PRELIMINARY DATA OF THE EFFECTS OF SELECTED DEEP-ROOTED VEGETATION ON THE SOIL STATE: RESULTS FROM AN IN-SITU TEST

Tagarelli Vito
Politecnico di Bari
vito.tagarelli@poliba.it

Cotecchia Federica
Politecnico di Bari
federica.cotecchia@poliba.it

Stasi Nico
Politecnico di Bari
nico.stasi@uniba.it

Abstract

The use of novel naturalistic interventions making use of selected vegetation have been already proven to be successful in the reduction of erosion along sloping grounds, or in increasing the stability of the shallow covers of slopes, whereas the suitability of vegetation as slope stabilization measure still needs to be scientifically verified for slopes location of deep landslides, whose current activity is weather-induced, as is often the case in the south-eastern Italian Apennines. In this contribution, preliminary field data representing the interaction of clayey soils with a selected vegetation species are presented and discussed. These have been logged within a full scale in-situ test site, where the deep-rooted crop spices have been seeded and farmed. The test site, being approximative 2000 m^2, has been set up in the toe area of the weather-induced Pisciolo landslide. The impact of the vegetation on the soil state is examined in terms of the spatial and temporal variation of the soil water content and suction from ground level down to depth, considering the interaction of the climate data recorded by a meteorological station, both inside and outside the vegetated test site.

1. Introduction

Bio-engineering interventions are often used to reduce the risk connected to natural disasters, such as landslides, flooding and erosion. Nonetheless, techniques using vegetation to either stabilize or protect slopes have been adopted for long, but their use has been so far based on empirical evidence (Gray & Sotir, 1996). In particular, the contribution of vegetation to the strengthening of soil, which is then turned into a root-soil composite material, is one of the bio-engineering issues most discussed in the literature (Ali et al., 2007; Guo et al., 2020). Rather, this work focuses on the effects that the vegetation cover has on the hydraulic domain present in the slope, which influences the stability of potential landslide bodies of depth from small to large. Even though the erosion mitigation determined by the vegetation could be relevant, the main consequence of a functional vegetation layer at the ground is represented by the reduction of the water infiltration rate, as already reported in the literature for both grass and tree species (Ng et al., 2013; Leung et al., 2015a). As a matter of fact, selected deep-rooted crops can impact strongly the hydrological balance at the ground surface, by increasing both the water interception and the runoff due to their aerial structure, which, on the whole, allows for a decrease of the rainfall infiltration.
At the same time, such vegetation can ensure a deeper and higher water uptake, by means of their deep root system (Ehlers et al., 1991), reducing the pore water pressure even at depth and, hence, increase the effective stresses and, in turn, the soil shear strength available in the slope (Fredlund et al., 2012). Therefore, such crops may provide a mitigation of the activity of deep weather-induced landslides.

The present contribution is the first to discuss experimental in situ test results about the role of selected deep-rooted vegetation among the full set of processes determining the soil-vegetation-atmosphere (SVA) interaction. In particular, the results of the field experiment will be presented as data of general value for a progress in the assessment of the effects of vegetation on the state of clays in slopes. To this aim, they will be discussed accounting for an insight into the basic features of the SVA interaction, i.e., accounting for the specific behaviour of the type of plant grown on the slope and the specific hydro-mechanical properties of the clay material location of the seeding. According to the used approach, with this first step, this work wishes to contribute to the advancement of a scientific design of the use of vegetation as bio-engineering risk mitigation measure.

2. The test site: objectives and general description

The test site is located in the toe area of the Pisciolo mechanism, being a roto-translational multiple landslide (Cotecchia et al., 2014, 2015, 2019, 2020a; Tagarelli & Cotecchia 2019 and 2020). The Pisciolo slope has been found to host seasonal weather-induced fluctuations of the pore water pressures even at large depth (i.e., up to 50-60 metres; Cotecchia et al., 2014) causing reactivations of deep and slow landslide bodies (namely, C9, C and A); in particular, the whole hydrological balance at the ground surface over a ‘seasonal’ time period, i.e., mainly the infiltration of the water rainfall and the evapotranspiration fluxes, has been found to trigger the landslide mechanism, by increasing the pore water pressures at depth, as verified both by in-situ monitoring and by means of numerical modelling (Cotecchia et al., 2014, 2019; Tagarelli & Cotecchia 2019 and 2020). The green quadrangular reported in Figure 1a and 1b represents the test site area, of about 2000 m^2, where selected deep-rooted crops were seeded. Whereas, spontaneous sparse vegetation covers the surrounding part of the slope, in a rather irregular way. The seeds were manually sowed inside the confined area in March 2017 with various crop species. Due to works required for preserving the functionality of the buried aqueduct pipeline, being recurrently damaged by the landslide displacements, a portion of the vegetation of the test site was compromised; however, in the early 2019 the vegetated area was then restored by seeding, with the hydro-seeding technique the same crop types already present in the test site.

