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Field and laboratory study on the deposition features of a debris flow

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ABSTRACT: The main features of a real debris flow can be inferred from field investigations and laboratory tests. The study takes into account data collected at the Acquabona debris flow catchment (Dolomites, Italy), where a debris flow monitoring system has been installed since 1997. Experimental tests of the deposition process have been carried out by means of a small flume, using mixtures of the natural debris flow material coming from the Acquabona catchment with different water contents. Through a comparison between the main deposition features as resulting from the laboratory tests and those of a debris flow deposit at field scale, this work implies the possibility to predict the main deposition angle which is an important parameter in debris flow counter measures designing, particularly of deposition basins.

1 INTRODUCTION

Debris flows are dangerous phenomena and often cause great damage and kill people worldwide. Several different kinds of structural and non structural countermeasures have been considered and set up in many places with very different conceptual ways of reducing the potential hazard associated with debris flow events. The design criteria of these countermeasures are far from being standardized and vary widely, even for structures based on a similar concept.

One of the most used countermeasures is to trap the debris flow material in a debris basin before it can damage a sensitive area; often the design of these kinds of basins does not take into account the rheological properties of the flowing material with the result that the project basin capacity could be insufficient to contain a debris flow, even if its total volume is lower than the basin capacity, if for its calculation a deposition angle higher than the real one has been considered. To overcome such dangerous mistakes simple design tools and criteria should be derived from measurements of the main deposition characteristics (runout, deposition angle) and then provided to the people (local authorities, forest services, etc.) in charge of providing debris flow countermeasures.

Several authors have set up many different laboratory flume apparatuses in order to simulate debris flows (Iverson et al. 2000). Some of these simulate the whole debris flow process, from initiation to deposition, but generally they are specifically made to study part of the process, the initiation, the flow, the deposition or other features, like impact forces on structures (Davies 1994, Scotton & Deganutti 1997). These flumes have been used both with natural and artificial materials.

Given the mechanical complexity of the interactions acting in debris flows, the problem of scale for the physical simulation of these phenomena is arduous; a number of dimensionless scaling parameters have been proposed (Iverson & LaHusen 1993, Davies 1994, Iverson 1997) and used to design laboratory flumes.

This paper presents a series of tests simulating the deposition process of a debris flow. They have been carried out in a laboratory flume, using natural debris flow material, sampled at Acquabona. The apparatus has been used for measuring the runout and deposition angle of coarse mixtures with different water content. The results have then been compared with field data on debris flow deposition at Acquabona.

2 THE FIELD STUDY SITE

In 1997 a debris flow monitoring system was installed along the Acquabona torrent (Dolomites, Italy) (Genevois et al. 2000) where events occur every year (Fig. 1).

