Int. J. of GEOMATE, Feb., 2016, Vol. 10, No. 1 (Sl. No. 19), pp. 1607-1614
Geotech., Const. Mat. and Env., ISSN: 2186-2982(P), 2186-2990(O), Japan

A CONCEPTUAL MODEL OF ENVIRONMENTAL, GEOLOGICAL AND GEO-TECHNICAL RESPONSE OF DREDGED SEDIMENT FILLS TO GEO-DISTURBANCES IN LOWLANDS

J. Rajaraman[1] K.Thiruvenkatasamy[2] and S. Narasimha Rao[3]
[1,2]Department of Harbour and Ocean Engineering AMET University, Chennai, India
[3]IIT Madras, Director, Dredging Corporation of India (Govt.of India)

ABSTRACT: In mineralogical evolution of clays, amongst the weathering phenomena, hydrolysis is very important. Clay minerals of 2/1 type, which first appear, are silica-rich with two tetrahedral silica sheets. The 1/1 clay minerals that follow have but one tetrahedral sheet and the last, gibbsite, has none at all. It is important to consider temperate and tropical environments. The kaolinite-gibbsite association is mostly characteristic of tropical environments. When all the silicates disappear to the gain of gibbsite, it is called total hydrolysis. Kaolinite and gibbsite are stable products in tropical environment. In temperate environment, weathering is often halted at the stage of 2/1 minerals (for example montmorillonite). This weathering can continue with kaolinite. In both cases it is partial hydrolysis only. This shows that the tropical environment is the only one to accumulate large quantities of gibbsite. In temperate climate only small amount of gibbsite is produced. In this paper a conceptual model of three layer system consisting of kaolinite, illite and montmorillonite is considered with symbols K, I, M respectively. The Geo- disturbance caused by dredging varies from pocket to pocket in the soil profile. The permutations and combinations of placed dredged materials are considered with different combinations of the three clay types (KIM). All possible combinations will yield 24 different Geo-Technical sequences. The above analysis is applied to important lowland Geo-technology problems in coastal areas such as sub-grade in pavement construction, land reclamation and fills to contribute to marine multi-inter-disciplinary research.

Keywords: *Hydrolysis, Geo-disturbances, Lowland-Geo-technology, Residual friction Tropical, Temperate environment*

1. INTRODUCTION

Many Geo-Technical engineering projects are not always under static loading alone, however, knowledge of dynamic properties and characteristics of soil is also important and needed for analysis and design. Dynamic loading can be grouped according to natural and anthropogenic origins: (a) natural sources of dynamic loads including earthquake, tsunamis, volcanic explosion, wind, rainstorm, waves, ice movement and current; and (b) anthropogenic sources of dynamic loads including machine vibrations, bomb blast, construction and quarry blasting, construction operation, traffic, ship impact and landing aircrafts. Each of these loadings presents unique challenges to the geo-technical engineer. In this paper the effect of heavy rainfall on fills of dredged materials in coastal areas, is considered.

2. DREDGING OPERATIONS

Once the soil is disturbed, the chaotic conditions start. The only way to understand Geo-technical behavior / response of the dredged soil, is to extract order out of chaos. In this paper an attempt is made to take out, order out of chaos. Dredged soil is influenced by many environmental factors.

Dredging itself creates chaotic condition in all Geo-technical aspects of the soil. Dredging causes loss of bonding stress, loss of fines with water.

3. STRENGTH OF SOIL INFLUENCED BY ENVIRONMENT FACTORS

3.1. Clay Minerals and Stability

As the ability of soils to resist deformation depends very largely on the internal friction, wet clay has the effect of reducing or canceling out the frictional resistance. It may also be pointed out that the so-called cohesive resistance is induced almost entirely by the clay fractions, and therefore that clean sands are non cohesive.

