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Effects of Structure on the Erodibility of Residual Soils of Gneiss

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Abstract. This paper presents a study about the effects of the structure on the erodibility of residual soils of gneiss. This study considers four soils, three saprolitic and one lateritic, from the city of Joinville, state of Santa Catarina, in southern Brazil. Experimental campaign comprises infiltrability and loss of mass by immersion tests to achieve erodibility of such soils. Such tests compose the MCT methodology. These tests were conducted on undisturbed and remolded samples, under natural moisture and air dried during 24, 48 and 96 hours. Grain-size distribution curves were obtained in tests with and without the use of dispersant solution. The suppressing of dispersant solution results in grading curves distinct from that obtained by standardized tests, which means that different erodibility parameter for USLE model can be obtained for the same soil. According to erodibility tests, the lateritic soil has low erodibility potential when compared to saprolitic soils. It agrees with in situ observations. Damaging soil structure makes the soils more susceptible to erosion process, mainly the saprolitic ones. In general, remolding is more effective to increase the erodibility than soil drying.

Keywords. Erosion, residual soil, soil structure, erodibility.

1. Introduction

Measuring soil erodibility has been one of the main tasks of scientists and governmental programs since the beginning of the 20th century [1]. Considering its implications in environmental, economic and social terms, erosion remains as an important topic of research. In urban areas, the hydric erosion causes problems to infrastructure, e.g., the siltation of water bodies, reservoirs, and storm sewers; changes in the slope topography that causes landslides; the formation of gullies; and the scour of bridges and piers [2,3,4,5].

One of the tasks in this sense is to predict the loss of soil mass by erosion using parametric mathematical models. These models are empirical formulations that aims to interpret the erosion mechanisms through its causes and effects [6]. Some examples of such models are USLE [7] and WEPP [8], among others. In general, such models consider the land use and soil coverage, topography, rain erosivity, and soil erodibility.

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Soil erodibility is the susceptibility of the soil to be eroded [9]. Nogami & Villibor [10] describe the erodibility (specific) as the intrinsic resistance of the soil to the detachment of particles under dynamic action of runoff and raindrops.

Among the soil properties, those that influence the erodibility are: shear strength, grain-size distribution, plasticity, permeability, mineralogy and structure [11, 7, 12-14]. Correlation between erodibility and such properties is well explored when the MCT methodology [15] is used. Such proposition is based on the measurement of erodibility through the infiltrability test, which provides the sorption coefficient, and the modified loss of mass test. Although the use of this methodology is basically restricted to Brazil, many works have shown successful results (see [11, 16, 17] for example).

Unlike other methodologies, the MCT erodibility criterion was developed with reference to the behavior of saprolitic and lateritic tropical soils. Soil structure has strong control over the behavior of such materials, including on the erodibility. Structure, by means of the cohesion, can improve the shear strength. Moreover, in the lateritic soils clayey lumps lead to inconsistencies in relationships between grain-size distribution and erodibility. Also, according to Bastos [11], the silt fraction of kaolin-micaceous saprolitic soils imposes high erodibility for tropical soils, contrasting with silts from quartz produced in the temperate climate.

This paper presents a study about the effects of the structure on the erodibility of gneiss-migmatite residual soils. It is sought to evaluate the implications of the structure to the parameters measured in the infiltrability and modified loss of mass by immersion tests. Also, this study aims to evaluate the implications of the structure on the determination of the granulometric curves, which provide decisive information for the calculation of the soil erodibility parameters in mathematical models to estimation of soil loss.

2. Experimental program

2.1. Studied area

Joinville is a municipality in southern Brazil. Its urban zone spreads along plane areas related to recent sedimentary deposits, but the urban occupation advances over some areas of small elevation, and the larger hills are covered by vegetation.

Hilly areas refer to metamorphic basements, typically gneiss and migmatite. Some elevations are pierced by N-S oriented quartzite veins. Soil alteration, mainly weathering, gave rise to deep profiles of residual soils. Because of the urbanization, these soils are cut to create flat areas, as well as are used in the construction of embankments. Thus, the exposition of these soils and the high annual rainfall levels (more than 2100mm/year) create an environment where the hydric erosion is intensified.

