LANDSLIDES IN SOILS OF DECOMPOSED ROCK DUE TO INTENSE RAINSTORMS

GLISSEMENTS DE TERRE DANS LES FORMATIONS DE ROCHER DECOMPOSE

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SUMMARY - In tropical countries, specially in Brazil, many slides of special type due to the simultaneous occurrence of colluvial and residual soils, with blocks and fragments of rock, and excepcional rains have been observed.

These slides, that had catastrophic consequences in Brazil in 1966 and 1967, when rains presented with a return period of 700 to 2000 years, are partially due to a deficient protection of the nature.

The paper classifies the slide phenomena that occur in such geological formations, describes the accidents that occurred in the "Serra das Araras" in 1966 and 1967 and discusses the processes employed to correct them, specially the methods of anchorage, largely used to stabilize such slides.

1. INTRODUCTION

1.1. - Topographic relief

As it is well-known, Brazil presents an orographic characteristic very unfavourable to its inland penetration: an important mountain chain extended near and along the coast for thousands of kilometers, just - in the most developed region of the country, including the cities of Curitiba, Santos, Rio de Janeiro, Niteroi and Vitoria.

Between Rio de Janeiro and S.Paulo, where the mountains are called "Serra do Mar", their steep slopes go down up to the ocean commonly.

1.2. - Geological aspects

At the region where the slides occurred in "Serra das Araras", from which we shall talk later, the striped gneiss (migmatite) is the most common rock, with decomposed parts, showing frequently veins of kaolinised pegmatite.

Such rocks, due to the local climate are covered with residual soil (eluvium) having, many times, a hundred of meters in thickness and with colluvial soil or talus, procceding from the sliped rock from the slopes and transported chiefly by gravity.

The soil thickness, on the sound rock, may vary from zero meters, where the rock appears in steep slopes as, for example, at Sugar Loaf, at the entrance of Guanabara Bay, up to 100 meters.

However, at regions where more numerous and catastrophic landslides occurred, as in Caraguatatuba at the coast of S.Paulo,

"Serra das Araras" and in Guanabara, the soil thickness on the rock very seldom reaches 6 meters.

Such a characteristic contributed to the little studied type of landslide, where erosion predominates. Whe shall return to this point later.

The decomposed rock which will be transformed in residual and colluvial soils presents from fractured and fissured forms, many times with conchoidal slices, to fine-grained soils, with predominance of the silty-sandy ones in the leucocratic gneiss and clayey in the biotitic one (kinzigites).

Photo 1
Residual slope with boulders (Rua Ramiro Monteiro - Rio)

However, it must be noted that the climate and the topography, including insolation, drainage and the slope angle have decisive influency upon the granulometry of the residual soil.

It is common, at the same valley, to have one of the slopes covered with a thicker and clayeyer layer of soil than the other one.

The local of the Funil Dam at the "Paraiba" river, near Itatiaia (Laginha Serafim and Costa Nunes - 1966) is an exemple of that.

Schematically, it is found, starting from the sound rock,a zone of fractured rock, followed by a resistent soil that keeps, many times, the texture of the matrix rock, and involving frequently spheroidal blocks of rock, sometimes of great dimensions, or boulders (Photo 1).

Locally, thys type of soil is called "moledo".

It is followed by a softer soil, still with a certain texture of the rock: this is "saibro". In this layer boulders are found too.

The upper layers of residual soil are many times porous, due to the lixiviation that, correspondingly, forms concretions of limonite type in the layers situated below.

By the future erosion, the boulders, chiefly those of the layer situated just over the sound rock appear at the surface (Photo 1) in sometimes unstable positions, as it happens frequently at the Brazilian cities already mentioned.

Very often, the colluvial soils present a collapsing structure which,under the water influence, loses a valuable part of their shearing resistance due to the development of neutral and percolation pore-water pressures.

These soils have their shearing resistance decreasing with the deformation and they are subject to the phenomenon of progressive rupture (Bjerrum - 1966).

The landslides of colluvial soils are those that oresent more difficulties to be foreseen and to be attacked.

There were thousands of landslides and the mountains seemed to have been dilacerated (Photo 2).

Photo 2
General view of the slide area

Most of them were of the erosion type leading to greater slides of the avalanche type, and, finally, at the low parts there was a flux of soaked earth which produced at the north end, on the two lanes of the road, near "the "Floresta" brook,a silting greater than 5 meters.

The sliped material obstructed culverts forming dams and destroying fills in many points of the highway.

In other places the erosion left apparent the rock surface with unstable blocks amount the pavement (Photo 3).

The two lanes of the - "Via Dutra" - - BR.116 - highway linking Rio to S.Paulo, the most important highway of the country, were destroyed in about 70 different points while new accidents were outlined.

It must be emphasised that the older lane in traffic for 40 years and situated in a upper level, was the most damnified during the storm in 1967 and had never had before any important accident.

Photo 3
View of the work in progress. In the background the unstable blocks uncovered by the erosion can be seen.

