Revista EIA, ISSN 1794-1237 / Year XI / Volume 11 / Issue N. 21 / January-June 2014 / pp. 87-95
Technical-scientific biannual publication / Escuela de Ingeniería de Antioquia —EIA—, Envigado (Colombia)

# INCIDENCE OF SHEAR STRENGTH RATE FOR RESIDUAL SOILS FROM AMPHIBOLITE IN THE SAN NICOLÁS VALLEY IN ANTIOQUIA, COLOMBIA

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## ABSTRACT

Due to their formation process, residual soils have special characteristics that are not included in traditional soil mechanics, which is devoted to sedimentary soils. The weathering processes according to cycles of exposure show variations in composition and mechanical behavior. Residual soils from amphibolite rock located in the San Nicolas valley, near the city of Medellin, have been recovered using thin-walled Shelby tubes and tested. The variation of the shear test speed versus undrained shear strength was evaluated by conducting direct shear tests on undisturbed samples. This study presents graphs of the variation of shear strength, cohesion, and friction angle versus speed and their impact on design, as well as conclusions and recommendations.

**KEYWORDS:** Residual soil; Shear strength testing; Testing speed; Shear strength.

# INCIDENCIA DE LA VELOCIDAD DE APLICACIÓN DE CARGA EN LA RESISTENCIA AL CORTE NO DRENADO DE SUELOS RESIDUALES DE ANFIBOLITA EN EL VALLE DE SAN NICOLÁS, ANTIOQUIA, COLOMBIA

## RESUMEN

Los suelos residuales por su proceso de formación tienen unas características especiales que no están caracterizados dentro de la mecánica de suelos tradicional dedicada a los suelos sedimentarios. El proceso de meteorización según los ciclos de exposición a los que sean expuestos presentan variaciones en su composición y comportamiento mecánico. Suelos residuales de anfibolita localizados en el Valle de San Nicolás, cerca de la ciudad de Medellín han sido recuperadas y ensayadas. La variación de la velocidad del ensayo de corte versus la resistencia al corte no drenada ha sido evaluada mediante la realización de ensayos de corte UU sobre muestras inalteradas recuperadas mediante la utilización de Tubos Shelby de pared delgada, se presentan las gráficas de variación de la el esfuerzo cortante, la cohesión y ángulo de fricción versus la velocidad y su incidencia en diseño, se presentan las conclusiones y recomendaciones al final.

**PALABRAS CLAVE:** suelo residual; ensayo de corte; velocidad del ensayo; resistencia al corte.

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*Paper history:*
Paper received on: 10-IX-2013 / Approved: 05-I-2014
Available online: May 12th 2014
Open discussion until May 2015

DOI: http://dx.doi.org/10.14508/reia.2014.11.21.89-97

# INCIDÊNCIA DA VELOCIDADE DE APLICAÇÃO DE CARGA NA RESISTÊNCIA AO CORTE NO DRENADO DE SOLO RESIDUAIS DE ANFIBOLITO NO VALE DE SAN NICOLÁS, ANTIOQUIA, COLÔMBIA

## RESUMO

Os solos residuais, devido aos seus processos de formação, tem uma caraterísticas especiais que não estão caraterizadas dentro da mecânica de solos tradicionais dedicada aos solos sedimentários. Os processos de meteorizarão segundo os ciclos de exposição aos que estão expostos apresentam variações na sua composição e comportamento mecânico. Solos residuais de anfibolito localizados no vale de San Nicolás, perto a cidade de Medellín foram recuperados e ensaiados. A variação da velocidade do ensaio de corte contra a resistência ao corte não drenado foram avaliados mediante a realização de ensaios de corte UU sobre amostras inalteradas recuperadas mediante a utilização de tubos shelby de parede fina, apresentam-se as gráficas de variação do esforço cortante, a coesão e ângulo de atrito contra a velocidade e a sua incidência em desenho, apresentam-se as conclusões e recomendações ao final.

**PALAVRAS-CHAVE:** Solo residual; Ensaio de corte; Velocidade do ensaio; Resistência ao corte.

## 1. INTRODUCTION

Residual soils are created by chemical and mechanical weathering on a rock over time (Wesley, 2010). This continual process decomposes the rock along multiple horizons in the soil, which greatly depend on the progress of weathering and the constitutive minerals in the rock that has been altered through each cycle over time.