This study was conducted in soils sampled in four sites, all of them in the urban area of Joinville (Figure 1). These sites were chosen in order to comprise areas where the residual soils are exposed due to cuts made in the hills. The soils sampled in EM, CO and XV sites are saprolitic and at the SS site the soil sampled presents lateritic features. At EM and CO sites, the erosive processes are more intense than in XV and SS.

Figure 1. Study sites (from N to S: site 1-EM, site 6-SS, site 4-XV and site 3-CO).

2.2. Methods

Undisturbed and disturbed soil sampling were carried out in each study site. Physical characterization comprises the determination of liquid and plastic limits and particle-size distribution. The dispersant agent used in sedimentation tests was sodium hexametaphosphate $(NaPO_3)_6$. Particle-size distribution tests without the use of dispersant agent were also carried out in order to evaluate soil structure features to soil texture. Mineralogical characterization was carried out by X-ray diffraction.

Undisturbed specimens for the erodibility tests were trimmed of undisturbed blocks. Remolded specimens were produced according to the procedure described in [18], i.e. static compaction using a hydraulic press in a mold. The soil was distributed in three equal layers in order to give uniformity to the specimen. The remolded specimens were prepared so that the void ratio, density and moisture content were similar to the values presented by undisturbed specimens.

The erodibility potential was measured through two tests: infiltrability and modified loss of mass by immersion. The tests were carried out using undisturbed and remolded specimens under natural moisture and in specimens air dried for 24, 48 and 96 hours. These tests are part of the set of experimental procedures of the MCT methodology [15].

Infiltrability test aims to measure de rate of water infiltration by capillarity and its variation along the time. This test is conducted by subjecting a specimen to the infiltration of water contained in a small diameter tube, which forms a meniscus. The meniscus displacement is measured during the tests and the infiltrability curve is drawn. The initial slope of this curve corresponds to the sorption coefficient (s). The equipment used holds meniscus with 5 mm diameter and carries specimens with 50 mm height and 48 mm diameter.

The “modified loss of mass by immersion” test is based in the loss of mass by immersion test proposed by the Brazilian standard DNER ME 256 [19]. A prismatic soil specimen (48 mm diameter, 50 mm height) is immersed in water for 20 hours. Soil specimen is restrained laterally by a ring and in one of the faces by a porous stone. This ring is hold 50mm above the tank bottom by a simple metallic apparatus. After this period, the percentage of desegregated soil mass (dry mass) with relation to the initial mass is determined. This percentage corresponds to the PI parameter. The term “modified” is used because in this case the height of the specimen is equal to the height of sampling ring. In the original test (for compacted soil), the soil is partially extruded from the ring. The use of the modified test is reported by [11] among others.

The erodibility parameter (erodibility potential) is given by the ratio PI/s. Thus, according to [15], soils that presents PI/s>52 should be considered potentially erosive. Pejon [20] suggests that a PI/s value of 40 should be used as the criteria to define a soil as erosive.

3. Results

3.1. Physical and mineralogical properties

The physical properties of the studied soils are summarized in Table 1. Grain-size distribution curves are presented in Figure 2, both for the tests using dispersant solution (CD) and the ones without dispersant solution (SD).

The fine fraction of the saprolitic soils (EM, CO and XV) is composed predominantly by kaolinite and quartz and a small amount of muscovite. The composition of SS soil is given mainly by iron oxides and hematite and a small amount of quartz.

Table 1. Physical properties of studied soils.

Soil	EM	CO	XV	SS
γ (kN/m^3)	1,46	1,59	1,79	1,71
G	2,720	2,667	2,708	2,745
e	1,43	1,01	0,94	1,01
w_{nat}	30,5	20,0	28,0	30,3
Sr	58	54	81	76
LL	49	44	38	68
IP	12	14	2	10
SUCS	ML	ML	ML	CH

The lateritization process of the SS soil led to an increase in the clay content, which results in higher consistency limits. Because of that, the soil from the SS site is classified, as CH and the soil from the other sites are classified as ML by the Universal System of Soil Classification (SUCS). Pedogenesis also causes an increase of iron oxides in the soil from the SS site. The iron comes from the former micaceous crystals that occur in the rock matter. The mineralogic composition also explains the difference in the specific gravity (G) of the lateritic and the saprolitic soils.

The difference between the grain-size distribution curves demonstrates the effects of the dispersant solution over the macrostructural features of the soil, as lumps (in the SS site) and pseudomorphs (in the other sites). Suppression of the dispersant solution reveals that, in situ, the particles of these soils are aggregated, forming larger particles of silt size.

