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SUSCEPTIBILITY TO COLLAPSE OF PODZOLIZED SANDS IN THE EAST OF SANTA CATARINA STATE – BRAZIL

SUSCEPTIBILIDADE AO COLAPSO DE AREIAS PODZOLIZADAS NO LESTE DO ESTADO DE SANTA CATARINA – BRASIL

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RESUMO - As areias podzolizadas são solos pouco desenvolvidos com um perfil arenoso abundante e predominância de grãos de quartzo. Estes solos têm coloração avermelhada e não apresentam mais do que 15% de argila. As areias podzolizadas estão distribuídas em toda a região costeira do estado de Santa Catarina, Brasil. O objetivo deste trabalho foi identificar a suscetibilidade ao colapso e explicar o comportamento mecânico destes solos, uma vez que estas características devem ser consideradas nos projetos de uso e ocupação da região. Foram realizados ensaios para a caracterização física e química dos solos, assim como para a determinação de seus parâmetros geotécnicos. Para a definição do potencial de colapso foram executados ensaios de compressão unidimensional, além de testes para a avaliação da influência do grau de saturação dos solos no potencial de colapso. Os solos foram classificados com gravidade do potencial de colapso como “nenhuma”, “moderada” ou “problemática”. Segundo os resultados obtidos nesta pesquisa, o grau de saturação do solo e a sucção natural das areias podzolizadas são fatores determinantes para a ocorrência do processo de colapso.
Palavras-chave: Colapso. Areias Podzolizadas. Sucção. Grau de Saturação.

ABSTRACT - Podzolized sands are poorly developed soils with an abundant sandy profile with predominance of quartz grains. They have reddish color and do not present more than 15% of clay. The podzolized sands are distributed throughout the eastern coastal region of the Santa Catarina state, Brazil. The aim of this work was to identify the susceptibility to collapse and explain the mechanical behavior of these soils, since these characteristics should be considered when carrying out projects of occupation in the region. Tests were carried out for the physical and chemical characterization of the soils, as well as for the determination of their geotechnical parameters. For the determination of collapse potential were performed oedometric tests and trials for the evaluation of the influence of the soils’ degree of saturation on the potential for collapse. The soils were classified as the severity of potential collapse as “none”, “moderate” or “problematic”. According to the results obtained in this work, the degree of saturation and the natural suction of podzolized sands are determining factors in the collapse processes.
Keywords: Collapse. Podzolized sands. Suction. Degree of saturation.

INTRODUCTION

The collapsible soils are defined as those that suffer a reduction of volume when experience an increase in the amount of water in the voids or when are moistened after the application of overloads. A wide range of soils’ deposits exhibit the collapsing phenomenon, including aeolian or wind deposits, water deposits, residual soils and colluvial deposits (Al-Rawas, 2000). The soil collapse process affects foundations of civil constructions due to significant settlements and is quite common in sandy soils and porous clay soils that are distributed in a large part of Brazil, mainly in the central-south and northeast regions.

The main characteristics presented by these soils are high void indices and, therefore, the presence of a porous structure with low moisture content and potentially unstable. The collapse process can be interpreted as a disruption of soil equilibrium, caused by the rearrangement of the particles that occupy previously existing voids due to the elimination of the bonds between the grains by a fluid and the application of overload. These bonds can be defined by the presence of electromagnetic forces on the surface of the grains, capillary forces, or cementitious compounds between the particles, such as carbonates and iron oxides, and fine-grained fractions of the soil as bonding for the larger-grained particles. Many causes can lead to the appearance of a percolating fluid in the soil, such as water or sewage rupture, rainwater infiltration, cracks in buried reservoirs, rising groundwater and excessive irrigation (Al-Rawas, 2000; Higashi, 2006; Oliveira, 2002).

The process of collapse in a soil occurs only once for an external effort and a maximum degree of saturation, because, after its completion, the soil has a stable structure. However, Silva & Ferreira (2004), based on electron microscopic analysis of the collapsible soils of Pernambuco, concluded that their structure after the collapse was still unstable, and the soil could present new processes.

The collapsible soil's location is of great importance, since these represent urban geological risks that can lead to different problems in buildings, such as cracks in walls, floor subsidence and impairment of water supply and sewage facilities (Vilar & Rodrigues, 2011). In larger constructions these damages may even endanger the safety of the property's users, leading to the state of service of the constructions and to the interdiction to perform repairs. A major solution that has been applied to collapsible soils is the dynamic compaction, as described by Rollins & Kim (2010), which is employed to improve the strength and decrease the settlement potential of these soils. Other treatment methods as soil replacement and chemical stabilization also presented a significant response to the settlement reduction (Al-Rawas, 2000).

Podzolization is a pedogenic process characterized by the transport of organic matter, iron and aluminum from the superficial horizons to the deeper horizons, where they precipitate. This process profoundly changes the primary and secondary minerals, leading to an enrichment of minerals more resistant to weathering, such as quartz and zirconium (Gomes et al., 2007). The podzolized sands occur mainly in areas of flat or smooth landforms and have a reddish color due to the distribution of iron oxides (Santos, 1997). These sands are found in several regions of the coastal zone of Santa Catarina (Brazil) and present a significant tendency to collapsible behavior. For this reason, the research aimed to determine the susceptibility to collapse of podzolized sands in the eastern portion of Santa Catarina, in the cities of Balneário Camboriú, Araranguá, Balneário Rincão and Jaguaruna (Figure 1).

