ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 2, Issue 12,December 2017

Paradoxical Behaviour of Shear Strength of Clay with Nano Materials and Additives

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Abstract: **-- Natural clay size soil particles are bigger than nanoparticles. Addition of nanoparticles in the presence of water modifies cohesion (c) and angle of internal friction(φ) of the clay soil. When organic materials are added the behavior is different. If inorganic material is added the behaviour is entirely different. Available research documents show that in a soil sample the cohesion increases and internal friction decreases with increase in clay fraction or the percentage. This is a normal Geotechnical behavior of clay and shear strength. But when organic fibers are added along with inorganic nano (Sio2) the Geotechnical behavior is entirely different. Both cohesion and angle of internal friction show an increasing trend. The normal association and dissociation adjustment between cohesion and angle of internal friction is followed in the presence of water and inorganic natural particles. If organic fibers are mixed Geotechnical behavior is entirely different and abnormal. The paradoxical behavior of shear strength of clay (increase in cohesion c and increase of angle of internal friction φ) is due to unnatural, manufactured nano Sio2 and fibers. The slope of the c, φ curve for a natural soil material is opposite to the slope of soil with artificial additive fibers. The conclusions are: 1. The paradoxical behavior of shear strength of clay is interpreted and explained. 2. In c,φ curve the slope is different and opposite to the natural behavior of clay confirms the presence of pollutants like nano Sio2 or fibers or any other artificial organic additives. 3. The opposite slope helps to detect and estimate organic pollutants.**

Index Terms— Cohesion, Angle of Internal Friction, Shear Strength of soils, Contaminated Materials, coaxial and non-coaxial strains.

I. ISOTROPIC STRESS AND DEVIATORIC STRESS

The amount of water existing in the soil mass will significantly influence the engineering behavior of soil. Karl Terzaghi has said, in effect, that there would be no need for soil mechanics if not for the water. This is because the presence of water affects the state of stress within a soil mass. The water content also has bearing on the potential volume change, progressive failure, densification, shear strength, and settlement. The mechanism of soil –water interaction is complex and its behavior is not only dependent on soil types, but is also related to the current and past environmental conditions and stress histories, In Fig 1(a) Isotropic stress acts equally in all directions, it results in a volume change of the body. In fig 1(b) Deviatoric stress, on the other hand, changes the shape of a body. [1].

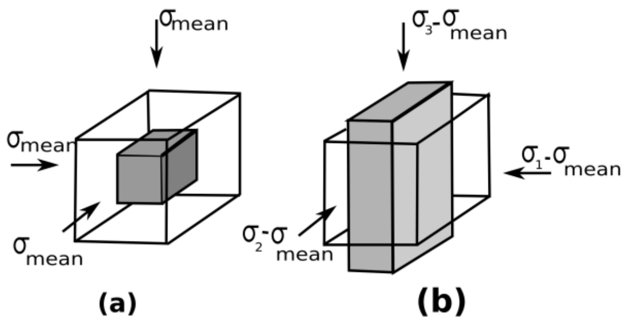

Figure 1 The mean (hydrostatic) and deviatoric components of the stress. (a) mean stress causes volume change and (b) Deviatoric stress causes shape change.

II. THE CONCEPT OF COAXIAL AND NON-COAXIAL COMPONENTS OF SHEAR STRENGTH

In a homogeneously strained, two-dimensional body there will be at least two material, lines that do not rotate relative to each other, meaning that their angle remains the same before and after strain. A material line connects features , such as an array of grains, that are recognizable throughout a body's strain history. The circle deforms and changes into an ellipse.

In homogeneous strain, two orientations of material lines remain perpendicular before and after strain. These two material, lines form the axes of an ellipse that is called strain ellipse. The principal incremental strain axes rotate to the finite strain axes, a scenario that is called non- coaxial strain accumulation. The case in which the same material, lines remain the principal strain axes at each increment is called coaxial strain accumulation. The coaxial component of shear strength is called pure shear and the non-coaxial component of shear strength is called simple shear. The combination of simple shear (a special case of non-coaxial strain) and pure shear (coaxial strain) is called general shear or general non-coaxial strain. Two types of general shear are possible. The following figure 2 explains simple shear and pure shear [1].

