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Correlation Between Shear Strengths of Disturbed and Undisturbed Soils at Three Sites in Burkina Faso

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Abstract: In the field of construction, performing laboratory tests of soil mechanics and geotechnics is a key step. Tests performed on undisturbed soil samples are sometimes required. The major difficulty in the success of these tests is in the prevention of any change in the state of these materials which may be due to coring, transport and sampling in the laboratory conditions. Physical factors, such as rainfall, temperature, are ones of the most which can change samples natural state. To facilitate obtaining the parameters of the mechanical behavior of undisturbed samples, this paper proposes to establish correlations between shear strengths of disturbed samples and those of undisturbed samples of tropical soils of Burkina Faso. Shear tests were performed using the Casagrande cell on disturbed and undisturbed samples from Kamboinsé; Loumbila and Saba sites. The tests carried out were Unconsolidated-Undrained; Consolidated-Undrained and Consolidated-Drained. For each test, linear correlation between shear strengths of disturbed and undisturbed samples was etablished under similar moisture content conditions. Results displayed a good correlation between shear strengths of undisturbed samples and those of disturbed samples. All correlation coefficients are greater than 0.9. Samples particles sizes distributions and their clay content did not have significant impacts on shear strengths.

Keywords: Disturbed, Undisturbed, Shear Strengths, Correlation, Tropical Soil

1. Introduction

In engineering, the study of soil behavior requires the collection and determination of physical and mechanical parameters such as: identification; deformability; shear strength and permeability.

Measurement of all these parameters on field, on a sufficient number of points allowing a complete study of building projects, is often difficult. Geotechnical investigations are most often limited to certain parameters. To contribute effectively to complementary parameters production, correlations between soil parameters have been developed.

Correlations that can be established between the physical and mechanical parameters of the soils are more or less general but their validity is often limited to the studied soil type. This technique is very useful in geotechnical studies. It is used to supplement data and test the probability of the results of field and laboratory tests.

Many correlations have been established between soil consistency parameters and its mechanical parameters [1-3] or between its different mechanical parameters [3-6].

Based on results of Proctor and Oedometric tests performed on a set of 70 samples from different types of soil material, Fleureau et al. [7] established correlations at Normal and Modified Proctor Optimum (OPN and OPM) between clay soil properties: liquid limit and negative pore pressure; negative pore pressure and void ratio. These correlations are all in agreement with those previously proposed by other authors [8, 9, 10]. From compacted soils and using the modified Cam Clay model [11], correlations linking the compressibility parameters (C_c and C_s) and the Atterberg limits (W_L) were revealed [12]. A correlation between shear strength and natural water content of Gulf of Guinea sediments is observed by laboratory measurements [13]. The peak of shear strength corresponds to a decrease in the natural moisture content.

Dolinar and Skrabl [14] propose some elementary relations between the mechanical properties of normally consolidated disturbed soils and the Atterberg limits. The authors found that the plasticity index (I_P) of the different clays they studied was closely related to the liquidity limit (W_L). This relationship further clarifies the general classification of silts and clays proposed by Casagrande [15].

In any geotechnical investigation involving soils such as clay, undrained shear strength σ_u and preconsolidation pressure σ'_p are relevant parameters in evaluating soil mechanical behavior. The first, although one of the most difficult to be accurately determined, both in-situ as well as in laboratory is also the most important factor. The correlation between σ'_p and σ_u have long been used to predict soil behavior. These correlations, linking two or more parameters of mechanical behavior of soils, have been proposed by many researchers [16-18]. Hansbo [18] proposed a correlation based on WL. The correlation was originally found for σ_p' but the correlation has since been considered to be equally applicable to σ_v' (Present Effective Vertical Stress). The clays present in Hansbo's study had not been influenced by over consolidation, which means the correlation is primarily defined for OCR (Over Consolidation Ratio) =1.

About correlations between σ_u and σ_p' Karlsson and Viberg [19] found no unique relationship and concluded that there are several factors influencing undrained shear stress. However, Mesri [20] proposed that the relationship between σ_u and σ_p' can be constant, which the more recent study by D'Ignazio et al. [4] proved.

The cone penetration test has also been used for a long time to explore the behavior of the soil, determining its bearing capacity [21] and one of the first applications concerned the undrained shear strength of soft soils. Applying one of the theoretical proposals for bearing capacity theory [22, 23], the undrained shear strength can be obtained very similarly in each of them and its general formula can be:

$$\sigma_u = (q_c - \sigma_0)/N_c \quad (1)$$

Where σ_u is the undrained shear strength; q_c is the cone resistance; Nc is the theoretical cone factor; σ_0 is the total horizontal, vertical or mean stress (depending on the theory considered).

The derivatives of these theoretical expressions have shown that a reliable correlation can be established between the undrained shear strength and CPT (Cone Penetrometer Test) tip resistance. These expressions were used later as, theoretical basis empirical or semi-empirical correlations that were commonly defined by the same form of equation, but to differentiate them from theoretical solutions, the empirical cone factor is noted by N_k [16] as:

$$\sigma_u = (q_c - \sigma_{v0})/N_k \quad (2)$$

Where σ_{v0} is the total overburden stress

The formula (2) has been slightly modified and the tip resistance values corrected by taking account the pore pressure effects (q_t):

$$\sigma_u = (q_t - \sigma_{v0})/N_{kt} \quad (3)$$

This equation (3) is better suited to the case of soft clays, where the measured pore pressure is often as high as the measured CPT tip resistance.

