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Comparative study on the geographical, physical and engineering properties of soils of West Beneal. Part-III (Engineering properties of soils of West Bengal excluding North Bengal and general conclusions)

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Abstract : In a series of Paper (I-III), attempts have been made to correlate the geographical characteristics, physico-chemical and engineering properties of soils of West Bengal. All the properties are to some extent interrelated. The engineering properties of soils of West Bengal (except for the North Bengal region) have been presented. However, for understanding the engineering properties of soils and their proper correlation with geographical and physico-chemical properties, a knowledge of different aspects of soil properties and their physico-chemical and engineering properties in general may be useful. These are given briefly before presenting the general conclusions regarding the engineering properties of soils of West Bengal.

Keywords : Bearing capacity, correlation, design purpose, engineering characterization, field tests, geographical properties, physico-chemical properties, soil, West Bengal.

Introduction

Lithosphere is the reservoir or sink of all substances including pollutants from the atmosphere, hydrosphere and biosphere. Soil, the most important ingredient on earth, has multifarious properties and uses[1-4] like :

(i) Cultivation of food i.e. in agronomy.

(ii) Engineering purposes i.e. construction of houses, roads, dams, factories, power houses etc.

(iii) Filtration and neutralisation and *reuse* of pollutants.

(iv) The sustenance of the biological world like man, animals etc.

(v) Source of all minerals.

The main objective of the present work is to determine the different engineer:ng properties of soil for the purpose of design of different structures like bridges, road, power houses, buildings etc. in different parts of West Bengal. The determination of various physico-chemical parameters and chemical constituents of soils are important factors associated with the properties of soils which change with the geographical character of the region. The physico-chemical parameters and chemical constituents of soils determine the engineering properties and agronomical aspects of soil. They also indicate the extent of pollution of soils by natural and man made activities which may be utilized for the proper soil management. All the properties are to some extent interrelated and an integrated approach for the correlation of the different aspects of soil science is relevant for the judicial use of soil. The importance of the study is emphasized in Part-I of this paper which also covers the experimental details and interpretation on some properties like grain size, free-swell index and permeability of soils of West Bengal.

In some of our previous publications[5-9], the methods for the collection of the samples and the experimental methods for the determination of some physico-chemical and engineering properties like Attenberg limits, liquid limits, plastic lımits etc. have been described. Some physico-chemical properties of soils in the deltaic region were also determined mainly from the agronomical point of view[10]. Except moisture content, clay, silt and sand percentages for the soils, the properties are not of much relevance for the engineering purposes.

In Part-II of the paper[11], the experimental details, tables and equations utilized for determining the engineering properties of soils and the experimental results on some typical soils of North Bengal are presented[11]. In the last part (Part-III) of the paper, the results of the engineering properties of soils of West Bengal (except for those described before) are presented.

However, for understanding the engineering properties of soils and their proper correlation with geographical and physico-chemical properties, a knowledge of different aspects of soil properties and their physico-chemical and engineering properties in general may be useful. These are given briefly before presenting the general conclusions regarding the engineering properties of soils of West Bengal.

Experimental

Sample collection and experimental details[5-11] for the determination of the engineering properties of soils like shear parameters [shear strength (C_u), friction angle (Φ), blow count (N)] were described in Part-I and particularly Part-II of this paper and other papers. The data collected from *in situ* tests (i.e. tests at site) or laboratory tests (on the collected undisturbed soil samples when a hole is bored) and equations and standard table described previously were utilized to calculate the allowable bearing capacity.

In dynamic cone penetration test, a cone was driven by impact load and the blow count (number of blows N) for 30 cm penetration was noted or a static cone was pushed in the sub-soil gradually to determine bearing resistance[11].

In general, stronger the soil, greater will be blow count and the shear parameter or greater will be resistance and hence the bearing capacity.

Table 1 shows some engineering characterization of soils.

The results are summarized briefly in Tables 2 and 3.