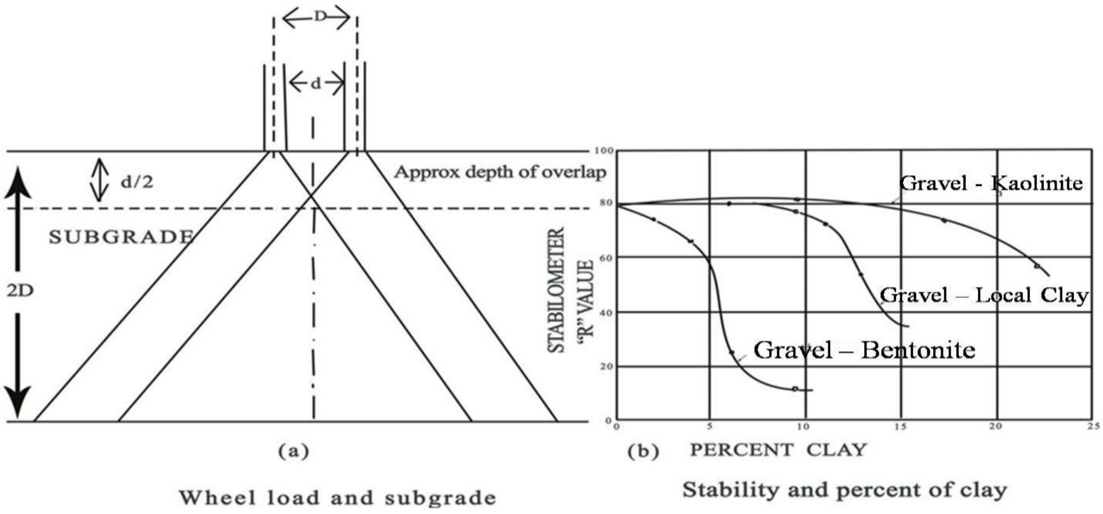

Fig.1 Stability of Clay Minerals Under Wheel and Axle. ($R=S_n$) [1]

Again we must note the important part played by water, as finely ground dry clay particles exhibit no cohesive properties. If water is added to a dry soil, the cohesive resistance will normally increase with the addition of moisture and in most cases the frictional resistance will not be greatly impaired until a certain amount of moisture is added. Beyond this point, the friction will diminish but the cohesive resistance may continue to increase up to some point of higher moisture content, after which both values will diminish as the soil approaches a completely fluid state.

Metals are typical substances having little or no internal friction; in them, resistance values are almost entirely a result of the cohesive or tensile strength. Fig.1 (a) shows wheel load and subgrade in road construction in lowland coastal area. Fig.1 (b) is a chart showing characteristic curves illustrating loss in stability or internal resistance of a crushed sandy gravel due to the addition of increments of 1plastic clay.The combined figures 1(a) and 1(b) clearly indicates the instability created by Montmorillonite (Bentonite), Illite (local clay), and Kaolinite in the presence of water. Bentonite fails first followed by Illite. Kaolinite is more stable. R value is taken as S_n, the stability number.

3.2. Moisture Content and Clay Minerals

Moisture content in the soil mass is a major factor for controlling the state of stress of the soil. In general, an increase in the moisture content or degree of saturation in soil will decrease the shear resistance as reflected by cohesion, c, or friction angle, φ. This relationship is shown in terms of cohesion by figures 2 and 3. Geo-Technical Behavior of Kaolinite, K, Illite, I, Montmorillonite, M in the presence of very heavy rainfall (moisture content very high %) of twenty four different combinations of KIM forming three layers of equal thickness. From fig.3 Kaolinite is assigned 150 %, Illite 50%, followed by Montmorillonite 300% as moisture content (weight ratio). The distribution of moisture content for saturated conditions for twenty four combinations of KIM will be:

1. KIM 150+ 50 + 300 = 500
2. MIK 300 + 50 + 150 =500
3. IMK 50 + 300 + 150 = 500
4. KKK 150+ 150 + 150 =450 (intermediate moisture)
5. III 50 + 50 + 50 = 150 (minimum moisture)
6. MMM 300 + 300 + 300=900 (maximum moisture)

   Similarly calculating for KII,IKI,IIK, the % will be 250 each.

   Similarly for others IKK,KIK,KKI, the % will be 350 each.

   Then similarly MII,IMI,IIM will be 400.

   KMM,MKM,MMK will be 750.

   KMI, IMM, MIM will be 500,650 & 650 respectively.

   And finally MMI,MKI,IKM will be 650, 500 & 500 respectively.

Considering all the combinations the % of moisture content varies from 150 to 900. Considering each combination of the twenty four figures the soil will be saturated if the % of rainfall over the dredged materials (Fill) reaches 900%. The cohesion becomes zero for the entire fill whatever may be the combination.

