RAINFALL AND MASS MOVEMENTS IN RIO DE JANEIRO

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Summary
This paper presents the criteria, methodology and the preliminary results used by GEORIO on the relationship studies between rainfall and mass movements, happened during the years of 1998 and 1999 in the City of Rio de Janeiro.

Introduction
Since December 1996, the Rio Watch System (Sistema Alerta Rio) has been recording the rainfall from its 30 raingages (remote stations), spread out in the area of the Rio de Janeiro County (Fig.1). The data acquisitions are made at each 15 minutes and automatically sent to the computers of the Central Station, located at GEORIO, the Rio de Janeiro Geotechnical Engineering Office.
Besides monitoring rain precipitation levels, GEORIO (the Public Department responsible for the slopes) carries out all the mass movement reports related to the geotechnical accidents that happen within the City's limits.
The data analysis (geotechnical and rainfall) taken to the 15 minutes precision, brought on the need to establish new criteria and methodology for the study and added important aspects that improved the knowledge on the failure processes that occur at the Rio de Janeiro's slopes.

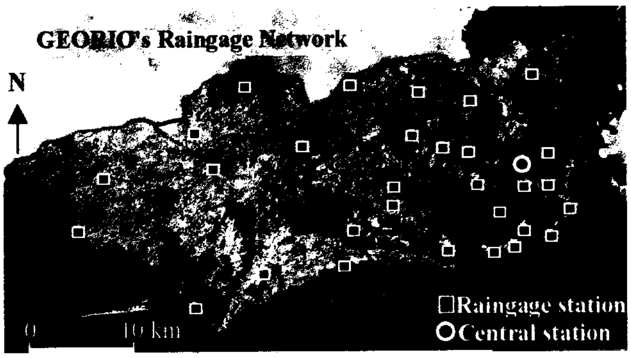

Figure 1 - Raingages stations distribution in Rio de Janeiro

Rain Event Criteria
What is a rain event ? The answer may be very simple or very complex depending on the monitoring area size and the number and type of the utilized raingages. If one uses only one raingage for the whole area, a rain event will be the time interval between the beginning and the end of precipitation recorded by the raingage. On the other hand, when using 30 raingages and the monitoring area is one city (a big one), it may occur that the rain ends at one raingage but persists in several others, just a few kilometers away. When the records are taken at every 15 minutes, it gets harder to establish the end and the beginning of the rain event, for rainfall could stop for only few hours, or even 15 minutes and then restart.
To solve this problem, the GEORIO's team responsible for carry on studies on relationships between rainfall and mass movements had to establish a criteria to define rain event - specifically for those studies - that took on consideration its the telemetric raingage network configuration and the critical rainfall levels for mass movements presented by d'Orsi *et al.* (1997). These criteria are synthesized in Table 1.

Beginning of a rain event (at least the occurrence one of the situations on the right column)	Time when a minimum of 20 raingages are recording at least 5,0 mm/h
	Time when a minimum of 10 raingages are recording at least 15,0 mm/h or 52,5 mm/24h
	Time when a minimum of 3 raingages are recording simultaneously at least 25,0 mm/h or 87,5 mm/24h
	Time when a minimum of 2 raingages are recording at least 30,0 mm/h or 105,0 mm/24h
	Time when a minimum of 1 raingage is recording at least 37,5 mm/h or 131,0 mm/24h
End of a rain event	Time when a all raingages are recording less than 2,5 mm/h or 8,8 mm/24h
Minimum time interval between two events	Minimum of 12 hours, in which all raingages must fulfill the "End of a rain event" criteria

Table 1 - Rain event time criteria

Time and Raingage Uncertainty Problems
One of the most common problem on the relationship studies between rainfall and mass movement in Rio faced by GEORIO's team is to know the exactly time that the mass movements occurred. Arriving at the site usually many hours (sometime days) after the end of the movement, the geologists and engineers responsible for the mass movement reports often find difficult to obtain, from local people, the right time related to the beginning of the movement. Many times the closest they get are information as: "in the middle of the night" or "between 2:00 and 5:00 AM". In the attempt of use all available data (which usually are not much), every time uncertainties like that occur, the used criterion was to use the time within the period ("middle of the night", between 2:00 and 5:00 AM", etc.) when the highest hourly intensity rainfall was recorded by the raingage.
Another problem that often occurs when compiling the rainfall data is to realize that the mass movement took place in a point approximately equally distant from two or more raingages. In these cases, the adopted criterion was to use the raingage data that showed the highest hourly intensity rainfalls.

