



# Evaluation of Geotechnical Parameters of Slopes at Blumenau, Santa Catarina, Brazil

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## Abstract

The state of Santa Catarina, Brazil, has climatic, biological, geomorphological and geological characteristics that contribute directly to the occurrence of landslides. From the geological point of view, colluvial materials resulting from landsliding deposited in the lower parts of the slopes are denominated as hillslope deposits although they do not necessarily originate from the same rock. This study evaluated the geotechnical parameters of the slopes at Blumenau, where intense rainfalls and potentially unstable soils are present on steep hillsides and give rise to unstable colluvial slopes below. These factors resulted in a large number of slopes covered by colluvial deposits. However, in geotechnical mapping these kinds of materials are treated as “hillslope deposits” units with similar behaviors even though they have different geological-geotechnical evolutions and have experienced distinct processes of pedogenesis. The paper covers the classification as colluvial soils and landslides, as well as the use of geotechnical laboratory tests and geotechnical mapping. Evaluation of the geotechnical behavior of the soils was based on geotechnical characterization tests and drained direct shear tests in which parameters of cohesion and internal friction angle were obtained. Thus, the goal of this study was to understand the variability of the geotechnical parameters of these colluvial soils that

formed as “hillslope deposits” units according to Davison Dias (1995) methodology, so that they could be classified based on their lithotypes. The study results will help in urban planning in Blumenau and contribute to safety and predictability of areas subject to possible landslides.

## Keyword

Colluvial soils • Residual soils • Geotechnical parameters • Blumenau • Brazil

## 1 Introduction

Natural disasters related to landslides are important processes to geomorphological and dynamic evolution of hillsides. In urban areas, besides gravity, it is possible to cite the anthropic activities (bad management of water resources, unplanned landfills, poorly executed slope cuts or vegetation cover removal) as factors for the occurrence of landslides. In Brazil, landslide is related to intense rainy seasons, which results in national disasters when it happens in big Brazilian cities (de Castro 2003).

The development of Geotechnical engineering in Santa Catarina state, southern Brazil, has been constant. In 2008, the region known as Itajai Valley was affected by several landslides and the socioeconomic impacts were significant, causing civil and governmental interest on the subject. In total, 60 cities and 1.5 million people were affected by landslides and floods. However, due to disorderly urban planning many occupations are in sites with a higher incidence of landslides.

Blumenau, situated in Itajai Valley and this paper’s study area, is highly susceptible to the occurrence of landslides, where factors include high rainfall weak soils and hill-sides. These factors resulted in the presence of slopes filled by colluvial deposits that may be directly associated to colluvial deposits occurrence.

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In subtropical climate regions, the intense and prolonged rain results in the development of residual soil profiles of great thickness and provides enough material to the remobilization and, consequently, colluvial deposits formation on the hillsides (Vitte 2005). The residuals soils are consequence of the weathering from their places of origin. Soil with small particles are found in soil surface and the grain size increases according to the analyzed depth (Das 2011). According to Lacerda and Sandroni (1985), colluvium is “a deposit consisting of blocks and/or grains of any diameters, carried by gravity and accumulated at the foot or in a short distance from slopes or rocky cliffs”. Two processes work like a trigger to colluvium, and both are related to intense and prolonged rainy seasons. The first one is the accumulation of soil in lower regions as result of slipping. The second is the movement of residual soil on the hillside itself. In this last case, the deposit can be found as disaggregated (Lacerda 2002).

This study was done following the methodology of geotechnical mapping proposed by Davison Dias (1995), one of the most applied methodologies in Brazil. However, in this methodology, the colluvial deposits are treated as if they all had the same behavior, although they have different geological-geotechnical evolutions and have been submitted to distinct processes of pedogenesis. Therefore, the main objective of this paper was to evaluate the geotechnical parameters of colluvial soils of the different lithologies and define whether lithology should be a factor in the Davison Dias’ classification of colluvial deposits.

## 2 Description of Study Area

Blumenau is located in Santa Catarina state, southern Brazil, and occupies an area of 519.837,000 m<sup>2</sup>, where approximately 40% represents urban area. The city is 150,000 km away from the state capital, Florianopolis. This region is characterized by occurrence of natural disasters such as landslides and floods, especially in rainy seasons.

