Improvement of the Geotechnical Properties of Brahmaputra River Silt

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Abstract:- *Brahmaputra silt from the Nimati Ghat area (South Bank of Brahmaputra) with locational coordinates (26.86Lat. 94.22Long.) in the Jorhat district of Assam has been collected to study the engineering properties and to propose a possible improvement to its engineering properties. The collected specimen of Brahmaputra silt was non plastic and exhibited a Liquid Limit of 33.80%, Maximum Dry Density (MDD) of 1.504gm/cc at an OMC of 20.40%. The CBR value, Permeability and Unconfined Compressive Strength were found to be 3.80%, 1.29x10^{-4} cm/sec and 0.082kg/cm^2 respectively. For the purpose of the improvement, various trials were conducted by mixing the collected specimen of Brahmaputra Silt with 5% Lime, 5% Bentonite and with 1.50%, 3.0%, 6.0% & 9.0% Lime in combination and with 2.0%, 5.0%, 7.0%, 10.0% and 12.0% Bentonite alone and tested for Liquid Limits, Plastic Limits, OMC-MDD value, CBR value, Permeability and Unconfined Compressive Strength. It was found that addition of Bentonite alone resulted in better improvement than with the addition of lime with or without Bentonite in composition. The results of the present study shall find utility in the adoption of Brahmaputra Silt for civil engineering construction such as roads, embankments etc. after suitable improvement to it.*

Key Words: Brahmaputra Silt, Soil improvement, Geotechnical properties, Lime, Bentonite

1. INTRODUCTION

Brahmaputra is the youngest among the major rivers in the world and the second longest in India after Indus. The river Brahmaputra originates from a glacier located at east of the Manasorovar lake in Tibet. From the headwater from snow fed catchments located at an altitude of 5,180 m, it traverses for about 2,890 km, of which approximately 1,625 km are in Tibet, 918 km in India and 337 km in Bangladesh with an average width of 8–10 km. The Brahmaputra valley in Assam is underlain by recent alluvium and represents a tectono-sedimentary province of 720 km long and 80–90 km width and elevation ranging from 120 m at Kobo in the extreme east through 50.5 m at Guwahati to 28.45 m at Dhubri in the extreme west. The bank material of the river mostly consists of varying proportion of fine sand, silt with only occasional presence of minor amount of clay (generally less than 5%) [1]. [2]; [3] have attributed the fine sand and silty nature of the river bank material and the unstable bank line along the most part of the river to create a highly favorable environment for bank erosion. Bank failures are composed of violent actions of the flowing water and the weak geotechnical properties of the bank materials. [4] have reported the average annual suspended load during flood at Pandu in Guwahati to be around 400 million metric tons. [5] Estimated the total average annual rate of erosion and deposition in the Majuli island of Brahmaputra alone to be 8.76 km^2/yr and 1.87 km^2/yr for period from 1966 to 2008. Also, a potential future increase of 40 % of transported sediments for the river Brahmaputra is predicted by [6] by creating simulation models with water discharge, lateral inflow, water temperature, sediment grain size distribution, Mannings' roughness coefficient and effective river width as input parameters. So, given the enormous volume of sediment transported and deposited in the banks by the river Brahmaputra, it becomes imperative to look for plausible utility of the deposited materials. However, the deposited materials being fine sand to silt, it calls for suitable improvement in the Engineering properties of the deposited materials to render those suitable for various construction purposes.

