Advances in Materials Physics and Chemistry, **2012, 2, 102-105**
doi:10.4236/ampc.2012.24B028 Published Online December 2012 (http://www.SciRP.org/journal/ampc)

Influence of Humidity on Yield Stress Determination by Slump Test of Slip-Prone Clayey Soils and Their Relation with the Chemical Properties

Arturo F. Méndez-Sánchez, Ana M. Paniagua-Mercado[1], Karen E. Nieto-Zepeda,
Leonor Pérez-Trejo, Elvia Diaz Valdés, Concepción Mejía García
Escuela Superior de Física y Matemáticas, Instituto Politécnico Nacional, Edif. Unidad Profesional Adolfo López Mateos, Col. Lindavista, México
Email: ampani@esfm.ipn.mx

Received 2012

ABSTRACT

In this work, the yield stress evaluation as a function of water content for slip-prone clayey soils is studied in order to understand how yield stress decreases as water content increases, and their relation with the chemical properties. The clayey soil samples were taken from the region of Teziutlán-Puebla-Mexico. Yield stress was calculated using the slump test in cylindrical geometry. Results show three zones. The first one shows an exponential decrement on yield stress due to lower water content in accord with clayey soils with high content of illita, followed by a second region where yield stress decreases dramatically at a certain critical water concentration, and the third one where yield stress dependence is not well-defined since the clayey soil flow is seen. Finally, it is discussed how yield stress variation due to the water increment influences the landslide risk increment.

Keywords: Clayey Soil; Yield Stress; Slump Test; Microstructure; Illita

1. Introduction

There are a few studies focused to analyze the modified physical parameters before a landslide occurrence [1-3]. Reference [1] implemented a debris-flow monitoring system employing real-time rain gauge data. The pre-warning for the time of landslide triggering derives from the critical rainfall peak obtained from historical events, involving regional rainfall patterns and geological conditions. Reference [2] proposed equations of state of soil prone to slum-type settlement, which take into account the degree of wetting in the initial stage. These equations were developed using models of deformation of the continuous and experimental results of cohesion and the angular coefficient of internal friction as well as the bulk compression and shear modulus. Those authors proposed a plasticity function that decreases exponentially when the wetting content in the soil is increased. It is clear that plasticity function is one of the most important modified parameters before of a landslide occurrence by rainfall. Hence, landslides can take place because of load excess generated by a water saturated soil overcoming yield stress [4-6], as well as, infiltrated water excess in the soil (decrement of the pore pressure) produces a yield stress decrement and the internal load overcomes the decremented yield stress.

In this work, the yield stress evaluation as a function of water content for slip-prone clayey soils due rainfall is studied in order to understand how yield stress is decremented by the water content. Yield stress was calculated for several water concentrations using the slump test in cylindrical geometry. Particularly, samples of the region of Teziutlán-Puebla-Mexico were tested and the results were analyzed and compared with the historical daily rain data of October 1999, when a landslide occurred in the zone. In addition, a comparison of the chemical microstructure and the compound determination using Energy Dispersive Spectroscopy by X-ray dispersion was performed. As well, clayey soils were characterized by SEM observation and X-ray diffraction.

2. Experimental Procedure

The studied clay corresponds to high risk zone located in the Aurora neighborhood in Teziutlán-Puebla-Mexico, where a landslide took place due to high rainfall in October 1999 [7]. The zone where the sample was taken corresponds to a transition zone of two physiographic units-the transversal volcanic belt and oriental mountain chain. Andosol is the predominant soil derived from volcanic materials; also, there are ignimbrites and clayey soils. This kind of soil is characterized by a variable high capacity of acquiring water and humidity.

Microanalyses of chemical composition were performed with an energy dispersive spectroscopy technique (EDS) attached to a scanning electron microscope FEI, Sirion. In addition, X-ray diffraction experiments were carried out employing a MMA, GBC diffractometer in order to determine the clayey compounds, by using $Co_{K\alpha}$ radiation (λ = 1.789Å) in the 2θ range of 5-120 degrees with a 0.02 step and 0.5s as step width and step counting time respectively.