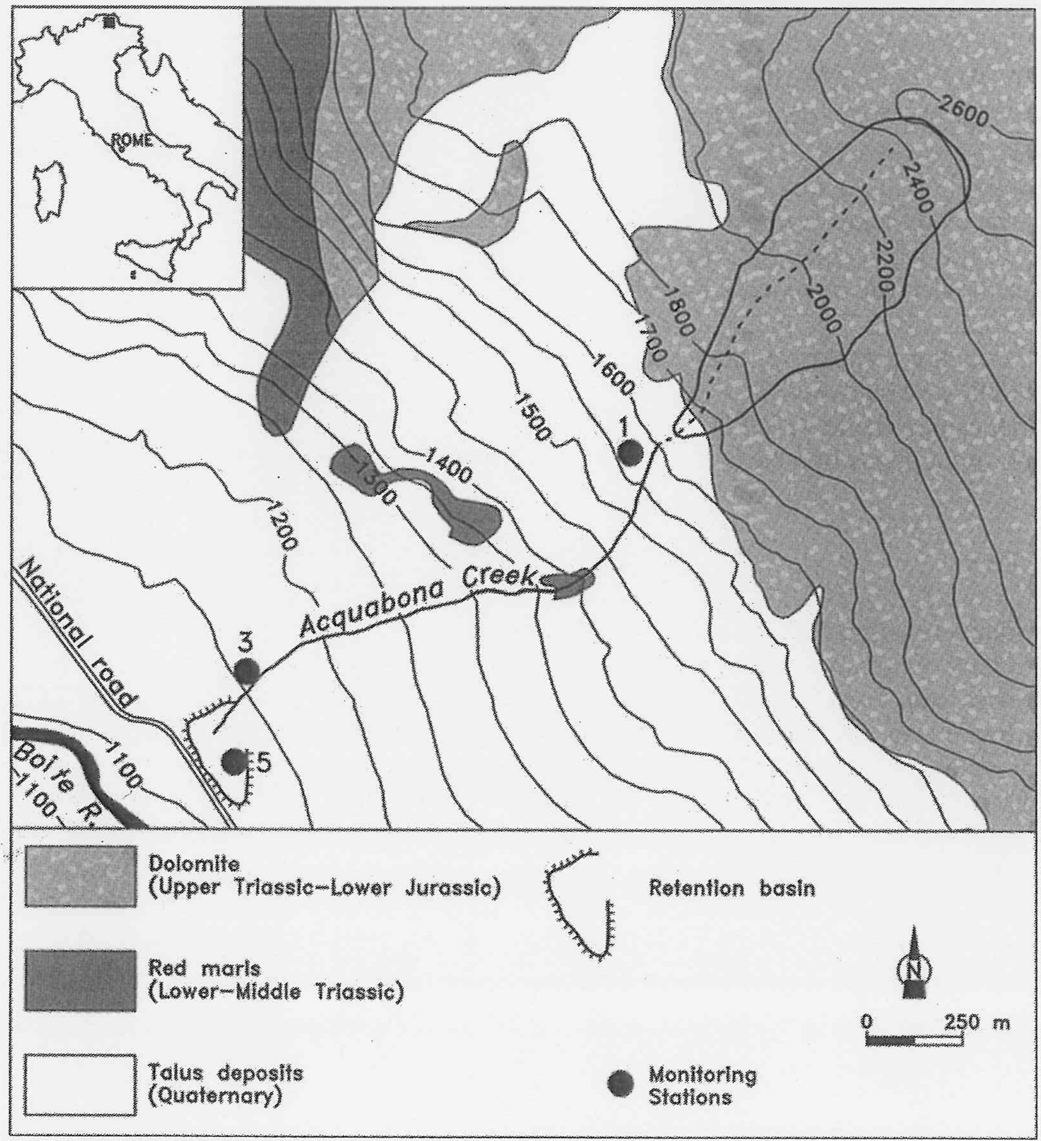

Figure 1. Acquabona catchment: geological sketch and location of monitoring stations.

The channel is deeply incised in scree and the flows convey coarse, poorly sorted sediment, ranging in size from silt to boulders of over 3 m in diameter.

Several times over the last years, debris flows hit a national road that crosses the main channel in its lower part, causing traffic interruptions and damage. In order to contain the debris discharged by the flows and to protect the important road, a deposition basin was built. This basin has a maximum width of 110 m and minimum width of 70 m, and its slope is 4° to 5°; the artificial embankment, made of the same material as transported by the debris flows, is about 4 m high and has a lowering in its distal part that works as a threshold outlet.

The Acquabona monitoring system is devoted to specific research purposes, mainly aimed at the knowledge of the meteorological and hydrogeological conditions leading to the debris flow initiation, of the rheological behaviour of the flowing mass and of the depositional process.

The monitoring system consists of three on-site measuring stations (Fig. 1) equipped with gauges and sensors for measuring rainfall, pore pressures in the channel bed and deposition basin, as well as in the talus at the initiation zone, flow depth, ground vibrations induced by debris flow, total normal stress and pore-fluid pressure at the base of the flowing mass. The monitoring station n. 5 has been installed in the debris basin, in order to study the deposition process. After every debris flow event a topographic survey is carried out along the lower part of the channel and on the deposition basin.