The raising lane,moderner and presenting better traffic conditions, had already suffered several interruptions in the past and it was also severely damaged in 1967,though in a less number of points.

It must be also noted that the region was enough protected by vegetation but the landslides reached the high part of the slopes (Photo 2) which were covered with natural forest or, at least, not touched in the last 70 years.

The phenomenon put out of order the most important part of the Rio-Light's hydroelectric plants, reducing about 50% of their electric-power supply to Rio.

About 50 landslides joined at the valley bottom where is situated the underground "Nilo Peçanha" power-plant and, as a mud

Table I (Seixas Ferreira - 1966) contains average values of geotechnical properties of regional granitic-gneissic soils.

SUMMARY OF THE MOST FREQUENT VALUES OF SOIL TESTS

	UNIT WEIGHT OF SOIL g/cm^3		C O H E S I O N kg/cm^2		ANGLE OF INTERNAL FRICTION (Quick-Consolidated Direct Shear Test) Ø	
MATERIAL	Natural state	Saturated state	Natural state	Saturated state	Natural state	Saturated state
SOIL I	1.8-1.9-56% 1.9-2.0-16% 1.7-1.8-15%	1.9-2.0-45% 1.8-1.9-32%	0.1-0.2-44% 0.2-0.3-36%	0.0-0.1-49% 0.1-0.2-34%	30-35º-30% 25-30º-17%	30 a 35º - 25% 25 a 30º - 16% 20 a 25º - 11%
SOIL II	1.5-1.6-47% 1.6-1.7-32%	1.7-1.8-38% 1.8-1.9-32%	0.1-0.2-36% 0.2-0.3-24% 0.0-0.1-15%	0.0-0.1-62% 0.1-0.2-27%	30-35º-33% 25-30º-21%	30 - 35º - 46% 25 - 30º - 19% 35 - 40º - 13%

Soil I - residual soil from predominantly migmatite
Soil II- residual soil from predominantly gneiss of leptinitic type

1.3 - Pluviometrical aspects

The "Serra das Araras" region receives the most intense rains all over Brazil.

The highest values till now recorded are:

Paranapiacaba - 5912mm in a year

Itapanhau - 620mm in 24h

Serra das Araras - 200mmm in 4h

Caraguatatuba - 586mm in 48h-1967

and again

Serra das Araras - 85mm in 1h-1967 (Santos Jr. 1967).

The phenomena that occured at "Serra das Araras" and "Caraguatatuba", in summer 1967, had an average return period of about 2000 years and they were more uncommon than those rainstorms that wasted Guanabara state in 1966 and 1967, where this period was about 700 years.

2. ACCIDENTS AT "SERRA DAS ARARAS"

These accidents of landslides were classified by the geologist of the US Geological Survey - Fred Jones - in 1967 - as those that moved greater volumes of earth than any other recorded in the geological and geotechnical literatures.

The storm occurred at night - from 22th to 23th of January 1967.

Rains started at 21h and reached, during 2h 10min, the intensity of 70mm/h.

The area covered by the disaster has a stretched form 24km long and 7,5km wide.

flux, overflowed the plant from bottom to top, submerging turbines, generators and control equipments.

Also the new plant of "Fontes" had its outlet channel and pipes of the turbine overflowed. The old plant received less damage, continuing in operation. The dams not suffered important damage.

At the low part of the valley, near a village called "Ponte Coberta", the mud flux submerged a great camp of a earth moving company as well as many trucks, buses and cars that travelled on the road.

It is estimated that about 1000 people were killed due to the catastrophe.

3. CLASSIFICATION OF LANDSLIDES IN TALUS AND IN RESIDUAL SOILS

The phenomena occurred at "Serra das Araras" and "Caraguatatuba", in 1967, in regions of tropical mountains, recommend the inclusion of a landslide type not yet considered in the existent classifications: the violent erosion type.

The subject has also been discussed by Milton Vargas (1967).

The development of the phenomenon may be summed up as follows:

Due to intense rainstorms that fall on the high parts of steep slopes in predominantly silty soils, erosion grooves are dug and the adjoining soil collapses towards their bottom, more and more increasing the phenomenon which increases its area, as an avalanche, and presents the triangular form with a vertex at its higher part (Photo 2).

Erosion undermines trees and blocks of rock which are drawn towards the lowest part of the valleys where they are accumulated together with rushing streams of water.

Afterwards, a selective secondary process of the materials, by their dimensions and specific gravity, starts: blocks of rock are less moved, some of them remaining "in situ" or a little dislocated in an unstable position; the earths are drawn to a great distance (5km or more in the case of "Serra das Araras") giving place to silting layers, many meters in thickness on the bottom of the rivers; and the trees are transported by flotation as far as the lowest part of the valley where, due to an accidental decreasing of the stream speed, all the wood is deposited, showing the characteristic aspect never observed before (Photo 4).

Photo 4
Debris carried by the flood after slides

In sum, the occurrence of landslides by violent erosion or by hydraulicking is favoured by the simultaneity of all or some of the following circumstances:

a. rains of exceptional intensity
b. silty and sandy-silty soils, easily affected by erosion
c. lack of suitable drainage
d. high average inclination of the ground
e. thin layer of soil upon the rock.