The important stages in the % of moisture content starts from III 150% (minimum) KKK 450% (intermediate) and MMM 900% (maximum %). The following figure explains how increase in degree of saturation decreases cohesion for weathered residual soil. The figure shows the effect of moisture content on cohesion for four basic clay minerals. The cohesion c becomes zero for Kaolinite at moisture content 150%, for Illite 50% followed by Montmorillonite 300%.

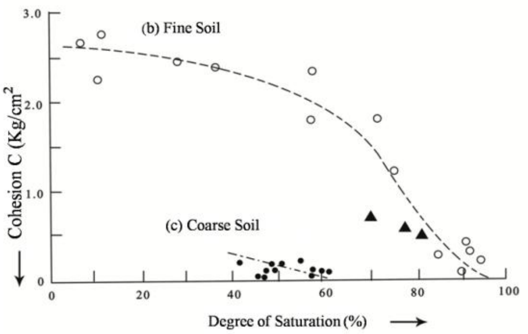

Fig. 2. Increase in degree of saturation decreases cohesion for weathered residual soils. [2].

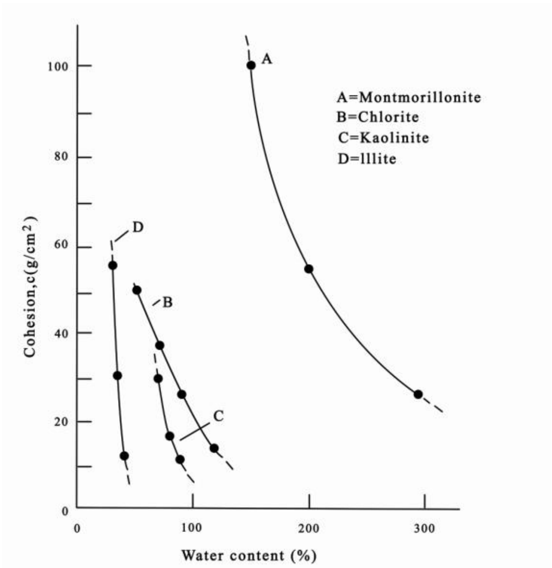

Fig. 3. Effect of moisture content on cohesion for four basic clay minerals. [3] [4].

3.3. Clay Minerals and Effect on Time

Shear strength of soils decreases with time, mainly caused by local environmental changes such as weathering, wet-dry cracking, creep and many others. These environmental factors can cause the loss of bonding stress between soil particles, resulting in a gradual loss of shear resistance as shown in fig. 4.

4. GEO – TECHNICAL RESPONSE OF DREDGED MATERIALS

The dredged materials represent Geo disturbed soils with erratic variation in Geo-technical properties. In a rainy season in the beginning the rain first compensates soil moisture deficiency.

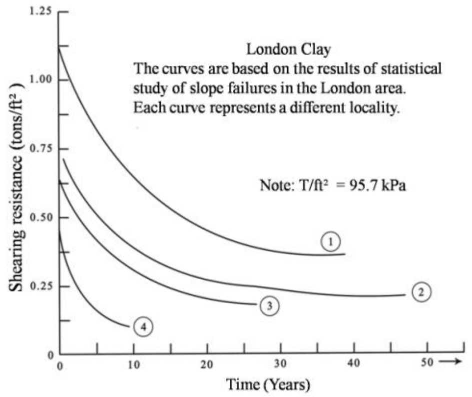

Fig.4. Gradual decrease of shear resistance of stiff clay with time. [5].

Different clays absorb different amount of water. Upto shrinkage limit the stability is not affected by ever increasing amount of water. When there is very heavy continuous rain the different clays reach liquid limit with time lag. One layer of pocket will reach liquid limit and other may not. But when there is very heavy downpour (rain) all the layers reach their liquid limit state simultaneously and due to this shear failure occurs upto the depth influenced by shrinkage index. It is easier method to connect stability of dredged soils and shrinkage index to explain shear failure or liquefaction of the dredged fills. Ultimately the understanding of the mineralogy and consolidation properties of the dredged materials will help to explain stability related problems. From Fig. 1a, 1b conceptual model of three layer system consisting of Kaolinite, Illite and Montmorrillonite is considered with symbols K, I and M respectively. The layers in order before dredging has become chaotic after dredging. In order to take order out of chaos, 24 different combinations of K, I and M are considered. The following combinations are

