第15卷 第1~2期
1996年6月

中 国 岩 溶
CARSOLOGICA SINICA

Vol. 15 No. 1~2
Jun. 1996

ENGINEERING GEOLOGICAL PROPERTIES OF GUILIN RED SOIL AND THEIR FORMATION CONDITIONS

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1 INTRODUCTION

Red soil is well developed and distributed in Guilin, on both peak forest and isolated peak plain. It is and will be the major construction place for the city. A thorough study on engineering properties of the red soil is of important significance for promoting the city's municipal construction and speeding up its tourism development.

2 LITHOLOGIC PROPERTIES OF GUILIN RED SOIL

Guilin red soil mainly consists of eluvium, slope wash-eluvium, slope wash-proluvium and alluvium-proluvium, which were formed in the Middle and the Late Pleistonce Epoch, and remoulded by late "wetting-hotting" (lateritization). Of them, the alluvium-proluvium has larger thickness (generally 10~25 m, locally over 35 m), and is characterized lithologically as brown-red and brown-yellow clay, loamy pebbles and gravels, and pebbly and gravelly clay and loam. In profile, the stratification is very variant. Most of pebbles and gravels are seriously weathered. The thicknesses of eluvium, slope wash-eluvium and slope wash-proluvium are small (3~12 m), and they are lithologically dominated by red, tangerine-red and yellow clay with iron nodules and a little rubbles. A relict structure of silicious and argillaceous limestone of Carboniferous System is found in the eluvium. The slope wash-proluvium contains a little pebbles and gravels with a poor psephicity.

The general characters of Guilin red soil with different genesis are as follows:

(1) With the increase in depth, the color alters from dark to light, that is, from top to bottom, brown-red→tangerine red (yellow-red)→brown-yellow→yellow; the consistency changes from hard to soft, that is, from solid→hard→plastic→soft; and the content of iron nodules decreases.

(2) The thicknesses of the soil layers are very changeable in a short distance.

(3) Soft soils and soil caves are developed.

3 COMPOSITION OF THE RED SOIL

3.1 Granulometric Composition

Based on the statistics of about 230 groups of grain size data, clay fraction accounts for 52.9%～61.5% (locally up to 85%) in the red soil of the eluvium, slope wash-eluvium and slope wash-proluvium, and is of less quantity in the alluvium-proluvium (Tab. 1).

Tab. 1 Granula (mean values) and mineral compositions of Guilin red soil

Genetic type	Content of grain fraction (%)		Mineral composition	Form of mineral crystals
	>2 mm	<0.005 mm		
Alluvium-proluvium *	1.41	47.5	K, I, V, G (hydrogoethite), M	K: angular or round sheet-like; V: thin sheet-like or slaty-band-like
Eluvium	1.9	62.0	K, I, Ch, M, In, G, O, calcite, etc.	K: automorphous or allotriomorphic, size: 0.5μ±, I: thin sheet-like or slaty-like; thickness: 0.1～1.5μ
Slope wash-eluvium	0.5	61.5	K, I, Ch, O, M, In	K: automorphous or allotriomorphic, size: 0.5～0.8μ; I: thin sheet-like or slaty-band-like; thickness: 0.5～0.8μ; Ch: thin sheet-like
Slope wash-proluvium	1.1	52.9	K, I, Ch, O, quartz, feldspar, calcite, dolomite	K: automorphous or allotriomorphic; 0.5～0.8μ (thickness); I: thin sheet-like or slaty-like; Ch: thin sheet-like

* The alluvium-proluvium loam isn't included for little samples

3.2 Mineral Composition

On the basis of the analysis of differential thermal, X-ray diffraction and electron microscope scanning (EMS) on the soil samples taken from different layers of various geneses, it is showed that the red soil contains considerable quartz grains, and also 40%～75% of clay minerals, which are kaolinite (K), illite (I), chlorite (Ch), goethite (G), ollite (O), montmorillonite (M), vermiculite (V) and interstratified mineral (In) with sheet-like, scale-sheet-like and slaty-band-like forms (Tab. 1, Fig. 1). These mineral particles are very fine (mostly smaller than 1μ). Because iron oxide deposits in between particles, the aggregates usually have crumb and honeycomb structure.