2. REVIEW OF LITERATURES

Lime stabilization reportedly works best with clayey soils due to the presence of a net negative charge. However, few researchers have also carried out lime stabilization studies of silty soils. According to [7], there exist two stages of lime stabilization. First stage involves ion exchange on the surfaces of clay minerals whilst the second stage removes silica and some alumina from the clay mineral lattice. [8] stated that Lime-soils reactions are complex and entail primarily, secondary and tertiary process. A high alkaline environment, with a pH greater than 12.4, needs to be maintained to enable the pozzolanic reactions to occur [9]. The minimum amount of lime required to achieve a high alkaline environment (pH greater than 12.4) in the soil is termed as "Lime demand". Amelioration period, also known as mellowing period, is the time required for lime to react with soil prior to compaction, has significant effects on strength gaining of stabilized soils. [10] Studied the use of Lime and Grand Granulated Blast Furnace Slag (GGBFS) in stabilizing desert silty sand for possible use in geotechnical engineering applications, especially for roadways and railways constructions. Their study reported that Lime addition has reduced the maximum dry unit weight and has increased the optimum water content of silty sand. Also, additions of lime and GGBFS in varying percentages have shown an increased in the unconfined compressive strengths. CBR values for samples with predominant lime concentration and low GGBFS concentration showed a decrease with increase in lime content for un-soaked conditions. However, samples with more GGBFS content (>10%) and high curing period showed a rise in soaked CBR test results with increase in lime content. [11] Studied the effect of different amounts of lime and natural pozzolan on geotechnical properties of a silty sand soil. The authors reported that adding lime or pozzolan or both of them to a silty sand soil, causes an increase in optimum moisture content and a decrease in the maximum dry density and using both of lime and pozzolan causes substantial increasing in compressive strength even to 16 times in comparison of natural soil. California Bearing Ratio (CBR) values were found to be increased up to 9 times in optimum water content condition and up to 12 times in saturated condition in comparison of the natural soil. However more than 5% lime content resulted in the decrease of CBR values. In the case of the unconfined compressive strength (UCS), the authors reported an increase in the UCS value upto a lime and pozzolan content of around 5% after which the UCS values declined for higher concentrations of lime and pozzolan. [12] Studied the hydraulic conductivity or permeability of lime treated soil as addition of lime results in a decrease in the Maximum Dry Density (MDD). The study found that even if addition of lime resulted in a dramatic change of the maximum dry density of the tested silty soil, its effect on hydraulic conductivity is limited. [13] Studied the effect of lime stabilization on properties of Black Cotton Soil and found the optimum lime content to be in the range of 3.5% to 4.5%. It was reported that addition of lime in the optimum range reduced the Liquid Limit by almost 11% and the Plastic Limit by 15%. The authors reported that for Black Cotton soil, on addition of Lime, the MDD remain unaltered, however OMC displayed a slightly decreasing trend. The swelling pressure at an optimum lime content of 3.5% decreases by almost 79% and CBR by almost 50%. Beyond the optimum points, LL, PL, OMC, Swelling Pressure and CBR showed an increasing trend. [14] showed that liquid limit decreases upto a certain lime content for expansive soils with high clay minerals as well for non cohesive soils with high silica content and beyond such threshold lime content and on increasing curing period, liquid limit increases for both expansive as well as non cohesive soils. Also, the authors found the PL to be increasing at a steep rate upto a threshold value of lime content. Beyond the threshold lime content, PL continued to rise but at a low rate. The overall pattern of variation of PL was similar for expansive as well as non cohesive silica rich soils for different curing periods although the magnitude of PL was different in each case.

Bentonite being a clay mineral with predominant montmorillonite content and having very fine texture is used to impart plasticity to coarse grained and non plastic soils to a desired degree. [15] studied the improvement of cohesionless soil by the addition of Bentonite in varying percentages of 3%, 6 %, 9 %, 12% and 15% by weight of soil. An increase in the Bentonite content from 3% to 9% was found to increase the maximum dry density by about 12% while it is increased by about 5% if the Bentonite content increased from 9% to 15%. Cohesion in the soil mixture was found to increase by 70% when Bentonite content is increased from 3% to 9%, while when Bentonite content varies from 9% to 15%, the soil cohesion increased by 19%. The value of angle of internal friction showed a decrease by 9% when Bentonite content was increased from 3% to 9% and by 3% when Bentonite content was increased from 9% to 15%. Similar studies were also carried by [16]; [17]; [18]; [19] who reported improvement in various geotechnical properties of cohesionless soils on addition of Bentonite in varying percentage compositions.

3. MATERIALS AND METHODS

The materials used in the project work includes Brahmaputra Silt sourced from the Nimati Ghat (South bank of river Brahmaputra) with locational coordinates (26.86Lat. 94.22Long.) in the Jorhat district of Assam, India. Other materials used as admixtures in treating Brahmaputra silt include commercially available Hydrated Lime or Calcium Hydroxide and commercially available Bentonite. Besides, Sodium hexametaphosphate and Sodium Carbonate (anhydrous) were used in carrying out the hydrometer test. The various geotechnical properties of the Brahmaputra Silt are tabulated below:

Table- 1: Geotechnical Properties of the Brahmaputra Silt

SOIL PROPERTIES	OBSERVED VALUES
Liquid Limit	33.80%
Plastic Limit	NP
Plasticity Index	NP
Classification of soil	SM
Optimum Moisture Content	20.40%
Maximum Dry Density	1.504 gm/cc
CBR Value (unsoaked)	3.80%
Unconfined Compressive Strength	0.082 kg/sq.cm

To determine a suitable admixture that can potentially enhance the engineering properties of the Brahmaputra Silt forms the basis of the present study. Accordingly, an empirical study was carried out taking Lime and Bentonite as admixture to study the changes in various crucial geotechnical parameters viz., Liquid Limit (LL), Plastic Limit (PL), Optimum Moisture Content (OMC), Maximum Dry Density (MDD), California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS) and

Permeability. An idea of the particle size distribution of the Brahmaputra Silt was gathered by carrying out the Sieve Analysis for faction coarser than 75μ and by Hydrometer Test for faction 75μ and finer. Subsequently, the following test program was designed to study the improvement of the Brahmaputra Silt in context of the parameters mentioned above.