The empirical cone factor N_k varies with soil type and has been studied by several authors as indicated on Table 1:

Table 1. *Cone factor N_k recommended values.*

N_k values range	Comments	References
11 – 19	Value of 15 for normally consolidated Scandinavian marine clays	[24]
20	Marine clays	[25]
15	Boulder clays	[25]
7.6 -28.4	Different soil types.	[26]
8-29	N_{kt} varies with OCR	[27]

Like penetrometer, the dilatometer (DMT) has also been widely used for establishing test methods and original correlations for the evaluation of selected geotechnical parameters such as undrained shear strengh. Comprehensive investigations were made to assess and enlarge the application of DMT in geotechnical engineering [28-33]. A new DMT-based chart is presented based on generalized soil behavior type descriptions and a method to evaluate the existence of microstructure in soils using a combination of CPT and DMT is also presented [31]. The author has shown that Relationships between the two in-situ tests can be used to expand and improve correlations and applications using experience and databases from one test and extrapolating to the other test. The overconsolidation ratio (OCR) was derived from CPTU, DMT and oedometric tests [29]. The tests revealed that for the assessment of changes in constrained modulus in the subsoil with CPTU and DMT, the formulas determining the correlation between cone resistance, DMT results and constrained moduli requires empirical coefficient different for soils of varied genesis. There are some of the relationships evaluating constrained modulus and undrained shear strength that routinely used intermediate parameters obtained from DMT readings [28, 34]. Lechowicz, et al. [28]. Performed dilatometer and laboratory tests on heavily preconsolidated boulder clays and Pliocene clays prevailing in the Warsaw region. Empirical coefficients for multi-factor correlation to obtain undrained shear strength from dilatometer tests for boulder clays and Pliocene clays were determined. Relationship between factor RM (depending to soil density index ID) and horizontal stress index (KD) for boulder clays was proposed for the evaluation of constrained modulus from dilatometer tests.

In literature, many correlations, mostly linear, have been established to describe soils behavior. These correlations correlate consistency parameters (Atterberg limits) and mechanical parameters, different mechanical parameters, in situ and laboratory results...... The consistency limits are determined on disturbed materials, so they do not take into account either the original structure or the variations of the soil constituents. To collect representative geotechnical data, testing should be performed on undisturbed samples to resemble actual in situ test conditions. However, samples disturbance phenomenon has long been a problem and difficulties in obtaining undisturbed samples was discussed [35, 36]. Although such correlations can be applied to uniform clay types if anisotropic conditions are considered [19].

The undrained shear stress measured by laboratory or in situ method, appears to be the most used in the correlations describing the mechanical behavior of soils. Today, an issue is that measured data from projects seldom deviate from established empirical correlations and the scatter of data is great. Thus, the reliability of the methods applied, regarding correlations, laboratory testing and field operations, are of increasing interest.

In spite of the high number of studies on correlations of soils mechanical behavior parameters, few of them are interested in the shear resistances measured respectively on undisturbed and disturbed tropical soils samples. For soils such as silt, peat and clays, the shear strength values of disturbed samples are always lower than intact samples. The aim of this paper is to study the tropical soils of Burkina Faso by establishing correlations between the shear strengths of disturbed normally consolidated (OCR=1) and undisturbed, over consolidated (OCR>1) samples. These will make it possible to deduce the shear strength of undisturbed soils without suffering the difficulties related to their handling. To achieve this goal, direct shear cell (NF P 94-071) was used and following tests was performed on disturbed and undisturbed laterite samples: Unconsolidated-Undrained (UU), Consolidated-Undrained (CU), Consolidated-Drained test (CD).

2. Materials and Method

2.1. Physical Description of the Samples

To constitute a fairly representative database, samples were taken at three different sites in Burkina Faso whose geographic coordinates are shown in Figure 1: the Saaba Basin (sample 1); the Loumbila Dam (sample 2 and Kamboinsé dam (sample 3).

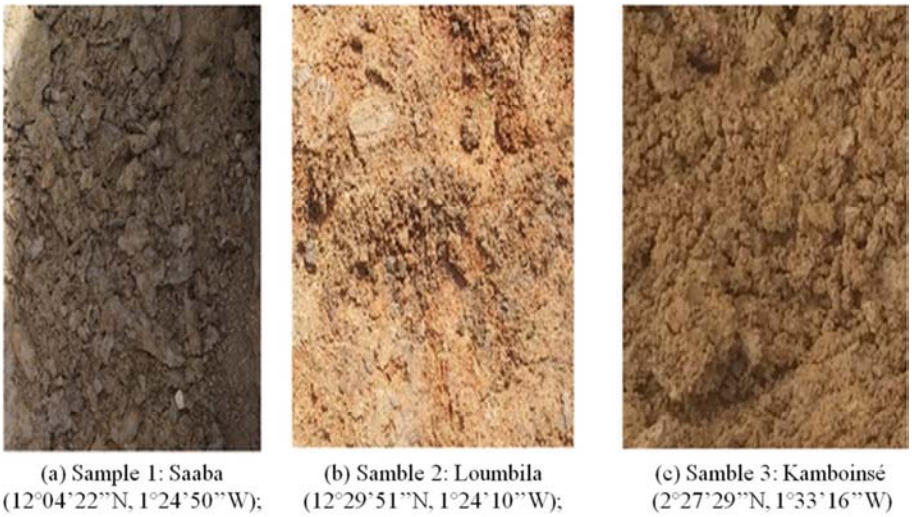

Figure 1. *Soils from the three different sites studied.*

Sample 1: It is a soil of fluvial origin. It was deposited in the old major bed of the temporary river running through the site, now dried up decades ago. This soil is very sticky and swelling.