Table 1

Nature of soil		Characterization	Bearing capacity
(A) Clay	(i) New deposit	Soft to very soft	Low
	(ii) Old deposit	Medium to high	Medium to high
	(iii) Intermediate	Intermediate	Intermediate
(B) Sand	(i) Very recent	Very loose to loose	Low
	(ii) Loose to medium		Medium
	(iii) Medium to dense		High

Table 2. Ranges of allowable bearing capacity value (t/m^2) obtained from penetration test

Site ↓ Depth →	0–3 m	3–6 m	6–9 m	9–12 m	12–18 m	15–18 m	18-21 m	Soil description
Lichupakuri, Darjeeling	5–45	2–110	70–180					Upper layer medium dense silty sand, then soft clayey silt, then medium dense to very dense silty sand with gravel.
Dauk Barrage, Baurigachh, North Dinajpur	10–60	60–120	70–130					Upper layer medium dense sand, then medium dense to very dense sand to gravelly sand.
Dauk-Nagar Main Canal, Islampur, North Dinajpur	10–40	15–70	70–82					Upper layers medium dense clayey sand, then medium dense silty sand.
Pagla Bridge, Panchanandapur, Maldah	5–50	3–8	30–105					Upper layer medium dense silty sand, then soft silty clay, then medium dense to dense silty fine sand.
Kaliganj, Nadia	5–12	45–150						Upper layers soft to medium stiff silty clay, then medium dense to very dense silty sand to fine sand.
River Bank of Padma, Akhrigarj, Murshidabad	10–15	10–60	50–125	50–175				Upper layers loamy silt (non-cohesive) with thin sand pockets, then dense to very dense silty fine sand to fine sand.

Table-2 (contd)

Karkaria Khal, Nadia	10–50	10–55	25–70					Upper layers medium dense to dense loamy sand then medium dense to dense loamy sand to silty sand
Bakreswar Dam, Birbhum	1–30	180 or above						Upper layers medium stiff to stiff loam, then decomposed rock
Murandi syphon, Ilambazar, Birbhum	10–20	20–40	20–95					Upper layers medium stiff to stiff silty clay, then stiff to very stiff loamy clay then medium dense to dense silty sand to sand
Daya Nullah Ausgram, Bardhaman	5–25	3–15	5–25	Above 80				Upper layers soft to medium stiff loamy sand (cohesive) to loamy clay below medium dense to dense sand
Balagarh, Hooghly	5–12	10–30	10–25					Upper layers soft to medium stiff loamy clay, then medium stiff to stiff loamy silt to loamy sand (cohesive)
Bhasraghat, West Medinipur	8–20	20–50	20–115					Upper layers medium stiff to stiff loamy clay, then medium dense to dense loamy sand (non cohesive) to sand
Danipur, Tamluk, East Medinipur	3–10	3–10	3–8	10–20	10–45			Upper layers very soft to medium stiff silty clay then stiff to very stiff silty clay to clayey silt
Dakshin Ramchandrapur, Haora	3–12	10–30	20–45	5–25	5–10	5–10	10–60	Upper layers soft to medium stiff silty clay, then medium dense to dense sandy silt, then soft to medium stiff silty clay, then medium dense silty sand
Pump House, Bagjola Khal, Dum Dum Park, Kolkata	5–10	5–12	5–10	5–12	10–25	20–35	45–60	Upper layers soft to medium stiff silty clay with organic matters then medium stiff to stiff silty clay then medium dense silty sand
Doharia Bridge, Nowikhal, New Barrackpore 24-Parganas (N)	5–10	5–10	5–10	5–10	5–10	10–25		Soft to medium stiff loamy clay to silty clay, then stiff silty clay to clayey silt
Ichhamati River Bank, Basirhat, 24-Parganas (N)	5–20	10	5–20	5–15	5–10	10-40		Upper layers soft to medium stiff silty clay, then stiff silty clay to medium dense silty sand
Hogal River Bank, Basanti, 24-Parganas (S)	5–10	5–10	5–10	5–10	5–10	5–10		Soft to medium stiff silty clay, loamy clay to lomy silt (cohesive)
Ganeshpur, Kakdwip, 24-Parganas (S)	5–10	10–145						Upper layer soft to medium stiff silty clay, then dense to very dense silty sand to sand
Digha Sea Beach, East Medinipur	20–40	5	5	5–10	5–15			Upper layers loose to medium dense fine sand, then soft silty loam with occasional sandy pockets

Allowable bearing capacity has been obtained from static cone penetration tests with a factor of safety 4 1 kg/cm^2 = 10 t/m^2

Table 3. Index properties of the soil samples collected from different sites of West Bengal