The samples were sifted with a standard mesh No. 8 (2.36 mm) mesh in order to eliminate larger debris. Samples of 0.3 kg of clay were prepared at 30-40 wt% of water concentration, and slump test experiments were carried out [8]. The method consists of filling a cylindrical frustum with the material to be tested in the specified way; lifting the frustum off and allowing the material to collapse under its own weight (**Figure 1**). The height of the final slumped material is measured and the difference between the initial and final heights is called the slump height (*s*). **Figure 1** outlines the experimental procedure.

Yield stress value (τ_y) was calculated by the equation of Pashias and coworkers, expression 1.

$$\tau_y = \rho g H \left[\frac{1}{2} - \frac{1}{2}\sqrt{\frac{s}{H}} \right]. \quad (1)$$

where ρ is the material density, *g* is the gravity, *s* is the slump height, and *H* is the frustum height. In this case, the slump height was measured at room temperature, after 40 seconds lifting the frustum off, as was suggested in a previous work [9,10].

3. Results and Discussion

Figure 2 shows SEM micrographs of clayey soil. It can be observed a granular shape with a fibrous surface of individual particles. **Table 1** shows the chemical composition determined by EDS analysis. High contents of aluminum and silicon were detected as expected for this type of material. Besides, a low content of Iron and Titanium was observed in this material. **Figure 3** shows the particle size distribution. It can be seen that 60% of the particle sizes are in the range between 300 and 1250 microns, the 10% are in the interval 1250- 2360 microns, and the rest 30% of the particle size is shorter than 200 microns.

The X-ray diffraction analysis of clayey soil shows the presence of compounds, such as illite (39.79%), gibbsite (33.74%) and cristobalite (26.47%). The peak identification is shown in **Figure 4** and the Percentage of mineralogical phases is shown in **Table 2**.

Figure 5 shows the plot of yield stress, τ_y, versus water concentration expressed in weight percentage. In the case of contents lower than 35.5 wt%, the yield stress decreases exponentially with concentration. The regression equation is also shown. These results are in agreement with Sultanov and Khusanov's model [2], as well as with that reported by Sánchez-Crúz [9].

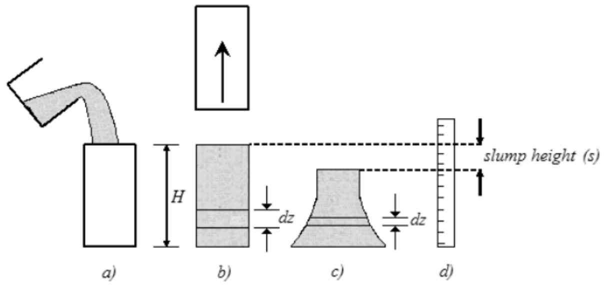
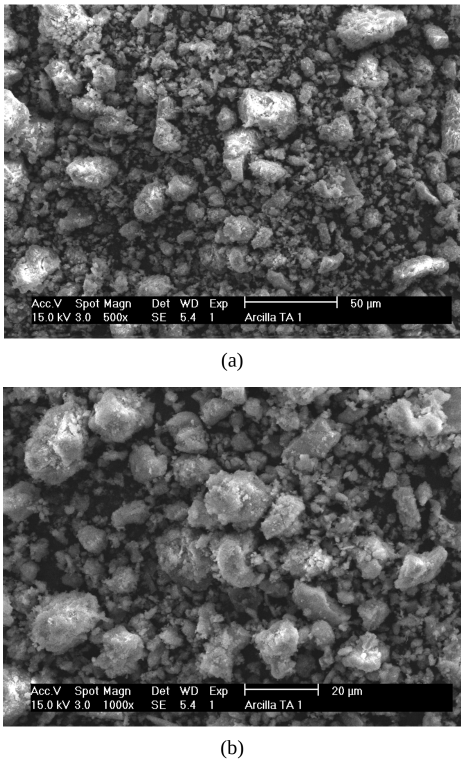


Figure 1. Slump test diagram, a) frustum filling, b) frustum lifting, c) collapsed material, and d) slump height measurement.



(a)

(b)

Figure 2. SEM images at a) 500x and b) 1000x, granular shape with fiber conformation.

Table 1. Chemical composition of clayey soil.