Samples 2 and 3 present similar physical aspects. They are all cohesive from the alteration of lateritic rocks under the effect of local climatic conditions (high temperature and humidity).

From each site were taken disturbed and undisturbed samples

At these three sites, the samples were taken at depths where the water content of the deposits is high enough to facilitate the coring operation (depth of 115 cm at the bottom of the dry Kamboinsé dam (sample 1); 55 cm at the bottom of the Loumbila dam (sample 2) and 115 cm in the minor bed of a river that crosses the Saaba site (sample 3).

Sampling of undisturbed samples for shear testing is accomplished by pushing a sharp-edged cylinder with the same dimensions as a Proctor mold. The samples thus obtained are protected with parafilms to preserve their moisture content and sent to the laboratory. From this, the samples intended for shear tests are cut with the dimensions of the shear box of Cassagrande.

Disturbed samples, for identification and shear tests was taken out immediately adjacent to the undisturbed samples and at the same depth to have the same soil composition as the undisturbed samples. In order to characterize the different samples, several laboratory tests were carried out during their extraction. First of all, Atterberg limits, particle size tests and moisture contents, the proctor test were made to determine the basic characteristics of the soil (table 1). The degree of consolidation was determined by oedometric tests.

Mechanical characteristics (φ', C_u and c') were evaluated using direct shear tests. Consolidation and shearing occurred under undrained isotropic conditions (τ_{CUI}, τ_{CUR}), drained conditions (τ_{CDI}, τ_{CDR}). Shearing was also cared out under unconsolidated and undrained conditions (τ_{UUI}, τ_{UUR}). Where τ_{CUI}, τ_{CDI}, τ_{UUI} are shear strengths of undisturbed samples and τ_{CUR}, τ_{CDR} τ_{UUR} are shear strengths disturbed samples.

The particle size analysis shows that samples consist of sand, silt and clay to significant proportions (Figure 2).

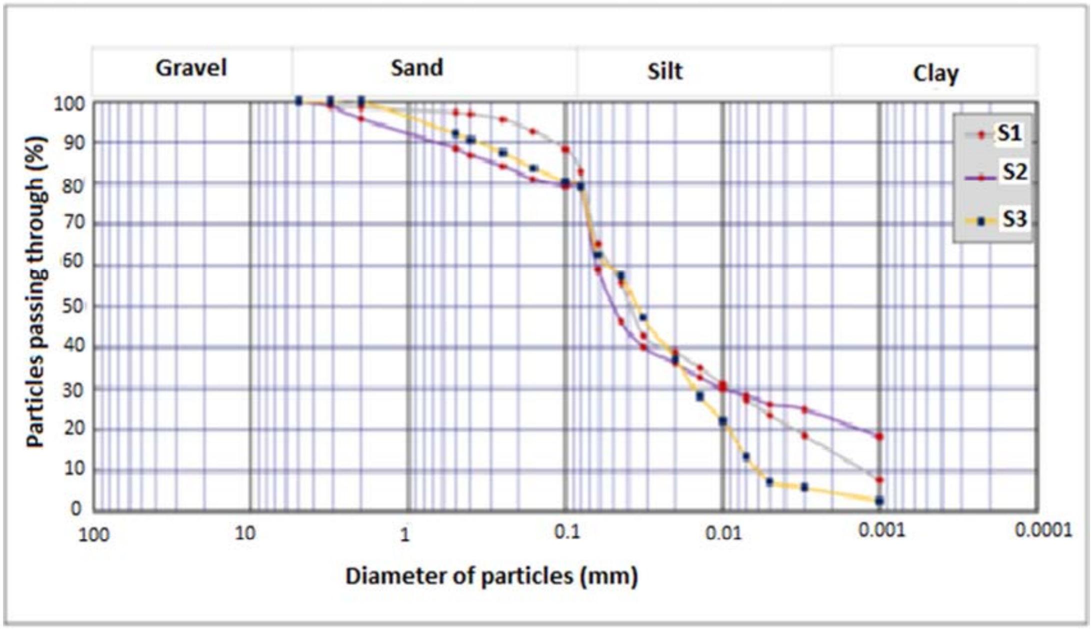

Figure 2. *Particles size distribution of samples.*

The effects of this composition are also observable on the consistency parameters (WL, Wp, IP) (Table 2).

The classification A.A.S.H.T.O standard provides a soil class A-6a for the sample 1; A-7-6 for sample 2 and A-6b for sample 3.

Table 2. *Characteristics of the 3 studied soils (NF P94-071 -1 standard.).*

Soil Parameters	Depth sampling (cm)	In-situ water content (%)	Granulometry			Optimum Proctor		Atterberg limits		
			Sand (%)	Silt (%)	Clay (%)	Dry density γ_{opt}	Water content W_{opt} (%)	W_L (%)	W_P (%)	IP (%)
Sample 1	70	17	36	44	20.0	1.88	13.60	24.45	12.04	12.41
Sample 2	55	25.5	42.5	30	27.5	1.77	17.20	42.90	14.52	28.38
Sample 3	115	18.5	38.5	51.5	10.0	1.90	14.50	31.50	13.58	18.07

2.2. Parameters of Direct Shear Test

The moisture content of the undisturbed samples before testing is at most less than that obtained in-situ by 0.1%. As for the moisture contents of the disturbed samples are substantially equal to those of the undisturbed samples before testing. This small difference in moisture content between disturbed and undisturbed samples makes it possible to compare in the mechanical strengths of these two types of samples. Shear velocity used for each test are those provided by the NF P94-071-1 standard [37]. For undrained tests (UU, CU) V = 1.5mm/min and for the drained tests (CD). During the test, temperature of the room was regulated at 25°C with an estimated range of variation between 23°C and 27°C.