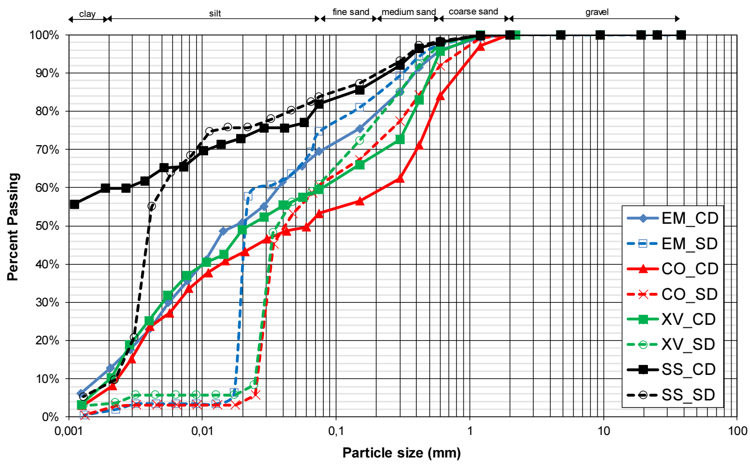

Figure 2. Grain-size distribution curves of the studied soils.

Considering that in situ there are no percolation of a fluid that can have dispersant effects, it is questionable to set erodibility parameters using the grain-size fractions determined by conventional tests (using dispersant solution) in residual soil, mainly in the domain of fine particles. One example is given using the K parameter used in the USLE model. The K parameter was calculated for the studied soils, considering the grain-size distribution curves obtained with the dispersant particle and those without the use of this solution. The test results are shown in Figure 3.

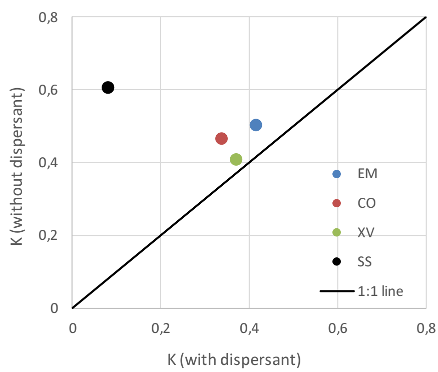

Figure 3. Effects of the use of the dispersant solution for the particle size determination in the calculation of K parameter.

According to [21], five soil properties are necessary to calculate such parameter: the percent of particles with size between 0.002 mm and 0.1 mm, the percent of particle of sand size (0.1 to 2.0mm), the amount of organic matter, the soil structure (given by a scale between 1 and 4) and the permeability (given by a scale between 1 and 6). In order to evaluate solely the effect of grain-size distribution in the K parameter, it was assumed for all the studied soils that the organic matter content is zero, the parameter of structure is 2 and the permeability is 4.

Therefore, in soils with important structure features the correlation between behavior parameters and physical indexes or properties cannot be totally reliable, as already observed with respect to residual shear strength by [22], for example.

3.2. Erodibility

The infiltrability and modified loss of mass by immersion test data are shown in Figure 4.

