Prediction of expansive soil based on the coefficient of linear extensibility (COLE)

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Abstract**—** *An expansive soil is any soil that is prone to large volume changes (shrinking and swelling) directly related to changing moisture conditions. The swelling capacity can cause heaving, or lifting of structures whilst shrinkage can cause differential settlement. The amounts by which the ground can shrink and/ or swell depend not only on the supply of moisture in the ground but also on the type and amount of clay minerals, internal structure and void ratios of the soil. Characterization of swelling potential is critically important to mitigate the adverse effects of expansive soils. Therefore, this study uses the coefficient of linear extensibility (COLE) as the controlling method to characterize swelling potential of expansive soils. The samples for this test were retrieved from two different locations in areas prone with expansive soils in Kibaha Township in Tanzania. Bulk density was determined on irregular soil clods and COLE was calculated as the difference between bulk density values at 1/3 bar and oven-dry condition. The coefficient of linear extensibility that ranged from 0.09 to 1.15 clearly indicated soils with high to very high shrink–swell potential. Lastly, a direct relationship existed between COLE and colloids contents with high degree of correlation (i.e. Correlation Coefficients (R) equal to 0.942 and 0.824 for samples RC5 and RB3 respectively) providing a confirmation to the presence of high to very high expansive potential of the soils.*

Keywords**—** ***Expansive soil, coefficient of linear extensibility (COLE), Clay content and shrink-swell potential.***

I. INTRODUCTION

Expansive soil is that which swells and shrinks under changing moisture conditions. It swells when the moisture increases and shrinks as moisture content decreases mainly during a long dry period or drought. Changing moisture conditions may be due to seasonal or interannual variations in rainfall, evapo-transpiration of vegetation, leaking water pipes or drains, landscape irrigation, cutting down or pruning trees etc. (Cheney, 1986, Biddle, 2001, Fredlund. & Hung, 2001 and Ito *et al.*, 2014).

The swell/shrink of expansive soil usually relates to the type and amount of clay minerals present in the soil, geological formation and environmental factors (Elarabi, 2004 and Azam *et al.*, 2013). The amount of clay mineral in soil largely depends on the type of parent material and the degree of chemical weathering. The swell/shrink behaviour of expansive soil usually causes a significant hazard to structures constructed in/on it. The pressure resulting from swelling usually causes uplift of the ground (i.e. heave), while shrinkage can cause settlement of the ground surface as well as structures on it (Freeman *et al.*, 1991, Fityus *et al.*, 2009 and Mokhtari & Dehghani, 2012). The fact that swelling and shrinkage are only partially, not fully recoverable, the adverse effects caused on structures are equally not reversible (Holtz & Kovacs, 1981). It is very important to recognize the existence and understand the potential problems of expansive soils prior to construction so that practical design options are identified that deal with expansive soil problems rather than waiting for costly remedial measures after construction. There are various methods to identify expansive soils both in the field and laboratory, so the choice is mainly dependent upon the type of structures to be erected and site condition, but many are also matters of choice. This study deals with the use of the coefficient of linear extensibility (COLE) to measure the shrink-swell capacity of soil clods for characterizing expansive soils.

The coefficient of linear extensibility (COLE) is one of the important engineering properties of soils which relates to the clay content of undisturbed samples and consistency to characterize the shrink-swell behaviour of soil (Franzmeier & Ross, 1968 and Grossman *et al.*, 1968). Many authors (Franzmeier and Ross, 1968, Anderson *et al.*, 1973 and McCormack and Wilding, 1975) have found that the clay contents highly correlate with the COLE of the soil. COLE is the measure of the change in sample dimension from the moist to dry state (Nelson and Miller, 1992, Mckenzie *et al.*, Lucian *et al.*, 2007 and Lucian, 2008). It is determined by the volume change of resin-coated clods at 33-kPa matric potential to characterize shrink-swell behavior of soil (McKenzie *et al.*, 1994 and Stewart *et al.*, 2012). It is used as a gauge of the shrink-swell potential related to the cube root of the volume change of the soil with drying or swelling and shrinkage (Grossman *et al.*, 1968). The shrink-swell potential correlates with clay contents, thus soils that have high clay content have high shrink-swell potential.