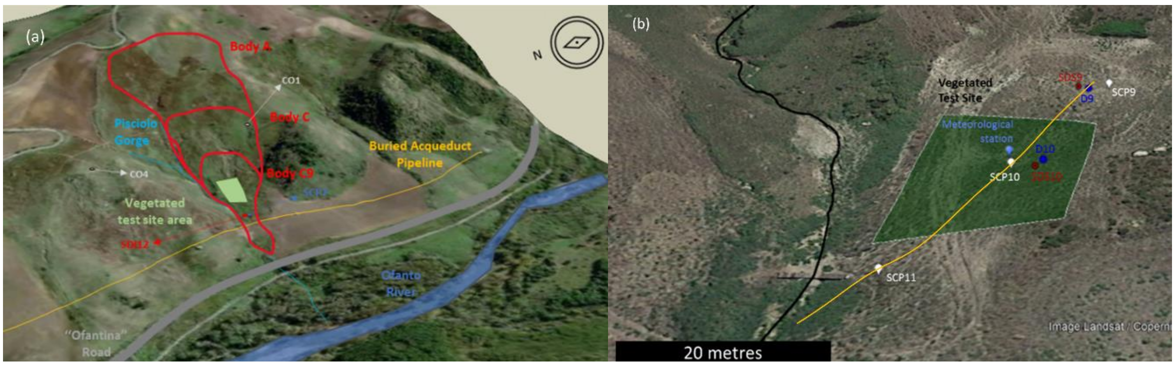

Figure 1 - Aerial 3D view (Google maps) of the Pisciolo landslide and of the test site (a). The figure provides evidence of the landslide bodies A, C and C9 (red lines), the trace of the aqueduct pipeline (yellow line) and the vegetated site area (light green quadrangle). Also, the Pisciolo gorge is shown in blue, which is the main watershed of the hillslope. 3D view of the test site area, together with all the installed instrumentations as described in the text (b).

The selection and the seeding of the crops was carried out by the Italian company “PratiArmati s.r.l.”, which has developed an innovative green technology to mitigate primarily rainfall triggered soil erosion (Cuomo et al., 2016). Whereas, within this research, it has been analysed the extent to which such technology is suitable to increase the soil suctions above the water table and to reduce the piezometric heads at depth, which represents the so-called “hydrological soil reinforcement” (Leung et al. 2015a; Tsiampousi et al. 2017) which may result from the vegetation.

At the test site, ten different plant types were seeded, belonging to either the Gramineae family or the Leguminosae one. The Leguminosae, though, were seeded mainly to provide nitrogen nutrients to the soil, since those plants contain symbiotic rhizobia bacteria within nodules in their root systems, which produce nitrogen compounds, prompting the growth of plants in the seeded soil. Conversely, the majority of the seeded species have been of the Gramineae family (i.e., Poacee), which belong to the microthermal species. These are commonly known as “evergreen”, thank to their resistance to medium humid climates and their two growth peaks, the highest in spring and the other during fall. They are indigenous within the Apennine region location of the Pisciolo slope, so that they match the spontaneous vegetation and suit the climate conditions in the area location of the test site.

A hydro-mechanical characterization of the soil cover has been carried out, in order to evaluate the composition, state, hydraulic and mechanical properties of the soils set in interaction with the crops. Furthermore, instruments were installed, both inside and outside the test site area to monitor both the climate and the soil state down to 7 m depth, inside and outside the on-purpose vegetated area. The monitoring data, of use for a phenomenological characterization of SVA interaction, are discussed in the following, after the presentation of the procedure adopted to set up the vegetated site and to equip it with the monitoring devices. The data are also meant to inform a computation platform for the thermo-hydraulic numerical modelling of the SVA interaction, which is wished to become a prediction tool of the evaporation and transpiration fluxes induced by the deep-rooted crop cover.