3 MATERIAL INVOLVED IN ACQUABONA DEBRIS FLOWS

The Acquabona debris flows consist mainly of poorly sorted gravely sand that transports angular dolomite boulders in excess of 2 m in diameter.

Grain-size analyses were completed on the fraction finer than 20 mm for 7 samples collected in the deposition area (Fig. 2).

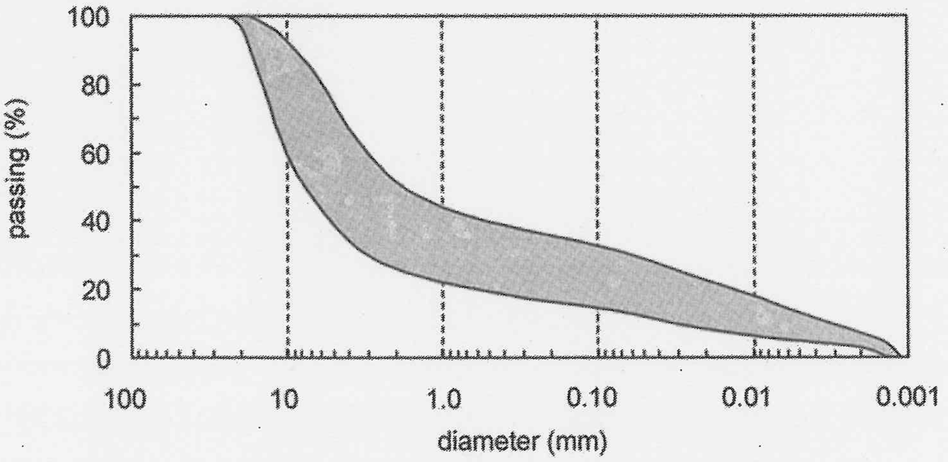

Figure 2. Grain size distribution of debris flow material (< 20 mm diameter).

Specific gravity of solid debris is 2.67, and bulk density is 1750 kg/m^3, particle size distributions display values of the average grain size of about 2.5-3.0 mm; the fines content is up to about 30 %, while the fraction coarser than 20 mm, obtained by field measurements, ranges from 22 to 28 % by weight. However, at the fronts and tops of deposits the coarsest fraction increases up to 75 % by weight, demonstrating the action of segregation processes (Suwa 1988).

Videos recorded in the lower channel during a debris flow, show that, within the same event, significant changes both in solid concentration and flow stage might occur, causing a different rheological behaviour, which ranges from a Newton-like to a viscoplastic fluid (Genevois et al. 2001, Pierson 1986).

Generally, when the debris flows reach the deposition basin, they form a flat lobe-shaped deposit (Fig. 3), with a nearly constant slope in the direction of the maximum runout. During the deposition phase muddy water drains from the terminal lobe through a rough spillway in the distal basin bank; sometimes debris overflows the spillway clogging the pipe (diameter is 1.8 m) that passes under the national road, spreading on the route below and reaching the Boite River about 50 m downstream, over a distance of 180 m.