In engineering projects, it is very important to know the speed at which loads are applied. Likewise, it is important to know what the soil's behavior will be when burdened with said loads. However, it is perhaps most important to know how the soil will react when the application speed of the loads varies.

Among the many parameters that are obtained from the soil, shear strength is especially important, especially due to its impact on the stability of structures (containing structures, slopes, and foundations, among others).

Many soil parameters influence shear strength, such as grain size, granulometric distribution, moisture, tension history, test speed, and simple size (Kramer & Rizkallah, 1976). However, other researchers have found that the equipment used and even the personnel involved in the recovery and testing of the soil sample have a considerable effect on the results (Shibuya et al. 1997, Stoewahse 2001). Therefore, the result of a soil sample test may be the combination of a series of events such as the soil type and the equipment used (Saada & Townsand 1981). There are so many variables involved in the measurement of soil shear strength that there is no consensus regarding one in particular (Rowe 1969).

Due to the fact that pore pressures cannot be measured in a direct shear test, the problem becomes determining the necessary testing speed for finding mechanical parameters according to the study's requirements. This article does not describe or analyze the effect of suction on resistance.

The shear strength testing machine was used in the controlled deformation mode, which can give reliable results.

## 2. LITERATURE REVIEW

The technical literature on this topic, written in different periods, focuses mainly on sedimentary soil. In their studies on clay in Cambridge and sand in Manchester, Casagrande & Shannon (1949) found a direct relationship between the time taken to complete the test and the resistance obtained: the longer the test takes, the lower the resistance to compression, and the less time the test takes, the higher the resistance.

Eid et al. (1999) performed tests on reinforced soils that had previously been saturated with confining pressures of 100, 200, and 400kPa and variable testing speeds between 0.015 and 36.5mm/min. They found that shear strength increased considerably when the speed with which the test was performed was increased.

Huat et al. (2006) found that the speed of load application has a profound effect on vacuum relationships and saturation degree, but that it does not have a significant effect on natural moisture that undergoes constant suction. In the case of soils without suction, it has an insignificant effect on vacuum relationships, moisture content, and degree of saturation. A faster load speed creates greater compression in the soil compared to slower speeds.

**Figure 1** presents a typical result of the shear test tension-deformation curve. **Figure 2** presents typical results of the cohesion calculation and the material's friction angle.

Shear strength is determined by the Mohr-Coulomb equation, which relates vertical geostatic stress ($\sigma v$), cohesion (C)and the material's internal friction angle ($\phi$), expressed by the **Equation 1**.

$$t=c+\sigma_v \tan\varphi \qquad \textbf{(1)}$$

Interpretations of shear tests have been considered by De Josselin de Jong (1972), who stated that the friction angle depends on the relative magnitude of the vertical and horizontal forces applied. This is understood to mean that the internal friction angle is different for soils that are normally consolidated and for soils that are over-consolidated. Airey & Wood (1985) hold that direct shear tests cannot easily be compared to tests performed using other methodologies. However, Laad (1973) reports that shear strengths calculated through slope stability analysis regressions have coincided to a high degree with shear test results.

## 3. GEOLOGY AND SAMPLE MATERIAL

The samples were collected from the testing site at the Antioquia School of Engineering in the San Nicolas valley using thin-walled Shelby tubes. The samples were extracted and immediately subjected to laboratory tests for classification, weight, moisture, granulometry, and mechanical characteristics using UU shear tests.

The soil studied is residual amphibolite soil with a very low number of blows according to the standard penetration test (STP), which could probably be similar to soils with very low shear strengths. However, these values must be corroborated in the laboratory to be properly classified with very soft conditions in the first 3m to 4m of depth, then change to a soil with a medium-high number of blows according to the standard penetration test (STP), which could be similar to soils with medium-high shear strengths.