1.KIM 2.MIK 3. IMK 4.KKK 5.III
6.MMM 7.KII 8. IKI 9.IIK 10.IKK
11.KIK, 12.KKI 13.MII, 14.IMI 15.IIM
16.KMM 17.MKM 18.MMK 19.KMI 20.IMM
21.MIM 22.MMI 23.MKI, 24.IKM The following Figures 5.1 to 5.10 represent the assumed order out of chaos of clay minerals after dredging operations. For simplicity out of 24 possible figures only ten figures are shown below as examples. In these figures the relationships among R value which is S_n, % of clay fraction and shrinkage index I_s is shown in fig.5.1 to 5.10.

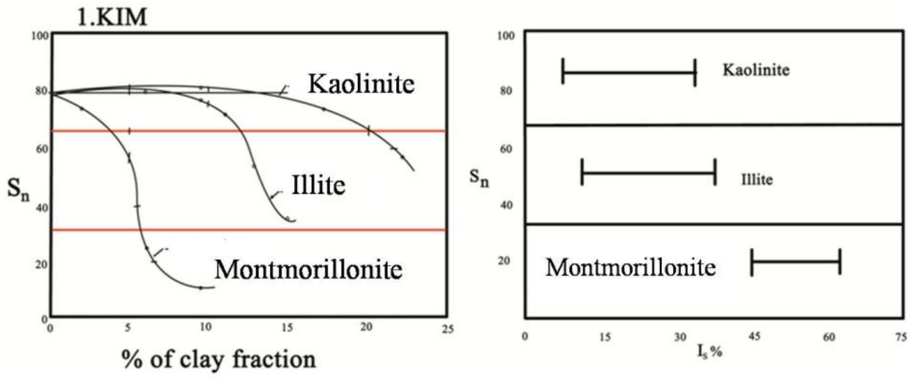

Fig.5.1 KIM - Shrinkage Index (I_S)

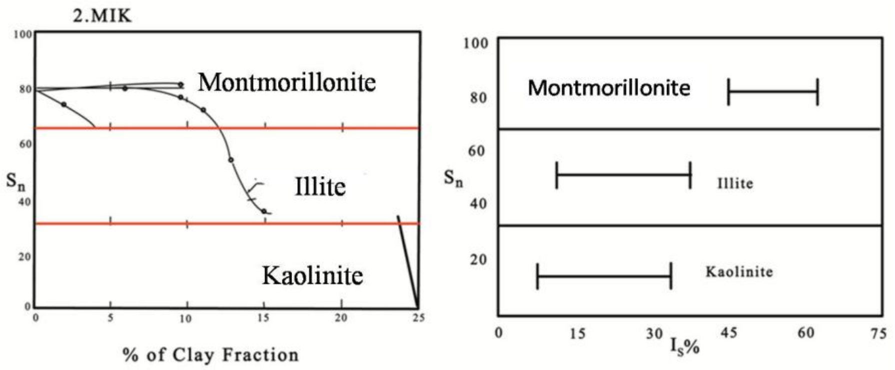

Fig.5.2 MIK - Shrinkage Index (I_S)

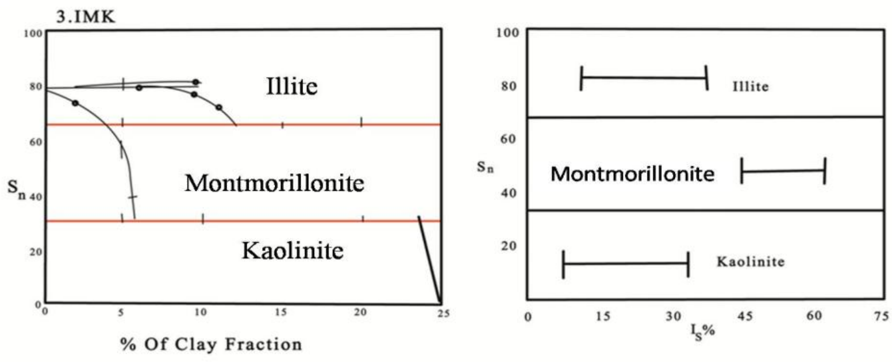

Fig. 5.3 IMK - Shrinkage Index (I_S)