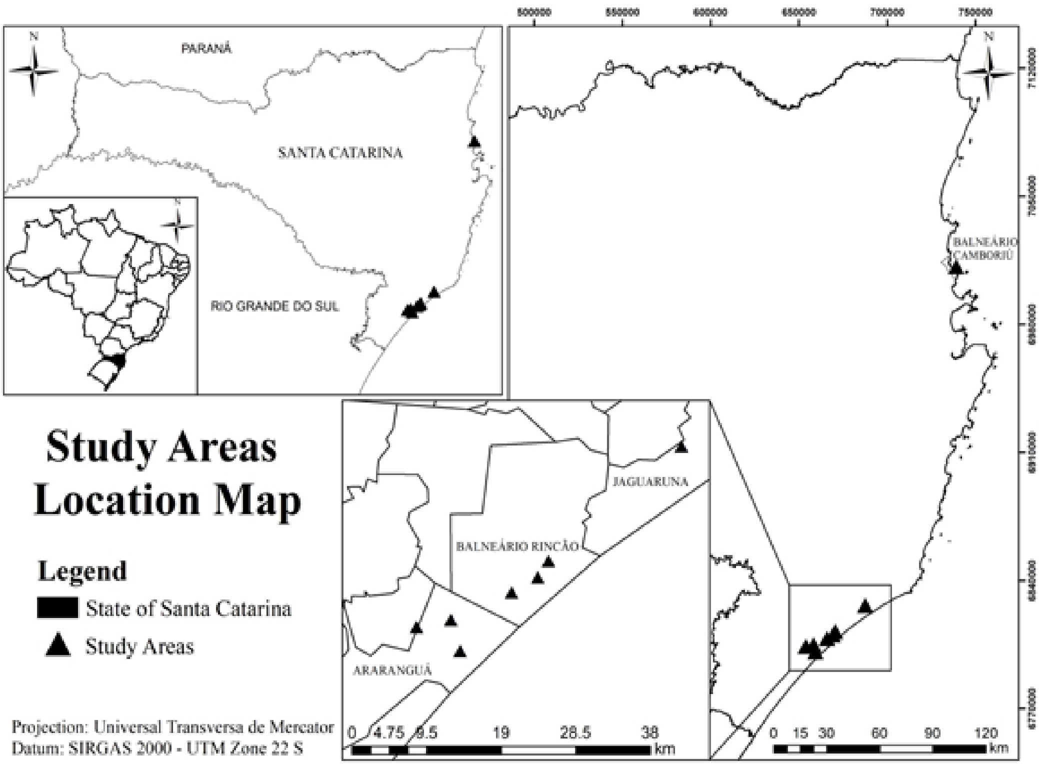

Figure 1 - Location of the study areas in the state of Santa Catarina.

COLLAPSIBILITY DETERMINATION

The criteria and collapsibility tests seek to evaluate the parameters that influence the collapsible soils behavior.

Some criteria are used for collapsible identify-cation in the laboratory with the use of x-ray diffraction, microscopy, physical indexes, and limits of consistency. The others are used for the quantification of the collapse that can be carried out in the laboratory by oedometric tests and axial compression or in field by load tests on piles and load tests on plate. Different empirical equations have been suggested in the literature relating conventional soil properties to its collapse-bility. It is important to highlight thought that these equations should be extended only for local soils for which they were developed (Li et al., 2016).

Among the laboratory tests for quantification of collapse, the oedometric test is the most classical method. The test considers the axial deformations caused by water inflow in the test specimens under a constant load and at certain moisture content. This test can be performed in two ways: either by the single test or by the double ring test. This equipment was used by Jennings & Knight (1975) to determine the collapse potential (CP) of soils, defined according to the equation:

$$\mathrm{CP} = \frac{\Delta \mathrm{e_c}}{1+\mathrm{e_0}} \times 100\% \text{ or } \mathrm{CP} = \frac{\Delta H_C}{H_0} \times 100\%$$

Where:

Δe_c - void index variation by the water inflow

e_0 - initial void index

ΔH_c - variation of the specimen height by the water inflow

H_0 - initial height of the specimen.

From the CP calculation, the severity of the problem can be classified according to table 1.

Table 1 - Collapse potential and the severity of the problem.

CP	SEVERITY
0 - 1%	Negligible
1 - 5%	Moderate trouble
5 - 10%	Trouble
10 - 20%	Severe trouble
> 20%	Very severe trouble

MATERIALS AND METHODS

The eight areas of study were determined from maps obtained from the Brazilian Institute of Geography and Statistics (IBGE), from the State Program of Coastal Management of Santa Catarina at a scale of 1:100,000. In addition to the digital elevation model of the Secretariat of Sustainable Development and satellite images of Google Earth Pro. After the definition of the study areas, fieldwork was carried out to collect deformed and undisturbed samples, one at each point. The presence of cuts and exposed slopes and the ease of access to the site influenced the collection location. The undisturbed samples were collected in cubic blocks, with 30 cm edges, and directly in the metal molds used in the direct shear test. For the blocks to be protected when transported, it was decided to cover them with plastic film and plaster bandage (Figure 2).

Figure 2 - Undisturbed sample collection using plastics film and plastered bandage.