According to Greene-Kelly, 1974, the increase in smectite and clay content increases the COLE values and shrink and swell potential of the soil. Because clay content is expected to decrease with the depth in the soil profile presumed to have formed in alluvial deposits lie that in Kibaha, COLE is expected to decrease with depth.

II. EXPERIMENTAL PROCESS

Three undisturbed clods/cores were retrieved from two different 3-metre deep open pits at the interval of 0.5 m located in expansive soil prone areas in Kibaha, Tanzania. The pits were limited to two because of the difficulties associated with this particular test. The retrieved clods were wrapped into aluminium foils and cling films to keep their state intact. The samples were transported to the soil laboratory at the Dar es Salaam Institute of Technology (DIT) for test. For simplification of the experimental processes, the coarse fragments in the clods were assumed to have negligible effect on the swell-shrink of soils. The clods weighing approximately 100 – 200 g each were briefly immersed in a flexible resin and allowed to dry in laboratory. The resin coating must be impermeable to water but permeable to water vapour (Thomas, 1998). The clods were put to field tension of 33 kPa or 10 kPa (1/3- or 1/10-bar tension), weighed in air and water to determine weight and volume using Archimedes principle. The clods were brought to oven dryness, their weight and volume measured again. Clod bulk densities were calculated both at 33 kPa and oven-dry, assuming a weight loss of 10% of resin due to drying. When coarse fragments are present, the COLE is calculated as follows:

$$COLE_{ws} = \left[\frac{1}{C_m * \left(\frac{\gamma_{d33<2mm}}{\gamma_{d<2mm}} \right) + (1 - C_m)} \right]^{\frac{1}{3}} - 1 \tag{1}$$

where $COLE_{ws}$ = coefficient of linear extensibility on a whole-soil base in cm cm^{-1}

$\gamma_{d33<2mm}$ = dry density at 33 kPa water retention on a <2 mm base (g/cm^3)

$\gamma_{d<2mm}$ = dry density, oven-dry or air-dry, on a <2 mm base (g/cm^3)

C_m = coarse fragment (moist) conversion factor.

C_m is calculated as follows:

C_m = [volume moist <2 mm fabric (cm^3)]/ [volume moist whole soil (cm^3)]

or C_m = (100-vol>2 mm)/100

where vol>2 mm = volume percentage of the >2 mm fraction.

If no coarse fragments, C_m =1, thus the previous equation reduces to:

$$COLE_{ws} = \left(\frac{\gamma_{d<2mm}}{\gamma_{d33<2mm}} \right)^{\frac{1}{3}} - 1 \tag{2}$$

The terms in equation (2) are as defined in equation (1).

According to the calculated COLE, a range of soil shrink- swell potential can be distinguished based on data in Table 2.10. The quantitative swell potential can also be estimated by correlating the colloids content and the COLE using Figure 1. COLE in the excess of 0.03 indicates the presence of a significant amount of montmorillonitic clay while COLE greater than 0.09 suggests a significant shrink-swell activity (Esu, 2010). Soils rated with shrink-swell potential in categories of moderate to very high can damage structures constructed on/in them.

TABLE 1
RANGES OF COLE TO DETERMINE SOIL SWELL-SHRINK POTENTIAL (Thomas *et al.*, 2000 and Vaught *et al.*, 2006)

Soil swell-shrink potential	COLE
Low	<0.03
Moderate	0.03-0.06
High	0.06-0.09
Very high	>0.09