3. Results and Discussion

3.1. Test Results

The experimental results obtained from direct shear tests are presented in two different groups: shear strengths (Table 3) and stability parameters (cohesion and internal friction angles) (Table 4). Table 3 presents the shear stresses obtained on each disturbed and undisturbed sample, each subjected to normal stress of 50 kPa; 100 kPa and 200 kPa. These results are also presented for the three different shear tests performed in this study: UU; CU; CD. As for Table 4, it summarizes the values of angles of friction and those of the cohesion corresponding to the same tests of Table 3. The indices "I" and "R" respectively indicate undisturbed and disturbed sample. In this paper, the shear strengths taken into account are those at the peaks of the strength-strain curve. Friction angles (Φ) and cohesions (C) are deduced by Coulomb's law:

$$\tau = C + \sigma \tan\Phi \quad (4)$$

Where τ is the stress or shear strength and σ the normal stress which induces it

The effects of site conditions (type of material, humidity, temperature.....) and type of shear test on shear strengths; friction angles and cohesions were observed using histogram graphs (Figure 3, Figure 4 and Figure 5). All the disturbed samples displayed lower shear strengths than the undisturbed samples.

The results of this comparison are consistent with literature publications such as the work of Martin et al. 2001 on sediments of the Saguenay Fjord, Quebec.

A significant difference was found between the disturbed and undisturbed behavior. For undisturbed samples, the shear strengths increase with depth, suggesting the effects of over consolidation ratio (OCR).

Jozsa [38] estimated relationship between undrained strength and OCR and concluded that undrained strength increased due to OCR. The author indicated also that stresses and deformations of retaining and other geotechnical structure can be influenced by over consolidation ratio. Thus, the samples are classified in order of increasing strength as follows: sample 2 (Loumbila site) - sample 2 (Saba site) - sample 3 (Kamboinsé site), extracted respectively at a depth of 55 m; 70 m and 115 m. This trend is observed on samples from three different sites and needs to be confirmed on each site. Concerning the effects of the type or the test conditions, the different results do not show any regular tendency

Table 3. *Shear strengths of the samples according to the three types of tests.*

(kPa)	Sample 1			Sample 2			Sample 3		
	50	100	200	50	100	200	50	100	200
τUUI (kPa)	69.06	92.65	130.55	53.90	71.59	92.65	70.33	104.44	144.87
τUUR (kPa)	42.95	56.85	83.38	32.85	40.85	56.85	44.64	61.48	90.54
τCUI (kPa)	68.22	84.22	122.13	57.27	64.85	92.65	72.43	101.07	142.76
τCUR (kPa)	45.48	58.96	89.278	32.85	40.27	57.27	45.48	58.96	89.28
τCDI (kPa)	70.75	91.80	132.65	54.75	75.80	96.86	74.12	101.07	144.87
τCDR (kPa)	42.95	66.54	90.96	35.79	42.11	63.17	42.95	66.54	90.96

Table 4. *Cohesion and internal friction angle of soils samples.*

Essai	Sample 1		Sample 2		Sample 3	
	Soil cohesion c (kPa)	Angle of internal friction ϕ (°)	Soil cohesion c (kPa)	Angle of internal friction ϕ (°)	Soil cohesion c (kPa)	Angle of internal friction ϕ (°)
UUI	50	18	44	11	50	21
UUR	30	12	24	7	30	14
CUI	49	16	43	11	52	20
CUR	30	13	25	7	30	13
CDI	50	18	44	12	52	20
CDR	31	14	25	8	31	14

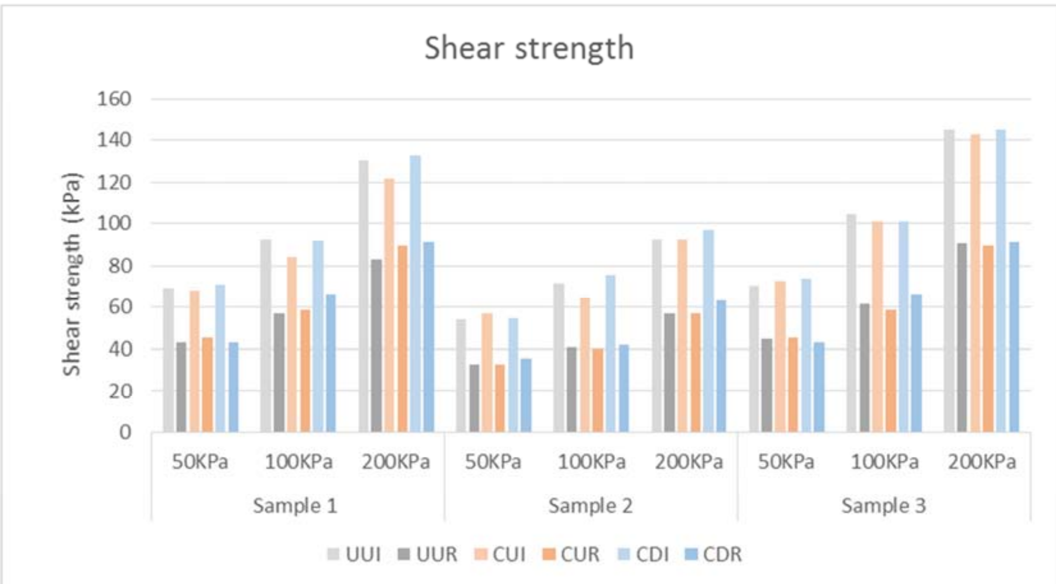

Figure 3. *Comparison between shear stresses for reworked and undisturbed samples.*