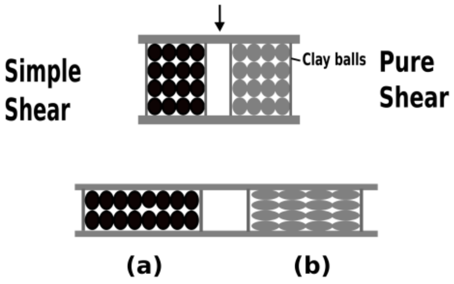

Figure. 2 Simple Shear and Pure Shear Explained

In Figure 2 The rigid spheres slide past one another to Accommodate the shape change without distortion of the individual marbles . In figure 4b the shape change is achieved by changes in the shape of individual clay balls to ellipsoids, are quite different.

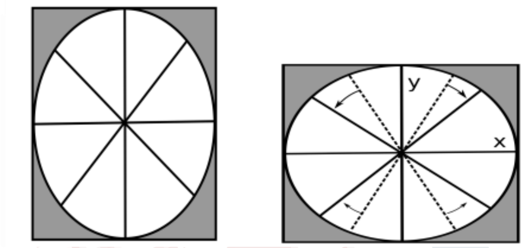

Figure.3 Homogeneous Strain

In Figure 3.Homogeneous strain describes the transformation of a square to a rectangle or a circle to an ellipse. Two material lines that remain perpendicular before and after strain are the principal axes of the strain ellipse [solid lines]. The dashed lines are material lines that do not remain perpendicular after strain; they rotate toward the long axis of the strain ellipse.

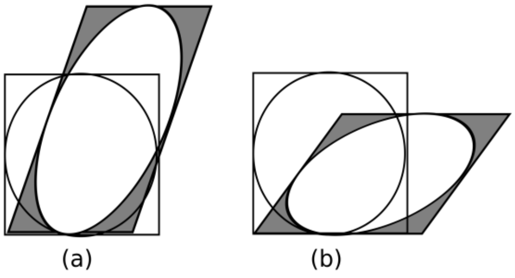

Figure.4 Combination of Simple Shear and Pure Shear

In Figure 4 a combination of simple shear [a special case of non-coaxial strain] and pure shear [coaxial strain]is called general shear or general non-coaxial strain. Two types of general shear are transtension [a] and transpression[b], reflecting extension and shortening components. [1]

III. THE PROPERTIES OF SEDIMENTS DERIVED FROM SECONDARY ROCKS AND MANIFESTATION OF COAXIAL AND NON-COAXIAL COMPONENTS OF SHEAR STRENGTH

The properties of sediments derived from secondary rocks are worth mentioning in this context:

(1)Rock is aggregate of minerals. Chemical composition is a direct function of mineralogy, and mineral composition varies with grain size. The major- element chemical composition of shales and mudstones is related also to grain size.

(2)Grain size and shape, control coaxial and non-coaxial strains of the sediments. Angular grains increase the angle of internal -friction of the soil.

(3)Because the chemical composition of siliciclastic sedimentary rocks is closely related to the mineral composition of these rocks, the chemical composition varies as a function of grain size along with variations in mineralogy. For example that SiO_2 abundance decreases progressively from fine sands to fine clays, whereas the Al_2O_3 content systematically increases.

(4)Quartz arenites composed of 90 to 95% siliceous grains quartz, chert, quartzose rock fragments).

(5)Fine grained siliciclastic sedimentary rocks, composed mainly of particles smaller than approximately 62 microns, make up approximately 50% of all sedimentary rocks in stratigraphic record.

(6)Quartz tends to be more abundant in coarse grained mudstones and shales, whereas clay minerals are more abundant in fine grain mudstones and shales.

(7)Quartz arenites are more poorly sorted and may contain high percentages of sub-angular to angular grains. Some quartz arenites exhibit textural inversions such as a combination of poor sorting and high rounding, a lack of correlation between roundness and size, such as small round grains and larger angular grains, or mixtures of rounded and angular grains within the same size fraction. These textural inversions probably result from mixing of grains from different sources, erosion of older sandstones, or environmental variables such as wind transport of rounded grains into a quiet- water environment.