2.1 Instruments installed to monitor the SVA interaction

As reported in Figure 1b, five boreholes were excavated at the test site area, namely SCP9, SCP10, SCP11, SDS9 and SDS10. Three boreholes were continuously cored (SCP9, SCP10, SCP11) and two were drilled by destructive coring (SDS9, SDS10). One electric piezometric cell was installed at the bottom (i.e., 7 metres b.g.l.) of each continuous coring borehole, while water potential probes (MPS-6) were installed at different depths into the destructive boreholes. The water potential monitoring verticals (i.e., SDS9 and SDS10) were placed very close to the boreholes equipped with the piezometers. Besides the piezometers and the suction probes, also two plastic tubes were installed down to 1.6 m depth into the slope (i.e., D9, D10 in Figure 1b), being of use for inserting a soil capacitive sensor used to measure water content profiles with depth. In particular, the D10 vertical was setup to carry out the monitoring of the water content inside the seeded area, whereas the D9 vertical was excavated outside the seeded area. Moreover, the weather has been monitored by means of a meteorological station (i.e., Davis Vantage Pro 2) placed within the test area at a 2 m height above ground level.

2.2 Soil sampling characterization

Several disturbed and undisturbed soil samples were taken during the drilling stages to assess the physical composition properties of the soil cover as well as their hydro-mechanical properties, as shown in Figure 2, where the location of samplings and monitoring probes is reported. Grading curves and Atterberg’s limit determinations, together with the analysis of the continuous cores have allowed for the reconstruction of the lithological setup of the test site area, which is reported in Figure 2; however, the material inside the test field is mainly a highly plastic and inorganic silty clay with sand, with high water retentive properties; in the framework by Cafaro & Cotecchia (2015) this material is also expected to exhibit a relatively high overconsolidation ratio (OCR) due to the large value of the air-entry value (AEV) with respect to the data measured by Pedone (2014); this circumstance may be reasonable if considering the geo-morphological process which shaped this hillslope (Tagarelli & Cotecchia, 2020).

3. Monitoring data of the soil-vegetation-atmosphere interaction

The piezometric heads recorded by each of the three piezometers (SCP9, SCP10 and SCP11), recorded no appreciable fluctuations with time, even if those are seen to tend to decrease with time. The reason why the piezometric heads do not fluctuate with time, despite this circumstance occur about all the piezometric verticals at the Pisciolo slope (Cotecchia et al., 2014, 2019), may be linked to the soil type in which the three piezometers have been installed; indeed, fractured rock blocks and coarser strata were found during the coring of the three boreholes, playing a role in modifying the seepage regime at those depths (i.e. about 7 metres b.g.l.). Figure 3 reports about the suction values in the soil at different depths, highlighting monitored values within the vegetated test site area higher than those measured at depth in the non-vegetated portion. In particular, during the first summer (i.e., 2018) the suction at 1 metre b.g.l. down the SDS10 vertical reaches values of the order of 1000 kPa, whereas the value reached outside is of the order of 30 kPa. Further on, a stronger impact of the vegetation has been recorded, since in the following summer (i.e., 2019) the suctions along vertical SDS10 have been slightly higher those measured in the previous year and have not reduced too much in the following autumn / winter. This is a very significant indication that the adopted deep-rooted vegetation is able to keep high suction value at depth all way through the year, i.e., also in the most rainy seasons, and may restrain the seasonal increase in pore water pressure. Conversely, in the vertical outside the vegetated test site area, i.e., SDS9, the suction tends to become lower in the autumn and winter seasons. With reference to 4 metres b.g.l. (i.e., Figure 13c) only monitoring data inside the vegetated test site with reference to the vertical SDS10 are available, showing no suction values higher than zero throughout all the monitoring period.