Sample no.	Site	Geographical region	Reduced level (m)	Figure no. 4	Depth below ground level (m)	Particulate size distribution: Gravel/Sand (>0.6 mm)	Silt (0.06–0.002 mm)	Clay (<0.002 mm)	Attenberg limit's: LL	PL	United soil classification	Dry density (g/cc)	Moisture content (%)	Shear parameters: C_u (kg/cm^2)	C (kg/cm^2)	ϕ	K (cm/s)	C_c
E-1	Bakreswar														0.8	16°		
F-1	Ilambazar													1.1				
F-2	Do													0.9				0 125
G-1	Bhasraghat										CH			2.3			2.3×10^{-7}	
G-2	Do										CH			2.16				0.12
G-3	Do										SC				0.28	17°		
H-1	Ausgram										SP						3.8×10^{-2}	
H-2	Do										CI				0.4	7°		
H-3	Do										SC-ML							
I-1	Akhriganj										ML				0.24	26.1°		
I-2	Do										SP					37°		
J-1	Kalignaj													0.39			9.8×10^{-7}	
J-2	Do															31°		
K-1	Karkana										SM-ML				0.08	31°		
K-2	Do										SM							
K-3	Do										SM							
L-1	Balagrah													0.7			12×10^{-8}	
L-2	Do														0.25	10°		
L-3	Do														0.15	6°		
M-1	Danipur					1.0	60 5	38.5						0.5				
M-2	Do					0.6	55.0	44.4										
M-3	Do					2.0	50.0	48.0										
N-1	Amta														0.42	8°	4.6×10^{-7}	0.17
N-2	Do										ML				0.69	9°		
N-3	Do											1.25	68.0	0.26				

Table 3 (contd)

O-1	Dum Dum Park							1 12	60 0	0 48				
O-2	Do							0 9	70 0		0 27	6°	4 9× 10 7	0 52
O-3	Do										0 18	8°		
O-4	Do										0 53	2°		
O-5	Do										0 28	16°		
P-1	Nowikhal										0 1	16 5°	6× 10 5	
P-2	Do										0 2	12°	1 1× 10^{-4}	0 10
P-3	Do									0 52			8 1× 10^{-6}	0 55
Q-1	Basirhat				42	25	CI			0 34				
Q-2	Do				68	23	CH			0 69				
Q 3	Do				55	22	CH			0 72				
Q-4	Do				51	25	CH			0 59				
Q 5	Do									0 47				
Q-6	Do	21 8	76 2	2 0			ML							
Q 7	Do				44	25	CI			0 46				
Q-8	Do									0 35				
Q-9	Do				62	36	OH			0 42				

Some typical soil profiles and bearing capacities which are important for engineering design purpose, obtained from field tests are given in Figs. 1 to 4.

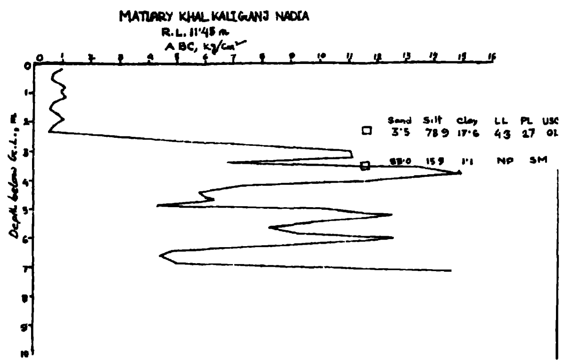

Fig. 1. Soil profile and bearing capacity at the site at Kaliganj, Nadia. Region-3 (Moriband delta).