(8)Angular grains may result also from development of secondary overgrowths.

(9)Now the problem has to do with the inherent relationship of parent rock grain size and size of rock fragments. Only fine size parent rocks yield substantial quantities of rock fragments of sand size. Therefore, coarse grained parent rocks are poorly represented by rock fragments in sandstones.

(10)Collectively, the changes brought about in the composition of sediment by weathering and erosion, transport, reworking at the depositional site can be significant. Provenance analysis requires that we cannot use the absence of particular constituents as a guide to provenance interpretation; we can use only the presence. The fact that feldspars and heavy minerals may be absent or scarce in sandstone, for example, does not mean that they were necessarily absent or scarce in the source rocks. Feldspars would have been converted chemically to clays.
The ultimate products of weathering following the above properties of sediments ends up in sand and clay. The coaxial and non-coaxial components of shear strength are the hidden signature to sediments in the presence of water.

IV. THE COMPLEX FUNCTION – PERMEABILITY [2]

Permeability is a complex function of particle size, sorting, shape, packing ,and orientation of sediments. These variable factors can be expressed in terms of heterogeneity factor. For a formation with a mixture of clay and sand the following equations with this heterogeneity factors and This variable factor CV is believed to decrease with decreasing particle size and decreasing0 sorting .This factor CV is affected by particle orientation. It is also affected by the orientation parallel to bedding plane or perpendicular to the orientation. To make it a simple factors for the purpose of calculation the heterogeneity of clay is taken as

C_{V_1} and for sand as c_{v_2}.

The general eqn for C_V total is (C_V = Coefficient of variation or Heterogeneity)

$$c_{v_{total}} = \sqrt{pc_{v_1}^2 + (1-p)pc_{v_2}^2}$$

P = 1 (Taking element No: 1 as clay)

Element 2 sand (1 - p) = o

$$c_{v_{total}} = \sqrt{1c_{v_1}^2 + (1-1)c_{v_2}^2}$$

$$c_{v_{total}} = \sqrt{c_{v_1}^2} = c_{v_1}\text{(for clay)}$$

Similarly for p = 0 for clay

$$c_{v_{total}} = \sqrt{0c_{v_1}^2 + (1-0)c_{v_2}^2}$$

$$C_{v_{total}} = \sqrt{c_{v_2}^2} = c_{v_2}\text{(for sand)}$$

The common shear strength eqn is $\tau = [C + \sigma \tan \phi]$ where τ is shear strength, C is cohesion and σ is normal stress and ϕ is the angle of internal friction of the soil.

$\tau = [C + \sigma \tan \phi] \cos \alpha$ x

$$\sqrt{pc_{v_1}^2 + (1-p)c_{v_2}^2}$$

$$\cos\alpha = \sqrt{pc_{v_1}^2 + (1-p)c_{v_2}^2}$$

$$\tau = (c + \sigma \tan\phi)\sqrt{pc_{v_1}^2 + (1-p)c_{v_2}^2}$$

When $\alpha = 90^0$, $\cos \alpha = 0$ for pure clay p = 1, Sand (1 - p) = 0, $\phi = 0$.

$$\tau = (c + \sigma\tan(0))\sqrt{c_{v_1}^2 + 0c_{v_2}^2}\text{, for } \cos(90^0) = 0$$

$$\tau = C(C_{v_1})\text{ for pure clay. } C_{v_1} = 1, \tau = C$$

For pure sand p = 1. $\tau = (C + \sigma \tan \phi)$

$$\tau = (C + \sigma\tan\phi)\sqrt{pC_{v_1}^2 + (1-p)C_{v_2}^2}\text{ for } \cos 0 = 1$$

For pure sand p = 0.

$$\tau = (C + \sigma\tan\phi)\sqrt{0C_{v_1}^2 + (1-0)C_{v_2}^2}$$

$\tau = (C + \sigma \tan \phi)(\sqrt{0} + C_{V_2}^2)$

$$\tau = (C + \sigma\tan\phi)C_{v_2}$$

For clay C = 0,
$\tau = (C_{v_2})\,\sigma\tan\phi\text{, and } C_{v_2} = 1$
Heterogeneity
$C_{v_1} \text{ or } C_{v_2} = 1$
$\tau = \sigma \tan \phi$,