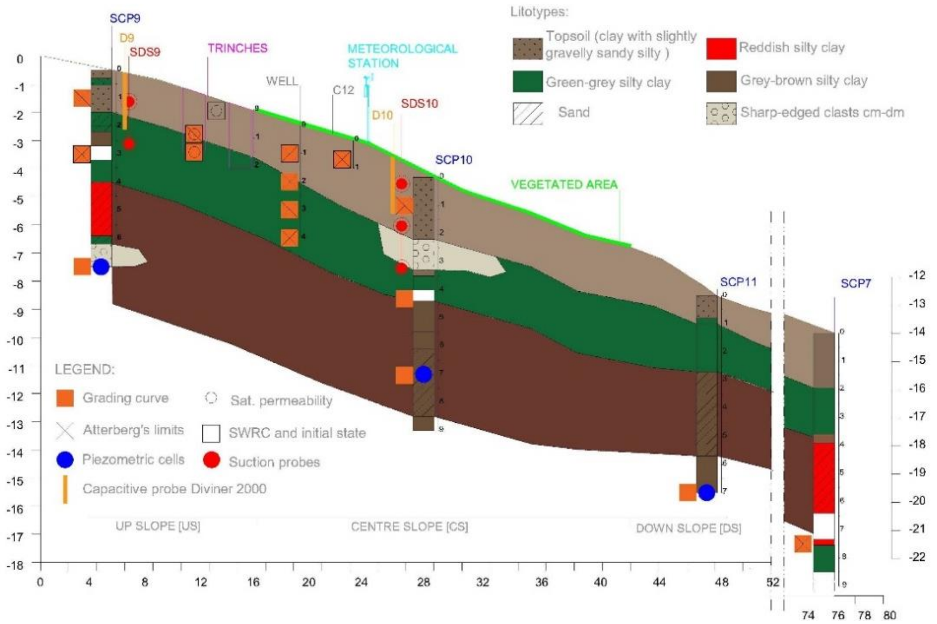

Figure 2 - Lithostratigraphic section (yellow trace in Figure 1) including the instrumentation installed on the cover and the samples collected during the campaign in different areas of the toe of the Pisciolo slope.

Figures 3d, 3e, and 3f also show the temperatures monitored in the soil in comparison with the mean daily atmospheric temperature. It is worth noting that the SDS9 probes show always higher temperature values than those recorded along vertical SDS10, resulting in about 5°C difference at 1 metre b.g.l. and about 3°C difference at 2.5 metres b.g.l.. Since the thermal conductivity of the material is supposed to be the same along the two monitoring verticals, the reason for this difference should be referred to the different state of the vegetation layer around the monitoring verticals. As matter of fact, the spontaneous vegetation outside the seeded area, where higher soil temperatures are recorded, is quite sparse, causing low Leaf Area Index (LAI) values. Inside the seeded area instead, where soil temperatures are lower, the vegetation is denser and creates a full cover on the soil with respect to the solar radiation.

The volumetric water content with depth in the soil along two verticals, both inside (i.e., D10) and outside (i.e., D9) the vegetated area has been also monitored and reported in Figure 4, where only water content profiles with reference to the 2019 for both the vertical outside (Figure 4a), and inside (Figure 4b) the vegetated test site.