**Figure 1:** Typical tension-deformation curve for a load application speed of 0.5mm/min

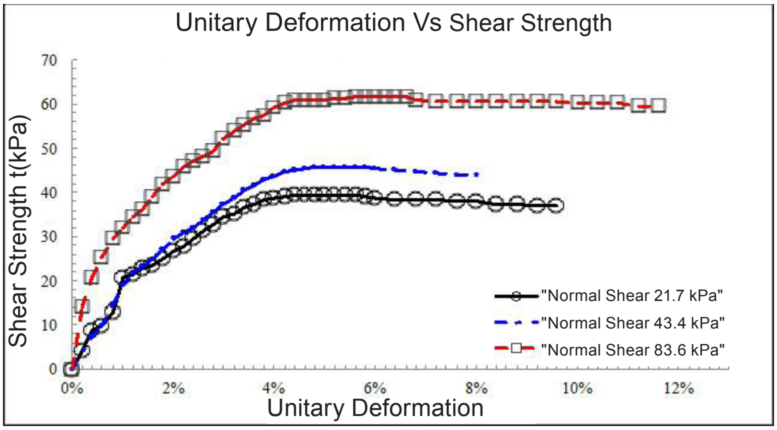
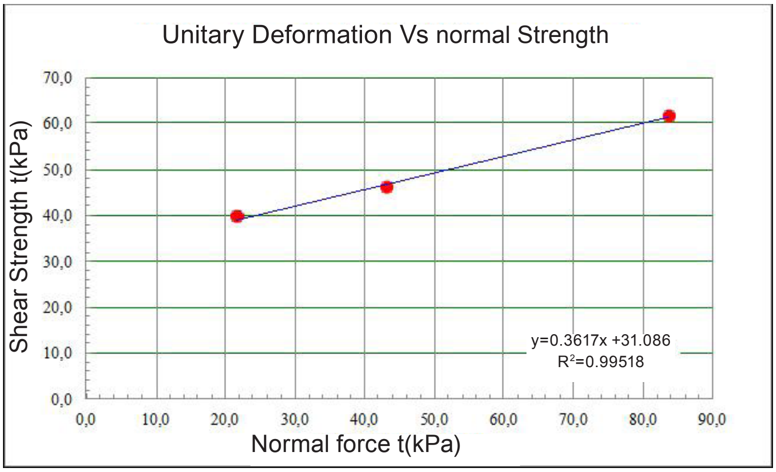


**Figure 2.** Shear strength vs. normal tension for a load application speed of 0.5mm/min



However, these values must be corroborated in the laboratory for proper classification and denomination with more rigidity to approximately 10m. There saprolite will probably be found to a depth of approximately 15 to 20m, where healthy rock will be found.

The different bodies of amphibolites considered in the area belong to the amphibolite facies in medium-grain metamorphosis conditions as is indicated by the type of calcium intermediate plagioclase with hornblende. As can be observed in **Figure 3**, the area within the circle is being evaluated in this study (Restrepo et al., 1991).

The amphibolites associated with syntectonic gneiss intrusions could have been created in large part due to thermal effects on green schist whose origin is related to volcanic events. The thin, short lenses and layers of amphibolite associated with light and feldspathic gneiss could have formed during regional metamorphosis due to metasomatic effects in the contact between pelithic sediments and calcareous shoals (Orville, 1969).

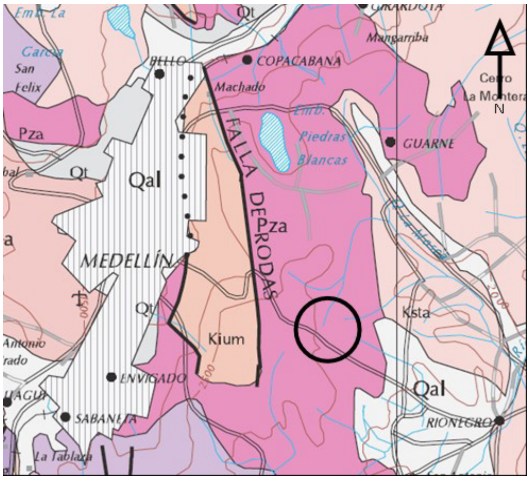
## 4. RESIDUAL SOIL

In general terms, rocks are decomposed by the chemical action of water that is partly unstable in feldspar and biotite, generating a change in the minerals of kaolinite-type clay and probable in other secondary minerals. An examination of the mineralogical content of the resulting soil appears to show that the plagioclase is broken first, followed by the orthoclase and the biotite, while the quartz remains intact. Even at the end of the weathering process, some particles of orthoclase and biotite can remain intact, although the size of the grain gets progressively smaller (Lumb 1962). During breaking, the altered products, such as colloidal silicon, are leached into a solution along with the secondary clay minerals, which implies an increase in porosity.

In general, the residual soil formation process is very complex and difficult to model and generalize. However, for practical reasons, it is necessary to simplify how weathering is described. This description should consider the degree of weathering, which varies the composition of the soil structure from the bottom up, which is seen in the field in the soil profile classification.