I. Tests on the virgin Brahmaputra Silt (VS) to gather information on its inherent geotechnical properties
II. Tests on the virgin Brahmaputra Silt with addition of 5% Lime (VS+5L)
III. Tests on the virgin Brahmaputra Silt with addition of 2% Bentonite (VS+2B)
IV. Tests on the virgin Brahmaputra Silt with addition of 5% Bentonite (VS+5B)
V. Tests on the virgin Brahmaputra Silt with addition of 5% Bentonite and 1.50% Lime (VS+5B+1.50L)
VI. Tests on the virgin Brahmaputra Silt with addition of 5% Bentonite and 3.0% Lime (VS+5B+3.0L)
VII. Tests on the virgin Brahmaputra Silt with addition of 5% Bentonite and 6.0% Lime (VS+5B+6.0L)
VIII. Tests on the virgin Brahmaputra Silt with addition of 5% Bentonite and 9.0% Lime (VS+5B+9.0L)
IX. Tests on the virgin Brahmaputra Silt with addition of 7% Bentonite (VS+7B)
X. Tests on the virgin Brahmaputra Silt with addition of 10% Bentonite (VS+10B)
XI. Tests on the virgin Brahmaputra Silt with addition of 12% Bentonite (VS+12B)

All percentage additions of the admixtures were done on the percentage oven dried weight of the virgin Brahmaputra Silt. The curing time after addition of lime for all the tests was maintained at 24 hours and all tests were performed as per the relevant Indian Standards.

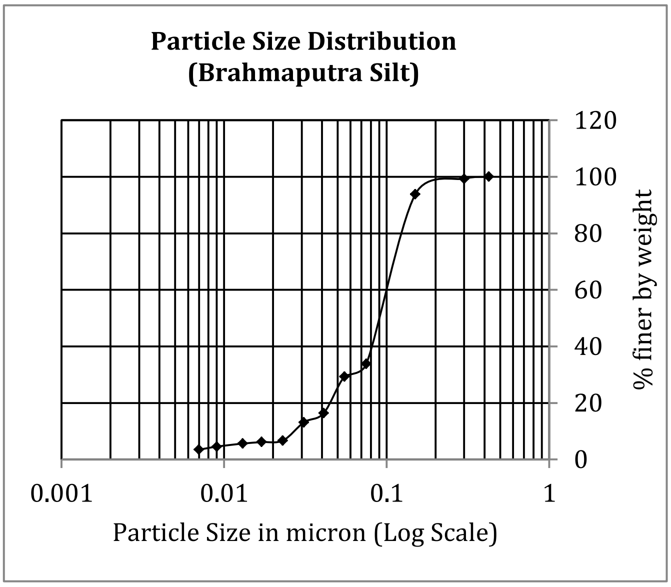

Chart-1: Particle size distribution of Brahmaputra Silt.

4. RESULTS AND DISCUSSIONS

4.1 Effect on Atterberg's Limits

Table- 2: Variation of LL, PL and PI with the addition of Bentonite and Lime

SAMPLE	LL (%)	PL (%)	PI (%)
VS	33.8	NP	NP
VS+5L	37.4	NP	NP
VS+2B	38.6	NP	NP
VS+5B	41.1	NP	NP
VS+5B+1.50L	43.1	NP	NP
VS+5B+3.0L	44.8	NP	NP
VS+5B+6.0L	45.7	NP	NP
VS+5B+9.0L	47.0	NP	NP
VS+7B	46.5	23.5	23.0
VS+10B	48.5	25.2	23.3
VS+12B	49.9	26.1	23.8

Liquid Limit (LL) shows an increase with the increase in percentage addition of Lime and Bentonite. In the case of addition of Lime to the soil samples premixed with 5% Bentonite, the increase in LL is prominent upto 3% addition in Lime and henceforth, the rate of increase in LL is found to slightly decrease. The LL increases by 11% on addition of 5% Bentonite and 3% Lime in combination and thereafter increases by only 2.2% upto addition of 5% Bentonite and 9% Lime. Addition of 5% Lime without part addition of Bentonite increases LL by 3.6%.