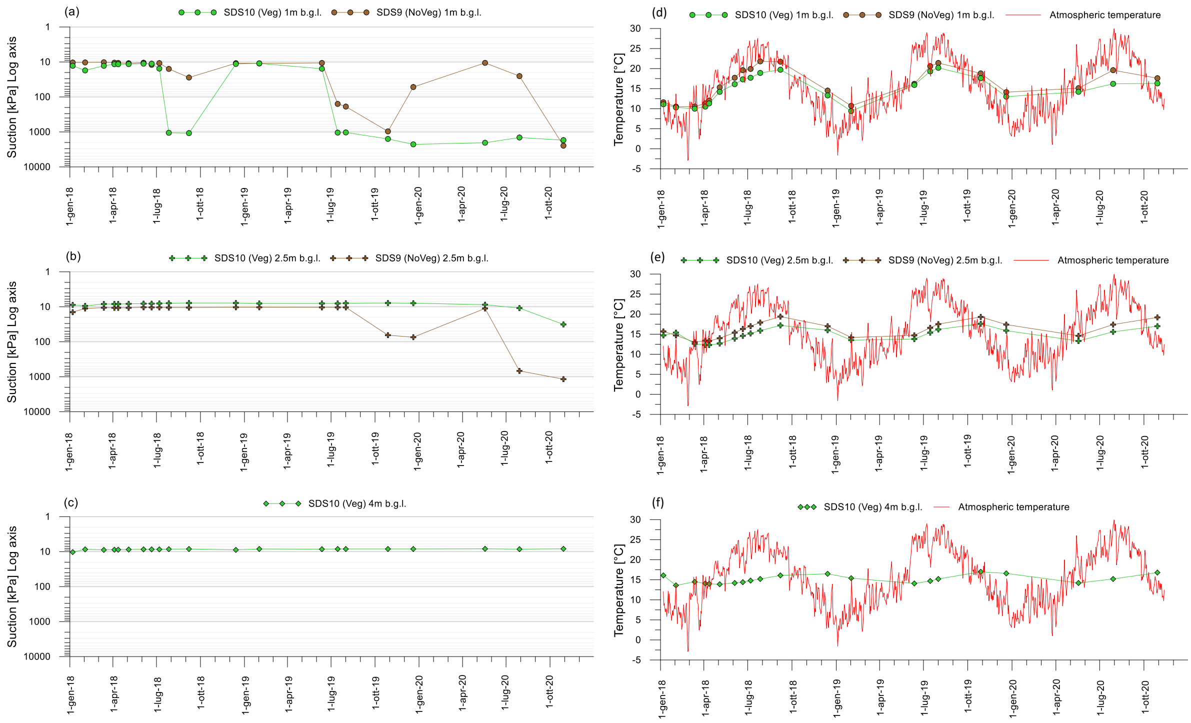

Figure 3 - Suction and temperature values monitored by MPS-6 probes along verticals SDS9 (black symbols at 1 m and 2.5 m b.g.l.) and SDS10 (blue symbols at 1 m, 2.5 m and 4 m b.g.l.) since January 2018.

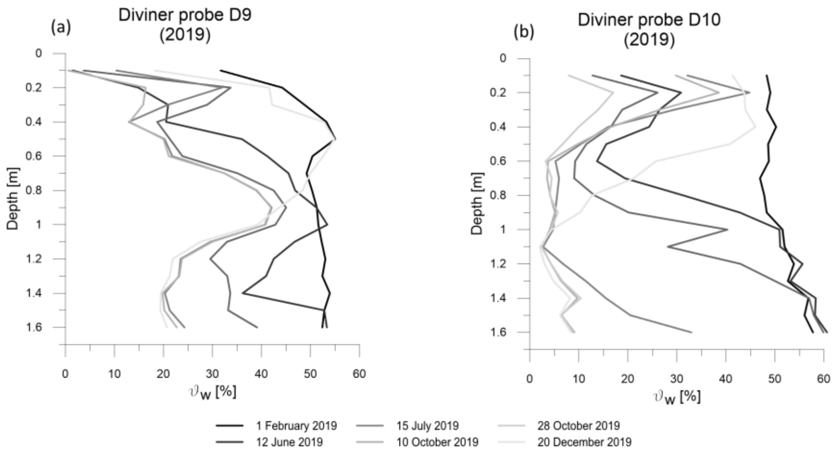

Figure 4 - Volumetric water content profiles with depth along the D9 (a, c, and e) outside the vegetated test site area and D10 (b, e, and f), being inside the vegetated area, with reference to the monitoring years 2019.

Remarkably, the overall variability of water content with time which is recorded at the same depth, from 0.1 m to 1.6 m, is much more evident along the verticals inside the vegetated area (D10 in Figure 4b) than outside of it (D9 in Figure 4a). This effect has to be related to the root system of the crops, which in 2019 should have reached a good development with depth. It appears clear that the transpiration process induced by the vegetation in the root zone may have caused a relevant decrease of the volumetric water content recorded in the whole length of the access tube along the vertical D10; whereas with respect to the vertical D9, a certain amount of transpiration due to the sparse vegetation is surely acting, but it is not efficient in extracting water from the soil as it seems to be the deep-rooted vegetation seeded in the vegetation test site. Further confirmation of all these circumstances will be investigated also by means of the monitoring of the root system in the soil, which has not been carried out yet.