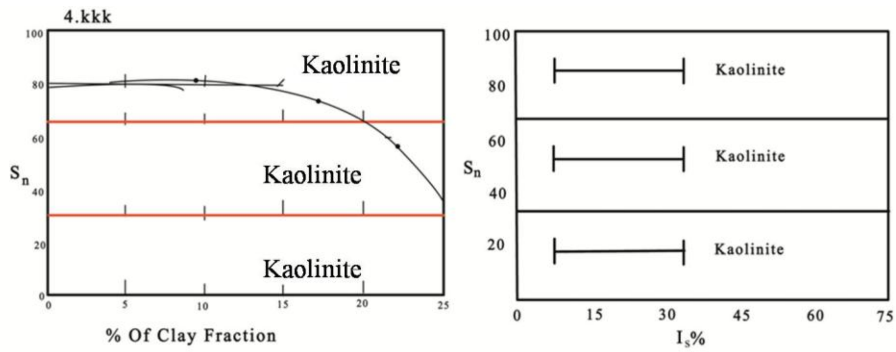

Fig.5.4 KKK - Shrinkage Index (I_S)

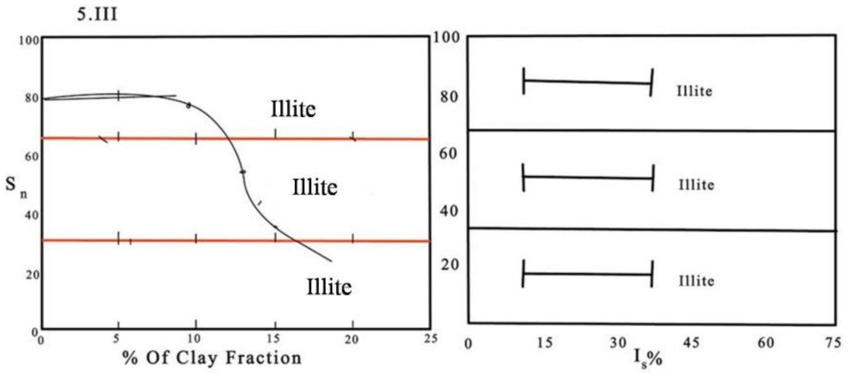

Fig.5.5 III - Shrinkage Index (I_S)

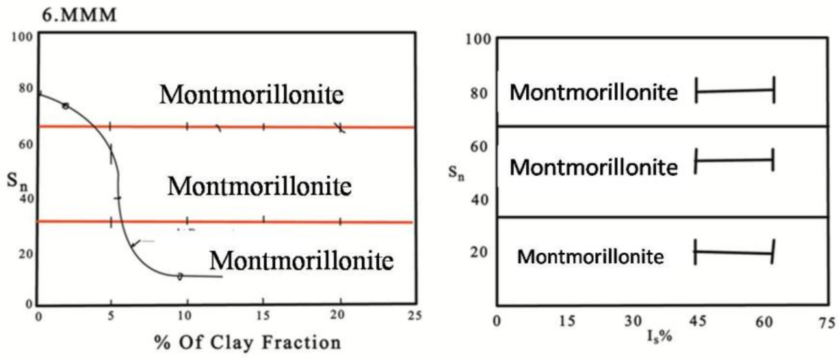

Fig.5.6 MMM - Shrinkage Index (I_S)

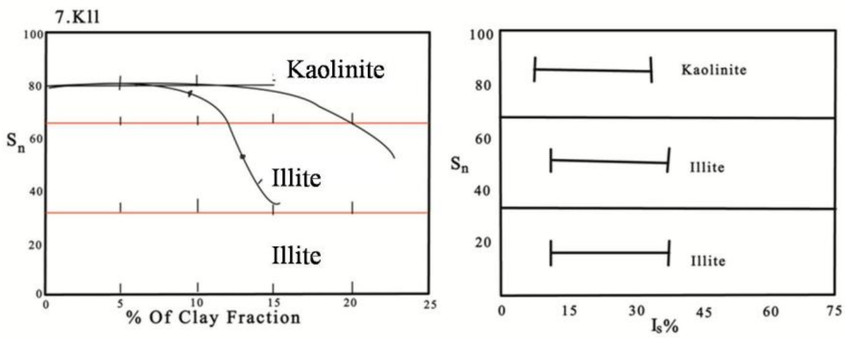

Fig.5.7 KII - Shrinkage Index (I_S)