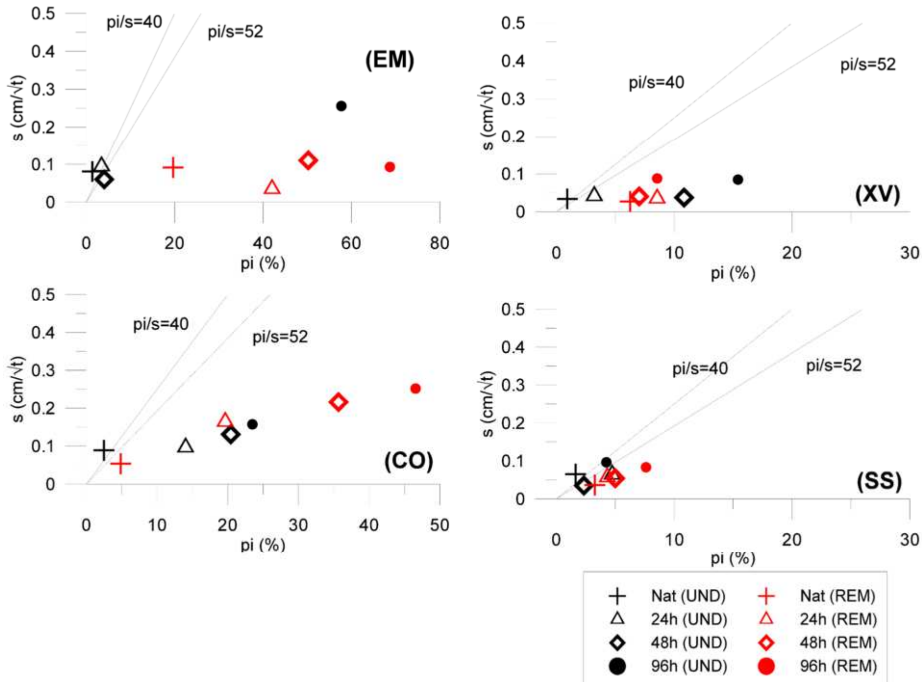

Figure 4. Erodibility test data for undisturbed (UND) and remolded (REM) soil specimens.

The experimental data plotted bellow the pi/s=40 and pi/s=52 lines reveals that such soils are susceptible to erosion, according to these criteria. The farther from the line is a given data point, the greater is the susceptibility to erosion. Thus, it is possible to conclude that both the drying and the remolding process cause an increase in the erodibility. The soil from the XV site can be considered non-erosive in its natural state, as can be seen in Figure 4. The soils from EM and SS sites are non-erosive in natural moisture content, but they become erosive after drying, mainly after 96 hours drying. The soil from CO site presents high erodibility even in the undisturbed condition.

The test results are in accordance with the features observed in situ, since some important erosion process took place in the sites CO and EM. In the other hand, they are restrained to a few furrows in in the sites XV and SS.

The tests in the remolded specimens show that the damage of macrostructure increase the soil erodibility, mainly for the soils from EM and XV sites. It is remarkable for the soil from EM site. the remolding effect is similar but less intense for the soil from XV site. It reveals that the soil erodibility can be strongly influenced by structure. The remolding causes an increase in the erodibility, but the effects of such procedure are like that caused by drying for the soil CO site. Remolding effects over the erodibility are more remarkable than drying for the soil from EM and XV sites.

The remolding process has no large effect and although the soil has been classified as erodible in the SS site, the measured erodibility is relatively low, like the observed in undisturbed specimens. It can be explained by the nature of this soil, which is formed by lumps visible to naked eye that are weakly connected. Internally, the lumps have high strength, since great effort is needed to break them. Such lumps are not crumbled by the process of sample preparation (for remolding) as what occur with the lumps and pseudo-crystals of soils from EM, CO and XV sites. Thus, remolded specimens of soils without complex macro-structural features in its natural condition are similar to the undisturbed ones. Likewise, as previously explained, the microstructure remains similar in the undisturbed and remolded specimens. Consequently, the infiltrability and the loss of mass by immersion are not significantly modified by remolding.

4. Conclusions

In all the studied soils the use of dispersive solution result in very different grain-size distribution curves from the tests without dispersive solution. With the latter procedure larger was the amount of silt size particle measured. Thus, one can verify that the calculation of K parameter of the USLE model [7] is significantly affected by this practice, mainly for the soil from SS site.

The results of infiltrability and the modified loss of mass by immersion tests in undisturbed samples are consonant with that observed in situ. Among the saprolitic soils, the soil from CO site has high erosive potential, the soils from EM and SS sites are less erosive than the first, and the soil from XV site is non-erosive. This indicates the suitability of the erodibility criteria suggested by [15] and [20] for the studied soils, although these criteria should be adjusted for local geotechnical conditions.

The tests in remolded specimens shown that the macrostructure degradation makes the soil more susceptible to erosion, mainly for the soils from EM and SS sites. In the CO site the remolding also increases the erodibility, but the effects of drying are as important as. For the lateritic soil from the SS site the remolding has no large effects over the erodibility that is low as those measured in the undisturbed soil. It can be explained by the soil nature, since it is composed by lumps weakly bonded, but that internally are very strong. The remolding seems not to change the microstructure (at least visually) and the macrostructure is not sufficiently developed to have great control over the erodibility.

Thus, it was found that the structure acts to render soils less susceptible to erosion through the erodibility test data.

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