There are several theories regarding how to classify weathering profiles. Among the best known are those proposed by Deere and Patton (1971), Dearman, W.R. (1974), the Geotechnical Engineering Office in Hong Kong, and Wesley (2010). A good weathering profile can give a great deal of useful intangible information in geotechnical engineering which can be beneficial for a project, just as an improper interpretation of a profile can be catastrophic for a project.

**Figure 3, General geology of the study area**



Source: Geological map of Antioquia, Ingeominas, 2001

**Table 1. Main characteristics of the soil studied**

| | |
|---|---:|
| Wet Density (kN/m3) | 15.4 |
| Natural Moisture (%) | 92 |
| Liquid Limit (%) | 69 |
| Plasticity Index (%) | 20 |
| Specific Gravity | 2.70 |
| USCS Classification | MH |

One of the main characteristics of residual soil is the union between particles produced by weathering from one part of the rock and the rigidity that is generally associated with it regardless of the history of shear stress and density.

There are several possible causes for the development of this union between particles. Cold welding could occur between particles in contact due to high pressure, the growth of contact due to chemical weathering of the minerals, or surface hardening could occur through deposits of carbonates, hydroxides, and organic matter, among others (Vaughan, 1988).

In general terms, residual soils are independent of shear stress history. They depend on surface hardening or unions generating during weathering and/or high pressure, and their behavior is highly related to discontinuities in the parent rock.

## 5. TESTING PROGRAM

The testing program considered completing an unconsolidated undrained shear strength test through controlled deformation on the same residual amphibolite soil horizon found in the testing area at a depth of 2.5m. The shear test speed was varied, and the speeds used were 0.5, 1.0, and 2.0 mm/min. The shear strength test was performed three times for each speed in order to obtain an acceptable mean value. The initial testing speed of 0.5mm/min was based on the results obtained by Horn (1964), which state that at this speed there is drainage of the material and the shear strength test can indeed be considered unconsolidated undrained, while at high speeds, there is a smaller possibility that the soil will drain. Vertical pressures of 21.7, 43.4, and 83.6 kPa were used, respectively. **Table 1** shows the main characteristics of the soil studied.

In many papers, direct shear strength tests have been performed on samples with square geometry (Shibuya 1997,Matsuoka al 2001, Lindemann 2003), but for the shear strength test performed in this study, cylindrical samples with a diameter of 6.35cm and a thickness of 2.55cm were used. These samples were carefully removed from the study area located on the Antioquia Engineering School campus in the San Nicolas Valley site using thin-walled Shelby tubes.

## 6. TESTING RESULTS

Independent of the process used for simple preparation, human error is inevitable. It is impossible to prepare samples is a perfectly identical way. The process of completely identical sample preparation, from the extraction process, through manipulation and remolding, including the effect of repetition, affect the results of the shear strength calculation considerably (Philipp 1991).

**Figure 4** shows the variation of mixed shear strength on the fault versus the variation in speed at which the load is applied. It can be seen that as the velocity increases, the shear strength for the same level of vertical force applied increases considerably. This is probably due to the fact that at a higher speed, the internal structure of the soil works together with pore pressure, indicating that both are likely redistributing the loads applied, explaining the increase in resistance.

