Back analysis debris-flow event in mountain areas with numerical simulation: an application on the coast of São Paulo State, Brazil

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1. Introduction

Debris flows are mass movements that develop along drainage networks and involve generally dense fluids, composed of materials of different grain sizes, as well as woods and variable amounts of water, identified as natural processes that constitute the dynamics and the modeling of the landscape. The most susceptible areas to the occurrence of these processes in Brazil are in the foothills of the Serra do Mar, Serra da Mantiqueira, and the Serra Geral, and on the north coast of São Paulo State. On 03/18/1967 there was an important landslide and debris flows that affected the region of Caraguatatuba and São Sebastião. In this area, a pipeline network is associated with Petrobras Treatment Units, other enterprises, structures, and a large urban area in growth. This work aims to show the results of the back-analysis of the debris-flow events that occurred in 1967 in a mountain area in the Serra do Mar in Caraguatatuba region (São Paulo State, Brazil) with RAMMS numerical simulation, using calibrated input parameters.

2. Study area

The study area includes the Santo Antônio and Guaxinduba catchments (Figure 1), and it is in the Serra do Mar mountain range, which is an escarpment area on the eastern margin of the Brazilian highlands; this area is known to be the most landslide- and debris flow-prone location in Brazil due to the local hot and humid climate and the long slopes (Cruz, 1990; Corrêa et al., 2021; Cabral et al., 2023).

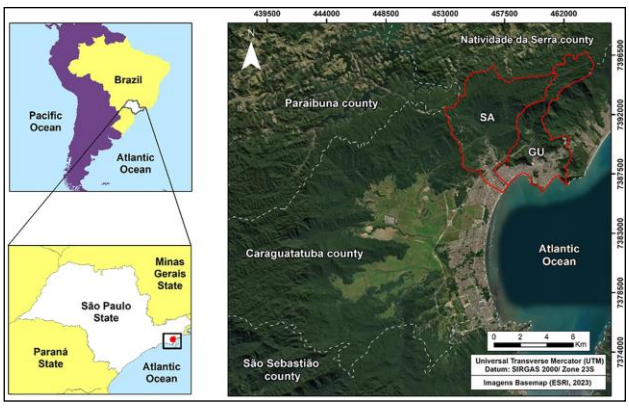

Figure 1. Map of the study area location.

2.1 The 03.18.1967 event

The occurrence of the 1967 event in Caraguatatuba is related to the incidence of high rainfall rates that affected the region in March of the same year. On the day of the event, 585 mm accumulated in 48 hours (Cruz, 1990). Landslides began on the morning of March 18th and were gradually occurring until the afternoon, in a generalized and simultaneous manner, particularly on slopes steeper than 22º (Cruz, 1990). So, the material mobilized by the generalized landslides converged almost simultaneously to the main hydrological network of the mountainous region and channelized (Figure 2).

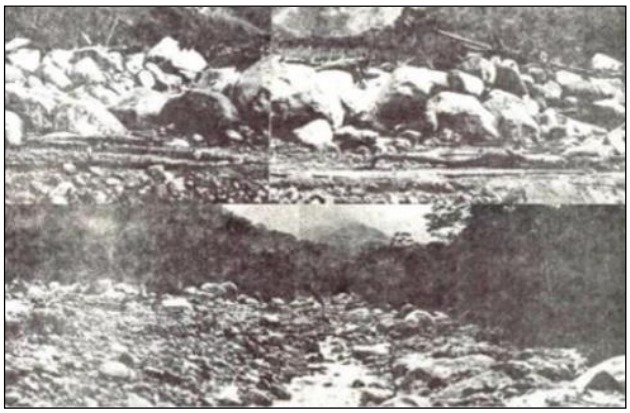

Figure 2. Blocks mobilized during the process, near the landslides, in the tributary channels, and in the middle section of the main river of the Santo Antônio basin (Cruz, 1990).

3. Materials and methods

3.1 Back-analysis studies of the 03/18/1967 debris flows

The back-analysis studies included the historical retrieval of the variables involved in the debris-flow processes in March 1967, the extraction of the landslide scars, and the mapping of the deposits and their respective thicknesses.

3.2 The RAMMS model

The numerical rapid mass movement simulation (RAMMS) model simulates debris flow as a single phase, not distinguishing between fluid and solid phases. The transported material is modeled as a bulk flow, and its rheology is ruled by the Voellmy relation (Mcardell et al., 2007).