Suction measurements were also carried out in the field, obtained by means of a tensiometer with a length of 18” from *Irrometer®*. The tensiometer is an instrument that was elaborated by Gardner and collaborators in 1922, with the objective of directly supplying the water tension in the soil. According to Marinho et al. (2008), the negative pressure of the water implies that the water is being "kept" in tension and the measu-rement of this negative pressure is of paramount importance in the analysis of the unsaturated soils behavior. The tensiometer used in this work presents a sealed pipe for the atmosphere and a porous tip connected to a pressure measurement system, with the capacity to measure the energy with which the water is retained in the soil. This equipment works from the formation of equilibrium between the solution present in the soil and the water present inside the apparatus when they are put in contact. If the water present in the soil is under tension, it will exert a suction on the equipment, reducing the internal tension of the same. With the aid of a manual auger, the soil profiles were drilled vertically in study area number 07 and horizontally to the other areas of study, to a depth of 45 cm, where the tensiometer could be fitted. The readings were carried out until the pressure measures stabilized.

The soil characterization, oedometric compression and direct shear tests were performed in the Soil Mechanics Laboratory (LMS) of the Santa Catarina Federal University (UFSC). For the soil characterization of each study area were performed particle size analyses, determination of solids specific gravity, natural moisture content, liquidity limit, plasticity limit and plasticity index. All these tests were carried out following the norms of the Brazilian Association of Technical Norms (ABNT).

In the direct shear tests natural and submerged conditions were used, summing up 64 tests. This type of analysis was used in order to evaluate the influence of moisture content on cohesion, that is, to evaluate the loss of cohesion caused by the water inflow in the specimen. For all the tests the shear velocity of 0.307 mm/min was adopted. In spite of being a relatively slow velocity for sandy soils and more used in clayey soils, this was chosen in order to guarantee the drained condition of the test, avoiding the increase of pore pressure. The normal stresses used in the test were 25 kPa, 50 kPa, 100 kPa and 150 kPa; therefore, four tests were performed for each condition per area of study. The consolidation phase lasted around 12 hours or less, when it was observed that the deformations had already ceased. The normal stresses were defined considering the same stresses applied in the oedometric compression tests.

To analyze the collapsibility of the podzolized sands, oedometric tests were performed, summing up 32 tests. Four specimens were molded for each study area, subjected to stresses of 25 kPa, 50 kPa, 100 kPa and 150 kPa. The normal stresses were defined considering previous studies on collapsible soils (e.g., Higashi, 2006; Christ, 2014). Initially, each specimen was loaded with one of the stresses and the stabilization of the vertical deformations was expected. After the deformation's stabilization was verified, water was applied to submerge the specimen and again the stabilization of the deformations caused by the water inflow was awaited. The readings used in the quantification of soil collapse were performed before and after the application of water in the test specimen. Digital strain gauges from *Mitutoyo*® were used, model IDS-1012-5, and analog strain gauges, model NO 2025F, both with precision of 0.01 mm.

Also, after comparing the results obtained with previous studies in the subject, it was noticed a discrepancy in the values of collapse potential. To understand this discrepancy, a new analysis procedure was adopted. This new analysis was based on evaluating the influence of the degree of saturation of the soils in the collapsibility process and was also conducted in the oedometric test equipment. Four new test specimens were obtained for each study area, summing up a total of 32 tests. The degree of saturation of these specimens was controlled until a lower degree of saturation, than that presented in the previously described tests, was reached. According to Jennings and Knight (1975), the collapse potential (CP) of the podzolized sands of each study area was calculated for 25 kPa, 50 kPa, 100 kPa and 150 kPa. From this, the soil could be classified as to the severity of the problem as: none, moderate, problematic, severe or very serious.

Scanning Electron Microscopy (SEM) was performed at the Electronic Microscopy Central Laboratory (LCME) of the Santa Catarina Federal University. The preparation of the specimens was carried out in accordance with the laboratory standards and due to difficulties in the preparation of the samples it was not possible to preserve the soil structure. Initially small clods of each soil sample were dried, and then taken to preparation at the LCME. The samples were stripped and fixed with the application of carbon tape, cut in small dimensions, in the sample holder of the microscope - "stubs" (Figure 3). Then the metallization of the samples with a thin layer of gold was carried out.

The images from the SEM, for each of the study areas, presented magnification of 50X, 200X and 500X. Energy Dispersive Spectroscopy (EDS) was also performed. EDS allows the minerals chemical composition identification, besides producing a mapping distribution of chemical elements by minerals.

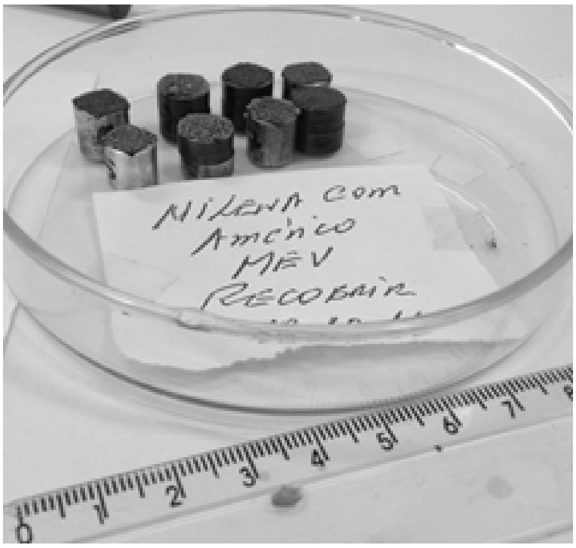

Figure 3 - Soil samples placed on stubs and glued with carbon.

RESULTS AND DISCUSSION

The characterization tests results are presented at tables 2 and 3, for each study area with the natural moisture content (w_{nat}), void ratio (e), porosity (n), degree of saturation (Sr), liquidity limit (W_L), plasticity limit (W_P), plasticity index (PI) and classification according to the Unified Soil Classification System (USCS).

Table 2 - Physical indexes and limits of consistency of the soils of the study areas.