**Figure 4.** Variation in shear strength vs. load application speed

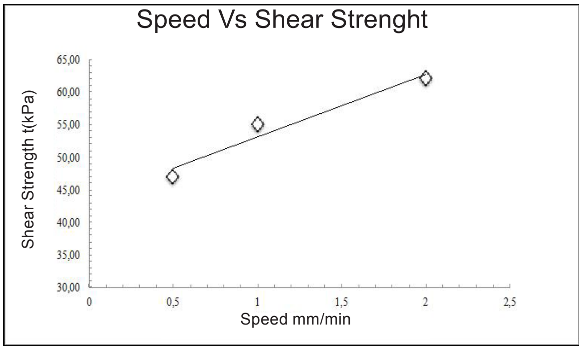


**Figure 5**. Variation of the modulus of elasticity with normal force

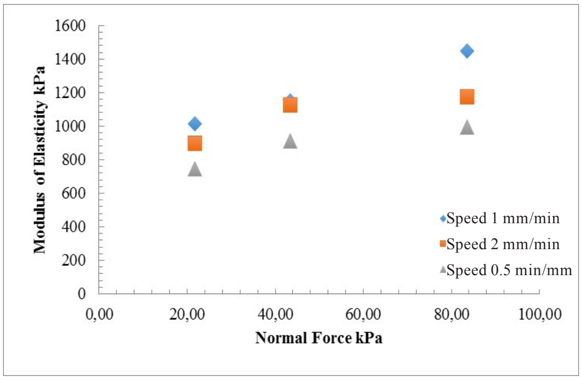
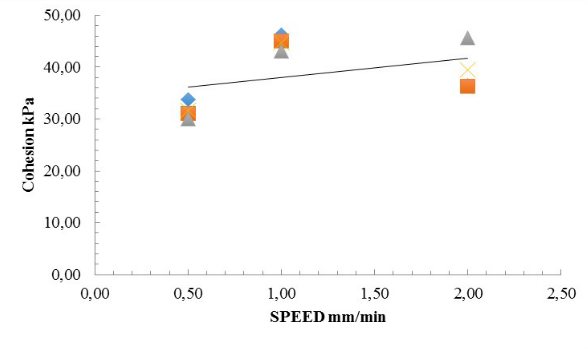


**Figure 6.** Variation in cohesion with speed



The variation in shear strength in relation to speed is nearly 30% with shear strength increasing as speed increases. The shear strength evaluated at a speed of 0.5mm/min is taken as a reference value.

**Figure 5** shows the variation in the modulus of elasticity in relation to the normal force applied for each testing speed. It can be observed that there are no significant variations in the values calculated for the different speeds, showing the same behavior tendency. This indicates that the value of the modulus of elasticity is probably independent of the load application speed and directly related to the vertical force such that a greater vertical force applied will cause an increase in the elasticity module.

**Figure 6** presents the variation in undrained resistance (Cu) versus testing speed. An increase in undrained resistance of nearly 25% can be observed as testing speed is increased. The test is completed with a cohesion reference value and a speed of 0.5mm/min. This is probably due to the fact that the load application speed is so fast that it does not allow for dissipation of pore pressure, which therefore interacts with the material structure, working with it to withstand the load.

**Figure 7** shows the variation in friction angle in relation to the testing speed. It can be observed that there is a slight increase in the friction angle as speed is increased and, in this case, compared to the result with a speed of 0.5mm/min, there is an 18% increase in this parameter. We could therefore say that speed has a low level of influence on friction angle. The variation is probable due to the interaction between pore pressure and the parent material structure since there is no dissipation of pressure and these two work together.

**Figure 8** shows the variation in the modulus of elasticity versus the normal force applied for each of the speed tested. It can be observed that for a speed of 0.5mm/min, the increase in the modulus of elasticity is directly proportional to the increase in the normal force applied. This follows the theory of elasticity for materials. When the analysis is completed for speeds of 1 and 2mm/min, no significant variations are observed between these two speeds. However, there is an increase in the modulus between when the test is performed at 0.5mm/min and 1 or 2mm/min with a variation of nearly 90% at a force of 21.4kPa. This is reduced with increases in force and speed until a value near 65% is reached at the maximum force applied, which, for this test, was 83.4kPa.