Finally, residual and colluvial soils do not require a special classification of mass motion which might be schematised on the synthetic table below:

MOTION OF THE EARTH MASS

1. Erosion
   1.1. - slow
   1.2. - violent
2. Displacement of the ground
   2.1. - Failure or fall of rock blocks or of residual soil
   2.2. - Slides or slumps
      2.2.1 - soils over soils (in this case very often the surfaces of rupture approch the theoretical one).
      2.2.2 - soils over rock - slumps of the mantle of decomposed rock.
   2.3. - Flows
      2.3.1 - creep (intermittent seasonal motion of top layers of the ground)
      2.3.2 - solifluction - phenomenon like creep but predominantly connected to thawing
      2.3.3 - mass flow - flow phenomenon connected to the development of neutral pore-water pressures and peculiar to soft soils and to collapsing structures such as recent fills and talus or to soil structures affected by the remolding. Liquefaction and mud flows are extreme cases of thie type of displacement.

4. RECOVERY OF THE "SERRA DAS ARARAS" HIGHWAY

The recovery of the Rio-S.Paulo Highway was a matter of the greatest importance to the country, because of the intensive traffic, as intense as 25000 cars a day, and economic consequences.

During the interruption, since January till September, the traffic between the two most important cities of the country was made through a long by-pass which increased in more than 2h the trip that took about 6h by car before.

It was necessary to adopt methods of stabilization of failed slopes fulfiling as much as possible the following conditions:
a. high safety factor, in view of the occurrence of exceptional rains in the region and of the difficult topographic and geological conditions.
b. speed of execution
c. possibility to open the traffic while the retaining structures were still being built.

The choice of the type of retaining structures or viaducts more suitable to each case, as well as the project of them and of the stabilization works in general were committed to the specialized company TECNOSOLO S.A.

As the conditions were as variable as possible at the accidents, different solutions were them adopted:
a. in case of small slope accidents, having resistent soil little deep, the simpliest solution was adopted - removing the failed material, lowering the slope angle and drainage.
b. where the height to be retained was small and the ground was resistent at moderate depth, classical retaining structures were used, such as gravity walls and reinforced concrete walls, counterforts type and crib walls, still depending on the disposable width to build them.

Generally, in the Brazilian conditions, such structures are economical as far as 5 or 6 meters high (Dantas, 1967) requiring,

however, good foundations.

Even crib-walls have bad performance on compressive foundations. Though it may be excellent from many points of view, accidents are common when this type of structure is built on unsuitable foundations.

c. in many cases, the allowable small width to build the structure, the necessity of not interrupt the lane and the rush to open traffic, conducted to the choice of anchored structures.

In this aspect, the recovering of the "Serra das Araras" seems to have been the very first important highway to employ, on a great scale, at least, anchored structures.

Topographic and geological alike conditions led to adopt such structures on the modern Curitiba-Paranagua highway (Lubina-1968).

The method permits 3 alternatives systems of construction:

c1) curtain walls of rails or steel H-piles driven into the ground and completed thrugt reinforced concrete (Photo 3).

The method has been also employed abroad, chiefly in Germany (Ranke and Ostermeyer 1968) and more recently in the United States (d'Apollonia 1967) and Canada (Golder-1967).

c2) curtain walls of reinforced concrete - poured from bottom to top.

This system is an adaptation from the conventional plain or reinforced concrete retaining walls, employing anchorage, due to economical reasons or in case that there is no space to a enough wide base to stabilize a reinforced concrete wall or yet due to particular conditions of the ground.

To employ this method it is necessary that the existent slops be stable all over the height to retain, with the slope angle that it has at the construction period.

c3 curtain walls of reinforced concrete poured from top to bottom.

This process was already described (costa Nunes - 1965) and it has been developed in Brazil to retain slides.

Really, the execution from top to bottom permits to build retaining walls in extremely narrow places and warrants the workmen who work protected by the courtain part already constructed (Photo 5).

Photo 5
View of anchored curtain during construction

d. There were places whers, due to the thick layer of soft soils, it was chosen the solution in walls supported by steel piles, in spite of greater difficulty and price.

e. Viaducts were built where great slides cut the highway. In some cases the viaduct crossed the area of deeper slides and was lengthened in anchored curtain.

f. Finally, in two cases the deeigner chose to fill on the slope, supported on the toe by rockfill and drained at different heights.

5. CONCLUSIONS

The landslides at "Serra das Araras", near Rio de Janeiro, Brazil, may be classified among the most numerous and important ones already recorded in comparable area.

The majority of them was of type not yet well studied in the specialised literature and they were due to a unfavourable combination of geomechanic, topographic and climactic factors.

The accidents, which caused large losses in lives and property, were repaired by several stabilization technics. The choice of the method in each case was orientated by comparative studies of the costs and conducted in many cases to modern methods of anchored curtains very much used in Brazil in the last years.

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