STUDY AREA	SPECIFIC WEIGHT OF SOIL SOLIDS (kN/m³)	W_{nat} (%)	e	n	Sr (%)	CONSISTENCY LIMITS		
						W_L (%)	W_P (%)	PI (%)
01	26.5	15.5	0.64	0.39	64	21	NP	NP
02	26.0	14.9	0.83	0.45	47	19	16	2
03	26.2	17.6	0.72	0.42	64	24	20	4
04	26.1	13.1	0.57	0.36	60	19	16	4
05	25.7	10.5	0.48	0.32	57	NL	NP	NP
06	25.9	6.6	0.46	0.31	37	NL	NP	NP
07	25.7	10.3	0.43	0.30	62	NL	NP	NP
08	26.0	10.5	0.52	0.34	53	NL	NP	NP

Table 3 - Granulometric analysis and USCS classification of the study areas.

STUDY AREA	GRANULOMETRY						USCS
	GR. (%)	C.S. (%)	M.S. (%)	F.S. (%)	Silt (%)	Clay (%)	
01	0.00	0.44	65.31	9.51	6.44	18.31	SC
02	0.00	4.74	37.92	36.22	4.08	17.04	SC
03	0.00	0.18	42.19	33.58	7.54	16.50	SC
04	0.00	0.08	78.43	7.84	4.20	9.45	SC
05	0.00	0.22	92.03	6.60	0.71	0.43	SM
06	0.00	0.25	90.36	6.05	1.45	1.89	SM
07	0.00	23.34	49.91	21.94	4.66	0.15	SM
08	0.00	0.67	71.73	12.17	14.23	1.20	SM

Note: GR. = gravel; C.S. = coarse sand; M.S. = medium sand; F.S. = fine sand.

Regarding the granulometry, the soils of areas 01, 02 and 03 presented more than 15% of clay in its composition, but with an excess of maximum 3.31% for area 01. The other areas of study presented less than 10% of clay in its granulometric composition. The soils of areas 01, 02, 03 and 04 were classified according to the Unified System as clayey sands (SC), while the soils of areas 05, 06, 07 and 08 were classified as silty sands (SM).

Regarding the consistency indexes, the plasticity indices presented by the soils were low, with percentages varying from 0% to 4.39%. According to Burmister (1949), the classification of the plasticity index qualitatively describes the study soils as non-plastic or slightly plastic, in the case of areas 02, 03 and 04. Suction measurements obtained with the aid of a tensiometer during fieldwork are shown in figure 4.

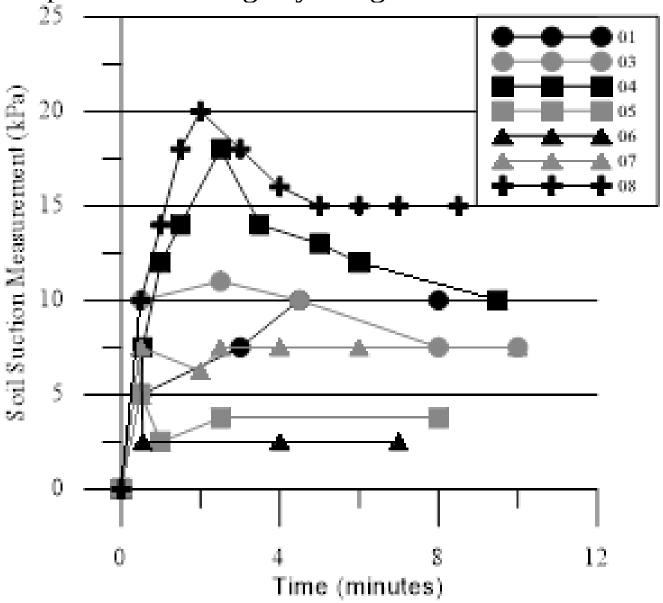

Figure 4 - Suction results measured with field tensiometer.

Ceratti et al. (1996) claim that since soils in tropical countries have their pores partially filled by water, in these pores the water pressure is negative and therefore less than atmospheric. Drying in the soil results in an increase in this negative pressure to values greater than 10 kPa. The suctions obtained for the study areas are similar with the expected low suctions of tropical and subtropical regions soils, that is, with values lower than 50 kPa. According to Santos (2006), in general, soils with low clay content also have lower suction values. The lowest suction values obtained in the field trials are related to the areas with lower silt and clay content, such as areas 05, 06 and 07, which presented, respectively, 0.43%, 1.89% and 0.15% of clay.

Table 4 presents all the results of soil strength parameters obtained under natural and submerged conditions. From the obtained results, it was noticed that the highest values of cohesion are related to the soils of areas 01, 03, 04 and 08 with the highest fine contents.

Table 4 - Results of resistance parameters of the studied soils.

STUDY AREA	FRICTION ANGLE (°)		COHESION (kN/m²)	
	SUBMERGED	NATURAL	SUBMERGED	NATURAL
01	28.1	27.4	5.3	18.1
02	29.0	-	1.0	-
03	26.4	32.1	7.4	14.9
04	30.6	35.1	4.7	14.2
05	33.1	36.0	1.1	4.5
06	29.7	31.8	2.9	4.6
07	36.8	-	1.3	-
08	36.3	36.4	0	7.8

As for the variation of the cohesion values and friction angle with the water inflow in the test specimens, cohesion, as expected, presented a great difference for most of the areas. At area 01 there was a reduction of 18.1 kPa (natural moisture content) to 5.3 kPa (submerged). The smallest difference between the values of cohesion with the water inflow was that of area 06, with values of 4.6 kPa (natural) and 2.9 kPa (submerged). It is important to emphasize that the high variation of soil cohesion with the water inflow in the soil specimen represents, as suggested by Higashi (2006), the soils structures fragility with the inflow of water. This fragility in the soil structure indicates a high susceptibility to the process of collapse. It is not usual to quantify the collapse in the direct shear test, mostly because of the tooth grid used in the test. However, it is possible to estimate the soil's behavior.