The combination of the intertropical and polar air masses has direct influence in the state’s climate, which is defined as subtropical. In Köppen’s climate classification, the most widely used in the world, Blumenau is characterized for being a city of humid mesothermal climate with well-distributed rains and hot summer.

There are four geological units in Blumenau’s area: the Santa Catarina Granulite Complex, Brusque Metamorphic Complex, Itajaí Basin and Quaternary Deposits. Blumenau’s relief is characterized by the presence of steep mountains which represent the main units (SCGC, BMC and IB) of the city. The alluvial deposits correspond to the central portion of the city and are cut by the Itajaí-Açu River.

## 3 Methodology

The pre-fieldwork activity follows the methodology of geotechnical mapping proposed by Davison Dias (1995). In which the geological and pedological maps are overlapped. Thus, a new geotechnical map is created and from this map, via aerial images, the sampling points are chosen for each geotechnical unit delimited.

Disturbed and undisturbed samples of 8 different lithologies were taken from 13 locations (Fig. 1) in both colluvial and residual soils. Disturbed samples were subjected to geotechnical characterization tests, whereas the undisturbed samples, which were taken in metal molds (Fig. 2), were subjected to direct shear tests. The sampling points are shown in Table 1.

Characterization tests follows the Brazilian Association of Technical Standards. The soil’s physical properties analysis and grain size analysis were performed to characterize the materials. The physical characterization test of the soil measured its water content, solid specific weight, void ratio, porosity and degree of saturation. The grain size test performed adopted the NBR 6502/95 standard. According to which the grain size distribution can be divided into gravel (>2.0 mm), coarse sand (2.0–0.6 mm), medium sand (0.6–0.2 mm), fine sand (0.2–0.06 mm), silt (0.06–0.002 mm) and clay (0.002–0 mm).

Metal molds that measure 104.04 cm<sup>2</sup> and 0.2 cm in height were used for the direct shear tests, both in drained and natural humidity conditions, under normal stresses of 33, 78 and 128 kPa. The shear speed was 0.307 mm/min. In each soil it was possible to define the Mohr-Coulomb envelope, as well as the internal friction angle and cohesion.

## 4 Direct Shear Tests in Colluvial and Residual Soils of Brazil

Some results for maximum shear stress from colluvial and residual soils of previous studies are presented in Table 2.

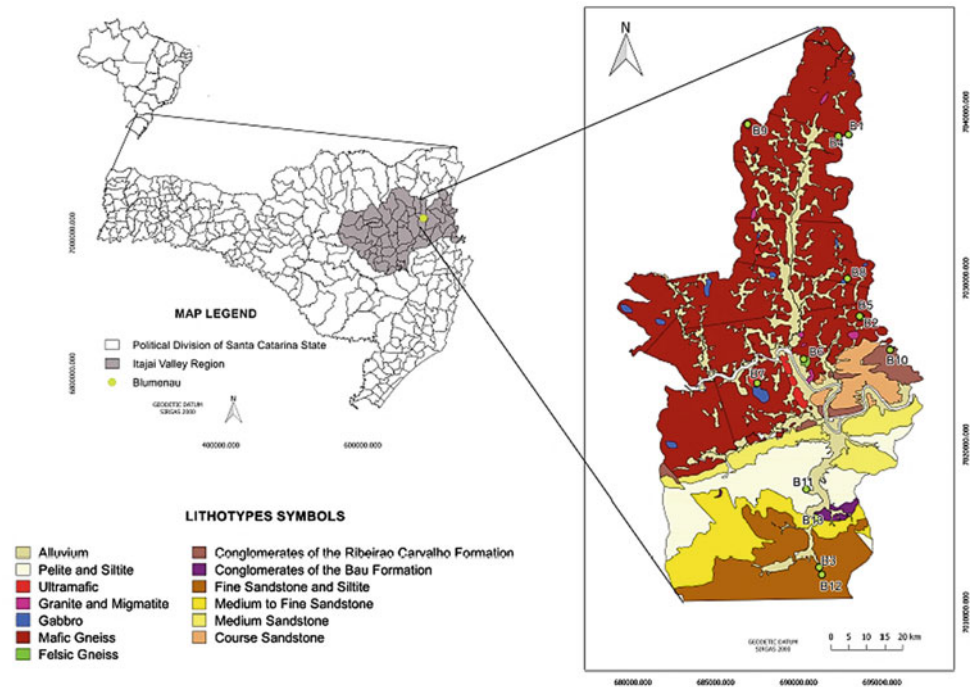
## 5 Results and Discussions

This chapter presents the results and discussions about the geotechnical characterization and direct shear test.