4. Conclusion

The interaction between the soil, the vegetation and the atmosphere consists of a very complex set of physical and chemical phenomena involving also a living entities (i.e., the vegetation), which has not been yet fully studied and schematized; however, the scientific research community has taken several steps toward a full understanding of such phenomena, which is a necessary condition if reliable numerical predictions are aimed at. With the purpose to deepen the knowledge about such phenomena and trying to check if selected deep-rooted vegetation may be suitable as a NBS for the landslide risk mitigation, a real scale test site has been set up in a very well documented deep and slow weather-induced landslide mechanism. This experience, still on going, testifies how an in-situ test may be dense of uncertainties, which make the whole process really tough on one hand, but also allows for a reliable test of how the deep-rooted vegetation crops may behave in the field, where dealing with conditions highly different than those in a laboratory. To conclude, the primary data herein reported have been shown that the selected deep-rooted vegetation adopted is able to impact on the SVA interaction in a not negligible way, encouraging the research programme to be further carried out in determining if and how this technique may be of use as a landslide remediation measure for such wheatear-induced mechanism.

References

Cotecchia, F., Vitone, C., Santaloia, F., Pedone, G. & Bottiglieri, O. (2014). Slope instability processes in intensely fissured clays: case histories in the Southern Apennines. Landslides 12, No. 5, 877–893

Cotecchia, F.; Petti, R.; Milella, D.; Lollino, P. Design of Medium Depth Drainage Trench Systems for the Mitigation of Deep Landsliding. Geosciences 2020b, 10, 174.

Cotecchia, F.; Santaloia, F.; Tagarelli, V. Towards A Geo-Hydro-Mechanical Characterization of Landslide Classes: Preliminary Results. Appl. Sci. 2020a, 10, 7960.

Cotecchia, F.; Tagarelli, V.; Pedone, G.; Ruggieri, G.; Guglielmi, S.; Santaloia, F. Analysis of climate-driven processes in clayey slopes for the early-warning system design. Proc. Inst. Civil Eng. Geotech. Eng. 2019, 172, 465–780.

Cotecchia, F.; Vitone, C.; Santaloia, F.; Pedone, G.; Bottiglieri, O. Slope instability processes in intensely fissured clays: Case histories in the Southern Apennines. Landslides 2015, 12, 877–893.

Cuomo, Sabatino & Sala, M. (2016). Spatially distributed analysis of soil erosion in a mountain catchment. 10.1201/b21520-83.

Ehlers, W., Hamblin, A.P., Tennant, D. et al. Root system parameters determining water uptake of field crops. Irrig Sci 12, 115–124 (1991). https://doi.org/10.1007/BF00192282

Fredlund, D.G.; Rahardjo, H.; Fredlund, M.D. Unsaturated Soil Mechanics in Engineering Practice; John Wiley & Sons: New York, NY, USA, 2012

Ghannoum O. C4 photosynthesis and water stress. Ann Bot. 2009 Feb;103(4):635-44. doi: 10.1093/aob/mcn093. Epub 2008 Jun 13. PMID: 18552367; PMCID: PMC2707343.

Gray D H and Sotir R B 1996 Biotechnical and Soil Bioengineering Slope Stabilisation: A Practical Guide for Erosion Control. Wiley, Chichester, USA.

Guo P, Xia Z, Liu Q, et al. The mechanism of the plant roots' soil-reinforcement based on generalized equivalent confining pressure. PeerJ. 2020;8:e10064. Published 2020 Sep 29. doi:10.7717/peerj.10064

Leung AK, Garg A, Coo JL, Ng CWW, Hau BCH (2015a) Effects of the roots of Cynodon dactylon and Schefflera Heptaphylla on water infiltration rate and soil hydraulic conductivity. Hydrol Process 29:3342–3354. doi:10.1002/hyp.10452

Ng, C.W.W. & Woon, K.X. & Leung, Anthony & Chu, LM. (2013). Experimental investigation of induced suction distribution in a grass-covered soil. Ecological Engineering. 52. 219–223. 10.1016/j.ecoleng.2012.11.013.

Pedone, G. (2014). Interpretation of slow and deep landslides triggered by slope–atmosphere interaction in slopes formed of fissured clayey turbidities. PhD thesis, Technical University of Bari, Bari, Italy.

Tagarelli, V.; Cotecchia, F. Deep Movements in Clayey Slopes Relating to Climate: Modeling for Early Warning System Design. Research for Land Protection and Development. CNRIG 2019. Lect. Notes Civil Eng. 2020.

Tsiampousi A, Zdravkovic L, Potts DM (2017) Numerical study of the effect of soil–atmosphere interaction on the stability and serviceability of cut slopes in London Clay. Can Geotech J 54(3):405–418.