3.3 Chemical Composition

The most important characteristics of the chemical composition in the red soil are as follows:

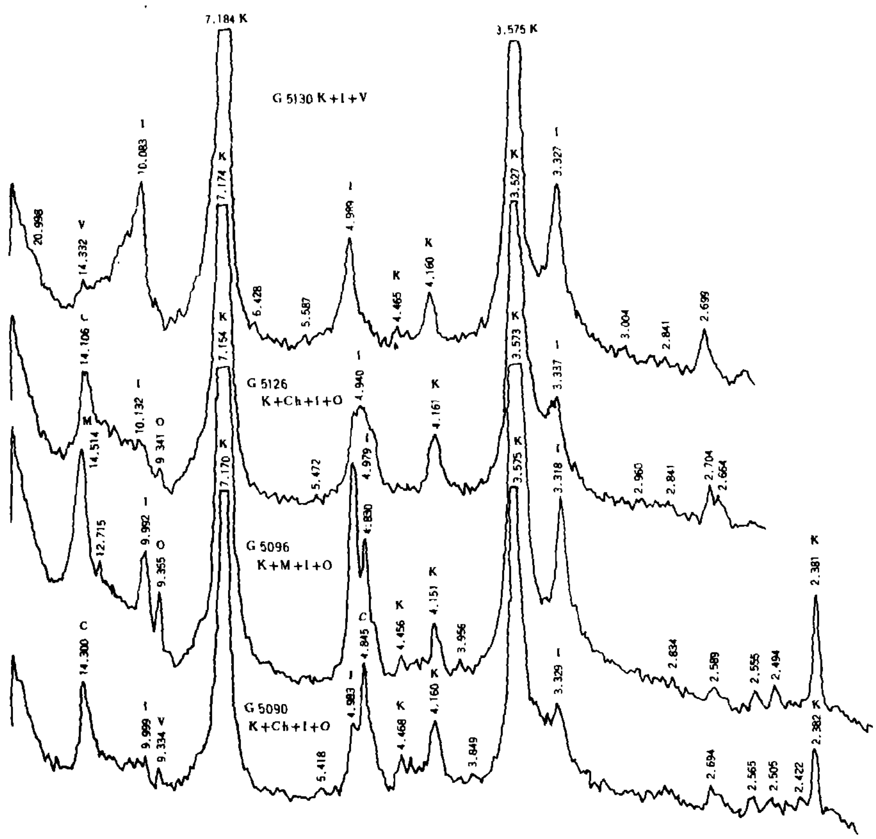

Fig. 1 Clay mineral X-ray diffraction spectrum of Guilin red soil

(1) The content of Fe_2O_3 and Al_2O_3 is relatively high, generally up to 25%~35%; and the content of alkali oxides (K_2O, Na_2O) and alkaline oxides (CaO, MgO) is low, usually below 5%.

(2) The content of soluble salts is low, and the content of single valence ions is under 1% in most of the cases.

(3) With the increase in depth, the SiO_2 content rises, and the content of Fe_2O_3 and Al_2O_3 reduces (Fig. 2), which shows that the wetting-hotting tends to go from intense to weak.

4 ENGINEERING GEOLOGIC PROPERTIES OF THE RED SOIL

4.1 Physical and Mechanical Properties

By synthetical statistics of about thousand groups of geotechnical test data, the basic physical and mechanical properties of the red soil can be summarized as follows:

(1) Large void ratio, low compressibility and high strength. In general, the void ratio is larger than 1.0; the coefficient of compressibility is less than 0.3 MPa^{-1} with a minimum of

0.03 MPa^{-1}; the cohesion and internal frictions angle are 110~130 kPa and 37°~40° respectively (Tab. 2).

(2) High natural water content, high liquid limit and high plasticity. According to the statistics, about half of samples have liquid limits more than 60%, and near 70% of samples plastic index over 20%. The red soil is marked on the right side of the upper part on plasticity chart[1]. The natural water content is between 26% and 40%.