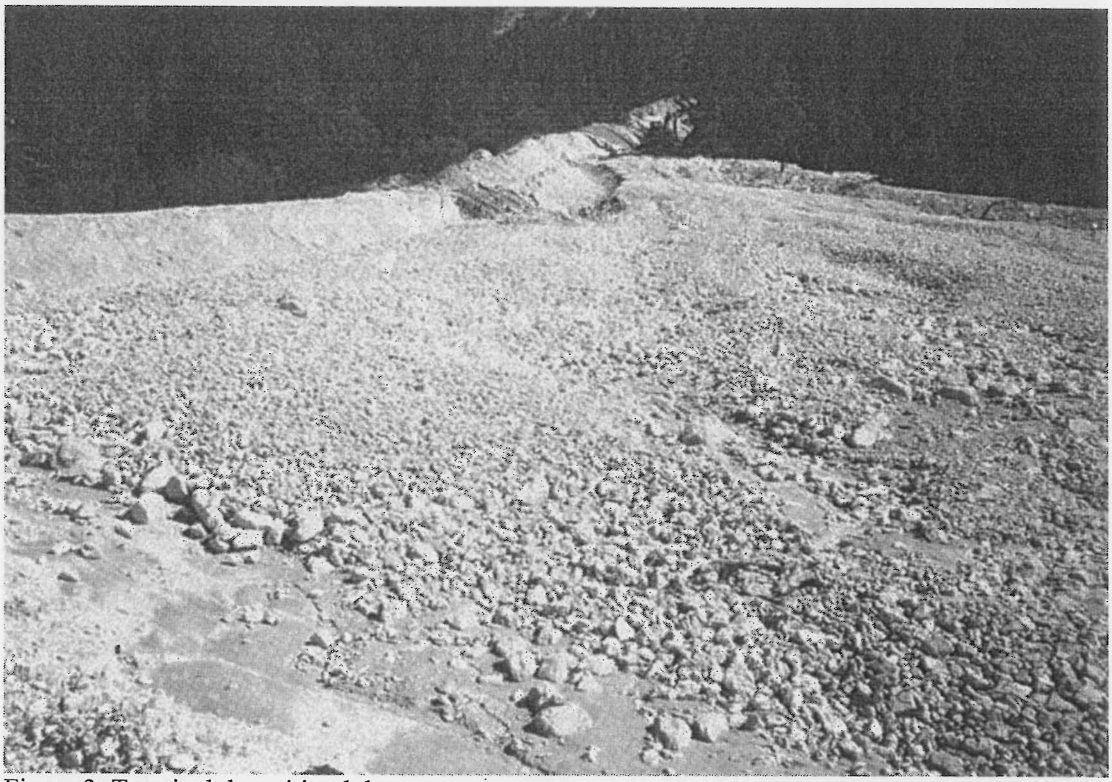

Figure 3. Terminal deposition lobe.

After the debris flow event of June 30, 2001, in order to measure accurately the deposit features, a topographic survey by means of a computer based 3D-Laser Scanner Cyrax 2440 has been carried out, getting the 3D deposit surface by means of a 7 cm cell mesh (figure 4).