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ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering
(IJERMCE)
Vol 2, Issue 12,December 2017

V. PARTICLES PATHS OR FLOW LINES DURING PROGRESSIVE STRAIN ACCUMULATION.

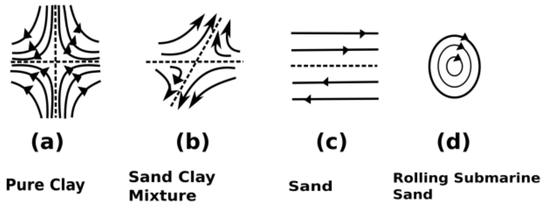

Figure.5 Particle paths or flow lines during progressive strain accumulation

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In Fig (5) flow lines represent pure shear [a], general shear [b], simple shear [c], and rigid –body rotation [d]. The cosine of the angle α is the kinematic vorticity number,W_k for these strain histories; W_k =0, 0< W_k <1, W_k=1, and W_k = ∞ respectively. Avoiding the math, a convenient graphical way to understand this parameter is shown in fig.7. When tracking the movement of individual points within a deforming body relative to a reference line, we obtain a displacement field (or flow lines) that enables us to quantify the internal vorticity. The angular relationship between the asymptotes and the reference line defines W_k. W_k =cos α.

For pure shear W_k= 0 fig. 7a, for general shear 0< W_k <1 fig. 7b and for simple shear W_k = 1 fig 7c . Rigid- body rotation or spin can also be described by the kinematic vorticity number (in this case, W_k = ∞ fig. 7d).When α = 0^0, Cos α= 1, represents simple shear. When α = 90^0, Cos α = 0, represents pure shear. (3).

The component describing the rotation of the material lines with respect to the principal strain axis is called the internal vorticity, which is a measure of the degree of non-coaxiality.

If there is zero internal vorticity, the strain history is coaxial, which is sometimes called pure shear. The non-coaxial strain history describes the case in which the distance perpendicular to the shear plane remains constant; this is also known as simple shear.

VI. THE RELATION BETWEEN COAXIAL AND NON-COAXIAL STRAIN AND SKEMPTON POINTS [3]

For interpretation the data (after Skempton,1964) indicating the variations of angle of internal friction (φ) with percentage of clay content is shown in a family of nine points, distributed over the first three quadrants as shown in fig.6.

This figure.6, shows the sharing of coaxial and non-coaxial strain or strength by different soil samples. No point lies in quadrant IV which is high cohesion and high friction zone but in nature high cohesion and high friction cannot exist together in a soil sediment system, when sharing the same volume or space between clay and sand (0.0,1.0 or 1.0,0.0).

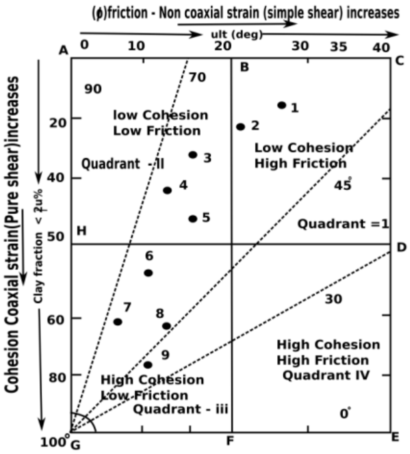

Figure.6 Variation of φult with percentage of clay content. (After Skempton 1964) All Skempton points lie in quadrants I, II,III [3].

In the above fig.6.,if ∝ = 0, the slope line coincides with x axis , GFE, cos ∝= cos0 = 1.0. If ∝ = 900, the slope line becomes vertical and coincides with y axis, GHA, cos∝ = cos 900 = 0.0.

VII. ANALYSIS OF GEOTECHNICAL DATA C AND Φ [4]

Table 1 shows variation of coaxial and non coaxial component of shear strength with percentage of clay content in each sample. In other words it is the variation of cohesion and angle of internal friction. The combined table is shown in figure x.