(3) High saturation and large natural unit weight. The saturation is over 90% and the natural unit weight generally from 18.2 kN/m^3 to 19.6 kN/m^3.

(4) Low permeability and small disintegration. The permeability coefficient often is between 1.58 × 10^{-8} cm/s and 5.0 × 10^{-8} cm/s. The slaking values are commonly under 1% (sometimes zero).

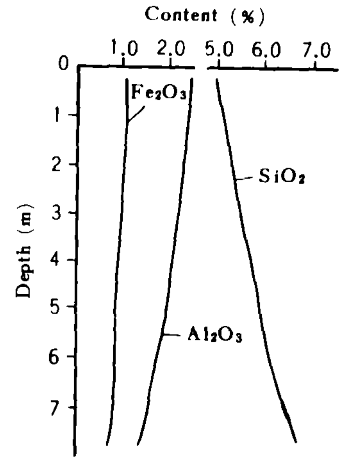

Fig. 2 Variation of SiO_2, Fe_2O_3 and Al_2O_3 with depth

(5) With the increase in depth, the water content and the coefficient of compressibility rise, and the plasticity and mechanical strength reduce. From upper solid and hard layers to low plastic layer, the water contents increase by 3% and 6% respectively. Compressibility coefficient of the plastic layer is 1.5 to 2.0 times as large as that of the solid and hard layers. The standard penetration test value generally is 10~12 hits and bearing capacity is 250~300 kPa for the solid and hard layers, whereas they are less than 3 hits and under 80 kPa, respectively, for the soft layer.

4.2 Swelling and Shrinkage

It has been found by experiment that the red soil has following characteristics: (1) weak to moderate swelling and shrinkage with the former larger than the latter; (2) the swelling and shrinkage deformations of the lower layer being greater than those of the upper layer. The statistics show that the red soil with swelling rate over 1% makes up about 36% of the whole, and degree of free swelling ranges from 30% to 40% (sometimes negative under a loading of 50 kPa). Volumetric shrinkage of the red soil is relatively large, being larger than 10% for 63% of the samples, with the maximum up to 28%. In addtion, the linear shrinkage is generally over 7.0%.

4.3 Physical and Chemical Properties

(1) The pH values of most of the smaples are 5.5~6.5 and less than that at the isoelectric point of R_2O_3 (iron and aluminum oxides).

(2) The cation exchange capacity (CEC) usually is low, i.e. less than 12 e · m for per 100 g dry soil.

Tab. 2 Physical and mechanical properties of Guilin red soil

Index	Eluvium			Slope wash-eluvium		
	max.	min.	general	max.	min.	general
Natural water content (%)	47.5	21.4	30.0~41.0	59.5	21.0	28.0~42.0
Natural unit weight (kN/m^3)	19.0	17.8	17.8~18.7	20.0	16.1	17.4~19.6
Specific gravity	2.81	1.69	2.72~2.80	2.87	2.67	2.73~2.77
Porosity (%)	58.0	42.0	48.0~53.0	60.0	40.0	45.0~55.0
Void ratio	1.31	0.73	0.8~1.10	1.56	0.63	0.88~1.12
Saturation (%)	100.0	79.1	88.0~97.0	100.0	68.0	93.0~100.0
Liquid limit (%)	72.4	42.5	43.0~70.0	82.0	27.0	45.0~70.0
Plastic limit (%)	47.6	18.3	27.0~40.0	51.8	20.0	24.0~35.0
Plasticity index (%)	27.1	17.0	18.0~27.0	41.6	10.0	20.0~36.0
Liquidity index	0.65	<0	<0~0.25	1.08	<0	<0~0.35
Permeability (cm/s)	4.95×10^{-6}	3.6×10^{-8}	1.57×10^{-7} ~2.9×10^{-6}	2.4×10^{-6}	2.9×10^{-8}	1.6×10^{-7} ~1.34×10^{-6}
Slaking quantity (%)			0.54			0.08~0.38
Compressibility (MPa^{-1})	0.19	0.05	0.07~0.17	1.00	0.07	0.18~0.3
Cohesion (kPa)	120	39	50~100	117	8	40~80
Angle of internal friction (degree)	44	13.2	15~30	38	4.0	15~26