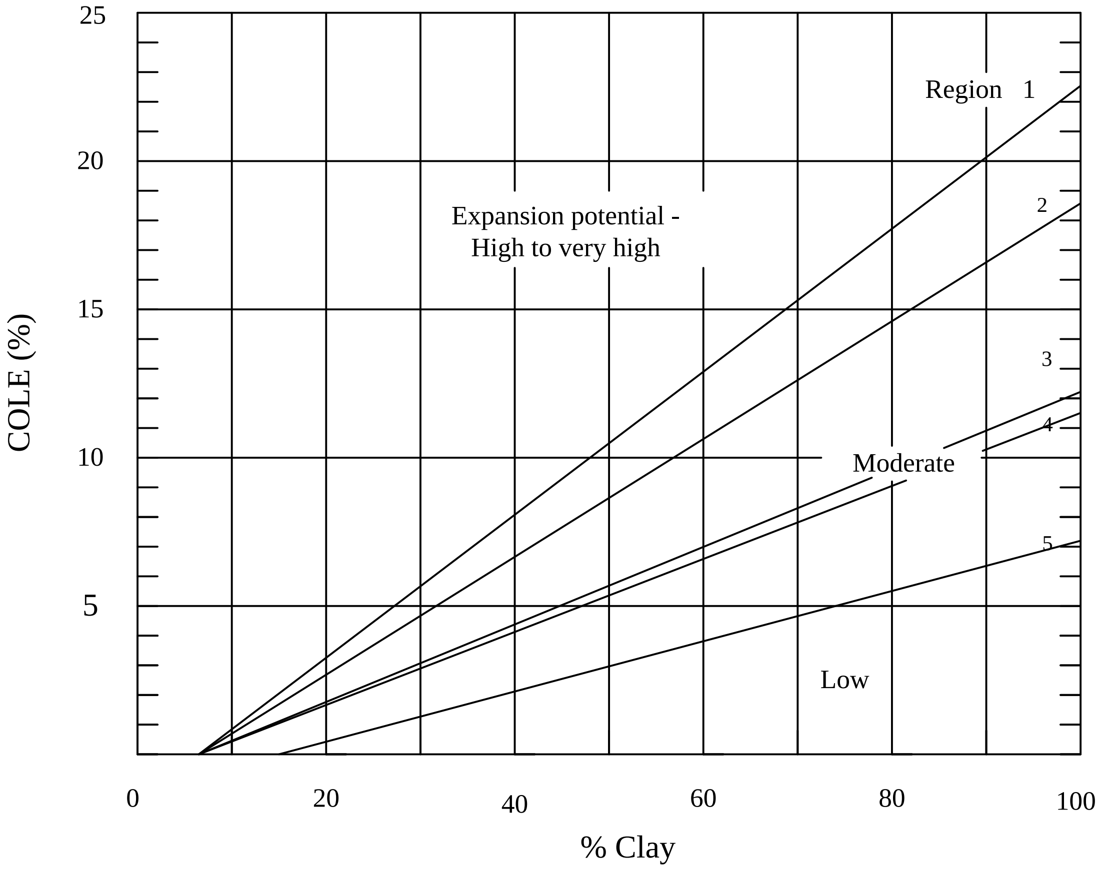


FIGURE 1: EXPANSION POTENTIAL AS A FUNCTION OF COLLOIDS AND COLE (HARDCASTLE, 2003)

III. RESULTS AND DISCUSSION

The test for the measure of shrink-swell behaviour namely coefficient of linear extensibility (COLE) was carried out and the COLE calculated using equation 2. Table 1 shows results of the coefficient of linear extensibility (COLE) and bulk densities of two samples retrieved from the area under study. It is noted from the results that the bulk density for clods at oven-dry condition increases relative to that at 33 kPa moisture tension. This is stemmed from the fact that upon drying the sheet-like particles of montmorillonite pack together to form a very compact rigid structure characterized by low porosity. The tested sample possessed coefficient of linear extensibility ranging from 0.09 to 1.15. The results indicate that these soils are classified as having high to very high shrink–swell potential. The quantitative swell potential was also estimated by correlating the means of colloids content and the COLE as in Figure 2. Once again, the samples fell in the region of high to very high expansion potential. Generally the coefficient of linear extensibility first decreased with increase in depths at surface horizon and then decreased with depths in the sub-surface horizon (Figure 2).

