pakistan sample. Indian and Pakistan sample have value of plastic limit of 51.39% and 46.41% respectively. The plasticity index for China, Pakistan and Indian sample are 75.33%, 38.08% and 31.11% respectively.

Using plasticity index, the activity for China, Pakistan and Indian samples are found to be 2.6, 2.4 and 1.25 respectively. Compared with the standard values China bentonite is judged as the most active bentonite than others. Linear shrinkage of china Bentonite sample is found to be highest and it is 22.76% whereas Pakistan and Indian sample shrinks 10.5% and 14.3% of their original length respectively. The flow curve for Pakistan sample is represented by Fig. 4.

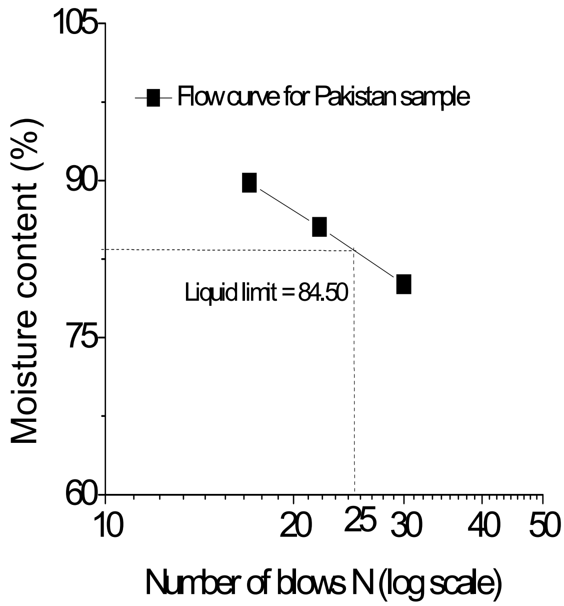

Figure 4. *Flow curve for Pakistan bentonite sample*

The flow curve for Indian sample is shown in Fig. 5.

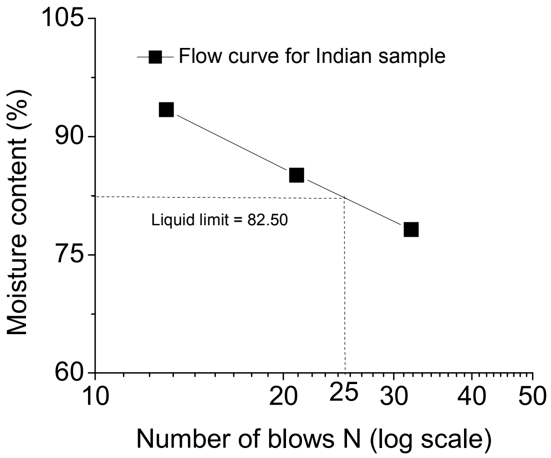

Figure 5. Flow curve for Indian bentonite sample

The China bentonite sample is very fine than that of other sample. This indicates higher proportions of clay in China bentonite sample. Pakistan and India have much higher value of fineness modulus. Grain size distribution curves are drawn by plotting percentage finer in the vertical axis and particle diameter in the horizontal axis. The hydrometer tests results in the proportion of sand, silt and clay proportion in the Bentonites samples. The plastic limit and linear shrinkage for the bentonite samples are presented in Fig. 6 and Fig. 7 respectively.