Geotechnical and Rainfall Data Compilation
The geotechnical and rainfall data compilation is one of the most important stage of the study. At this point, it is important to mention that the data analyses only initiate many days after the end of the rain event, when all the technical reports are finally available for consultation. Every year GEORIO technicians accomplish about 900 technical visits (all of them generating technical reports) related, somehow, to geotechnical problems at slopes. When a important rain event occurs, triggering mass movements of all kind, routine technical visit reports sometimes get mix to mass movement reports specifically related to the intense rain event. Another important aspect to be considered is that about 30% of the technical visits carried on during the crisis period (up to 3 days after the end of intense rain event) are

06-09 January 1999 Rain Event											
Location	Date	Time	Brief Description	Type	Volume (m^3)	Damages	Rainfall (mm)			Raingage sta.	Report
							1h	24h	96h		
R. Rita Vieira, 40 - Madureira (favela)	Jan. 06	17:30	Rock slab fall	Q/R	-	Street partially blocked	7,3	13,1	44,0	Madureira	016/99
Trevo das Margaridas - Irajá	Jan. 06	19:30	Top soil slide vertical cut slope 5,m height	ES/tc	4;0	no	20,8	29,9	45,3	Irajá	055/99
Rua Jutuarama, 575 - Rocha Miranda (favela)	Jan. 08	At night	Soil and rock slide on rock cut slope	ES/R/tc	3,0	1 hut partially destroyed	32,9	33,7	92,8	Madureira	080/99
R. Frei Gaspar 371 - Vila da Penha	Jan. 09	At dawn	Old gravity wall partially failure	REC	3,0	no	27,2	27,4	88,4	Penha	021/99

Table 2 - Worksheet with mass movement and rainfall data

merely related to serious people's concern about slope conditions next to their house that actually hasn't showed any movement. These cases have been classified by GEORIO as "panic" situation. So, when the data compilation starts, an "separate the wheat from the chaff" operation has to be carried on. After this step, each mass movement report directly related to the rain event has their data summarized are transferred to a worksheet making it easy to build graphics of different types. Table 2 shows an example of worksheet with geotechnical and rainfall data.

Mass Movement Typology in Rio de Janeiro

Although many mass movement classifications are available in technical bibliography, the GEORIO's team responsible for the relationship studies found necessary to subdivide mass movements typology so that it could fit better to the specific slope accidents occurred in the City of Rio de Janeiro. After the analysis of the 466 technical reports from 1998 and 1999, it was possible to gather all the reported accidents in 13 different types of mass movement. Table 3 presents the Mass Movements classification used at GEORIO.

Symbol	Description
ES/tc	Soil slide on cut slope
ES/R/tc	Soil and Rock slide on cut slope
ER/tc	Rock slide on cut slope
ES/en	Soil slide on natural slope
ES/R/en	Soil and Rock slide on natural slope
ER/en	Rock slide on natural slope
RA	Fill failure
Q/R	Rock fall/roll
ET	Talus deposit slide
REC	Stabilization work failure
EL/E	Garbage waste and construction debris slide
C	Debris flow
PE/A	Surface erosion process

Table 3 - GEORIO's mass movement classification

Some observations regarding Table 3 must be mentioned. First the symbols were created by acronyms of the Portuguese words for each type of movement, making it easier for the team to memorize and deal with the hundreds of reports. Second, two of the "mass movement types" (REC and PE/A) are not typical mass movements, but because of their relevance as slope accidents in Rio, they were included in GEORIO's classification. Finally, the term "REC" refers mainly to the no authorized (by GEORIO) of stabilization works (structures), particularly those built by layman at the favelas (slums) without the necessary technical criteria.