In the case of addition of Bentonite, the LL is found to increase considerably upto 7% addition in Bentonite and thereafter the rate of increase in LL is mild. The LL increases by 12.7% upto addition of 7% Bentonite and thereafter on addition upto 12% Bentonite, LL increases by 3.4%.

Plasticity behavior was prominently shown only after addition of 7% Bentonite. The Plastic Limit (PL) increases by 2.6% on addition upto 12% Bentonite and Plasticity Index (PI) shows a slight increase of 0.8% on increasing Bentonite content from 7% to 12%.

The reason for increase of LL, PL and PI in all the cases of addition of Lime may be attributed to the formation of Pozzolanic substances producing water holding gelatinous materials. In the case of addition of Bentonite, the increase in LL may be attributable to the increase in plasticity of soil.

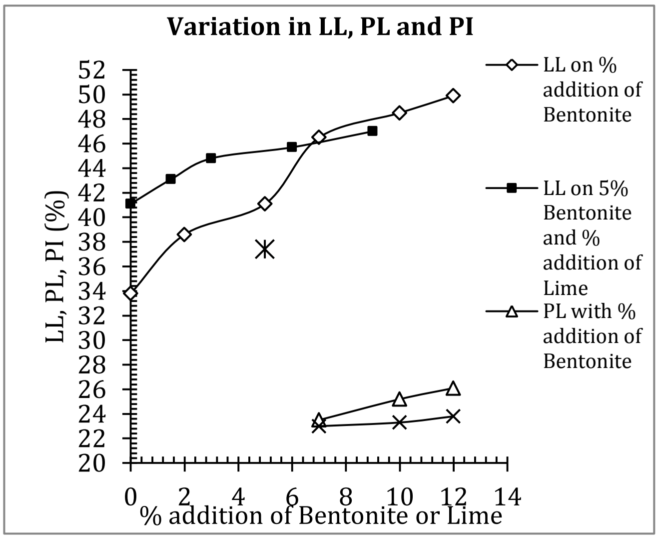

Chart- 2: Variation in LL, PL and PI on addition of Bentonite and Lime

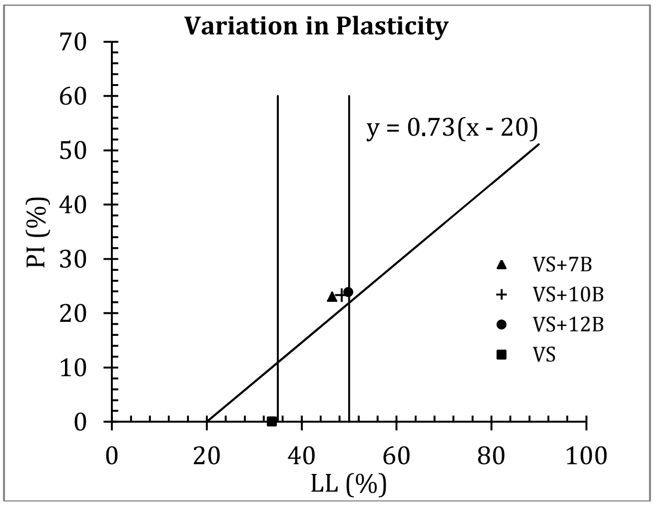

Chart- 3: Variation in plasticity on addition of 7% to 12% Bentonite

4.2 Effect on Maximum Dry Density (MDD)

Table- 3: Variation in MDD with the addition of Bentonite and Lime

SAMPLE	MDD (gm/cc)	SAMPLE	MDD (gm/cc)
VS	1.504	VS+5B+6.0L	1.512
VS+5L	1.470	VS+5B+9.0L	1.510
VS+2B	1.540	VS+7B	1.574
VS+5B	1.561	VS+10B	1.584
VS+5B+1.50L	1.544	VS+12B	1.520
VS+5B+3.0L	1.530		

Maximum Dry Density (MDD) decreases on the addition of Lime. On addition of 5% Lime to the virgin soil sample, the MDD is decreased by 2.26%. For samples premixed with 5% Bentonite, increase in the percentage addition of Lime resulted in the decrease in the MDD. Stark decrease in MDD is observed upto 6% addition of Lime in samples premixed with 5% Bentonite and slight decrease on further addition of lime. Addition of upto 6% of Lime in samples premixed with 5% Bentonite decreased the MDD by 3.14% of the sample mixed with 5% Bentonite alone. MDD increases upto 10% addition in Bentonite and on further increase in Bentonite content to 12%, a sharp decrease in MDD is observed. MDD of virgin soil increased by 5.32% on addition of 10% Bentonite.