Table 1: Laboratory Test Results

Sample	Clay Content (%)	NMC (%)	PI (%)	C (KPa)	ϕ°	C_c	e_o
A	6.8	10.2	12.1	40	28	0.05	0.42
B	7.0	10.0	13.2	66	25	0.05	0.4
C	16.9	9.9	16.7	120	24	1.0	0.38
D	22.3	10.3	18.2	140	20.2	0.12	0.35
E	24.1	10.1	20.3	142	20	0.12	0.34
F	27.0	10.0	22.1	150	17.5	0.12	0.20

G	27.5	10.4	23.2	155	15	0.2	0.19
H	29	10.3	25.0	163	15	0.18	0.15
I	30	10.0	26.6	163	12.6	0.18	0.1
J	31.2	10.2	26.6	165	12.6	0.19	0.1

NMC- Normal Moisture content, PI- plasticity index, C-cohesion,φ0-Angle of Friction, Cc –Compression index, e0-Initial void ratio

A matrix curve is prepared taking C, φ values and the percentage of clay content. This is called Table(1) Curve.

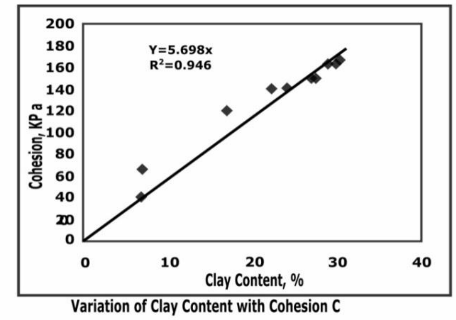

Fig 7 Variation of Clay Content with Cohesion C

Figure 7 shows a graph of the clay content and the cohesion taken (From Table1). The cohesion increases with increasing clay content. In other words the coaxial component of shear strength increases with clay content.

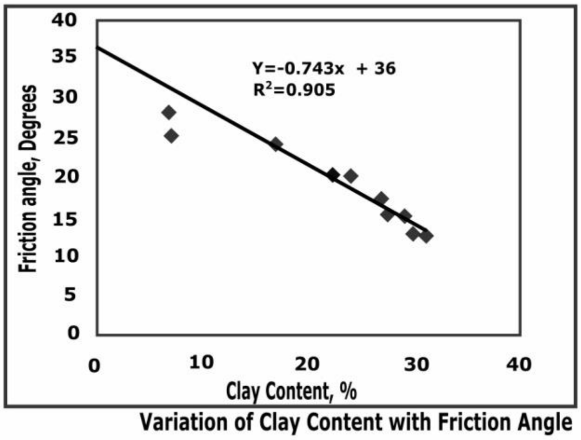

Fig 8 Variation of Clay Content with Friction Angle

The graph of clay content and friction angle taken (From Table1)is presented in fig 8. In other words the non coaxial component of shear strength decreases with increasing clay content.

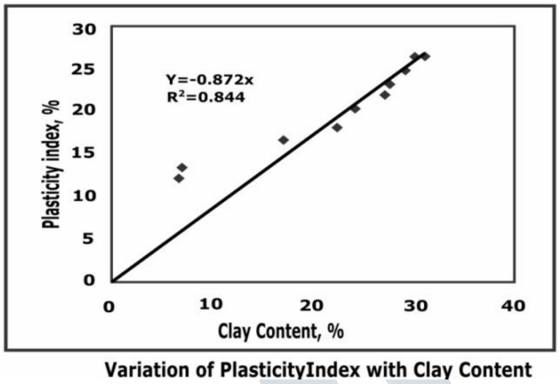

Fig 9 Variation of Plasticity Index with Clay Content

Fig 9 shows the variation of plasticity index (PI) with increasing clay content taken (From Table1). The plasticity index is moisture sensitive. The clay content and moisture content manifests and create association and dissociation property of shear strength of clay in terms of coaxial and non coaxial components of shear strength.

VIII. STRENGTH PROPERTIES OF SOFT CLAY TREATED WITH MIXTURE OF NANO-SIO2 AND RECYCLED POLYSTER [5]

The shear strength parameters of specimens are illustrated in table 2. It is clear from table 2 that the specimens reinforce with recycled polyester fiber exhibit an increase in the shear strength parameters.

Table 2
Shear parameters of fiber reinforced clay.