Data Analysis

Searching for constant improvement, particularly on the crisis situations related to mass movements triggered by intense rains, GEORIO has since implementation of Alerta Rio System (d'Orsi *et al.* 1997) been collecting data that would help to answer for some general questions: Which are the most common types of mass movement in Rio ? How are the movement distribution frequencies within the City's territory ? Are the used critical rainfall levels for mass movements well fitted to Rio's reality ?. One of the most evident fact that has arisen from the analysis was that ES/tc is doubtless the most frequent (40%) type of mass movements. Figure 2 shows the number of mass movement for each typology in 1998 and 1999.

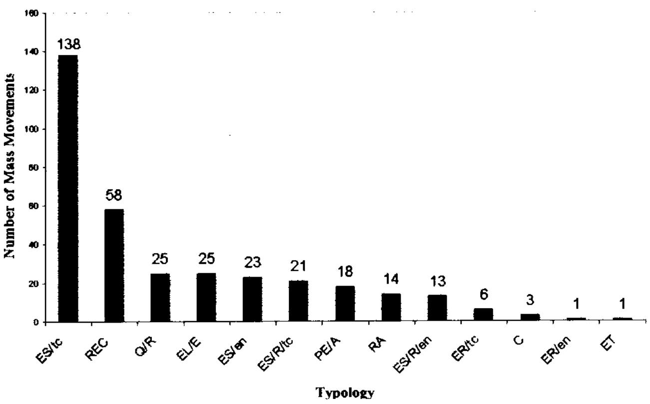

Figure 2 - Number of mass movement per typology.

After ES/tc comes REC, with almost 17% of all recorded movements. Together ES/tc and REC (induced mass movements) reach the impressive figure of 57% of all movements in Rio, showing that the lack of care (respect for the proper technical procedures) when cutting (creation of vertical soil slopes) or building stabilization works is the most important problem to be fight with, when damages from intense rain events wish to be reduced.

Another important result from the data analysis arises from Figure 3. Santa Tereza, Tijuca, Sumaré and and Grajau raingage stations- all of them located on the north side of Tijuca Mountain Range (TMR)-, are, together, responsible for more than 36% of all recorded mass movements. Taking into account that the

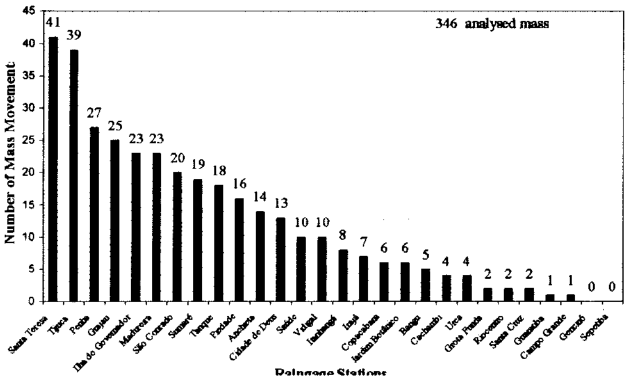

Figure 3 - Number of mass movements per raingage station

North side of TMR correspond to just 7% of the entire City and that the raingage network covers almost all the City's districts, it becomes easy to realize where the most fragile area of the City lies and therefore where to invest money and effort to mitigate losses from intense rain events.

Since the beginning of the Alerta Rio System, better adjustments of the critical rainfall levels for mass movements has always been a major concern. Due to the previous shortage of data (particularly regarding to hourly rainfall), the initial used criteria for critical hourly and daily rainfall levels, had to be adapted from existed criteria, mainly those presented by Tatizana et all (1987) and GEO (1996) and discussed by d'Orsi et al (1997). It was also defined that the criteria would aim at the major and catastrophic rain events (more than 125 mass movements triggered in a short period of time within the City's limits) only, meaning that warning would not be issue for rain events capable to cause just a few and localized mass movements. It was also established four main categories of rain event based on the associated number mass movements (table 4).

Category of Rain Event	Number of Mass Movements
Minor	up to 25
Moderate	25 to 125
Major	125 to 250
Catastrophic	more than 250

Table 4 - Classes of rain event.