Element	Wt%	Int. Error
O	49.09	0.55
Al	18.17	0.59
Si	23.1	0.55
Ti	1.42	3.37
Fe	8.23	1.46
Total	100	

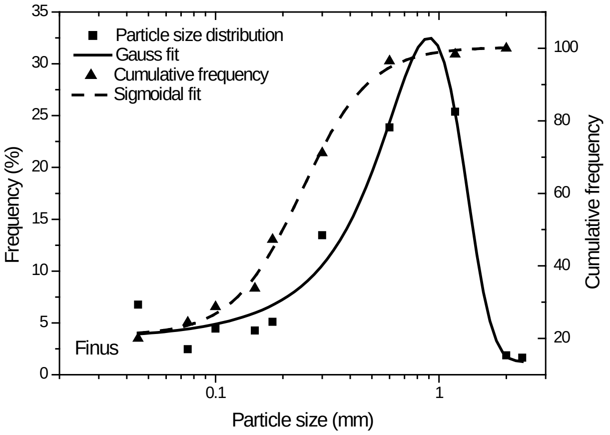


Figure 3. Particle size distribution of the clayey soil.

Table 2. Percentage of mineralogical phases.

Element	Percentage %
SiO_2	39.79
$KAl_2(SiAlO_{10})(OH)_2$	33.74
$Al_2O_3H_2O$	26.47
Total	100.00

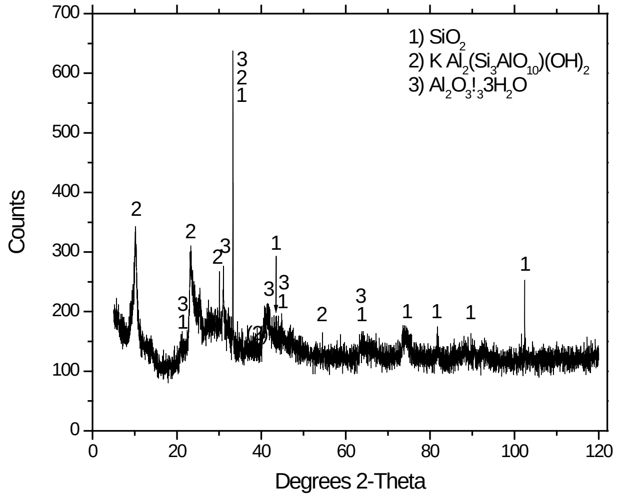


Figure 4. X-ray diffraction pattern of the clayey soil.

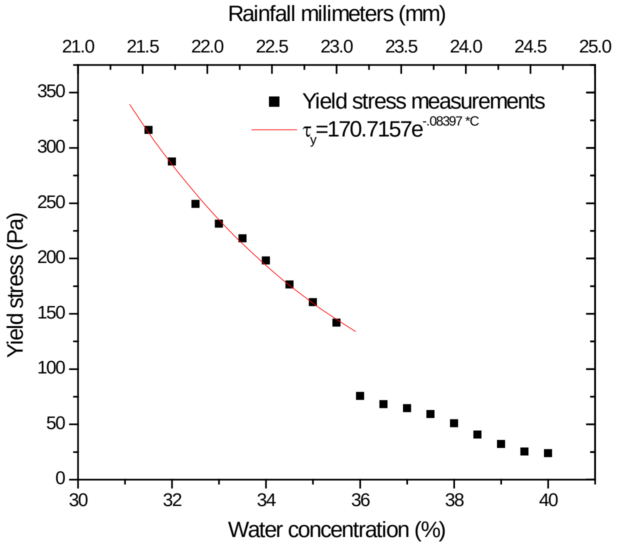


Figure 5. Yield stress versus water percentage concentration.

These authors studied a clayey soil with the presence of illite, which showed a similar behavior. In the case of contents between 35.5 wt% and 36 wt%, the yield stress shows an abnormal behavior and it decreases substantially, up to 50 percent of its initial value. At this point, it is possible to elucidate an increment in the landslide risk, since the sample has changed from solid-plastic to solid-viscous behavior. It is important to mention that this decrease in yield stress was not predicted by the Sultanov and Khusanov's model, in spite of having included the plastic and the viscous behavior in their model. For higher water concentrations (>36 wt %), a non-linear decrement on yield stress is seen and it differs from the exponential or power-law behavior. We believe that this response is due to a combination of non-Newtonian behavior and yield stress and this is not possible to separate them in the slump test.