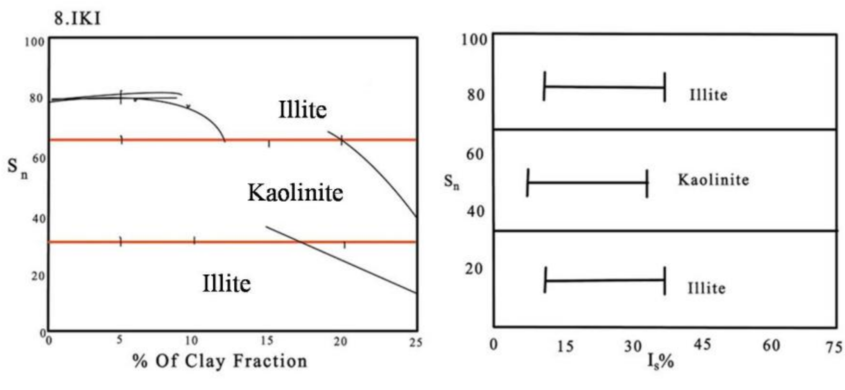

Fig.5.8 IKI - Shrinkage Index (I_S)

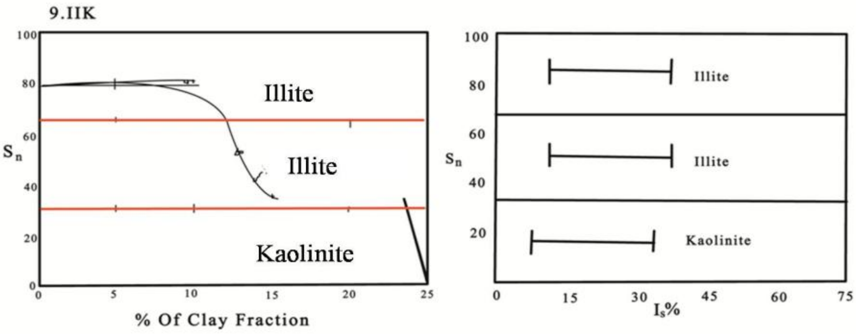

Fig.5.9 IIK - Shrinkage Index (I_S)

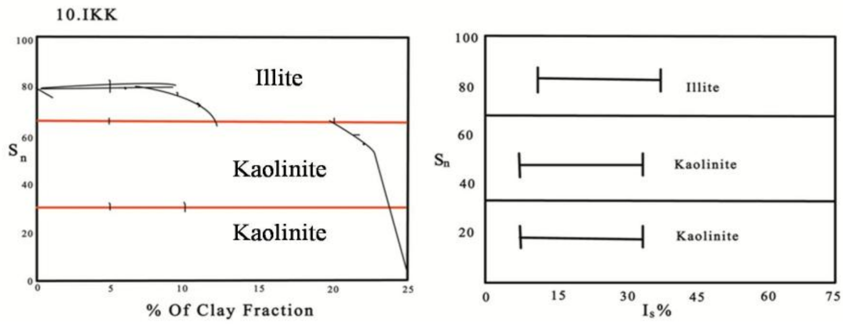

Fig.5.10 IKK - Shrinkage Index (I_S)

5. THE ROLE OF CO-EFFICIENT, C_V, AND SHRINKAGE INDEX, I_S, IN DREDGED MATERIALS

In Geo-technical Engineering it is always desirable to relate c_v to index properties of the sediments. Out of plasticity index and shrinkage index, in documented research papers it is found that c_v has a better correlation with shrinkage limit and hence it is used in the discussion. The important equations are:

Coefficient of consolidation c_v (in m^2/s) can be expressed as: [6]

$$c_v = \frac{K}{\gamma_W m_v} \quad \text{Eq. (1)}$$

$$c_v = 3/100\,(I_S)^{3.54} \quad \text{Eq.(2)}$$

For which correlation co-efficient is r = 0.94 for equation 2

Where k=hydraulic conductivity (m/s)

m_v =coefficient of volume change (m^2/kN)

γ_w =unit weight of pore fluid (kN/m^3)

I_S = Shrinkage index =($W_L - W_{SL}$)