After two complete rainy seasons (November to March 97-99) of data analysis using the GEORIO's raingage network, the rain events were plotted on graphics (Figures 4 and 5). The graphics' analysis show that most of the events refer to the minor category, and there was no catastrophic event in the period. When the average critical rainfall level for the most frequent mass movements typologies (ES/tc and REC) were plotted on that graphics, both typologies showing relative low values, it made easier to understand why the abundance of minor events: relative low rainfall values are enough to triggered induced mass movements in Rio. Finally, and still as a result from these analysis, it was modified the initial rate for the critical daily rainfall level from 117 mm/24h present in d'Orsi at al. (1997) to 175mm/24. The initial critical hourly rainfall level, has, so far, remained consistent with the original proposition.

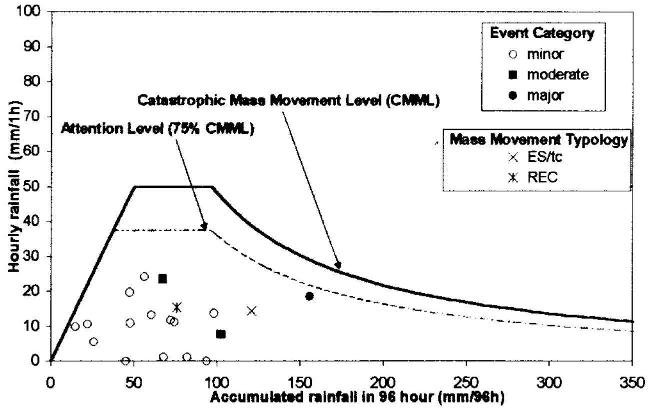

Figure 4 - Hourly intensity rainfall and the precedent 96 hours rainfall for each type of mass movement.

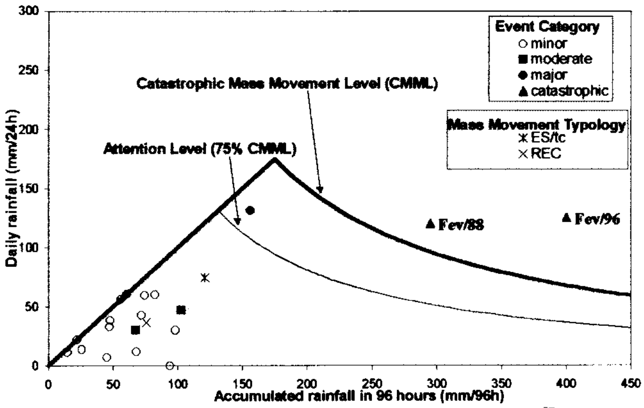

Figure 5 - Average 24hours accumulated rainfall and the precedent 96 hours rainfall for each type of mass movement.

Crisis Situations Management

One of the main concerns during the event of crisis - particularly in those related to mass movements - is the prompt answer to the requests from the general public for a technical visit. Although in most of the incidents the simple presence of a technician at the risk site can not avoid the mass movement, his evaluation of the risk level together with the establishment of the safety limits and his decision on whether or not to prohibit the area (usually homes!) are of utmost importance. The right decision may prevent casualties. Therefore, it is important for the crisis manager to estimate the number of public requests for each event, as the crisis develop, so that the appropriate number of human resource (geotechnicians) are summoned and the rational task distribution is carried on.

Aware of this fact, a correlation studies has been experimentally carried out taking into account the accumulated rainfall in 24 hours for each one of the 30 raingages. Because of geological and occupational aspects, the raingages have different weights, meaning that for the same Expected Number of Technical Visits(ENTV), some raingages must record higher rainfall rates than others (different fragility). The overall Expected Number of Technical Visits requested per rain event is obtained summing up all the 30 weighted rainfall rates and applying this figure in the equation: $ETNV=2{,}17e^{0{,}032Ac_{wa}}$. This equation was determined using the real number of technical reports related to past rain events and GEORIO's rainfall data base. Although the majority of the rain events has shown some coherence between the rainfall rates and the Number of Requested Technical Visits - NRTV (the higher is the rate the greater is the NRTV), there were a few events that the produced NRTV exceptionally high. This fact may be attributed to many aspects, from the rain event date (during the rainy season, on a holidays, etc.) to the media effect (when TV and radio station present repeatedly news about rain and bad weather, it's been noticed an increase of technical visits).