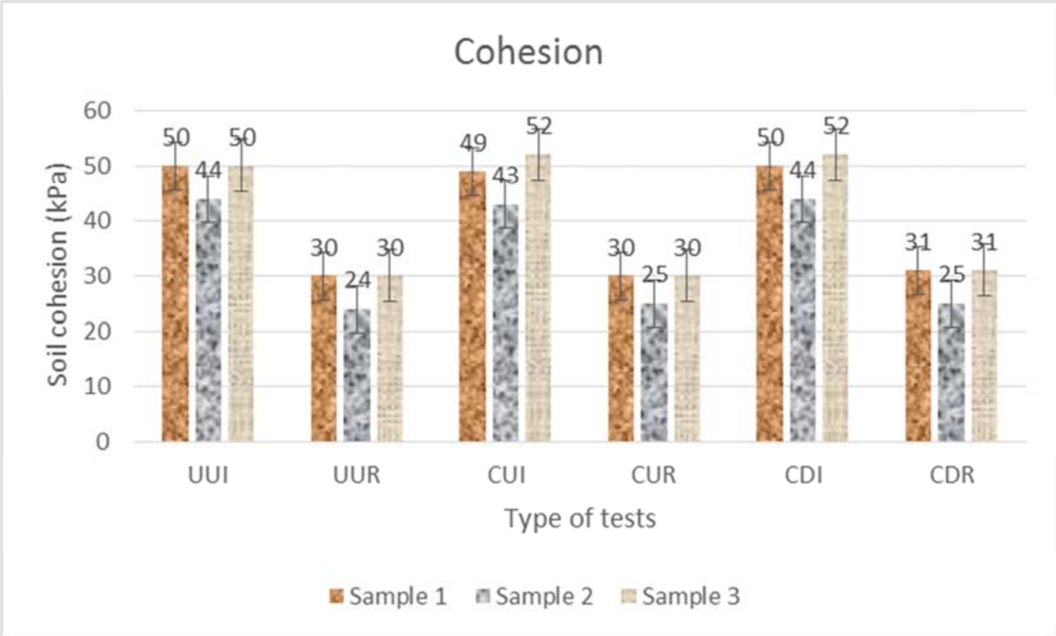

Figure 4. Comparison of intact and reworked soil cohesion.

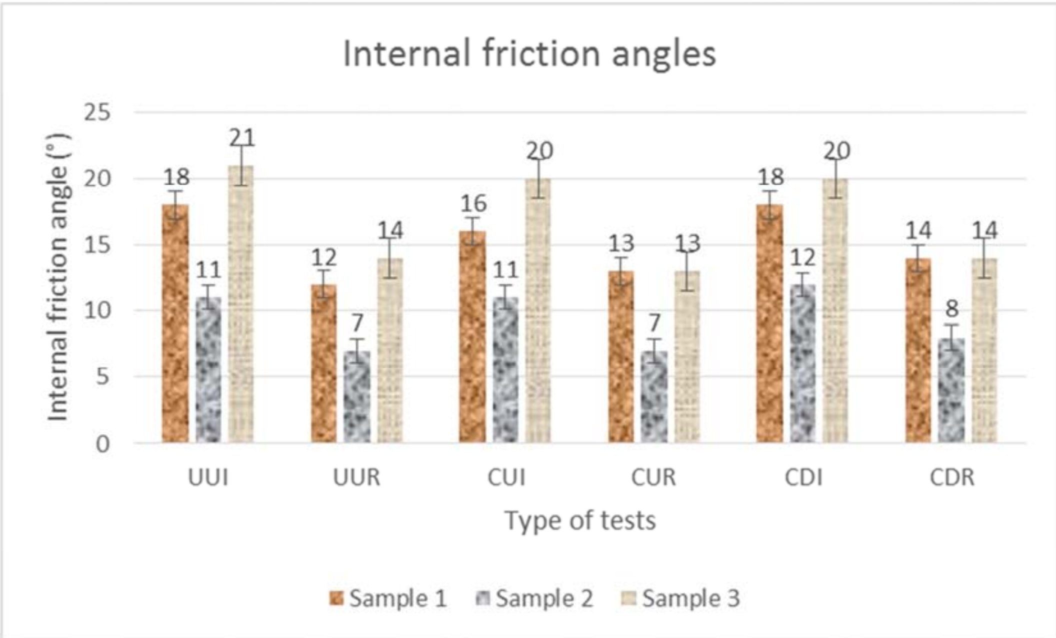

Figure 5. Comparison of internal friction angles of intact and reworked soils.

3.2. Descriptive Statistics

Submitting the results of the measurements to a statistical analysis, allows a relatively objective choice of values of the geotechnical characteristics. The descriptive statistical, average value $\bar{x}$; the variance v(x); the covariance Cov (x, y); the standard deviation σ_x and the coefficient of correlations r (x, y) can be determined.