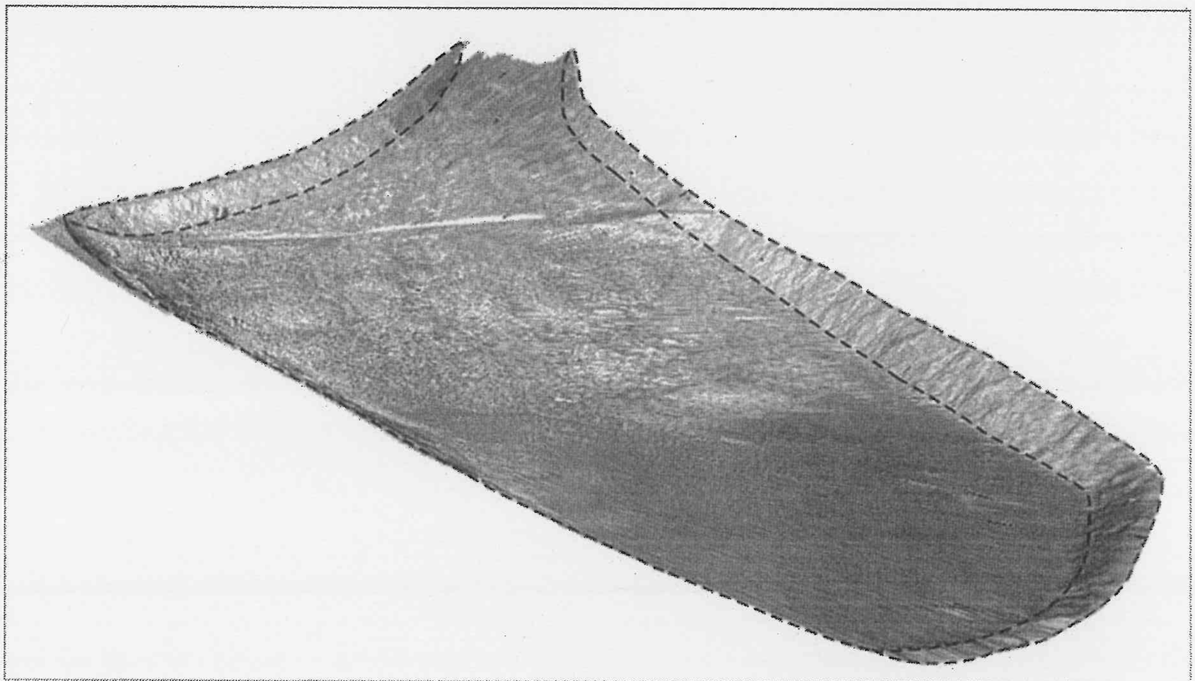

Figure 4. 3-D Laser Scanner survey restitution of the deposition basin after the June 30, 2001 event.

A number of longitudinal sections have been drawn along the terminal deposits from the monitoring station n. 3 up to the embankment (Fig. 5).

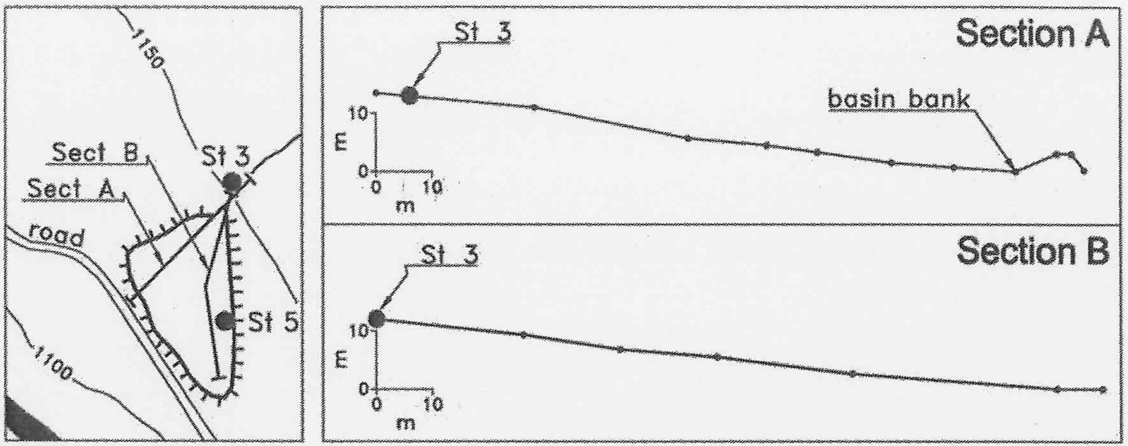

Figure 5. Longitudinal sections through the deposition basin after June 30, 2001 debris flow event.

From this survey it is possible to observe that the deposit is quite regular with a general flat shape with small lobe features; so it is possible to measure a deposition angle, in the direction of the maximum runout, of 7° to 8°.

Some preliminary tests have been carried out to evaluate the shear strength of the material; the friction angle has been measured through both tilting table tests in a completely loose state, and shear tests (triaxial and direct shear) (Genevois et al. 1999). The results obtained with the tilting table show, in dry conditions, quite high values of the friction angle j, ranging from 54° to 56°. The observation of the tests indicates that the increase of the shear strength could be the result of the presence of an apparent cohesion, due to the presence of silt and clay acting as a weak cementation; since there is a high clay and silt fraction the effect of grain interlocking is considered much less important.