In general, it was concluded that the apparent cohesion was a complementary force acting in the increase of the soils shear strength. The added strength verified, offered by the presence of suction in the soils, has already been identified by other authors, such as Soares & de Campos (2005).

Soil collapse potential

In addition to the determination of the collapse potential, in this item, it is also presented the data of the degree of soil saturation influence on collapsibility analysis. Figure 5 shows all collapse potentials (%), for each stress (kPa), obtained for all study areas.

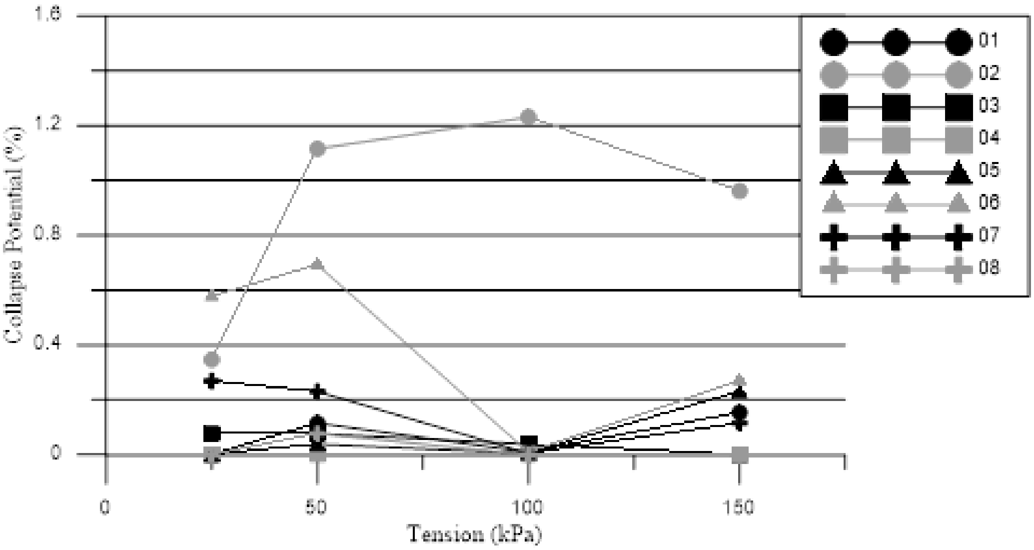

Figure 5 - Curves of the potential of collapse versus tension of all areas studied in this work.

Areas 02 and 06 presented the greatest potential for collapse, but only area 02 was classified, according to Jennings & Knight (1975), with moderate problem. In addition, area 02 presented greater collapse potential for all stresses, compared with other areas in general. The area 04 presented values of collapse potential much smaller when compared with the other areas. Therefore, its potential for collapse is shown in figure 5 with a value of 0% for all applied stresses. The table 5 shows the results obtained for each study area along with the severity of the problem classification, according to Jennings & Knight (1975).

Table 5 - Results of the potential for collapse and classification of the severity of the problem according to Jennings & Knight (1975).

STUDY AREA	COLLAPSE POTENTIAL (%)							
	25 kPa	SEVERITY	50 kPa	SEVERITY	100 kPa	SEVERITY	150 kPa	SEVERITY
01	0	Negligible	0.12	Negligible	0.01	Negligible	0.15	Negligible
02	0.35	Negligible	1.12	Moderate trouble	1.23	Moderate trouble	0.96	Negligible
03	0.08	Negligible	0.08	Negligible	0.04	Negligible	0	Negligible
04	0	Negligible	0	Negligible	0	Negligible	0	Negligible
05	0	Negligible	0.04	Negligible	0.01	Negligible	0.23	Negligible
06	0.58	Negligible	0.69	Negligible	0.01	Negligible	0.27	Negligible
07	0.27	Negligible	0.23	Negligible	0	Negligible	0.12	Negligible
08	0	Negligible	0.08	Negligible	0	Negligible	0	Negligible

It is important to note that for most areas, except for 02, the percentages of collapse potential were extremely low, classifying the soils as with no problem and therefore no susceptibility to collapse. The area 02, located in Balneário Camboriú city, presented for the tensions of 50 kPa and 100 kPa potential of collapse above 1%, being therefore classified for these tensions with moderate problem.

Analyzing the values of the sands collapse potential obtained from this work and comparing them with those determined by Christ (2014), which evaluated the collapse potential of podzolized sands in Florianópolis, Brazil, it was noticed a large discrepancy (the author obtained collapse potentials with higher percentages, from 1.33% to even 4.8%). To understand this discrepancy, a new analysis procedure was adopted.

The results of the collapse potential obtained with the variation of soil saturation are shown in figure 6. With the degree of saturation change, areas 01 and 03 showed a great increase of the collapse potential. This increase elevated the classification of the problem, from area 01, in the stresses of 25 kPa and 100 kPa to moderate. On the other hand, the problem of collapse, from area 03, in the tensions of 25 kPa and 50 kPa, had its classification increased to moderate, and in the tension of 150 kPa elevated to problematic. It was noticed at area 01 that for the 50 kPa stress the increase of the collapse potential was very low, this point being related to uncertainties of the test, since for the other stresses applied the collapse potential decays linearly.