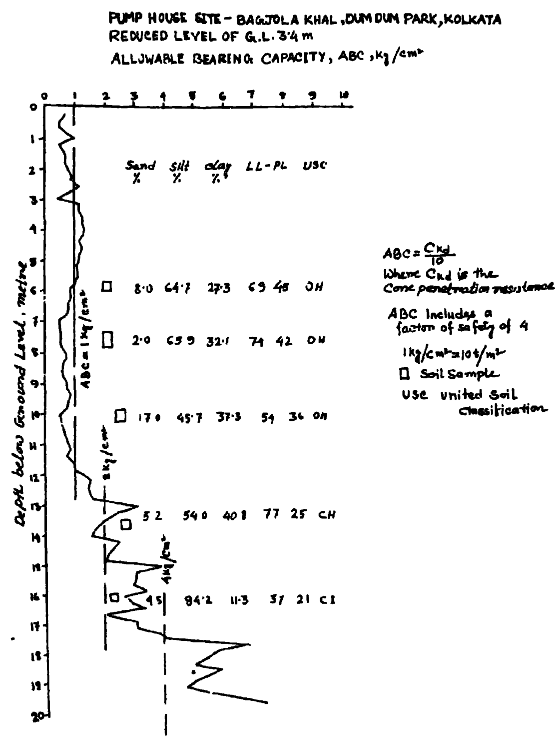

Fig. 2. Soil profile and bearing capacity at a site in Kolkata. Region-6 (Mature delta).

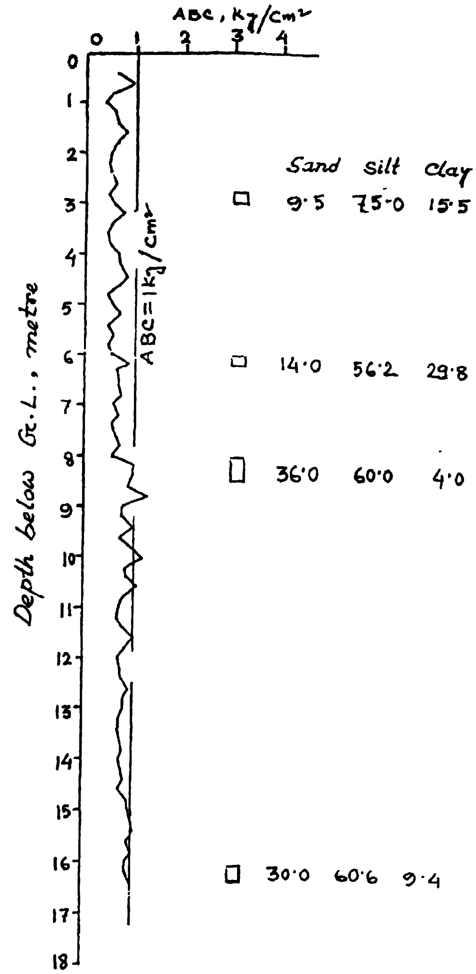

Fig. 3. Soil profile and bearing capacity of the Hogal River Bank at Vasanti, 24-Parganas (S). Region-7 (Recent alluvium).

Discussion

Most of the investigations on the engineering properties of soil in West Bengal were carried out in the River Research Institute, Haringhata. Data from the technical reports of RRI were also utilized[12]. The study is extensive nevertheless very limited though such integrated study is very significant to make a through utilization of soils for various purposes and to visualize the engineering properties of soils in different places based on geographical and physico-chemical properties of soil as these properties are interrelated.

The experiments are limited to riverine or adjacent to river tracts of different districts of West Bengal. The investigations are usually meant for small to medium structures limited to shallow depths (within 10 m, 12–15 m and 15–30 m). The data are necessary in connection with hydraulic and other structures constructed under supervision of Irrigation Department which requires understanding of soil types and knowledge of the bearing capacity of

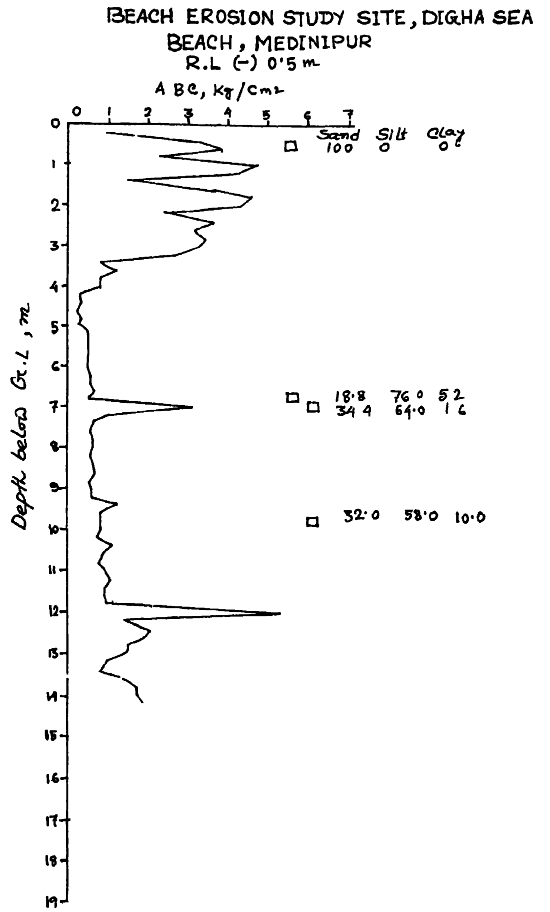

Fig. 4. Soil profile and bearing capacity at the site Digha Sea Beech, East Medinipur. Region-8 (Marine deposit).