Index	Alluvium-proluvium			Slope wash-proluvium		
	max.	min.	general	max.	min.	general
Natural water content (%)	50.0	17.7	20.0~40.0	52.0	18.0	26.0~36.0
Natural unit weight (kN/m^3)	21.6	17.2	17.6~20.0	20.1	16.2	17.2~19.4
Specific gravity	2.83	2.67	2.72~2.80	2.83	2.7	2.72~2.80
Porosity (%)	58.4	31.5	41.0~54.0	60.3	43.4	43.0~54.0
Void ratio	1.54	0.46	0.74~1.06	1.18	0.71	0.8~1.00
Saturation (%)	100.0	68.0	91.0~100.0	99.0	79.0	92.0~98.0
Liquid limit (%)	66.0	31.5	42.0~55.0	65.0	33.0	35.0~60.0
Plastic limit (%)	42.3	13.0	18.7~35.7	43.2	19.0	22.0~40.0
Plasticity index (%)	30.0	10.0	19.0~31.0	24.5	14.0	17.0~22.0
Liquidity index	1.06	<0	<0~0.3	0.59	<0	<0~0.28
Permeability (cm/s)	2.18×10^{-3}	5.6×10^{-8}	3.8×10^{-6} ~5.6×10^{-6}			
Slaking quantity (%)			0.0~0.23			0.0~0.89
Compressibility (MPa^{-1})	0.77	0.09	0.1~0.36	0.67	0.03	0.06~0.3
Cohesion (kPa)	130	14	39~84	107	4	47~75
Angle of internal friction (degree)	39.9	5.0	14~28	39	4.0	14.9~32.0

(3) The total specific surface area generally is great and often up to 110～200 m^2/g (maximum 281 m^2/g). After deironing it increases obviously and is 3～8 times as large as that before deironing (Fig. 3). Guilin red soil differs from Lubuge red clay of Yunnan. The specific surface area of Lubuge red clay decreases when iron oxides are ridded up[2].

(4) The test data from various soil layers show that the red soil has some regularities, i. e., the deeper the soil layer is, the larger the CEC is. For example, the CEC of the eluvial red soil near the Carborniferous bedrock surface in the western suburb of Guilin City is 2. 5 times as large as that of the surface layer, and the saturability of its salt-radical decreases from 80% to 11%. The characters above show that soil leaching can not go on thoroughly at the bottom and the soil possesses more mobility.

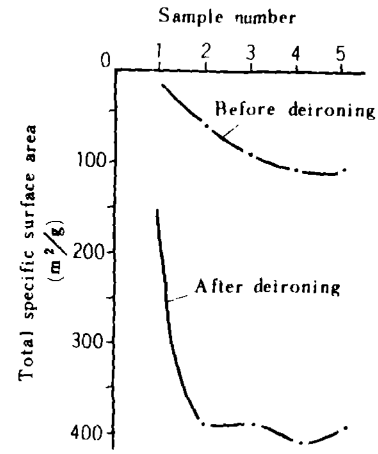

Fig. 3 Specific surface area values of soil before and after deironing

5 FORMATION CONDITIONS OF THE ENGINEERING GEOLOGICAL PROPERTIES OF THE SOIL

It seems contradictory that the red soil has high water content and high void ratio, but low compressibility, large internal friction angle and cohesion. However, it is true in fact. It is just an concrete expression of the peculiar engineering geologic properties of the red soil. The formation of these peculiar properties are not accidental because there exist corresponding material base and good environment for soil formation.