The result gives basic information, as minimum, maximum values and the population mean $\bar{x}$. The standard deviation quantifies the variation of a dataset. In a dataset with normal distribution about 68.2% of the sample population will fall within the interval of one standard deviation [39]. The standard deviation is given by formula:

$$\sigma_x = \sqrt{\frac{1}{N}\sum_1^N (x_i - \bar{x})^2} \quad (5)$$

Where x_i is an observed value.

3.3. Correlations and Linear Regression

The Pearson correlation coefficient, r allow to analyze the correlation between two variables, X and Y. It is defined as the covariance of the variables divided by the product of the variable's standard deviations [39]:

$$r(x,y) = \frac{Cov(x,y)}{\sigma_x \sigma_y} \quad (6)$$

Pearson's coefficient r provides a measure of the bivariate linear correlation between the two variables X and Y. It has a value between -1 and +1. +1 represent a total positive and -1 a total negative linear correlation. If r=0, it means no correlation between the two variables and their changes are not at all correlated. For a linear correlation between the strengths, the values of r (x, y) must be different from 0 (zero). The closer the values of r (x, y) are to 1 (≥0.8), the better the linear correlations between the two variables [39].

As for linear regression, it models the linear relationship between a dependent variable Y and an independent variable, X. His analysis represents a line corresponding to an observed data set of Y and X. The line equation is of the form: Y=aX+b which can be written versus average values $\bar{x}$ and $\bar{y}$ as:

$$Y = \frac{Cov(x;y)}{V(x)} X + \bar{y} - \frac{Cov(x;y)}{V(x)} \bar{x} \quad (7)$$

Where "a" is the intercept of linear regression line with y-axis and "b" its slope. The linear regression can be presented in a scatter plot with the dependent and independent variable on the y- and x-axis, respectively. In the statistical analysis, scatter plots may be presented with regression lines fit to the data and confidence or prediction intervals to verify or reject a hypothesis. The coefficient of determination, R^2, is used as a measurement of how well independent variables explain the variance in the dependent variable. Its value varies from 0 to 1.1 means that all variance in the dependent variable is described from the independent variables and 0 means that there is no correlation between the variance and the independent variables

3.4. Correlation Between Shear Strengths of Disturbed and Undisturbed Samples According Each Type of Test

A statistical analysis of the database constituted by shear strengths; cohesions and friction angles was performed and correlation laws established. The correlations concerned the disturbed and undisturbed samples from the three studied sites. Statistical parameters such as average values, variances, covariances, standard deviations, Coefficients of linear correlation were determined using classical statistical relationships. Results were analyzed according to site conditions, the type of tests and according to the state of disturbing of the sample. Average values of shear strength from the three sites were very close meaning that samples particles sizes distributions, their moisture content and their clay content (limit of plasticity) did not have significant impacts on shear strengths. The average values of shear strengths of the undisturbed samples appear slightly higher than that of the disturbed samples for all the tests carried out. The dispersion expressed by the standard deviation is more important for the undisturbed samples. Positive covariance's obtained, indicated that as one of the two shear strength deviates from the mean, the other shear strength deviates in the same direction. For each test, the existence of a correlation has been proved by the linear correlation coefficient. This coefficient proved to be greater than 0.9 in all three cases studied. Linear regression laws have been drawn (Figure 6) and the quality of this prediction has been checked by the standardized coefficient of correlation (Pearson product-movement correlation coefficient). These coefficients are all positive and at least equal to 0.96 indicated better correlations between the disturbed and undisturbed shear strengths samples.