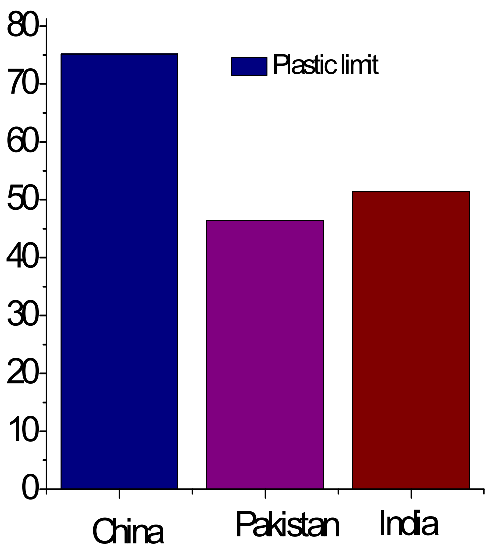

Figure 6. Plastic limit for different bentonite samples

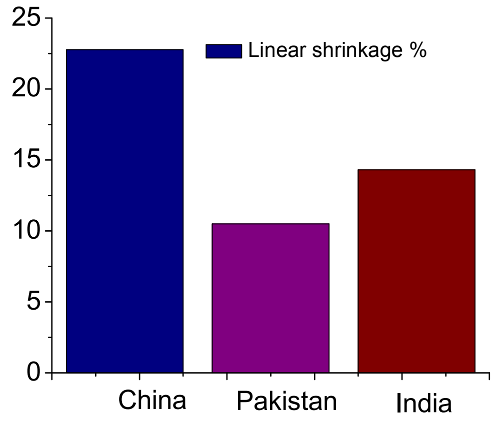

Figure 7. Linear shrinkage for different bentonite samples

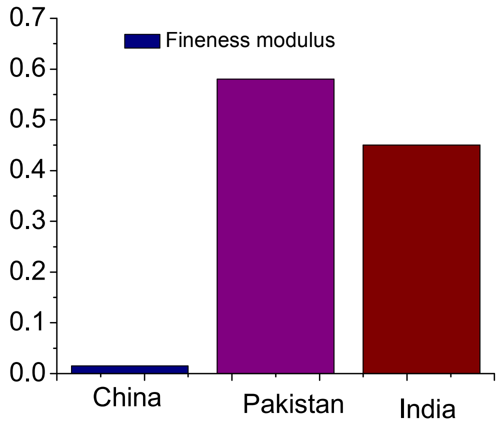

Figure 8. Fineness modulus of different bentonite samples

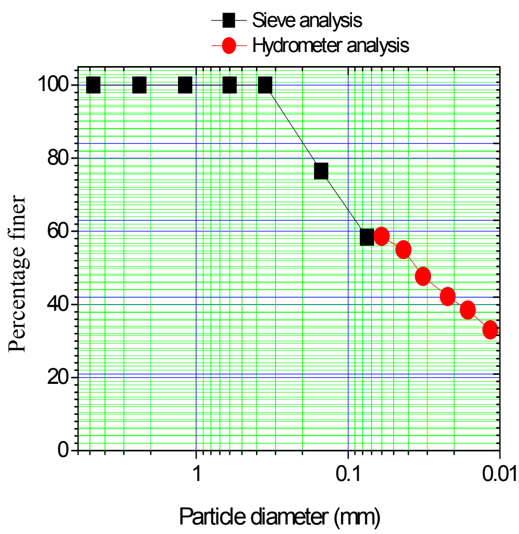

Figure 9. Grain size distribution curve for China sample

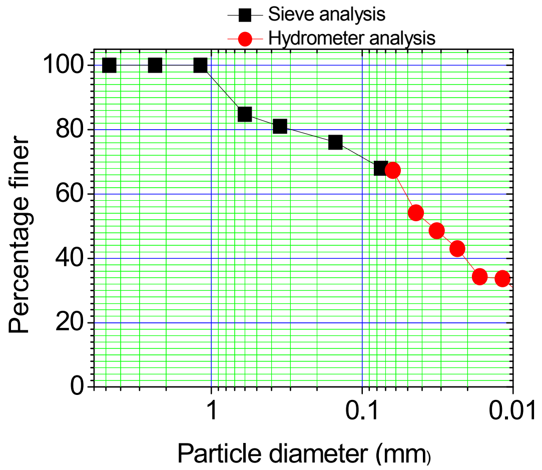

Figure 10. *Grain size distribution curve for Pakistan sample*

From the results it is found that, all the samples of bentonite possess larger proportion of clay. However, China sample carry the largest proportion of clay than that of other samples and it is 75%.Moreover, sand proportion in the China bentonite is the lowest and it is only 5%. The color of the samples is light white. Fineness modulus of the bentonite samples are presented in Fig. 8. Grain size distribution curves for China, Pakistan and Indian samples are presented in Fig. 9, Fig. 10 and Fig. 11 respectively. Grain size distribution curves describe both the sieve analysis and hydrometer analysis results of the tests. These graphs are drawn by plotting percentage finer versus particle diameter. Particle sizes are plotted in log scale wheares percentage finer is in normal scale.

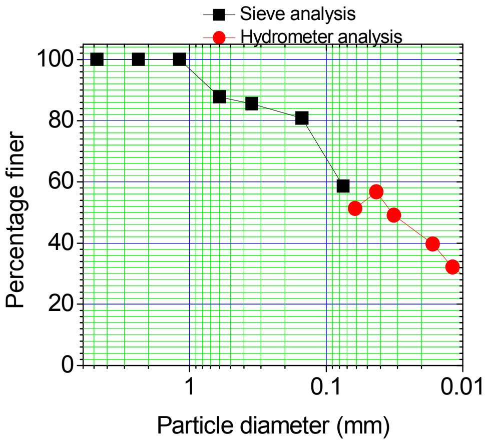

Figure 11. *Grain size distribution of Indian sample*

6. Conclusion

Bentonite samples were collected from Dhaka and Chittagong of Bangladesh. These samples are tested in geotechnical lab in CUET. From the test results, the physical properties and composition of above bentonite samples have been compared with the standard value. The sample of China has found to be highest specific gravity value due to higher percentage of clay. The China sample are of high compressibility and the remaining two samples are of medium compressibility , considering the value of liquid limit .The plasticity index of all sample are found to be highly plastic. Considering activity, the China and Pakistan bentonite are found active which contain mineral montmorillonite. However, China sample is most active. On the other hand Indian bentonite is close to active. The sample of China bentonite is found to be high percentage clay particle but other samples contain fewer amounts in comparison with the China sample. The fineness modulus varies between .015to .58 for all samples. The linear shrinkage of China sample is relatively higher than that of other samples. The China bentonite sample is the cheapest than Indian and Pakistan bentonite samples. So, China bentonite sample is the most suitable option among the three bentonite smaple (China, Pakistan and Indian) considering its engineering properties and economical point of view.

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