The decrease in the MDD on the addition of Lime may be attributed to the aggregation and subsequent increase in the particle sizes and void ratio resulting from the pozzolanic reactions forming larger particle agglomerates. The increase in MDD on the addition of Bentonite is due to the decrease in the void ratio by filling of finer clayey particle and rearrangement of soil grains. However, as the plasticity of soil considerably increases on addition of 12% Bentonite, the MDD starts decreasing.

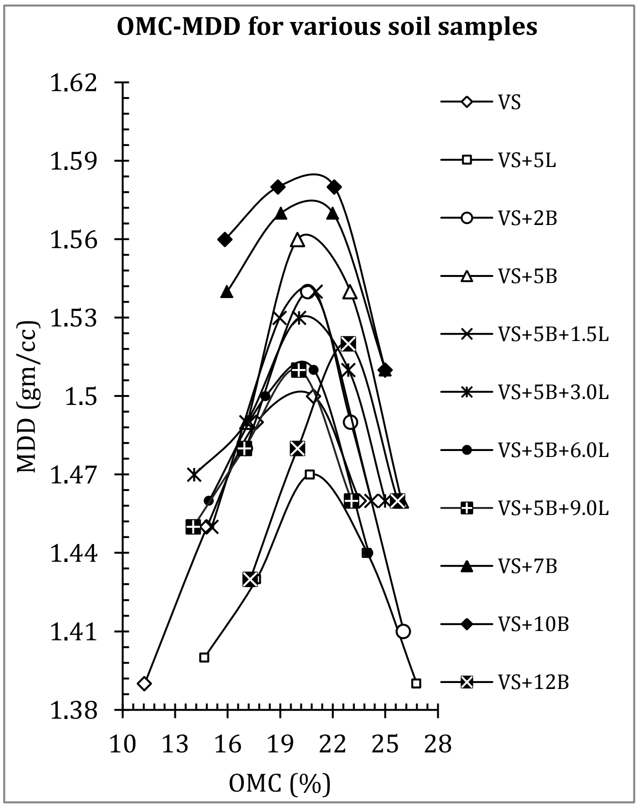

Chart- 4: Variation in MDD on addition of Bentonite and Lime

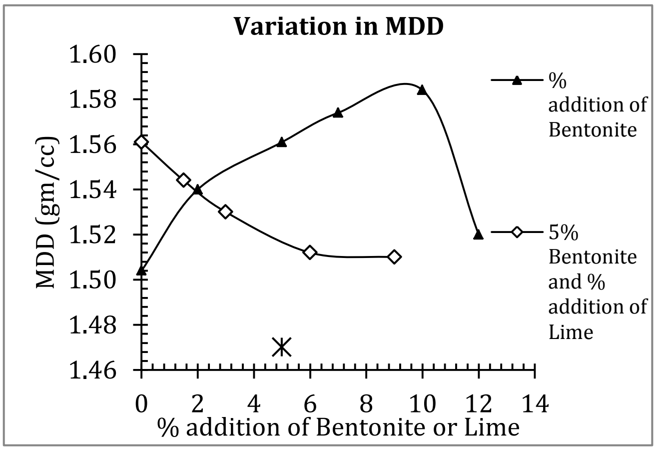

Chart- 5: OMC-MDD relationship for various soil samples tested

4.3 Effect on California Bearing Ratio (CBR)

Table- 4: Variation in CBR with the addition of Bentonite and Lime

SAMPLE	CBR (%)
VS	3.80
VS+5L	3.99
VS+2B	7.01
VS+5B	7.86
VS+5B+1.50L	7.20
VS+5B+3.0L	6.81
VS+5B+6.0L	6.48
VS+5B+9.0L	6.42
VS+7B	8.05
VS+10B	8.84
VS+12B	7.66

California Bearing ratio (CBR) increases slightly by 0.19% on 5% addition of Lime to the virgin soil sample. For samples premixed with 5% Bentonite, increase in the percentage addition of Lime resulted in the decrease in the CBR. Addition of upto 9% of Lime in samples premixed with 5% Bentonite decreased the CBR by 1.44% of the CBR value of the sample mixed with Bentonite alone. CBR increases upto 10% addition in Bentonite and on further increase in Bentonite content to 12% results in a sharp decrease in CBR. The CBR of virgin soil increased by 5.04% on addition of 10% Bentonite.

The decrease in the CBR on the addition of Lime may be caused by similar reasons causing a drop in the MDD. The increase in CBR on the addition of Bentonite can be attributable to the formation of denser soil matrix on addition of Bentonite. However, as the plasticity of soil considerably increases on addition of 12% Bentonite, the CBR starts decreasing.