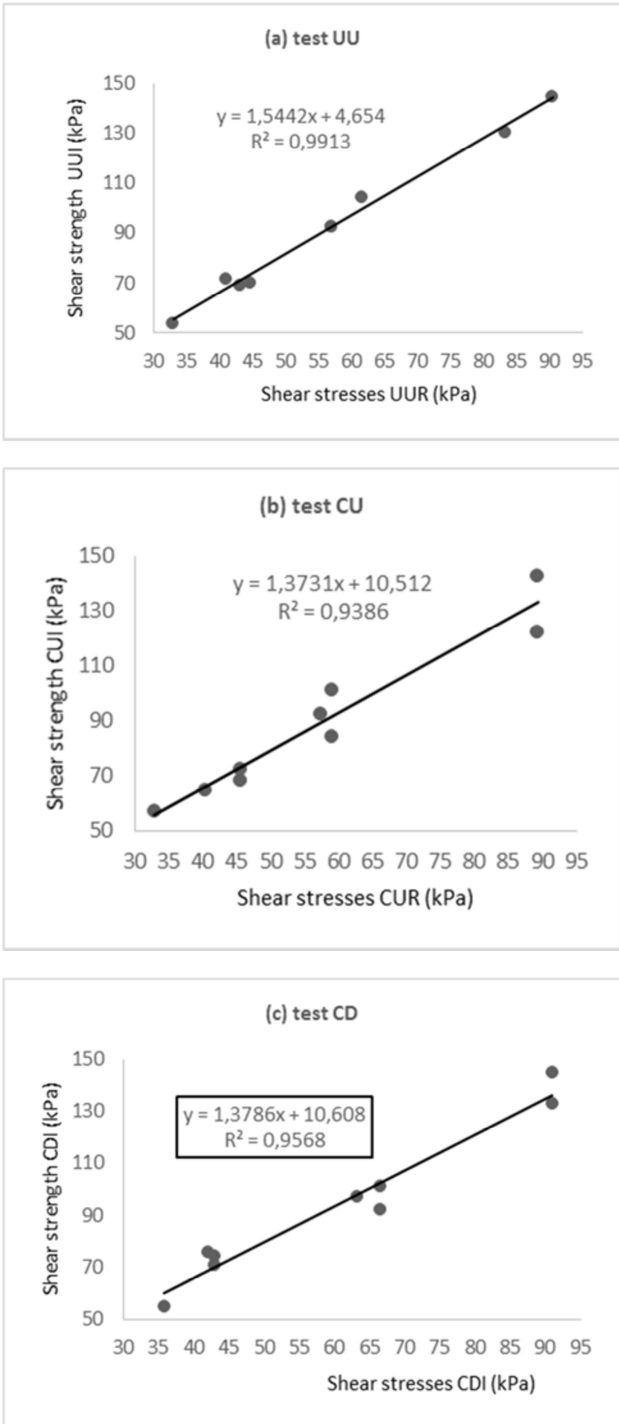

Figure 6. *Linear correlation between shear resistances of disturbed and undistrurbed soils.*

4. Conclusion

In this paper, tropical soils from three different sites in Burkina Faso have been studied. Samples particle size analysis and their consistence parameters have shown that they are each composed of important proportions of silt; sand and clay. This triple composition makes their identification and classification complex. Casagrande cell shear tests were performed under drained and undrained conditions and shear strengths determined on disturbed and undisturbed samples of these materials. Statistical parameters such as average values, variances, covariances, standard deviations, Coefficients of linear correlation were determined. They were analyzed taking into account the disturbed character or not of the sample; its provenance site and the type of test. The impact of particles sizes distributions; moisture content and clay content (limit of plasticity) was appear to be minimal on shear strengths of samples. Positive covariances obtained, indicated that as one of the two shear strength deviates from the mean, the other shear strength deviates in the same direction. Linear regressions between shear strengths of disturbed and undisturbed samples for each type of test were established. Determination coefficient from this regression analysis was about 0.95 to 0.99. Quality of this prediction from these correlations has been checked by the standardized coefficient of correlation. These coefficients are all positive and at least equal to 0.96 indicated better correlations between the disturbed and undisturbed shear strengths samples.

References

[1] R. Saim, «Des comportements repères des grains sans colle à un exemple de sol réel», Thèse de doctorat, Ecole Centrale de Paris., Paris, 1997.

[2] J. Biarez et J. Favre, «Corrélations des paramètres en Mécanique des sols», chez Table ronde nationale Ecole centrale de Paris., Paris., 1972.

[3] Society, Swedish Geotechnical, «Direkta skjuvförsök – en vägledning», SGF Notat 2: 2004., Linköping, 2004.

[4] M. D'Ignazio, K.-K. Phoon, S. A. Tan, T. Länsivaara et S. Lacasse, «Reply to the discussion by Mesri and Wang on "Correlations for undrained shear strength of Finnish soft clays», Canadian Geotechnical Journal, vol. 54, n° %15, pp. 749-753, 2017.

[5] J. Monnet, Les essais in situ en géotechnique, ISTE Editions., 2016.

[6] G. Mesri et C. Wang, « Discussion of "Correlations for undrained shear strength of Finnish soft clays», Canadian Geotechnical Journal, vol. 54, pp. 1-4, 2017.. l, 54. [This issue.]. 10.1139/cgj-2016-0686. Lien, Google Scholar.

[7] J.-M. Fleureau, J.-C. Verbrugge, P. J. Huergo, A. G. Correia et S. Kheirbek-Saoud, «Aspects of the behaviour of compacted clayey soils on drying and wetting paths.», Canadian Geotechnical Journal, vol. 39, n° %16, pp. 1341-1357, 2002.

[8] G. Ring, J. Sallberg et W. Collins, «Correlation of Compaction and Classification Test Data, Hwy. Res. Bull. No. 325, Highway Research Board, National Research Council, Washington, D. C., (1962), pp. 55-75;», chez 41st Annual Meeting of the Highway Research Board, Washington DC, United States, 1962.

[9] J. Biarez et J. Favre, «Statistical estimation and extrapolation from observations», chez Rapport à la Session Spec. N°6, C. R. du 9ème congrès Int. Méc. Sols Trav. Fond, Tokyo., 1977.

[10] J. Favre et A. Rahma, «Classification Logic and Correlation between Soils Parameters: Application to an Elasto-Plastic Law.», chez In: Breysse D. (eds) Probabilities and Materials. NATO ASI Series (Series E: Applied Sciences), vol 269., Dordrecht, Springer, 1994.

[11] [K. Roscoe et J. Burland, «On the generalised stress-strain behaviour of 'wet' clay», chez in: J. Heyman, F. Leckie (Eds.), Engineering plasticity, Cambridge, Cambridge University Press, 1968, pp. 535-609.

[12] L. Boutonnier, Comportement hydromécanique des sols fins proches de la saturation. Cas des ouvrages en terre: coefficient B, déformations instantanées et différées, retrait/gonflement, https://books.google.bf/books?id=HRZEXwAACAAJ, 2007, p. 394.

[13] [P. Di Gennaro, E. Collina, A. Franzetti, M. Lasagni, L. A. D. Pitea et G. Bestetti, «Bioremediation of diethylhexyl phthalate contaminated soil: a feasibility study in slurry-and solid-phase reactors.», Environ. Sci. Technol., vol. 39, n° %1325, 2005.