soils on which the structures will be founded or rested.

The ultimate bearing capacity is the maximum load the foundation will just bear without high deformation of structure. However, for an overall integrity of different members of structure, only a little deformation can be allowed. So the ultimate bearing capacity is divided by a suitable factor of safety to reach an allowable bearing capacity values for design purposes. The allowable load is such that the deformation of soil and foundation associated with it is little and can safely withstand by the members of the superstructures.

The foundation of substructure is chosen according to the load of the superstructure and the properties of the sub-soils[13,14]. Some aspect of ground improvement or soil stabilization techniques are described elsewhere[7,8]. Stabilization by lime, sodium silicate have been found to be useful.

Soil[1-3,15-17] :

Soil, usually finally divided heterogeneous porous materials made of minerals, results from the physical, chemical and biological (i.e. abiotic and biotic) weathering of crystal rocks (igneous and metamorphic) over extended periods. Pore spaces are filled with air and/or water depending on moisture conditions (a physico-chemical character very much important for agriculture and engineering purposes). Soil formation is a continuous process and dependent on natural and anthropogenic factors. Soil is actually three phase mixtures and different physico-chemical, engineering and agricultural properties originate from the variations of the interactions involving three phases[1-3,15-17].

Soil may be

(i) Cohesionless soils (sand) resulting from physical disintegration of rocks.

(ii) Cohesive soils resulting from chemical weathering.

(iii) Residual soils which remain in place directly over long time.

The homogeneity or heterogeneity and depth of the soils depend on the manner of soil transportation by water, ice, wind, gravity etc.

Soils are :

(i) Glacial drift formed due to glaciers.

(ii) Aero line i.e. wind blown deposits like dune and sand.

(iii) Colluvial soils i.e. soil transported by gravitational force.

(iv) Alluvial, marine, or lacustrine i.e water borne soil deposits (We are concerned with the last two types of soil).

Soil, though consists mainly of inorganic minerals but contains about 1–5% (or more in some special cases i.e. peats, surface layers of forest soils) arising from the decomposition of organic matter of plants and animal tissues (roots of growing and dead plants or animals) and litters (leaves and branches) degraded to different extents using soil micro-organisms like bacteria, fungi, actinomicetes, protozoa, earth worms. These are of immense utility due to their ability to enhance aeration and water movement and to translocate organic matter within the surface soil. The percentage of organic matter plays a significant role in various physical, chemical, agricultural and engineering properties of soil.

Soils have a wide range of properties depending on geographical origin and nature of the parent material and geomorphic environment (air, solar radiation, water etc.) within which they are weathered and transported. The variation is evident on both the horizontal and vertical scale and over time known as soil profiles[18,19].

Soils are usually combination of clay, silts, sands and other mineral components. Clay sized fraction is heavy and has poor drainage and aeration capability (permeability low). Silts are combinations of clay minerals, organic matter and finely divided primary minerals like hydrous Fe- and Al-oxides. They are fine materials with large surface area, have good adsorption and exchange capability (responsible for the presence of exchangeable ions like Na^+, K^+, NH_4^+, H^+, Ca^{2+}, Mg^{2+}, etc.). They interact with chemicals and are highly productive plant medium, (applicable to all regions of West Bengal, except parts of Darjeeling, Purulia, Bankura and West Medinipur). Sands are light, have good drainage but poor aeration capability, chemically inert to some extent. They are poor sources of nutrients but can be readily aerated.

Soil minerals [4,7,15-17] :

Mineral, a naturally occurring chemical element or compound formed by geologic processes from rocks, consists of mixture of hydrated alumina and original minerals like quartz and some other minerals like hydrated ferric oxides etc. The clay mineral structures usually built of basic structural units i.e basic silicate units like silicon-oxygen tetrahedron (silica), aluminum-oxygen octahedron (gibbsite), magnesium-oxygen octahedron (brucite) etc.