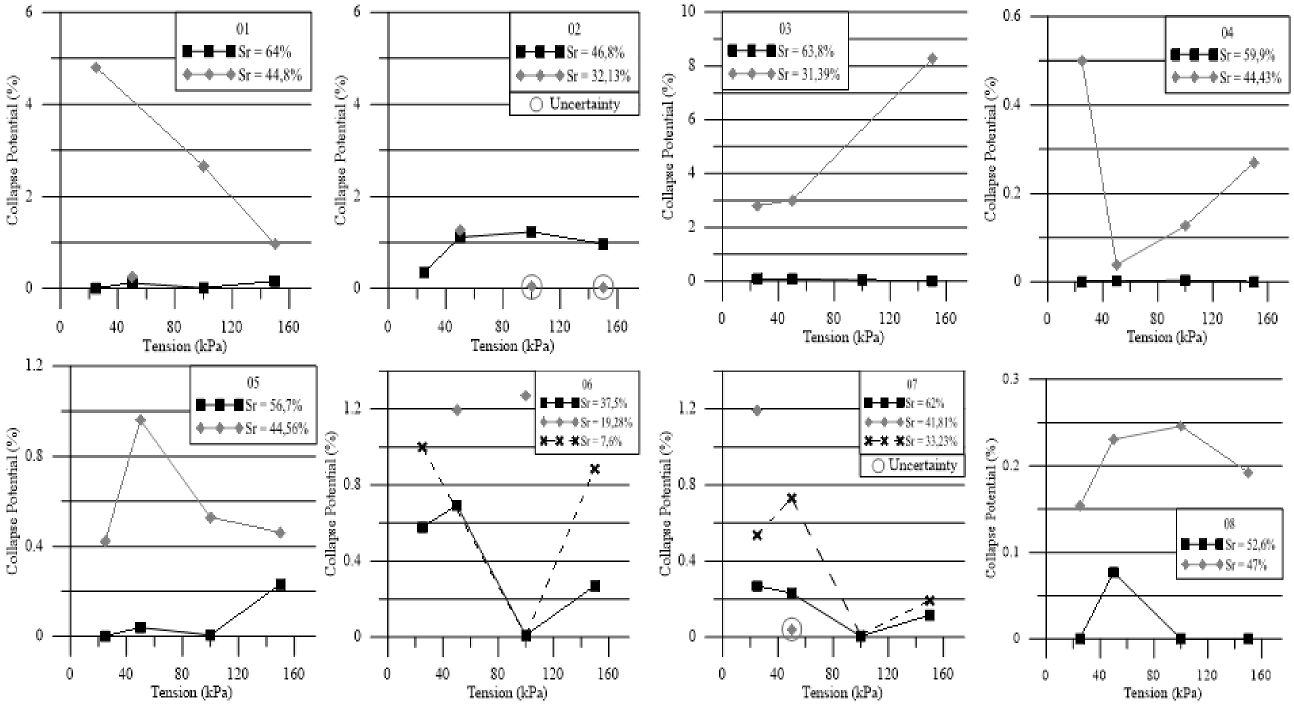

Figure 6 - Results of the potential of collapse with the influence of the variation of the degree of saturation.

Area 02 at 50 kPa showed an increase in collapse potential with a decrease in the degree of saturation from 46.8% to 32.13%, but this decrease is not very significant.

During the molding of the specimens to perform the test, it was noticed that the undisturbed sample had lost moisture. It was estimated that this change is related to the uncertainties presented for the stresses of 100 kPa and 150 kPa. At points 04, 05 and 08, the potential for collapse was raised with the decrease of the degree of saturation, however, from the scale of the graph, it was verified that this variation is small and does not alter the classification of this soil with no problem of collapsibility.

From the results obtained for areas 06 and 07, it was identified that there is an intermediate degree of saturation in which the potential of soil collapse tends to be high, classifying it with moderate severity. If the degree of soil saturation was below or above this intermediate value, the absence of suction, apparent cohesion, made the potential for soil collapse to be very low.

Table 6 presents the results of the collapse potentials obtained for each area according to the degree of soil saturation. In addition, it presents the severity of the problem classification according to Jennings & Knight (1975).

Area 07 was the only point without podzolization. Because the granulometric composition showed less than 5% of silt and clay, it was known that this soil presented suction as the main factor acting on the union (apparent cohesion) between the particles. It was evident that with the decrease of saturation, for an intermediate value, the subsequent soil saturation had a greater influence on the soil, increasing its potential for collapse. In table 7 a summary of the results for the soils collapse potential obtained with the variation of the degree of saturation is presented.

Table 6 - Results of the influence of degree of saturation on soil collapse potential.