The COLEs thereafter were correlated with clay contents and a high degree of correlation was obtained between clay contents and COLE (Figures 3 & 4). The summary of Linear Regression Results for the two Samples namely RC5 and RB3 is given in Table 2. For sample RC5, the significant effect of clay content in the quantity of COLE was shown by high value of the simple correlation (R) which is equal to 0.942 indicating a high degree of correlation. The correlation coefficient (R^2= 0.89), which is also very large, indicates how much of the total variation in the dependent variable (COLE) can be explained by the independent variable (Clay Content). Clay content also correlated positively with COLE in the samples from profile RB3, although the correlation coefficient was somewhat lower ($R^2 = 0.678$) but the simple correlation (R) equals to 0.824 indicating strong positive correlation. For both samples, the **ANOVA** results signifying how well the regression equation truly represents the set of data (i.e. independent variable predicts well the value of dependent variable), yielded the statistical significance of the regression models $p < 0.001$ and $p < 0.023$ for RC5 and RB3 samples respectively, which are both less than 0.05, indicating that the overall regression models passes the threshold of statistical significance, thus the independent variables statistically significantly predict the dependent variables close to the observed values. Finally, the **Coefficients** section in Table 2 provides the necessary information to predict COLE from Clay Content, as well as determine whether Clay Content contributes statistically significantly to the model. Therefore, two models for RC5 and RB3 samples are **COLE = 0.0048(Clay Content) – 0.0215** and **COLE = 0.007(Clay Content) - 0.129** respectively in which Clay Content contributes statistically significantly to both models because both of their p-values are less than 0.05. Once COLE is calculated by inserting clay content in the model, the expansion potential can be ascertained.

TABLE 1
CALCULATED COEFFICIENT OF LINEAR EXTENSIBILITY (COLE) OF TWO SAMPLES, RC5 & RB3

Sample	Depth (m)	Bulk density		COLE (cm/cm)	Clay content (%)
		Oven-dry	33 kPa		
RC5	0.0	1.73	1.23	0.12	28
RC5	0.5	1.75	1.22	0.13	32
RC5	1.0	1.84	1.24	0.14	34
RC5	1.5	1.82	1.21	0.15	35
RC5	2.0	1.83	1.23	0.14	32
RC5	2.5	1.85	1.32	0.12	30
RC5	3.0	1.83	1.33	0.11	28
RB3	0.0	1.65	1.29	0.09	31
RB3	0.5	1.68	1.22	0.11	33
RB3	1.0	1.67	1.2	0.12	34
RB3	1.5	1.65	1.21	0.11	31
RB3	2.0	1.61	1.21	0.10	32
RB3	2.5	1.59	1.23	0.09	31
RB3	3.0	1.67	1.30	0.09	30

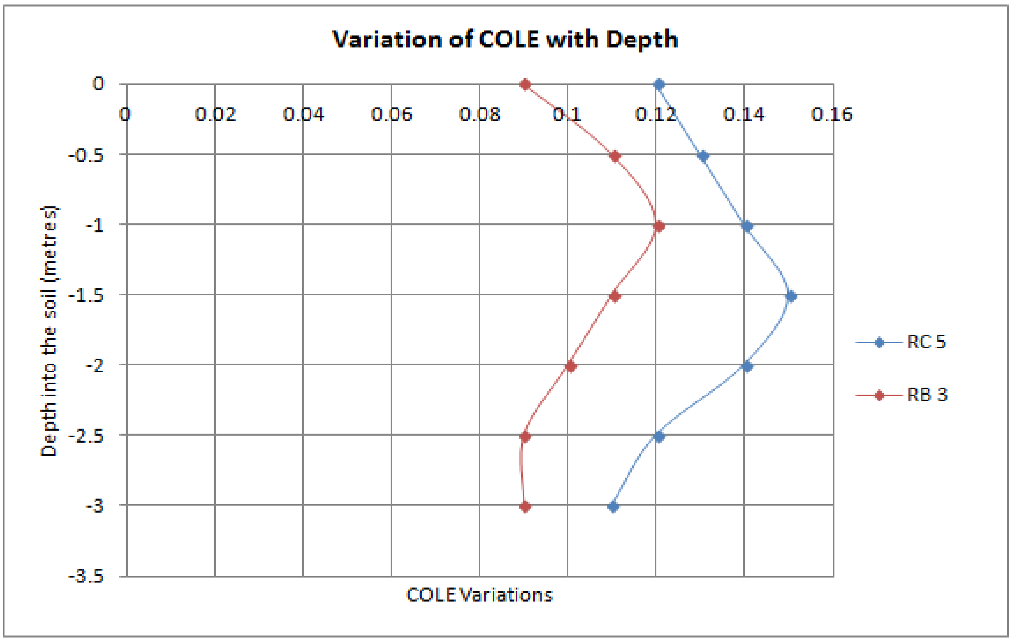


FIGURE 2: COEFFICIENT OF LINEAR EXTENSIBILITY FOR SAMPLES RC5 AND RB3.