The actual behavior of the natural clay is dependent on the constitution of the different clay mineral contents like kaolinite (weakest), halloysite, illite and montmorillonite (most active) present in the natural clay.

Structure :

Structure means the way in which the individual particles are aggregated together to form large units. Structure is a field characteristic and influences soil permeability, compressibility, shear strength etc. Organic matter acts as a cementing agent and plays an important role in developing key structure. Other chemical entities and the nature of the parent materials are also determining factors.

The honey comb, flocculant and dispersed structures; are found in fine grained soils. In a mixed soil (i.e. composite soil) beyond a 10–20% clay content (depending on clay mineralogy), clay property dominates and the mixed soil behaves as a cohesive soil.

A normally consolidated (NC) clay is the soil that exists in a natural load system which is the maximum since its origin. An over consolidated clay (OC) exists under a load which is less than a higher load the clay experienced in the geological past. A normally consolidated clay is soft to medium consistency and possesses flocculated structure but in an OC, some degree of parallelism is observed and it is medium stiff to stiff in consistency.

Engineering and physico-chemical aspects[20-22] :

In situ behaviour of soil is basically a function of structure i.e the arrangement of soil particles and the electrical forces [like primary valence bond (ionic, covalent, co-ordinate or metallic bonds) (strongest), hydrogen bond (weak) and secondary valence bonds i.e. dispersion forces (weakest) acting between particles and the pore fluid]. Moreover, moisture and clay contents of the soils are very important. For general construction or engineering purposes, H-bonding and Vander Waals (dispersion) forces rather than primary valence bonds are more important. Though the magnitude of the forces of these bonds is small but multiplicities of these bonds gave the structure unusual strength. Moreover, due to it co-planarity, directional and orientational capability of water due to H-bonds, water can orient the soil to the organic residue in clays and associated sand particles to a desirable extent.

Soil water system, usually colloidal in nature, are dependent on electrolyte concentration, ion-valence, anion adsorption, size of hydrated ion etc. Tendency of flocculation or dispersion is caused by changing these factors. Direct measurement of particle orientations is difficult and has not been attempted. These properties are very much important in deltaic and estuarine regions.

It is found that at initial stage of compaction particle array is random, flocculated but beyond OMC, higher moisture content causes more orderly arrangement or dispersion of particles[21]. However, colloidal phenomena or forces are not confined only to two adjacent particles and are less important in non-clay particles where other forces like surcharge, seepage force in super structure load are of importance in an actual *in situ* soil.

Attenberg limit tests on sand-clay mixtures indicate that some clay is required to fill the voids of the sand but beyond that clay percentage the sand particles float in clay water system and LL and PI values are found to be proportional to the clay percentage. It has been found that illite-bentonite mixtures show less plasticity and swelling tendency compared to kaolinite-bentonite due to interstratifications[23].

Different equations[24–27] are used for engineering purposes but no correlation was attempted with data determined by us. The proportionality between C_u (undrained shear strength) and p (surcharge) of NC clays had been interpreted using the concept of bonds at inter-particle contacts which are the only significant between soil grains where stress due to superimposed load can be transmitted[28]. The contacts are effectively different for solid to solid bonds of varying strengths and may have bonds between opposing atoms. Activation energies for the deformation processes suggest that inter-particle bonds are strong nearing the primary valence bonds. In general, similar activation energy for sand and clay justifies the similar behaviour of sand and clay. The role of water appears to influence the number of bonds to form. The proportionality between C_u and p, suggest, that reduction of p, effective consolidation pressure or surcharge, is not accompanied by disappearance of bonds formed during consolidation. This is the cause of cohesion of OC clay under drained shear test.

Quick clays formed in marine environment is due to the deposition of clay in water containing very high salt concentration[22]. It can be assumed that the deposit may get uplifted with percolation of ground water through it. Thus, hundreds of year of leaching may result in a different salt concentration in pore fluids causing quick clays (Estuarine and deltaic regions). In the past, in marine condition the deposits were in highly flocculated condition having high water content. After leaching the clay particles would tend to be in dispersed condition. For the same water content this would lead to very low shear strength. Upon disturbances by piling actions etc. the clay becomes almost slurry losing strength considerably.