STUDY AREA	25kPa						50kPa					
	CP (%)	Sr (%)	S.	CP (%)	Sr (%)	S.	CP (%)	Sr (%)	S.	CP (%)	Sr (%)	S.
01	0	64.00	N	4.81	44.80	M	0.12	64.00	N	0.25	44.80	N
02	0.35	46.80	N	-	-	-	1.12	46.80	M	1.27	32.13	M
03	0.08	63.80	N	2.81	31.39	M	0.08	63.80	N	3.00	31.39	M
04	0	59.90	N	0.50	44.43	N	0	59.90	N	0.04	44.43	N
05	0	56.70	N	0.42	44.56	N	0.04	56.70	N	0.96	44.56	N
06	0.58	37.50	N	1.00	7.60	N/M	0.69	37.50	N	1.19	19.28	M
07	0.27	62.00	N	1.19	41.81	M	0.23	62.00	N	0.73	33.23	N
08	0	52.60	N	0.15	47.00	N	0.08	52.60	N	0.23	47.00	N
STUDY AREA	**100kPa**						**150kPa**					
	CP (%)	**Sr (%)**	**S.**	**CP (%)**	**Sr (%)**	**S.**	**CP (%)**	**Sr (%)**	**S.**	**CP (%)**	**Sr (%)**	**S.**
01	0.01	64.00	N	2.65	44.80	M	0.15	64.00	N	0.96	44.80	N
02	1.23	46.80	M	0.04	32.13	N	0.96	46.80	N	0.01	32.13	N
03	0.04	63.80	N	0.03	31.39	N	0	63.80	N	8.27	31.39	T
04	0	59.90	N	0.13	44.43	N	0	59.90	N	0.27	44.43	N
05	0.01	56.70	N	0.53	44.56	N	0.23	56.70	N	0.46	44.56	N
06	0.01	37.50	N	1.27	19.28	M	0.27	37.50	N	0.88	76.00	N
07	0	62.00	N	0	33.23	N	0.12	62.00	N	0.19	33.23	N
08	0	52.60	N	0.25	47.00	N	0	52.60	N	0.19	47.00	N

Note: CP = collapse potential; Sr = degree of saturation; S. = severity; N = negligible; M = moderate trouble; T = trouble.

Table 7 - Results of the collapse potential of podzolized sands.

STUDY AREA	Collapse Potential (%)							
	25 kPa	SEVERITY	50 kPa	SEVERITY	100 kPa	SEVERITY	150 kPa	SEVERITY
01	4.81	Moderate trouble	0.25	Negligible	2.65	Moderate trouble	0.96	Negligible
02	-	-	1.27	Moderate trouble	0.04	Negligible	0.01	Negligible
03	2.81	Moderate trouble	3.00	Moderate trouble	0.03	Negligible	8.27	Trouble
04	0.50	Negligible	0.04	Negligible	0.13	Negligible	0.27	Negligible
05	0.42	Negligible	0.96	Negligible	0.53	Negligible	0.46	Negligible
06	1.00	N/M	1.19	Moderate trouble	1.27	Moderate trouble	0.88	Negligible
07	1.19	Moderate trouble	0.73	Negligible	0	Negligible	0.19	Negligible
08	0.15	Negligible	0.23	Negligible	0.25	Negligible	0.19	Negligible

For the most part, the results of the collapse potential showed an increase with the reduction of the degree of saturation. This increase, for areas 01, 03, 06 and 07, elevated the level of the soil to moderate or problematic collapse severity according to Jennings & Knight (1975) classification. Bastos (1991), differently from what is proposed in this study, defined that structural relation commanded the collapse process of the soils of Porto Alegre city, and that there was no influence of soils degree of saturation in this process. However, Holtz & Hilf (1961) defined that the collapse of the soils is a result of the capillary pressures approaching zero and the degree of saturation reaching 100%. In addition, Burland (1965) described that the wetting in the soil leads to the decrease of the negative pore water pressure at the interparticle contact points, which causes grain slippage and distortion.

Analysis of scanning electron microscope and dispersive energy spetroscopy

As the study areas represent very similar soils, are shown in figure 7 the SEM images obtained only for the study area 08.

In general, the grains had a size of 200 μm to 500 μm and were classified according to the Wentworth scale (1922) as fine to medium sands. As for their rounding, the grains were classified according to Krumbein (1941) as sub-rounded or sub-angled. In the images B and C, with a magnification of 200X and 500X, the presence of clay and silt coatings was observed in the sand grains, which compose the cementation of these soils.

Table 8 shows the results of energy dispersive spectroscopy (EDS) for all study areas. The high percentages of Si and O relates to the grain mineralogy predominantly composed of quartz. Secondly, percentages of Al in greater quantity and Fe were identified. These chemical elements are transported by the podzolization process from superficial horizons to deeper horizons, which causes its enrichment in the deeper ones.