**Figure 7.** Variation in friction angle with speed

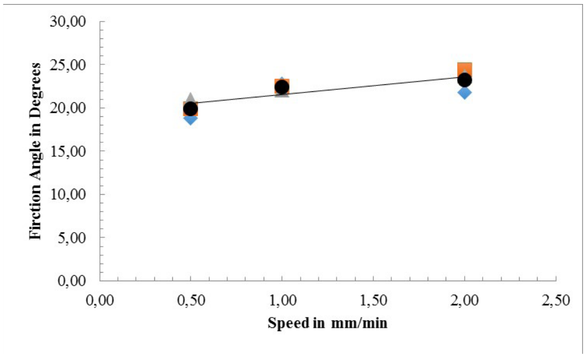


**Figure 8.** Variation in the modulus of elasticity vs. normal force applied for each of the speeds tested

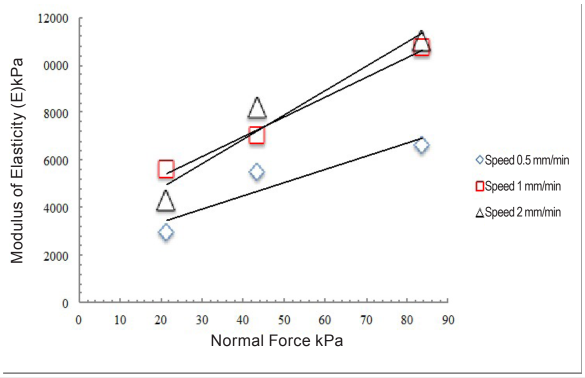
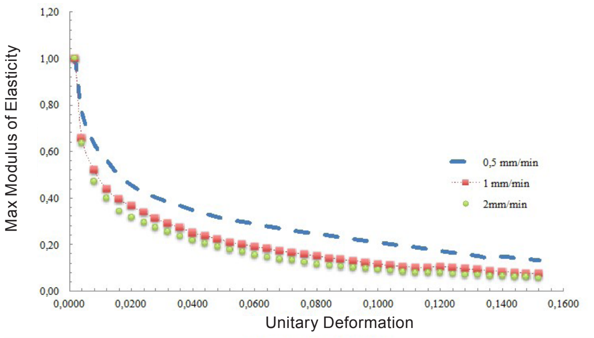


**Figure 9.** Modulus of elasticity degradation with unitary deformation



This increase in the modulus of elasticity could be associated with the low dissipation of pore pressure as shear speed increases due to the fact that pore pressure and the microstructure will be constantly working together as a single element that can probably withstand the increase in force applied.

**Figure 9** shows the degradation of the modulus of elasticity in relation to the increase in deformation. It can be observed that the soil shows a strongly nonlinear degradation up to small deformation ranges near 0.004 independently of the speed applied. From this point, the change begins to decrease as deformation increases until the point at which the values probably tend to become asymptotic.

It can be observed that degradation is lower when the shear stress is applied at a lower speed, while degradation is higher when the speed is greater, showing a certain dependency in terms of soil degradation and the speed at which the test is performed.

**Figure 10** shows how variations in speed influence the basis parameters of cohesion and friction angle for the same soil. It can be observed that as speed increases, the relationship between cohesion and friction angle increases in an almost parallel manner.

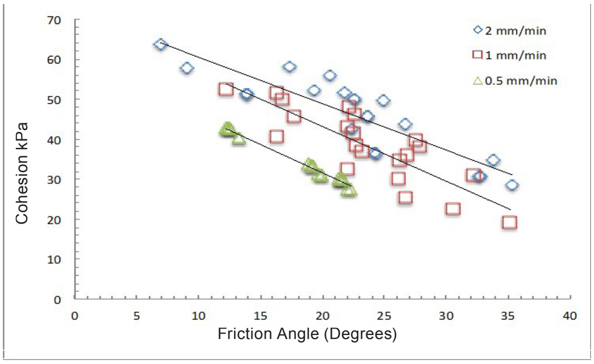
By taking the combination of parameters at a speed of 0.5mm/min as a reference, we find that by changing to a speed of 1mm/min, there is an increase in the parameters of 36%. When the speed is increased to 2mm/min, the increase in the parameter behavior trend is of 54%.

## 7. SUMMARY AND CONCLUSIONS

Amphibolite residual soil samples were collected and tested in a shear strength testing machine, varying the testing speed between 0.5, 1.0, and 2.0mm/min.

The variations found were presented in relation to shear strength versus testing speed, showing an approximate variation of 50%. When the modulus of elasticity was evaluated, significant variations were found between the reference speed of 0.5mm/min and the 1mm/min speed. However, no significant variations were found between 1mm/min and 2mm/min.

**Figure 10.** Variation in cohension and friction angle with speed



The modulus of elasticity shows a nonlinear behavior trend in which its value increases as the force level is increased.

Resistance parameters such as undrained cohesion showed a variation of 25%, while the internal friction angle showed a variation of 18%. For all evaluations, the values obtained when testing at a speed of 0.5mm/min were taken as a reference value.

The degradation of the modulus of elasticity with increases in unitary deformation show a similar behavior trend independent of speed, while its values do show variations in relation to the speed applied.

The shear strength of the residual soil from amphibolite is directly proportional to the speed at which the test was completed. This highlights the importance of a proper speed selection when tests are completed in geotechnical engineering.

## ACKNOWLEDGEMENTS

The author would like to thank those who revised the article for their excellent contributions and for the discussion that was generated around this topic.

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Builes-Brand, M. (2014). Incidence of Shear Strength Rate for Residual Soils from Amphibolite in the San Nicolas Valley in Antioquia, Colombia. *Revista EIA*, 11(21) January-June, pp. 87-95. [Online]. Available on: http://dx.doi.org/10.14508/reia.2014.11.21.89-97