Recently, different types of correlation between rainfall rates and ENTV (such as the accumulated rainfall in 24 hours and maximum 24 hours rainfall per specific time period) has been carried out, however, due to the shortage of data all the equations will be reassessed on a regular basis. Table 5 and Figure 6 show how to obtain ENTR per event.

Rain Event (Jan 07/08 -1998)			
Raingage station	**weight**	**mm/24 hours**	**mm/24 hours X weight**
01 - Vidigal	3,0	117,3	351,9
02 - Urca	1,0	74,4	74,4
03 - São Conrado	4,0	120,4	481,6
04 - Tijuca	4,0	233,8	935,2
05 - Santa Tereza	4,0	165,9	663,6
06 - Copacabana	2,0	110,3	220,6
07 - Grajaú	4,0	177,2	708,8
08 - Ilha do Governador	4,0	145,7	582,8
09 - Penha	4,0	64,2	256,8
10 - Madureira	4,0	138,5	554
11 - Irajá	2,0	78,1	156,2
12 - Bangu	2,0	66,0	132
13 - Piedade	3,0	140,9	422,7
14 - Tanque	3,0	163,4	490,2
15 - Saúde	3,0	135,1	405,3
16 - Jardim Botânico	2,0	163,9	327,8
17 - Itanhangá	2,0	185,3	370,6
18 - Cidade de Deus	3,0	156,7	470,1
19 - Riocentro	1,0	204,8	204,8
20 - Guaratiba	1,0	91,6	91,6
21 - Gericinó	1,0	51,5	51,5
22 - Santa Cruz	1,0	64,2	64,2
23 - Cachambi	1,0	146,9	146,9
24 - Anchieta	3,0	76,2	228,6
25 - Grota Funda	1,0	229,8	229,8
26 - Campo Grande	1,0	69,1	69,1
27 - Sepetiba	1,0	47,9	47,9
28 - Sumaré I	3,0	177,9	533,7
29 - Mendanha	1,0	73,1	73,1
30 - Itauna (Barra)	1,0	97,1	97,1
Weighted Average Rainfall			**134,9**

Table 5 - Determination of the weighted average rainfall in 24 hours, for a specific rain event.

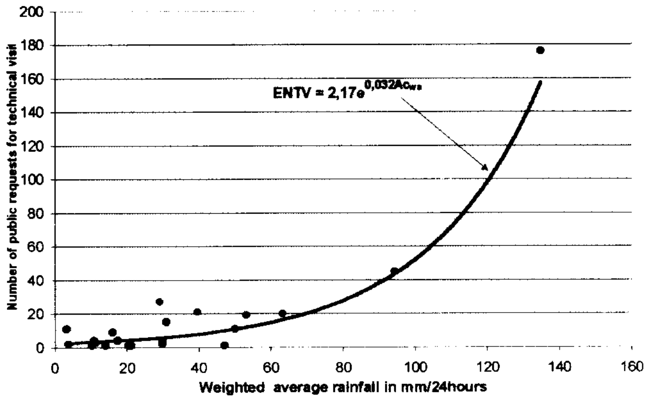

Figure 6 - Expected Number of Technical Reports as a function of the weighted average rainfall in 24 hours of rain events.

Conclusions

The access to uninterrupted rainfall data acquisition, provided by the 30 raingage stations network at every 15 minutes and to all public technical report related to mass movement in the City of Rio de Janeiro, bring up entirely new perspectives in the local rainfall and mass movement correlation analysis. From the better understanding of their frequency and distribution to the precise definition of the critical rainfall rate for each mass movement typology, new detailed studies become feasible.

The sharp precision and high raingage density require the development of new methodology and the establishment of new criteria and concepts. Nevertheless, like every other methodology, the continuos reassessments and adjustments (as time brings new data) are of utmost importance for its consolidation, and because of the rainfall data nature, the necessary time can take several years.

Although specifically developed to Rio de Janeiro's conditions, the authors believe that the same kind of analysis can be carry out in others cities, as long as high raingage density network is installed and that there are some fairly organized and updated mass movement recording.

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