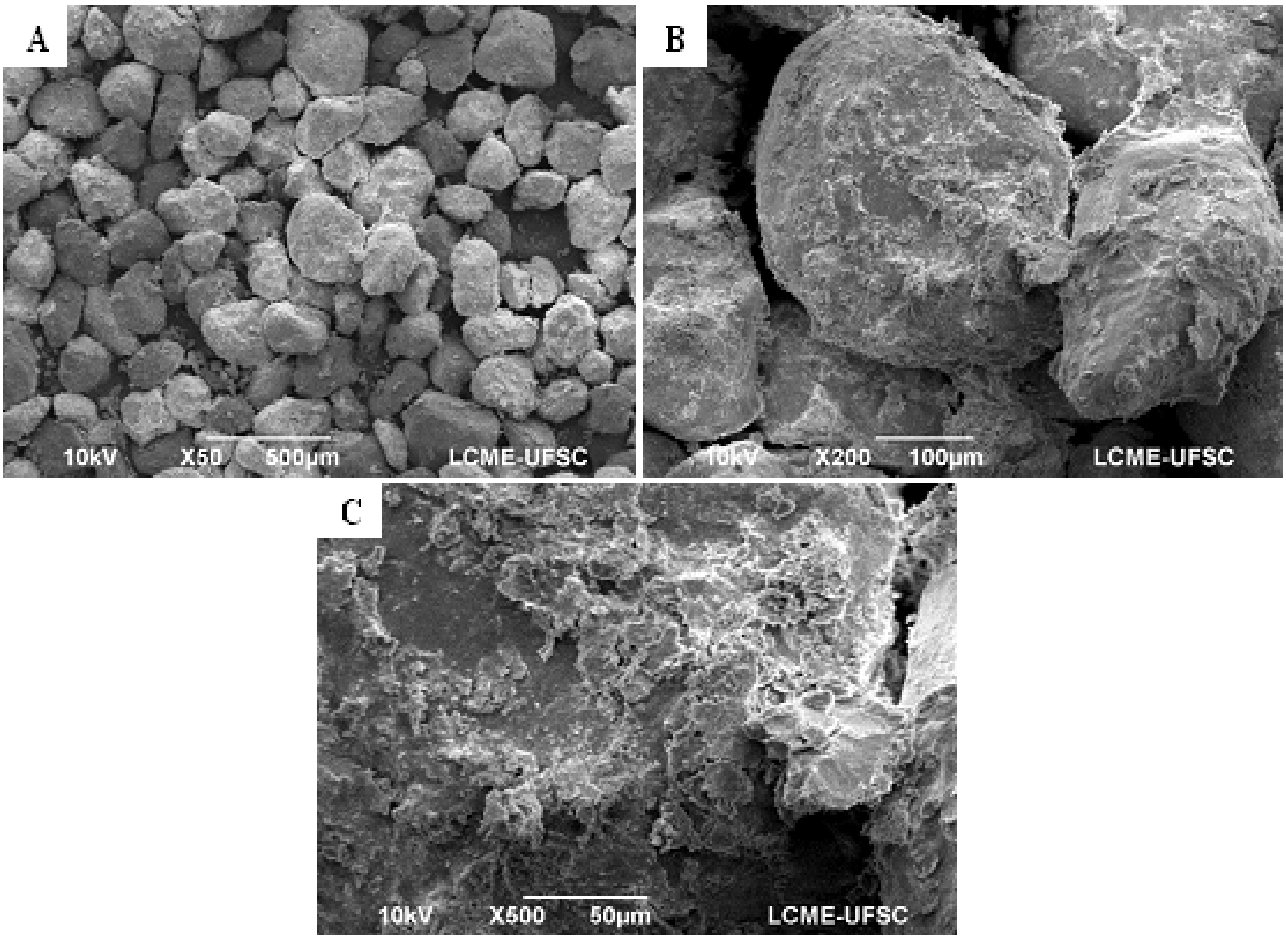

Figure 7 - Images obtained by scanning electron microscopy from area 08.

Table 8 - Chemical composition of soils obtained by energy dispersive spectroscopy.

STUDY AREA	CHEMICAL COMPOUNDS (%)			
	O	**Al**	**Si**	**Fe**
01	41.2	20.1	37.5	1.2
02	42.7	17.8	39.4	0
03	48.9	15.4	35.6	0
04	42.6	16.4	39.5	1.5
05	43.5	17.5	39.0	0
06	43.4	10.5	46.0	-
07	44.2	7.5	48.3	-
08	42.6	14.3	40.7	2.4

CONCLUSIONS

Due to the wide distribution of collapsible soils in the Brazilian territory and its potential to cause problems to engineering constructions, it is fundamental to carry out geotechnical studies that aim a better understanding and prediction of their behavior. The eastern portion of the Santa Catarina state (Brazil) is an area of essential need for collapse phenomena evaluation, since it presents a high growth of urbanization and soils composed of podzolized sands present in the entire region.

The comparison between the direct shear tests in submerged and natural conditions showed a significant decrease in the shear strength parameters of the soils with water entry, mainly in the cohesion. This loss evidences the performance of the suction in the shear strength of these soils.

According to the tests for determination of soil collapse potential, the podzolized sands may be very susceptible to collapse, with potential for moderate or problematic collapse according to the classification of Jennings & Knight (1975), depending on the degree of saturation *in situ*. The application of stresses in the soil will inevitably cause deformation. Further, an eventual saturation of the foundation soils may lead to an increase in the degree of saturation and to the reduction of natural soil suction, which, according to the results obtained in this work, will lead to processes of collapse from moderate to problematic.

Jennings & Knight (1975) argue that when the degree of saturation is greater than 60% the fine sands are non-collapsible and when is less than 50%, they are collapsible. Areas 01, 02, 03 and 07 of this study showed agreement with such classification.

Christ (2014) defined the potential for collapse of sands with degrees of saturation of 21% and 31%. When comparing the results obtained by the author with this work it was noticed that the discrepancy between the collapse potential, previously mentioned, was related to the soils degree of saturation. When reaching a degree of saturation approximated to those determined by the author, the soils of this study had greater collapse potentials and, therefore, close to those obtained by Christ (2014).

The suction was the main influent factor in the collapse process of the podzolized sands under study, and not the presence of clay buttresses acting as cementation in these soils. The decrease in the degree of saturation is directly related to the increase of the apparent capillarity, or suction, present in the soil. The suction gives the soil some stability in its structure that is strongly shaken with its saturation. It is also important to note that, with high or very low saturation, suction ceases to act on soil cohesion. Clemence & Finbarr (1981) pointed out that the collapse caused in soils where the grains are held together by suction is more immediate when compared to the case where chemical cementing or clay buttresses are presented.

To quantify the collapse potential of a soil, it is necessary to determine and evaluate many characteristics and parameters, since a simplified evaluation of the soil behavior can generate future problems in occupancy constructions. In this context, it was highlighted, in this work, the variation of soil saturation degree that had great influence on the susceptibility of the podzolized sands to collapse.

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