### 5.1 Geotechnical Characterization and Grain Size Analysis

The geotechnical characterization results and grain size analysis data are presented in Tables 3 and 4. The characterization

**Fig. 1** Localization map and lithological map of Blumenau



**Fig. 2** Metal molds to the drained shear test

defined soil physical characteristics as solid specific weight ( $\gamma_s$ ), water content ( $w$ ), void ratio ( $e$ ), porosity ( $n$ ) and degree of saturation ( $S_w$ ).

In colluvial soils (B1, B2 and B3), the variation in grain size was expected due to the heterogeneous of grain sizes, according to Lacerda and Sandroni (1985). The grain size distribution in colluvial soils presented a high silt and clay content, ranging from 54.63 to 67.18%. In addition, the sand content ranged from 29.94 to 38.93%.

In residual soils it is necessary to highlight the amount of gravel at point B9. This may be related to the sampling depth, close to the bedrock.

## 5.2 Direct Shear Test

To define the Mohr-Coulomb envelope at least three tests were necessary under normal stresses of 33, 78 and 128 kPa. Thus, it was possible to define the parameters of cohesion and internal friction angle.

The direct shear test results in inundated conditioning are shown in Table 5.

In colluvium materials, the lowest and highest cohesion value (5.9 and 19.4 kN/m<sup>2</sup>) were obtained in soils developed in mafic gneiss (B1) and fine-grained sandstone and siltite (B3), respectively. In the meantime, the lowest and highest angle of internal friction (21.0° and 30.7°) were obtained at points B3 and B1, respectively.

In residual soil the lowest cohesion value (8.1 kN/m<sup>2</sup>) was obtained in residual soil from mafic gneiss (B5). The highest (23.9 kN/m<sup>2</sup>) was obtained in residual soil from granite and migmatite (B9) (Figs. 3 and 4).

**Table 1** Description of the sampling points

Point	Description
B1–M117	Colluvial soil developed in mafic gneiss
B2–M128	Colluvial soil developed in mafic gneiss
B3–M126	Colluvial soil developed in fine-grained sandstone and siltite
B4–M118	Residual soil from mafic gneiss
B5–M129	Residual soil from mafic gneiss
B6–M120	Residual soil from felsic gneiss
B7–M121	Residual soil from ultramafic
B8–M119	Residual soil from gabbro
B9–M116	Residual soil from granite and migmatite
B10–M122	Residual soil from conglomerate
B11–M124	Residual soil from pelite and siltite
B12–M125	Residual soil from fine-grained sandstone and siltite
B13–M127	Residual soil from medium to fine-grained sandstone

**Table 2** Compilation of maximum shear stress results in colluvium and residual soils (Perazzolo 2003)

Reference	Soil	c' (kPa)	$\phi$ (°)
Fonseca et al. (2002)	Colluvial soil developed in mafic gneiss and granitic rocks	6–8	36.2–26.5
Soares et al. (2001)	Residual soil from mafic gneiss	0 a 16.7	26.4–30.6
Soares e Politano (1997)	Colluvial soil developed in mafic gneiss and granitic rocks	10–98	38–48
Avelar e Lacerda (1997)	Colluvial and residual soils developed in mafic gneiss and granitic rocks	22.3	26.4
Campo et al. (1997)	Colluvial and residual soils developed in migmatite	1.5–2.9	32.4–32.8
Abramento e Pinto (1993)	Colluvial soil	0	38–40
Brugger et al. (1993)	Colluvial and residual soils developed in mafic gneiss and granitic rocks	0–85	25–40
Clementino e Lacerda (1992)	Colluvial soil developed in and granitic rocks	38.8–42.9	19–32