It is well known that the coefficient of consolidation is a parameter that indicates the rate of compression of a saturated soil undergoing compression, which in turn directly depends on the hydraulic conductivity of the soil medium undergoing compression The authors feel that for a soil that is more plastic as indicated by higher plasticity index or shrinkage index(Montmorillonite),hydraulic conductivity of the soil at any stress level will be less as compared to a soil that is less plastic. The reason being that the thickness of diffuse double layer (ddl) will be relatively larger for a highly plastic soil as compared to a less plastic soil. The thicker the ddl, the greater the reduction in the effective pore size for flow, and hence, reduction in the hydraulic conductivity of soil.This is the reason for c_v values being relatively higher for less plastic soils than for more plastic soils, though their liquid limit is nearly the same.

As the effective consolidation pressure for a normally consolidated soil increases, the soil particles become more oriented and also come close to each other. a consequence, for more plastic soils (Montmorillonite), the diffuse double layer repulsive forces mobilize, acting against the external loading, and hence, offer more resistance to compression (both rate and amount). This may be the reason for the decreasing trend of c_v versus σ'_v for more plastic soils. In the case of less plastic soils(Kaolinite, Illite) whose compressibility behavior is governed mainly by mechanical forces, as the consolidation pressure increases, the gravitational forces increase and will override the little repulsive pressure at the particle level in retarding the compression of soil, and hence, the increase in the rate of compression of the soil, i.e., an increase in c_v with pressure. This explains the varying trends of c_v versus σ'_v for soils with different plasticity properties.

6. CLAY MINERAL STRUCTURES

1.Kaolinite Group: Members of this group are considered 1:1 minerals because there is 1 tetrahedral sheet for every octahedral sheet. Within the octahedral layer there are generally aluminum atoms , and within the tetrahedral layer the cations are silicon.
2. Illite Group: Illite has a 2:1 structure and consists of a gibbsite sheet between two silica tetrahedral sheets, with the layers bounded together by potassium cations in the inter layer region.The octahedral cations are aluminum, magnesium or iron, and the tetrahedral cations can be aluminum or silicon.
3. Montmorillonite Group: Montmorillonite is a 2:1 mineral and consists of two sheets of silica tetrahedra on either side of a gibbsite sheet. Sodium (Na) Montmorillonite is a common form of the clay within bentonite, and expansive clay often specified in conjunction with drilling muds, borehole ceiling, and waste containment.

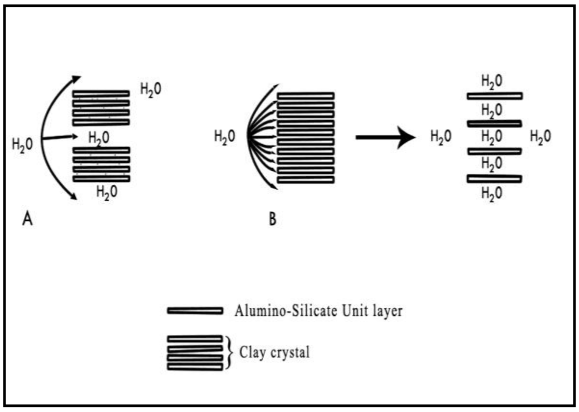

Fig.4. Moisture up take by clay minerals. A. with non-expanding Lattice. B. with expanding Lattice. [7].

Apart from the smectites other minerals with expanding lattices which are capable of taking up water on internal surfaces include vermiculite, swelling chlorites, halloysite and some interstratified mixed –layer minerals. The extent of swelling is more restricted than in the case of Na-montmorillonite.

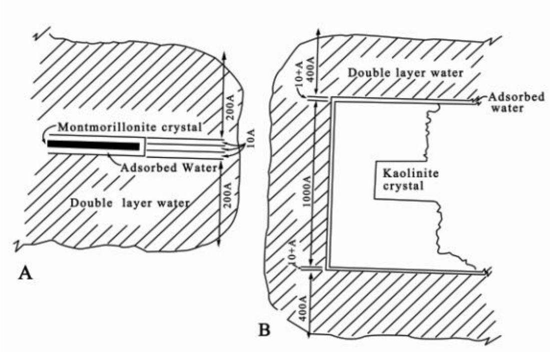

Fig.5. Relationships of clay crystals to surface and double layer water.(After Lambe, 1958 b, p.17).
A. typical Montmorillonite particle 1000Å/10Å.
B. typical Kaolinite particle 10,000Å/1000Å. [7].