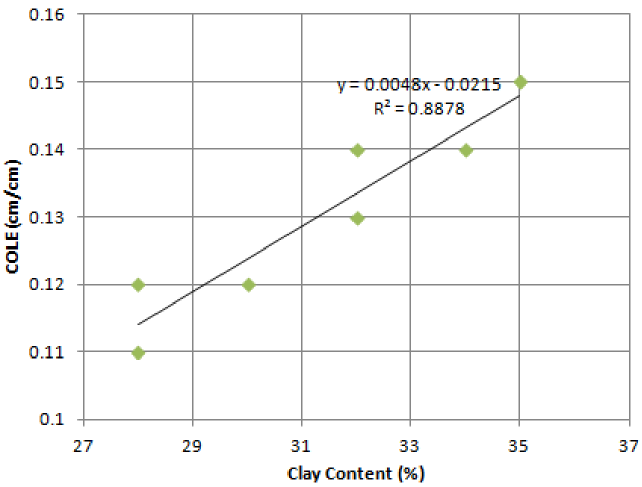


FIGURE 3: RELATIONSHIP BETWEEN COLE CLAY CONTENT IN RC5 PROFILE

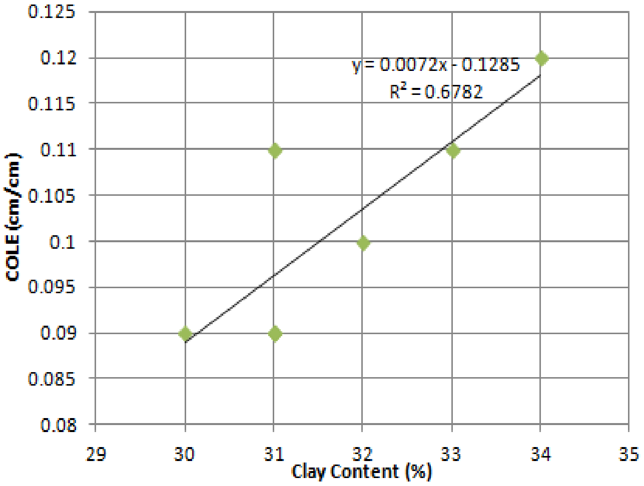


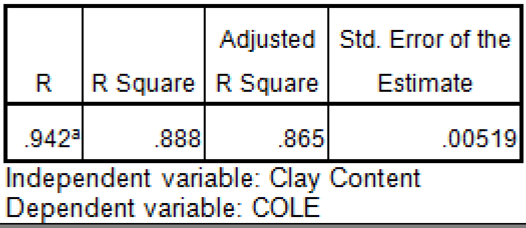
FIGURE 4: RELATIONSHIP BETWEEN COLE AND CLAY CONTENT IN RB3 PROFILE

TABLE 2

SUMMARY OF LINEAR REGRESSION RESULTS FOR EXPANSIVE SOILS SAMPLES RC5 AND RB3

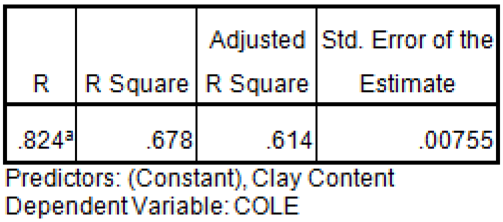
Sample RC 5 | **Sample RB 3**

Model Summary



R	R Square	Adjusted R Square	Std. Error of the Estimate
.942^a	.888	.865	.00519

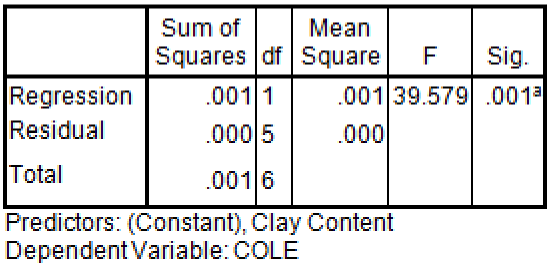
Independent variable: Clay Content
Dependent variable: COLE