**Table 3** Soil physical characterization results

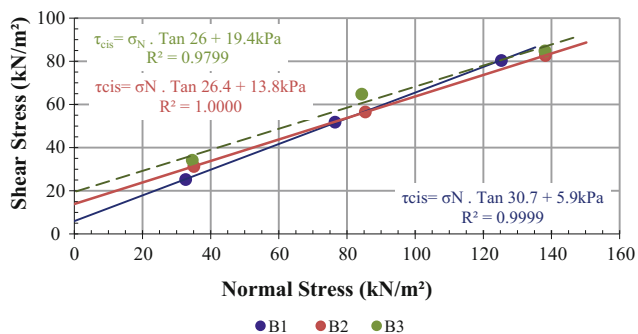
Point	Solid specific weight (kN/m <sup>3</sup> )	W (%)	e	n	S <sub>w</sub> (%)
B1	27.6	38.89	1.68	0.63	63.77
B2	27.1	41.70	1.34	0.57	85.18
B3	26.3	23.94	0.85	0.46	65.93
B4	26.3	20.43	0.64	0.39	83.55
B5	26.9	37.06	1.26	0.56	79.20
B6	27.6	35.83	1.07	0.52	91.64
B7	26.5	29.70	0.93	0.48	83.98
B8	26.8	42.23	1.65	0.62	69.70
B9	26.9	7.76	0.44	0.31	46.12
B10	26.7	16.28	0.60	0.37	72.55
B11	26.7	29.88	0.85	0.46	93.31
B12	26.2	21.24	0.77	0.43	71.87
B13	25.5	26.28	0.87	0.47	76.56

**Table 4** Grain size results

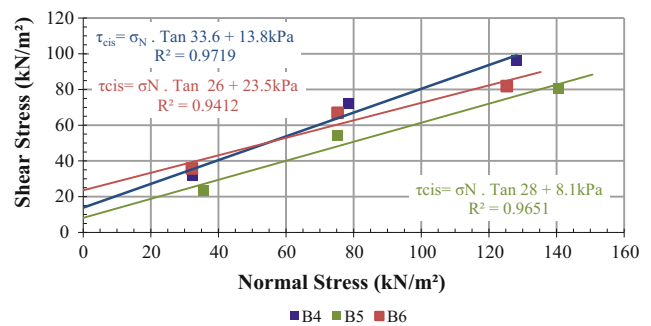
Point	Grain size distribution					
	Gravel (%)	Course sand (%)	Medium sand (%)	Fine sand (%)	Silt (%)	Clay (%)
B1	6.44	4.15	13.42	21.36	36.21	18.42
B2	0.82	3.59	13.78	12.57	53.80	15.45
B3	1.09	0.66	8.86	22.21	19.46	47.72
B4	1.44	9.91	29.99	23.27	28.85	6.54
B5	0.00	0.42	10.88	15.91	47.24	25.56
B6	0.10	1.22	4.58	4.16	51.18	35.75
B7	0.91	6.23	13.93	17.87	37.48	23.82
B8	0.44	3.97	17.52	12.72	52.75	12.59
B9	9.60	21.82	37.18	13.31	13.83	4.26
B10	0.60	8.37	33.54	11.14	25.87	20.47
B11	0.04	2.02	3.59	5.79	59.63	28.94
B12	0.00	0.07	15.49	20.09	36.22	28.13
B13	0.74	3.19	4.22	5.36	67.21	19.28