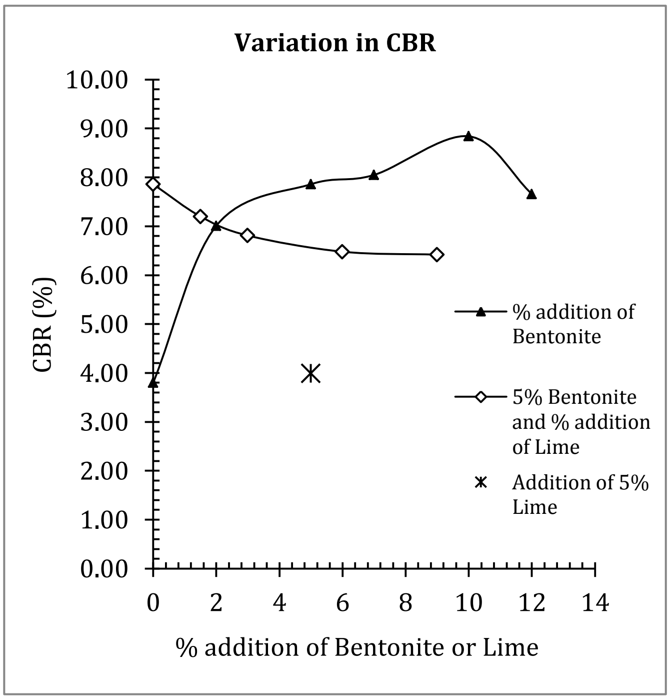

Chart- 6: Variation in CBR on addition of Bentonite and Lime

4.4 Effect on Unconfined Compressive Strength (UCS)

Table- 5: Variation in UCS with the addition of Bentonite and Lime

SAMPLE	UCS (kg/sq.cm)	SAMPLE	UCS (kg/sq.cm)
VS	0.082	VS+5B+6.0L	0.083
VS+5L	0.129	VS+5B+9.0L	0.067
VS+2B	0.129	VS+7B	0.177
VS+5B	0.134	VS+10B	0.196
VS+5B+1.50L	0.119	VS+12B	0.168
VS+5B+3.0L	0.099		

Unconfined Compressive Strength (UCS) was found to increase by 57.32% on direct addition of 5% Lime but on addition of Lime to the virgin soil sample premixed with 5% Bentonite, increase in the percentage addition of Lime resulted in the decrease in the UCS at a fairly steady rate. Addition of upto 9% of Lime in samples premixed with 5% Bentonite decreased the UCS by 50% of the sample mixed with 5% Bentonite alone. UCS increases upto 10% addition in Bentonite and on further increase in Bentonite content to 12% results in a decrease in UCS. The UCS of virgin soil increased by 139.02% on addition of 10% Bentonite.

The decrease in the UCS on the addition of Lime may be caused due to shorter curing time (24 hours) maintained while carrying out the tests which resulted in the formation of less pozzolanic compounds or the addition of Lime might have served as a lubricant to the soil particles and thereby decreasing the strength. It might also be due to a combination of the above two reasons. The increase in UCS on the addition of Bentonite can be attributable to the formation of denser soil matrix on addition of Bentonite. However, as the plasticity of soil considerably increases on addition of 12% Bentonite, the UCS starts decreasing.