The discussion are also relevant with alluvial, marine deposits. Townsend[29] reported a study on geotechnical characteristics of residual soils. Residual soils are products of chemical weathering and their characteristics depend on environmental factors like climate, parent materials, topography, drainage, age etc. These factors are optimized in tropics where well-drained regions produce reddish lateritic soils rich in iron and aluminum sesquioxides and kaolinitic clays (Purulia, Birbhum, Bankura, Part of West Medinipur). Conversely, poorly drained areas tend towards montmorillonitic, expansive black soils. Andosols rich in amorphous silica (allophane) and metastable halloysite develop over volcanic ash and rock regions[29].

Most pedologists suggest that basic igneous rocks (basalt, dibase etc.) weather rapidly and acidic quartz-rich rocks (gneiss, granite etc.) are weathering resistant. Basic rock minerals (olivines, pyroxenes, calcium palgiolase etc.) are probably less resistant to weathering than the acid rock minerals (quartz, feldspars, hornblende, micas etc). So zone of alteration of profile is thicker over acid rocks. Rainfall supplies moisture for chemical reactions and leaching of soluble materials and temperature influences reaction rates. Effect of parent rock materials is more pronounced at initial stages of weathering but during later stages, other factors predominate. This is the reason why laterite occurs on basic rock (basalt etc.) and acid rocks (granite etc.). Study of weathering sequences of different rock minerals suggest that sesquioxides of iron and aluminum can occur due to weathering of practically all igneous rocks but montmorillonite may be precursor.

Topography and drainage have a marked effect on chemical weathering. Steep slopes are conducive to rapid run off and physical weathering (upper tract of North Bengal). Flat low-lying areas experience poor drainage and soluble constituents remain in the environmental waters inhibiting further breakdown of parent minerals causing circumstances conducive to alkaline environment.

Ideal chemical weathering is attained on rolling, gently sloping uplands which are well drained.

The 2 : 1 clay minerals (illite, montmorillonite etc.) are favoured in alkaline non-leaching environments and 1 : 1 clays (kaolinite, halloysite) are favored by acid leaching environments. Laterites/Lateritic soils, high weathered residual tropical soils, have concentrated oxides of iron and aluminum with kaolinite as a predominate clay mineral. A laterite hardens upon exposure due to increased cementation by oxidation of the minerals. The shear parameters are higher than those suggested by plasticity indices and the greater than anticipated strengths are due to cementing materials and micro cluster structure. But there are occurrences of landslides due to rainfall in laterite tracts, possible reasons may be (i) reduction in pore water tension, (ii) seeping forces through the interstices, (iii) loss of strength of cementing materials by wetting[29].

In general, it has been found that addition of chemical affects the values of liquid limit (an index property) of a clay to some extent but excess amount is not much effective. As the clay particles are negatively charged and cations play dominant role but anions have some contribution. The chemicals ultimately have some effect on the engineering properties like shear strength, permeability compression index etc.

In case of sands, grain size and shape, grain packing at contact points etc. contribute to the engineering properties. Some of these aspects have been discussed in Part-I of the paper. But in case of clays, surface activity of clay particles is important. So not only the geological past but the clay content and clay mineralogy have effects on the engineering behaviour. Cation exchange capacity of the clay mineral in soils control their surface behaviour.

Due to different physiographic, nature of parent rocks and their geological history, mode of genesis and geomorphological agents etc., the soils of different region of the state of West Bengal are different. Naturally, their physico-chemical, engineering and agricultural properties are different.

(1) North Bengal :

Uplands are mountainous formed of solid and decomposed rocks. Land slope is high. Rainfall is fairly high in rainy seasons and enormous water flow is observed with high velocity. Water retention capability is low. Physical disintegration is dominant with little chance of chemical weathering of the rock minerals. Bearing capacity is high. Soils in Tarain region lack in finer grains, acidic and are better in fertility.

Riverine tracts are alluvial. Clayey soils in the upper layer are soft to medium in shear strength. Sands are medium dense to dense. Overall, soils are medium to high in bearing capacity except in some low lying pockets of low bearing capacities.

In some parts of Barind tract, red soil or laterite alluvium of the western region is noted.