**Table 5** Direct shear test results

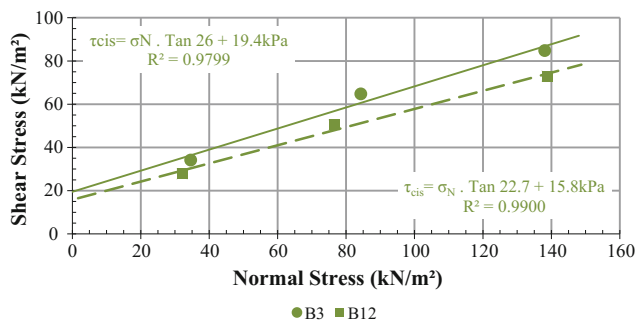
Point	Cohesion—c' (kN/m <sup>2</sup> )	Angle of internal friction—φ (°)	R <sup>2</sup>
B1	5.9	30.7	0.9999
B2	13.8	26.4	1.0000
B3	19.4	26.0	0.9799
B4	13.8	33.6	0.9719
B5	8.1	28.0	0.9651
B6	23.5	26.0	0.9412
B7	23.7	24.5	0.9349
B8	12.8	25.1	0.9834
B9	23.9	41.4	0.8900
B10	20.3	23.0	0.9669
B11	11.8	32.0	0.9907
B12	15.8	22.7	0.9900
B13	10.8	21.3	0.9822



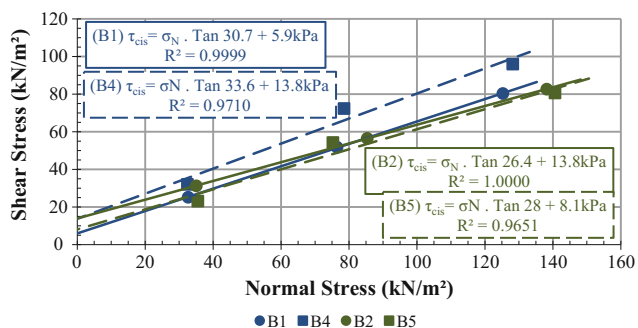
**Fig. 3** Colluvial soils from B1, B2 and B3 points



**Fig. 4** Residual soils from mafic gneiss



**Fig. 5** Residual and colluvial soils from fine-grained sandstone and siltite



**Fig. 6** Residual and colluvial soils from mafic gneiss

The residual soils are represented by squares and dashed lines in Figs. 5 and 6. While colluvial soils are represented by circles and solid lines. Equal colors represent colluvial and residual soil sampled at nearby points, as with points B1 and B4, for example.

## 6 Conclusions

When comparing the granulometric compositions and direct shear results of the colluvial soils and their respective residual soils, such as B1–B4, B2–B5 and B3–B12, no similar compositions or trends are found, whereas the behavior of the colluvial soils relates to the grain sizes presents.

For the colluvial materials the soil's behavior is directly regulated by the granulometric composition. It is verified that the highest cohesions are associated with the finer materials (B2 and B3). Meanwhile, the course-grained material (B1) is the one with the highest effective internal friction angle.

Residual materials also tend to behave according to their granulometric compositions. However, points such as B5, B9 and B11 do not follow this trend and show discrepancy according to the granulometric criterion. The lithotypes of these materials are associated with metamorphic processes and sedimentary structures, which may have influenced cohesion and internal friction angle.

There are no trends related to shear strength parameters ( $c'$  and  $\phi$ ), either between the colluvium and residual soils with same lithotype or among colluvial soils with different lithotypes. Thus, it is possible to conclude that colluvial deposits should be treated as independent geotechnical units in Davison Dias' (1995) methodology.

## References

- de Castro, A.C.C.: Manual de Desastres, 1st edn. Ministério da Integração Nacional, Brasília (2003)
- Das, B.M.: Fundamentos de Engenharia Geotécnica, 7th edn. Cengage Learning, São Paulo (2011)
- Davison Dias, R.: Proposta de metodologia de definição de carta geotécnica básica em regiões tropicais e subtropicais. Revista do Instituto Geológico, 51–55 (1995)
- Lacerda, W.A., Sandroni, S.S.: Movimentos de Massa Colúviais. In: Conferência brasileira de estabilidade de encostas, 1–19. Clube da Engenharia, Rio de Janeiro (1985)
- Lacerda, W.: Comportamento geotécnico de massas colúviais. In: Simpósio de Prática de Engenharia Geotécnica da Região Sul, Joinville (2002)
- Perazzolo, L.: Estudo geotécnico de dois taludes da Formação Serra Geral, RS. 2003
- Vitte, A.C.: Relações entre a estratigrafia de rampas de colúvios e a evolução das vertentes na bacia do Ribeirão Juncal, município de Salto de Pirapora, SP. In: Anais do X encontro de geógrafos da América Latina, São Paulo (2005)