Specimens No.	Fiber content (%)	Cohesion, c (kPa)	Angle of internal friction, ϕ (°)
1	0	38	13.5
2	0.1	56	14.6
3	0.3	59	19.3
4	0.5	64	23.3

In table 3 it is shown that the increase in nano –Sio2 content, the shear strength parameters also increase.

Table 3
Shear strength parameters of clay stabilized with nano-SiO2.

Specimens No.	Nano-SiO_2 content (%)	Cohesion, c (kPa)	Angle of internal friction, ϕ (°)

1	0	38	13.5
2	0.5	40.6	21.8
3	0.7	42.3	27.92
4	1	45	29.46

Table 4 shows the shear strength parameters of fiber-reinforced clay stabilized with 0.5% nano-sio2. In this case also the shear strength parameters increase with fiber content.

Table 4
Shear strength parameters of fiber-reinforced clay stabilized with 0.5% nano-SiO2.

Specimens No.	Fiber content (%)	Cohesion, *c* (kPa)	Angle of internal friction, ϕ (°)
1	0	38	13.5
2	0.1	65	23.55
3	0.3	73	27
4	0.5	83	30

Similarly in table 5 the shear strength parameters increase with fiber reinforced clay stabilized with 0.7% nano-Sio2 .

Table 5
Shear strength parameters of fiber-reinforced clay stabilized with 0.7% nano-SiO2.

Specimens No.	Fiber content (%)	Cohesion, *c* (kPa)	Angle of internal friction, ϕ (°)
1	0	38	13.5
2	0.1	90	25.4
3	0.3	100	33
4	0.5	103	32

Table 6 shows increase in shear strength parameters with fiber reinforced clay stabilized with 1% nano- Sio2.

Table 6
Shear strength parameters of fiber-reinforced clay stabilized with 1% nano-SiO2.

Specimens No.	Fiber content (%)	Cohesion, *c* (kPa)	Angle of internal friction, ϕ (°)
1	0	38	13.5
2	0.1	93	33.8
3	0.3	107	36.8
4	0.5	113	38.5

It should be noted that plastic pollution is a threat to marine eco systems as plastics are persistent, toxic and accumulate up the food chain. This study assessed the abundance of small pieces in along, India. It is estimated that an average of 81mg of small plastic fragments per kg of sediment which is due to the direct result of ship breaking. The paradoxical behavior of the sediment sample is due to the presence of organic pollutants. Hence this opposite slope method which is discussed in this paper gets paramount importance in the study of pollution and their effect on geotechnical behavior of clay. [6]

IX. APPLICATION OF OPPOSITE SLOPE METHOD TO DETECT CONTAMINATED ORGANIC AND INORGANIC POLLUTANT.

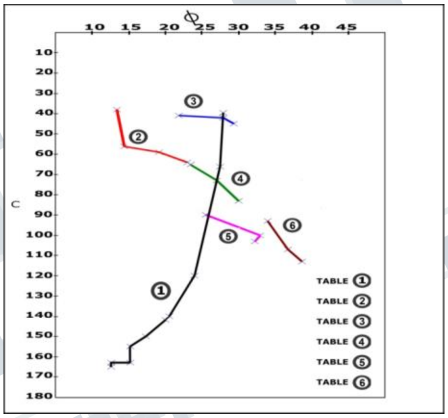

Fig 10 Combined figure (Master Figure) for all tables.

Table 2, 4, 5 and 6 reprent organic and fiber pollutants modifying cohesion and angle of internal friction. Table 3 reprents inorganic SiO2 pollutants . In Fig 10 the curve prepared from Table 1 is the usual shear strength sharing definite trend in slope. All the ___ curves reprented by Table 2,3,4,5 and 6 show opposite slope compared to slope of the curve prepared from (_____ curve) Table (1) The slope of the curve from contaminated clay shown opposite slope which is paradoxical behaviour from normal trend of the slope

X. CONCLUSIONS

The conclusions are: 1. The paradoxical behavior of shear strength of clay is interpreted and explained. 2. In c,φ curve if the slope is different and opposite to the natural behavior of clay confirms the presence of pollutants like nano Sio2 or fibres or any other artificial organic additives. 3. The opposite slope helps to detect and estimate organic pollutants.

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