(2) Central Bengal (Nadia, Murshidabad) :

Soils are alluvial. In the upper layers, clayey soils are soft to medium density and dense in some places. Soils are of medium bearing capacity. Deposition mainly and erosion have been occurring there.

(3) Western districts (Purulia, Birbhum, Bardhaman, West Medinipur, Bankura, Part of Hooghly) :

Purulia uplands are made of decomposed rocks of the Ayodhya hills and mostly granitic and gneissic, rainfall is fairly high during rainy seasons, with turbulent water flow possessing low water holding capacity and deficient in organic matter and plant nutrients. The soils are acidic, hard with cementing materials but lack in fines. Rest of the lands are gently sloped rolling lands with humid atmosphere and fluctuating ground water table. These provide conditions congenial to chemical weathering. The soils are loamy, fertile with higher content of fines. Both deposition and erosion have been going on. Soils are residual in some places and old alluvium at other places. Laterite and lateritic soils such as murum or iron stone gravel having honey comb structure are red in color (high % Fe-oxides), acidic, poorly aggregated.

Transported lateritic soils or red soils are found in the valleys.

Overalls soils are of medium to stiff consistencies and medium to high bearing capacity.

(4) South Bengal (Deltaic region) :

In the south, the sediments are river borne soil particles. The silt laden river water interact with tides with settlement of soils at different riverine tracts after leaching (by run off due to rain), drying and wetting cycles, aeration due to exposure to atmosphere. These together with other natural phenomena and enhanced industrial and agricultural activities (human) to cater the needs of a vast and highly dense population in this region, cause different changes in soil structure and ultimately the present state in reached. Deposition is the main phenomena.

The delta is composed of the Ganga alluvium which are alkaline, rich in plant nutrients, grey in color. In the deposits alternate beds of sand and clay are noticed. Deeper clay beds are found more south wards. However, the grey clay of soft to medium consistencies is relevant with the upper horizon but in the lower horizons stiff brownish clay and sand are found.

In the Sunderbans the soils are mostly silty with varying proportions of clay, grey, dark grey or blackish in color (indicating the presence of organic matter), alkaline, saline (rich in exchangeable ions like Na^+, K^+, Ca^{2+}, Mg^{2+} etc.). By leaching or water flushing due to rain, the soils have been found to be fit for cultivation.

The narrow coast of Medinipur (East) district has low slope. The soils are mainly sandy, fine in texture and occasionally clay soils are found below the sandy top. The soils are saline but reclamation by protective dykes and leaching has made the soils fit for cultivation at some places.

Bearing capacity of soils are in general soft to medium in southern regions but low in Sunderbans and coastal region of East Medinipur.

It is apparent that correlation of physico-chemical, geographic and engineering properties is difficult. But in spite of limitations, a gradual change in physico-chemical and engineering properties is observed with geographical changes. Moreover, soil properties and engineering properties change with depth (and place) as it will be evident from soil characteristics (clay, silt and sand, Attenberg limits etc.) and the bearing capacities (table). It is difficult to reach a conclusion regarding the correlation between the properties of soils with geographical, physico chemical, agricultures and engineering properties inspite of data presented in Part-I and Part-III of the papers. More intensive studies regarding mineralogical, physico-chemical and agronomical properties are needed. Moreover, the soil is very much affected by natural and more effectively by human phenomena (effects due to intensive cultivation and increase of use of chemical, extensive denudation of forests and mining in the upper reaches), industrialization (to meet the ever increasing needs due to population explosion in this region). Thus it is difficult to derive a definite conclusion from the stray study (even extensive). Moreover, the physico-chemical processes and their effects are time taking in geological time scale and nearly impossible to model in laboratory.

However, inspite of all limitations, it is apparent that physico-chemical and engineering properties show a gradual variation with the geographical nature of the land (ultimate sink for all substances in air, water and soil). Soil is very much affected and is likely to be affected much more in near future due to reasons given before. So, attempts for an integrated research involving geographical, physico-chemical, agricultural and engineering aspects of soil including mineralogical studies of soil is very relevant for the proper development of the country.

Due to increase in population, globalization, and rapid industrialisation and affluence of a sizeable section of community, excessive use of minerals, chemicals (fertilizers and pesticides) cement, paints, synthetic chemicals etc. are on the increase. They will not only pollute the soils but also change the engineering properties.

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