[14] B. DOLINAR et S. Skrabl, «Atterberg limits in relation to ather properties of fine-grained soils», ACTA GEOTECHNICA SLOVENICA, 2, pp. 5-13, 2013.

[15] A. Casagrande, «Characteristics of cohesionless soils affecting the stability of slopes and earth fills», J. Boston Society of Civil Engineers, vol. 23, n° %11, pp. 13-32., 1936.

[16] Z. Rémai, « Correlation of undrained shear strength and CPT resistance», Periodica Polytechnica Civil Engineering, vol. 57, n° %11, pp. 39-44., 2013.

[17] [W. Bo, M. Rasmus et L. Stefan, «Evaluation of undrained shear strength of Swedish fine-grained sulphide soils», Engineering Geology, vol. 188, n° %17, pp. 77-87, April 2015.

[18] S. Hansbo, «A new approch to the determination of thr shear strength of clay by the fall cone test», R. Swed. Geotch. Inst. Proc., pp. 14-47, 1957.

[19] L. V. R. Karlsson, «Ration C/P' in relation ro liquid limit and plasticity index with special reference to Swedish clay», Swedish Geotechnical Institute, vol. 6, n° %123, pp. 43-7, 1967.

[20] G. Mesri, «New design procedure for stability of soft clays», Journal of Geotechnical and Geoenvironmental Engineering, vol. 101, n° %1GT4, pp. 409-4012, 1979.

[21] A. Mahler, «Use of cone penetration test in pile design», Periodica Polytechnica – Civil Engineering, Vols. %1 sur %2, 47, n° %12, pp. 189-197, 2003.

[22] K. Terzaghi, «Theoretical Soil Mechanics», chez John Wiley and Sons, 1943. 18 Vesic A, Principles of pile foundation design, Durham, Duke University, Durham, NC., 1975.

[23] E. De Beer, «Static cone penetration testing in clay and loam, Sonder Symposium, In:», chez Proceedings of Sonder Symposium,., Fugro, 1977.

[24] T. Lunne et A. Kleven, « Role of CPT in North Sea Foundation Engineering, I», Symposium on Cone Penetration Engineering Division, ASCE, p. 49–75., 1981.

[25] O. Jörß, «Erfahrungen bei der Ermittlung von cu-Werten mit der Hilfe von Drucksondierungen in bindigen Böden», Geotechnik, n° %121, pp. 26-27, 1998.

[26] B. Gebreselassie, «Experimental, analytical and numerical investigations of excavations in normally consolidated soft soils», PhD thesis, University of Kassel, Vols. %1 sur %2, 2003.

[27] N. Rad, S. Sollie, T. Lunne et B. A. Torstensson, «A new offshore soil investigation tool for measuring the in-situ coefficient of permeability and sampling pore water and gas», Norwegian Geotechnical Institute, n° %1176, 1988.

[28] Lechowicz, Z., Rabarijoely, S., & Kutia, T. «Determination of undrained shear strength and constrained modulus from DMT for stiff overconsolidated clays. » Annals of Warsaw University of Life Sciences–SGGW. Land Reclamation, 49 (2), 107-116, 2017.

[29] MŁYNAREK Z., WIERZBICKI J., LUNNE T.: «On the influence of overconsoli-dation effect on the compressibility as-sessment of subsoil by means of CPTU and DMT». Ann. Warsaw Univ. of Life Sci. – SGGW, Land Reclam. 48 (3), 189–200, 2016

[30] SILVESTRI V., TABIB C. 2015: Applica-tion of the MCC model for the estimation of undrained geotechnical parameters of clays from dilatometer tests. Proc. 3rd Int. Conf. on the Flat Dilatometer DMT'15, Roma, Italy, 431–438

[31] ROBERTSON P. K. 2015: Soil behavior type using the DMT. Proc. 3rd Int. Flat Dila-tometer Conf., Roma, Italy, 243–250.

[32] CAO L., CHANG M. F., TEH C. I. 2015: Analysis of dilatometer test in clay. Proc. 3rd Int. Conf. on the Flat Dilatometer DMT'15, Roma, Italy, 385–392

[33] SCHNAID F. 2009. In situ testing in Geome-chanics – the main tests. Taylor and Fran-cis Group, London. TC16 2001: The flat dilatometer test (DMT) in soil investiga-tions. A Report by the ISSMGE Commit-tee TC16. May 2001. Reprinted in Proc. 2nd Int. Conf. on the Flat Dilatometer, Washington D. C., 7–48

[34] BRIAUD J. L., MIRAN J. 1991: The flat di-latometer test. Civil Engineering Depart-ment, Texas A&M University for Federal Highway Administration. Publ. FHWA--SA-91-044

[35] E. Persson, Empirical correlation between undrained shear strength and preconsolidation pressure in Swedish soft clays., Stockholm: Rayal Institute Technology, KTR, 2017, p...

[36] C. Caldenius et T. Hultin, «Grundundersökningar i Göteborgs hamnområde», Tekniska samfundets handlingar, vol. 2, 1937.

[37] NF. P94-071-1, «Sols: reconnaissance et essais - Essai de cisaillement rectiligne à la boîte - Partie 1 cisaillement direct», AFNOR, 1994.

[38] V. Jozsa, «Empirical correlations of overconsolidation ratio, coefficient of earth pressure at rest and undrained strength:», chez 2 CJRCE-Second Conference of Junior Researchers in Civil Engineering, Budapest, Hungary, 2013.

[39] A. Field, J. Miles et Z. Field, « Discovering statistics using R», Sage publications, 2012.