5. 1 Continuous Wet-Warm Climatic Environment—A Prerequisite for the Formation of the Peculiar Engineering Geological Properties

The thickness of the Upper Palaeozoic carbonate rocks is over 4000 m in Guilin area[3]. Because of intense compression of multiperiodic tectogenesis, the folds and fractures are developed in the carbonate rocks, which provides a substantial base for the formation of Quarternary sediments. After Tertiary Period, it became hot and rainy, and the vegetation was exuberant. Under such environment, loose accumulates which were formed before and in Middle and Late Pleistocene Epoch were obviously remoulded by wetting-hotting, and a great amount of carbonate components were dissolved and moved out from the soil layer. After the leaching of carbonate components, the silicate minerals began to be hydrolyzed. Under the intense and continuous wetting-hotting, the silica decreased and the iron and aluminum oxides accumulated greatly. Soon afterwards, a lot of highly despersive, fine sheet-like, scale-like and slaty-like clay minerals (K, I, Ch, V, M, etc.) were formed. At the same time, a lot of iron nodules and free iron oxide films wrapping the surface of the clay particles were developed.

5.2 Special Composition—A Material Base for the Formation of Unusual Engineering Geological Properties of the Red Soil

The red soil contains a lot of sheet, scale and slaty-band clay minerals which are less than 1.5μ, in high dispersion and possess large specific surface area. Consequently, under the natural conditions, the minerals can absorb a large amount of water molecules on the surface of the clay particles and a thick bound water layer can be formed, which results in that the red soil possesses high water content and saturability. Since the clay particles are very fine and interparticle pores are numerous and small, the red soil has high porosity and low permeability. Secondly, because of the high content of free iron oxides in the red soil, under weak acidity condition the free iron oxides with positive charges are absorbed on the surface of the clay minerals which carry negative charges[4], they may replace, in a certain range, lower electrovalent cations, such as K^+, Na^+, Ca^{2+}, Mg^{2+}, etc.. As a result, the double electrical layer begins to thin to form the crumb and honeycomb structure with strong interparticle bond, namely, called as "domain"[5]. For these reasons, in spite of high water content and large void ratio, Guilin red soil is still of relatively high shearing strength, low compressibility and small disintegration.

Similarly, the weak-moderate swelling and shrinkage properties of the red soil are deter- 1
mined by its composition. As mentioned above, there are a little of montmorillonite, vermiculite and interstratified minerals in the red soil. Montmorillonite and vermiculite are aluminosilicate minerals, and their unit structural layer consists of two layers of Si-O tetrahedron with one layer Al-(O,H) octahedron in between. These layers are connected mainly by oxygen atoms, and interparticle bond is weak[6]. Because of having unstable lattices, aluminosilicate minerals can expand and shrink easily. The interstratified mineral, based on the observation by EMS, is composed of different crytical cells of montmorillonite and illite, and possesses swelling-shrinkage lattice as well. Because of existence of these minerals, the Guilin red soil usually displays swelling-shrinkage properties. But the swelling-shrinkage is relatively weak as the content of these minerals is low. Even if infiltrating water is comparatively rich in rainy season, the minerals can not absorb too much water into their lattices, which leads only to a slight expansion due to the high water content and high saturability in the red soil. Oppositely, under dry and evaporation conditions the red soil can release a lot of water, which results in the obvious shrinkage. The soil layer is deeper, the higher the water content and the more obvious the shrinkage. That is why the red soil commonly possesses a weak-moderate expantion-shrinkage and its deformation is dominated by shrinkage, and the deformation of the low layers is stronger than that of the upper layers.