3.3 Debris-flow modeling

Before numerical modeling in RAMMS, the program input parameters were listed and modified according to the model's needs. Thus, the topographic data from the DEM was converted to ASCII format. Moreover, the calculation domain and the release area were transformed to the shapefile format, and the release height was inserted in the program/ imported of the shapefile attribute table of the release areas. The modeling step in the RAMMS version 1.5 program was performed with a

simulation routine, based on different release heights, material density, and viscosity (ξ).

4. Results and Discussion

Before the modeling in the RAMMS program, the input parameters were adjusted according to its requirements (Table 1).

Input	Source	Numerical parameter
Topographic data	DEM (1:10,000 scale)	Grid of 8 meters
Release area	Landslide scars from aerial photos (1973)	----------
Release height	Back analysis and fieldwork observations	1.0, 1.3 and 1.5 meters
Calculation domain	Santo Antônio and Guaxinduba catchments	----------
Erosion information	Back analysis	5 meters
Debris-flow duration	Back analysis	45 minutes (2.700 seconds)
Material density	Back analysis	1,700; 1,800; 1,900 and 2,000 kg/m^3
μ (dry Coulomb-type friction coefficient)	Back analysis	0.05
$\mathcal{E}$ (viscous–turbulent friction coefficient)	Back analysis	190 and 200 m/s^2

Table 1. Input parameter, data source, and numerical parameter required in the RAMMS model.

The simulations of the different scenarios showed that the materials mobilized by the landslides in the escarpments of the tributaries of the Santo Antônio and Guaxinduba rivers were channeled in the thalwegs and advanced downstream, where slopes lower than 5º prevail (Figure 3 and 4). The debris-flow fan could not be represented by the simulations due to the Digital Elevation Model used (1979). The limitation of DEM is that there are no older topographical bases for the place, since the first aerophotogrammetric surveys in the region date back to 1974 and correspond to the 1:50,000 scale.

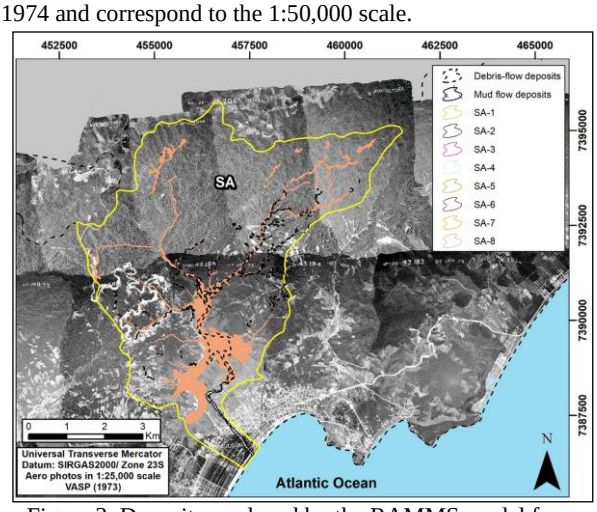

Figure 3. Deposits produced by the RAMMS model from a release height of 1.0 meter vs. deposits mapped on 1973 aerial photographs.

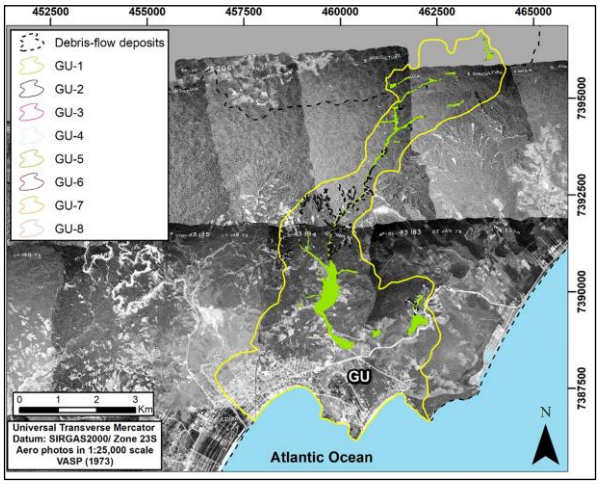

Figure 4. Deposits produced by the RAMMS model from release height of 1.0 meter vs. deposits mapped on 1973 aerial photographs.

5. Conclusions

The debris-flow processes that occurred in the Caraguatatuba region on 03/18/1967 were induced by widespread landslides on the slopes of the Serra do Mar, which, upon reaching the drainage channels, generated hyperconcentrated flows of a strictly granular nature with a large volume of mobilized material. Results of the retro-analysis and modeling showed that the areas of deposition of the debris-flow process to the place are preferably in regions of low slope (<5º).

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