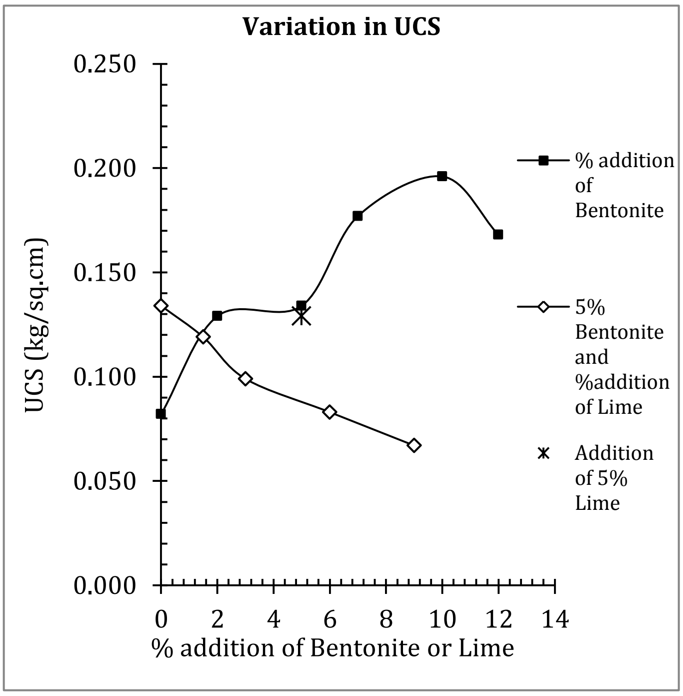

Chart- 7 Variation in UCS on addition of Bentonite and Lime

4.5 Effect on Permeability

Table- 6: Variation in Permeability with the addition of Bentonite and Lime

SAMPLE	PERMEABILITY (cm/sec)
VS	1.29×10^{-4}
VS+5L	8×10^{-5}
VS+2B	2.1×10^{-5}
VS+5B	1.85×10^{-5}
VS+5B+1.50L	1.71×10^{-5}
VS+5B+3.0L	1.58×10^{-5}
VS+5B+6.0L	1.34×10^{-5}
VS+5B+9.0L	9.31×10^{-6}
VS+7B	2.53×10^{-6}
VS+10B	1.12×10^{-6}
VS+12B	8.3×10^{-7}

The addition of 5% Lime to the virgin soil decreases the permeability by almost 38%. On increasing the Lime content in soil premixed with Bentonite, the permeability decreases at a fairly steady rate. The addition of 5% Bentonite and 9% Lime decreases the permeability by almost 93% of the virgin soil. In the case of addition of Bentonite, even a small addition of 2% Bentonite drastically reduces the permeability by almost 84% of the virgin soil. The addition of 7% Bentonite was found sufficient to render the sample almost impermeable with a permeability of 2.53×10^{-6} cm/sec. The permeability continues to decrease with the increase in the Bentonite content and corresponding to 12% Bentonite addition, the permeability was measured to be 8.3×10^{-7} cm/sec.

The reduction in permeability on addition of Lime may be attributed to the reduction in interconnected voids due to products of pozzolanic reactions. In the case of soil samples mixed both with Lime and Bentonite, the reduction in permeability is more due to the presence of Bentonite than Lime. There was only a reduction of 7.6% in permeability in the sample mixed with 5% Bentonite and 1.50% Lime than the sample with only 5% Bentonite. Similarly, the sample mixed with 5% Bentonite and 9% Lime showed only around 50% reduction in permeability from the sample with 5% Bentonite. The reduction of permeability on addition of Bentonite is definitely attributable to the reduction in voids and formation of a denser soil matrix on the addition of Bentonite.

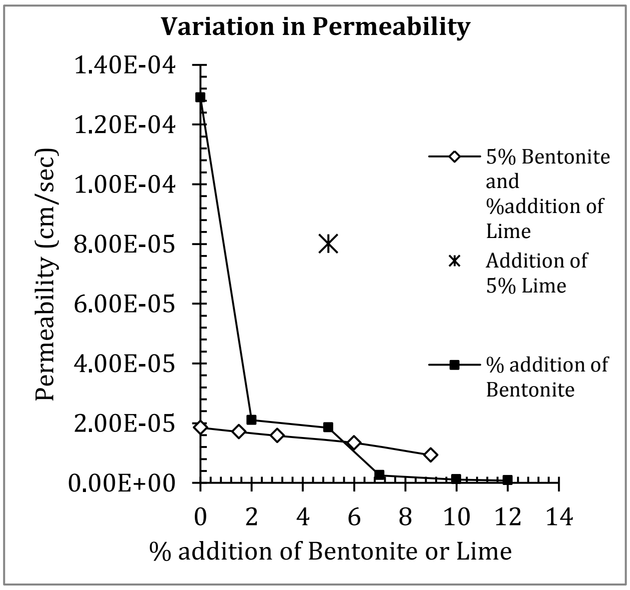

Chart- 8 Variation in Permeability on addition of Bentonite and Lime

4.6 Variation on the various Geotechnical properties observed

It was found that the sample of virgin soil mixed with 5% Bentonite and 1.50% Lime (VS+5B+1.5L) and that mixed with 2% Bentonite alone (VS+2B) showed almost the same extend of improvement. Also, the best improvement was shown on addition of 10% Bentonite to the virgin soil which can be recommended as the optimum quantity of Bentonite required to bring about improvement to Brahmaputra Silt.