6 CONCLUSIONS

(1) Guilin red soil mainly consists of eluvium, slope wash-eluvium, slope wash-proluvium and alluvium-proluvium which formed in Pleistocene Epoch and were remoulded by subsequent "wetting-hotting". It is a red or red-like clay rich in iron and aluminum oxides. The clay minerals are mainly kaolinite, illite, and chlorite. In addition, there are a little of montmorillonite, vermiculite and interstratified mineral in the red soil. The content of clay fractions is over 50%. The red soil is in high dispersion and the fractions are fine and smooth.

(2) The engineering geological properties of the red soil are as follows: the water content, the void ratio, the liquid limit and the shearing strength are high; the natural unit weight, the saturability and the specific surface area are large; the CEC, the permeability coefficient and the slaking are small. Besides that, it possesses weak-moderate expansion and shrinkage properties. The formation of these peculiar engineering geological propenties are related to composition of the red soil, specifically to the high content of free iron oxides.

(3) The characteristics that the wetting-hotting becomes weak with the increase in depth result in the vertical zonation of the composition and mechanical strength. Therefore, in engineering design, we should take the hard or hard-plastic layers which have a relatively high strength as the ground for construction.

(4) The weak-moderate expansion-shrinkage and the deformation dominated by shrinkage are attributable to the existance of montmorillonite, vermiculite and interstratified and the high water content under the natural conditions.

AcknowledgementS

The paper is checked and guided by Prof. Ling Zeming and Prof. Xie Yunhe. The author is deeply greateful to them for their help.

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桂林红土的工程地质性质及其形成条件*

韦复才

摘　要

桂林红土主要由更新世残积、坡残积、冲洪积及坡洪积经后期湿热化改造而成。在物质组成上，其粘粒含量较高，一般都在50%以上；矿物成分以次生的高岭石、伊利石、绿泥石、滑石、针铁矿以及蒙脱石、蛭石、混层粘土矿为主，含量通常在40%～75%；化学成分上铁铝氧化物大量富集，钾、钠、钙、镁等碱和碱土金属氧化物明显减少，前者一般达25%～35%，后者常常在5%以下。

经近千组土工试验资料综合分析，桂林红土具有以下几个基本特征：

(1)土的孔隙比大、压缩性小、强度高。孔隙比通常大于1.0；压缩系数一般在0.3 MPa^{-1}以下，最小可至0.03 MPa^{-1}；内聚力和内摩擦角最高可分别达110～130 kPa和37°～40°。

(2)高液限、高塑性、高含水量。液限、塑性指数、天然含水量一般各自为42%～60%，18%～31%和26%～40%。

(3)透水性和崩解性较小，饱和度较高。渗透系数多在1.5×10^{-5}～5.0×10^{-8} cm/s，崩解量一般小于1%，饱和度通常在90%以上。

(4)比表面较大，阳离子交换量较小。前者最高达281 m^2/g，后者一般小于12 EPM。

(5)普遍具有中－弱胀缩性，而且缩大于胀。自由膨胀率一般为30%～40%，在50 kPa压力下，膨胀率相当部分显示负值，而体缩率和线缩率则分别达6%～12%和1.3%～3.3%。

桂林红土工程地质性质的特殊性的形成，主要由其特定的物质组成所决定。化学分析及电镜扫描业已证实，桂林红土中含有较多的游离氧化铁。这些游离氧化铁被表面带负电荷的粘粒强烈吸附，并以胶膜的形式将相邻的粘粒胶结在一起，形成孔隙虽较大但连结力仍较强的土粒集合体，致使红土表现出较大的孔隙性的同时，仍具有较强的水稳定性和较高的力学强度。此外，由于土中粘粒含量较高，且含少量的蒙脱石、蛭石及混层矿物，使得土的含水量较高并普遍具有中－弱胀缩性。

关键词　桂林红土　物质成分　工程地质性质　形成条件

* 系"桂林环境工程地质研究"项目(获地矿部科技成果三等奖)部份成果。

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