Additionally, upper horizontal axis in **Figure 5** shows the variation of yield stress versus equivalent millimeters of rainfall. In this case, it was supposed that all of the water was absorbed by the clayey soil. Millimeters of rainfall (*h*) were calculated by using the expression 2.

$$h = \frac{V_w}{A}. \tag{2}$$

where V_W is the water volume in the frustum, and A is the frustum cross section.

Under this assumption, it can be seen that only 23 mm of water are enough for the soil to start to flow. However, this value is lower in comparison with the historical rainfall data obtained in the studied geographical zone [7], where the maximum rainfall peak was reached (360 mm of water) the day before the landslide and considering that in the previous ten days, an unusual accumulated rainfall reached 908 mm (compared with the medium annual rain 1593 mm). This difference arises from the small quantity of the rainfall absorbed by the soil (nature's soil) and by the fact that most of the water moves down due to the region´s inclination (23 degrees). In order to clarify this, it would be necessary to carry out the yield stress determination immediately after the occurrence of a landslide and measure the absorbed rainfall water.

4. Conclusions

Yield stress determination as function of water content by a slump test for a clayey soil from a Teziutlán-Puebla-Mexico zone was performed. The results showed an exponential decrement of yield stress followed by an abrupt reduction of it with the increase in water concentration. From this value, an increment of the risk of landslide was revealed. At high water content (36%), a decrease in yield stress was observed, and a more complex behavior was exhibited. Finally, a correlation of yield stress with rainfall was done, but results were below the values reported in the literature.

5. Acknowledgements

The authors thank to Professor V. M. López-Hirata by his useful comments.

REFERENCES

[1] C. Chien-Yuan, C. Tien-Chen, C. Y. Fan-Chieh, Y. Wen-Hui, T. Chun-Chieh, "Rainfall duration and debris-flow initiated studies for real-time monitoring," Environment Geology, vol. 47, p.p. 715–724, 2005.

[2] K. S. Sultanov, B. E. Khusanov, "State equations for soils prone to slump-type settlement with allowance for degree of wetting," Soil Mechanics and Foundations Engineering, vol. 38, No. 3, p.p. 80-86, 2001.

[3] I.A. Caldiño-Villagómez, I. Bonola-Alonso, G. Salgado-Maldonado, "Estudio experimental del esfuerzo de cedencia con relación al flujo de lodos y debris," Asociación Internacional de Ingeniería e Investigaciones Hidro-Ambientales vol. 8, [Memorias del XXII Congreso Latinoamericano de Hidráulica, Guayana, Venezuela].

[4] D. F. Van Dine, R. F. Rodman, P. Jordan, J. Dupas, "Kuskonook Creek, an example of a debris flow analysis," Lanslides vol. 2, p.p. 257-265, 2005.

[5] R. M. Iverson, "The physics of debris flows," Reviews of Geophysics, vol. 35, No. 3, p.p. 245–296, 1997.

[6] R. P .Denlinger, R. M. Iverson, "Flow of variably fluidized gra-

nular masses across three-dimensional terrain 2. Numerical predictions and experimental tests," Journal of Geophysical Research, vol. 106, No. b1, p.p. 553–566, 2001.

[7] P. Flores Lorenzo, I. Alcántara Ayala, "Cartografía morfogenética e identificación de procesos de ladera en Teziutlán, Puebla," Investigaciones geográficas Boletín, vol. 49, p.p. 7-26, 2002.

[8] N. Pashias, J. Boger, D.V. Summers, D. J. Glenister, "A fifty cent rheometer for yield stress measurement," Journal of Rheology, vol. 40, No. 6, p.p. 1179-1189, 1996.

[9] P. Sánchez Crúz, "Análisis del esfuerzo de cedencia de suelos arcillosos como posible indicador de un derrumbe," Bachelor Thesis, ESFM, Instituto Politécnico Nacional, Mexico, 2008.

[10] A. F. Méndez-Sánchez, L. Pérez-Trejo, A. M. Paniagua Mercado, "Determinación del esfuerzo de cedencia para suelos vulnerables a deslizamientos originados por lluvias," Boletín de la Sociedad Geológica Mexicana, vol. 63,No 2, p.p. 345-352, 2011.