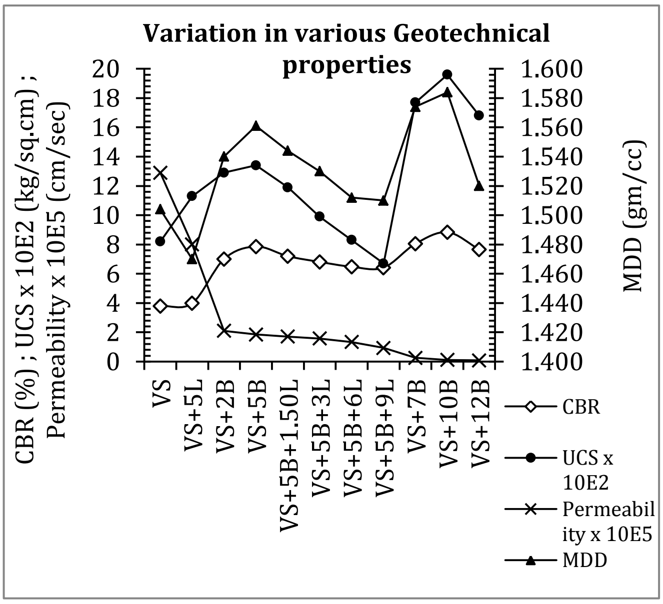

Chart- 9 Variation in various Geotechnical properties on addition of Bentonite and Lime

5. CONCLUSIONS:

1. The soil sample sourced from the Nimati Ghat (South Bank) of Brahmaputra in Jorhat was found to be of Silty Sand in classification with no clay content. The absence of clay fraction in the soil resulted in no overall improvement being taken place on direct addition of Lime although an increase in the CBR and UCS and decrease in permeability was observed. However, these changes are insignificant when compared with the changes on addition of Bentonite alone.

2. Liquid Limit was found to be increasing on increasing the percentage addition of Lime in soil mixed with 5% Bentonite. On increasing the percentage addition of Bentonite alone, LL is found to increase considerably upto 7% Bentonite and thereafter the rate of increase in LL is mild. The LL increases by 12.7% upto 7% addition of Bentonite and thereafter on addition upto 12% Bentonite, LL increases by 3.4%. That is, an overall increase of LL of virgin soil by 16.10% was found on addition of 12% Bentonite.

3. The soil samples are found to be Non Plastic in nature upto 5% addition of Bentonite. On addition of 7% Bentonite, plasticity in soil is exhibited. Plastic Limit (PL) increases by 2.6% on addition upto 12% Bentonite and Plasticity Index (PI) shows a slight increase of 0.8% on increasing Bentonite content from 7% to 12%. The classification of the soil was found to change

from Silty Sand (SM) to Intermediate Clay (CI) upon addition of 7% to 12% Bentonite.

4. Proctor test results showed that Maximum Dry Density (MDD) decreases on the addition of Lime. On addition of 5% Lime to the virgin soil sample, the MDD is decreased by 2.26%. For sample mixed with 5% Bentonite and 9% Lime, MDD decreased by 3.27% of that of the sample mixed with 5% Bentonite alone. Addition of Bentonite enhanced the MDD of the soil samples. MDD of virgin soil increased by 5.32% on addition of 10% Bentonite. Further addition of Bentonite to 12% resulted in reduction of MDD. In case of OMC, no particular trend could be extracted from the test results.

5. CBR and UCS increases by 0.19% and 57.32% respectively on addition of 5% Lime. However, these increments are insignificant when compared with the changes on addition of Bentonite. Also, in contrast, addition of Lime to soil mixed with 5% Bentonite results in the decrease of CBR and UCS in comparison of the sample mixed with 5% Bentonite alone. In the sample mixed with 5% Bentonite and 9% Lime, the CBR and UCS decreased by 1.44% and 50% respectively of that of the sample mixed with 5% Bentonite alone. The addition of Bentonite upto 10% resulted in increase in the CBR and UCS values and thereafter the CBR and UCS values decreased on addition of 12% Bentonite. 10% addition of Bentonite increased the CBR value of the virgin soil by 5.04% and the UCS by 139.02%.

6. Reduction in permeability is achieved on addition of both Lime and Bentonite, although the changes on addition of Bentonite are more prominent than on addition of Lime. Addition of 5% Lime reduced the permeability by almost 38%. For soil samples mixed with 5% Bentonite and Lime, maximum reduction in permeability was observed for the sample with 5% Bentonite and 9% Lime with permeability reduced to almost 93% of the virgin soil. In the case of Bentonite, maximum reduction in permeability is achieved by the soil mixed with 12% Bentonite which rendered the sample almost impermeable with a permeability of 8.3×10^{-7}cm/sec.

7. It was found that the sample of virgin soil mixed with 5% Bentonite and 1.50% Lime (VS+5B+1.5L) and that mixed with 2% Bentonite alone (VS+2B) showed almost the same extend of improvement.

8. The best improvement was shown on addition of 10% Bentonite to the virgin soil (VS+10B) which can be recommended as the optimum quantity of Bentonite required to bring about improvement to Brahmaputra Silt.

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