R	R Square	Adjusted R Square	Std. Error of the Estimate
.824^a	.678	.614	.00755

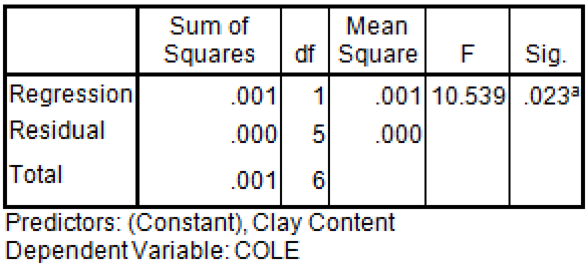
Predictors: (Constant), Clay Content
Dependent Variable: COLE

Analysis of Variance (ANOVA)



	Sum of Squares	df	Mean Square	F	Sig.
Regression	.001	1	.001	39.579	.001^a
Residual	.000	5	.000		
Total	.001	6			

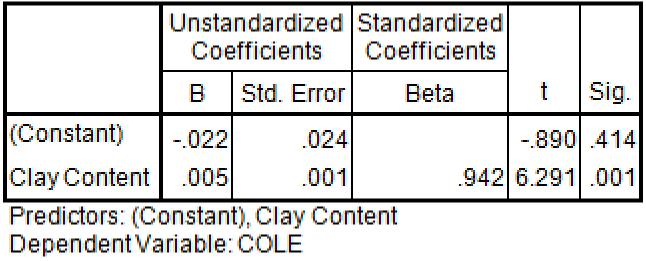
Predictors: (Constant), Clay Content
Dependent Variable: COLE



	Sum of Squares	df	Mean Square	F	Sig.
Regression	.001	1	.001	10.539	.023^a
Residual	.000	5	.000		
Total	.001	6			

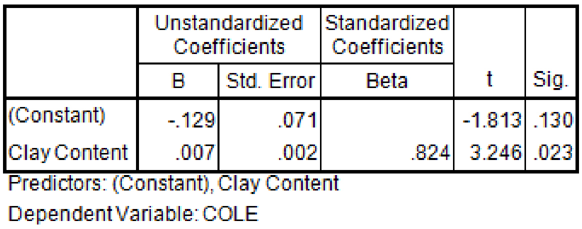
Predictors: (Constant), Clay Content
Dependent Variable: COLE

Coefficients



	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	-.022	.024		-.890	.414
Clay Content	.005	.001	.942	6.291	.001

Predictors: (Constant), Clay Content
Dependent Variable: COLE



	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	-.129	.071		-1.813	.130
Clay Content	.007	.002	.824	3.246	.023

Predictors: (Constant), Clay Content
Dependent Variable: COLE

IV. CONCLUSION

The estimation of the swell potential based on the coefficient of linear extensibility (COLE) provides a means to rapidly and inexpensively quantify a soil's shrink-swell potential. It gives the possibility to identify the soils susceptible to shrink-swell behaviour that might greatly affect the stability of the structures on them. The coefficient of linear extensibility (COLE) was computed from the bulk density of clod at suction of 33 kPa and dry density of oven-dry clod. All tested samples possessed coefficient of linear extensibility ranging from 0.9 to 1.4 in the soil horizons, and generally increasing at the surface horizons and then decreasing in the subsurface horizons with increasing depth. The trend towards increasing COLE with depth at the surface horizons is attributed to a decrease in organic matter in soil with depth while the decreasing COLE with depth in the subsurface horizons is due to decreasing clay contents because of increasing settlement of coarse fragments with increase in depth. According to Thomas *et al*. (2000) classifications, the under contemplation soils are classified as soils with a high to very high swelling potential. The results of this research indicate that COLE is very useful in predicting a soil's shrink-swell potential. Once such soils have been identified, anti-swelling measures such stabilization and heat treatment may be employed to arrest the situation.

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