7. DREDGED SEDIMENTS AND COAXIAL AND NON-COAXIAL COMPONENTS OF SHEAR STRENGTH

The basic equation for shear strength is $\tau = c + \sigma \tan\phi$ When moisture content is increased (Figs.2 and 3) the cohesion for all the clay minerals approximately reaches zero. The cohesion represents the coaxial component of shear strength or pure shear. Once the sediments lose their binding effect what remains is the only the residual angle of internal friction (ϕ) or non-coaxial component of shear strength or simple shear, which may not be sufficient to resist ever increasing water in lowland coastal areas. In this state shear failure or landslide will be the only choice.

8. CONCLUSIONS

1. Dredging operations which is one of the anthropogenic activity, interferes and interrupts Geological formations and their processes. It creates imbalance to soils, flora and fauna, especially in the cases of 2/1 and 1/1 clay mineral types like Montmorillonite, Kaolinite and Illite.
2. The Geo-technical behavior of dredged sediments are drastically modified due to excessive rainfall.
3. The cohesion of the dredged sediments consisting of KIM (Kaolinite, Illite and Montmorillonite) decreases with increase in moisture content and hence decreases shear strength of the sediment fill.
4. The water absorbing and retaining capacity even at higher moisture content percentage depends upon the type of clay minerals.
5. Retaining shear strength at very high moisture

content depends upon the shrinkage index I_S where $I_S = (W_L - W_{SL})$ Where W_L is liquid limit of the soil and W_{SL} is the shrinkage limit of the soil expressed in %.

6. When the shear strength approximately becomes zero the moisture content requirement for loss of shear strength varies from pocket to pocket variation in soil types. In other words the Montmorillonite combination (MMM) can tolerate moisture content upto 900% before failure in an ideal situation. And this combination, MMM is one of the 24 possibilities as shown in figure 5.6

7. In the random variation of dredged materials and their Geo-technical properties depend mainly upon shrinkage index (which is different from shrinkage limit).

8. When clay minerals take water from dry state to liquid limit state the clay minerals with ddl (diffuse double layer) convert water into solid water which is included in ddl and offer resistance to effective stress which in turn modifies co-efficient of consolidation and permeability of the sediments.

9. When dredged materials are used as a fill in coastal areas invariably saline water is included as pore water and hence the Geo-technical index properties are modified along with shear strength.

10. However, when there is heavy downpour of rain, all the above mentioned and discussed Geo-technical parameters which resist the incoming water or flood water fail in shear. No matter what the soil type is out of the 24 combinations which is only order out of chaos and not an exhaustive list of permutations and combinations and probabilities.

11. The dredged sediments should be treated as remolded samples.

12. The final conclusion is that water is more powerful than solids of the soils and sun is more powerful because it converts water into water vapor.

9. REFERENCES

[1] Francis N Hveem, “Importance Of Clay In Applied Soil Mechanics, Clays And Clay Material”, 1952 Vol.1,No.1, pp.191-195.

[2] Lumb P, “The Properties Of Decomposed Granite, Geo-Technique”, 1962,Vol.12, No. 3, pp.226-243.

[3] Shibuya T, “Geological Study Of Landslide Clay”, KICT Report No.10 Kajima Institute of Construction Technology, Tokyo, July,1973 pp.37

[4] Fang HY, “Introduction To Environmental Geo-Technology”, CRC Press, Boca Raton, FL, 1997 pp.652.

[5] Skempton AW, “Long – Term Stability Of Clay Slopes”, Geo-Technique Vol. 14 No.2 1964, pp.77-102.

[6] Sridharan A, Nagaraj HB, “Coefficient of Consolidation and its Correlation with Index Properties of Remolded Soils” Geotechnical Testing Journal, Vol. 27, No.5 Paper ID GTJ10784

[7] Jacke Gillott, “Clay in Engineering Geology” Division of building research, National Research Council of Canada, Ottawa, Ont., Canada (Elsevier Publishing Company, 1968, pp.109-111.

Int. J. of GEOMATE, Feb., 2016, Vol. 10, No. 1 (Sl. No. 19), pp. 1607-1614.
MS No. 4171 received on June 16, 2014 and reviewed under GEOMATE publication policies.

Corresponding Author: J. Rajaraman