Triaxial (consolidated undrained, with pore water pressure measurement) and direct shear tests, carried out on reconstructed saturated samples, show, in fact, lower peak friction angle values (from 38° to 42°), with cohesion values close to zero. In dry conditions, the results are similar (j = 37° to 41°), but with not negligible values of the cohesion (c' = 2 to 4 kPa).

4 LABORATORY TESTS

Since our goal was to perform some simple tests useful for debris flow countermeasures designing, a simple laboratory apparatus has been built (Fig. 6).

It is constituted by a 2 x 1.5 m tilting plane with an adjustable slope from 0 to 38° on which a 30 cm wide flume has been installed. A fixed horizontal plane, where the material deposits, has been joined to the lower flume end; a steel tank with a removable gate is fixed at the upper flume end.

The natural Acquabona debris flow material finer than 20 mm, sampled in the deposition area, has been used for the tests. To simulate the natural basal friction, a steel grid (with 2 cm square cells) has been put on the flume bed as well as on the horizontal deposition surface; a layer of debris material has been spread, it is trapped by the grid, so forming a “natural” friction surface.

The tests were performed by putting the dry material in the steel tank then the flume was tilted up the desired slope; the water was mixed with the material in the tank and the gate was quickly removed from the tank.

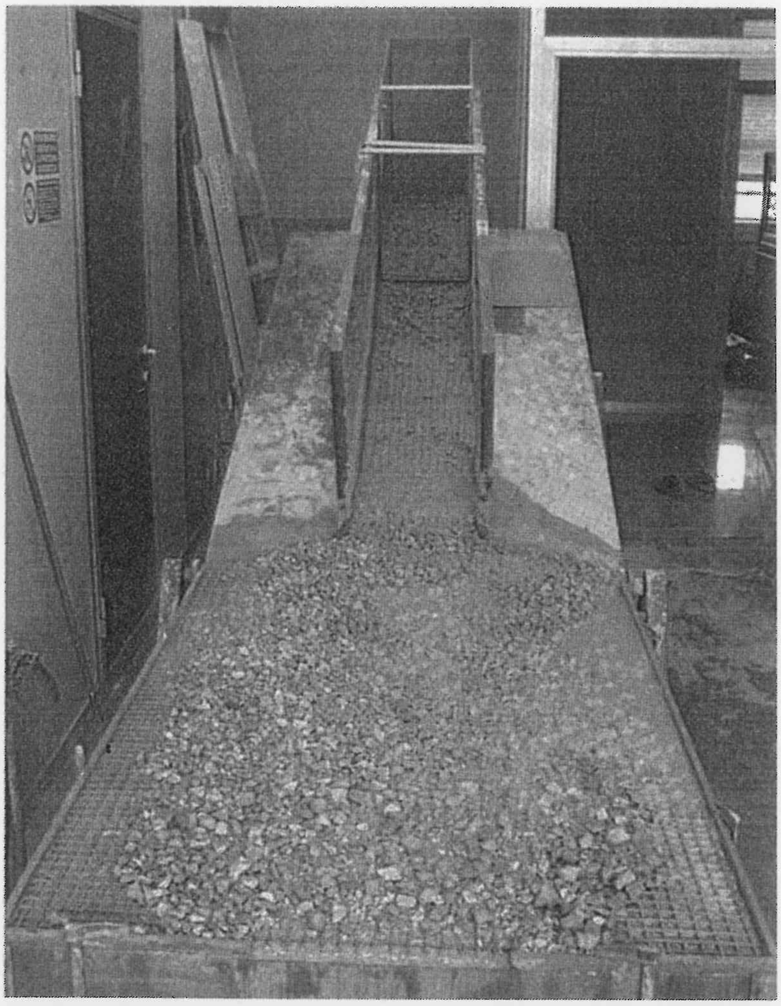

Fig. 6. Laboratory flume. The photo show the deposit formed on the runout surface at the base.

The tests were conducted with a solid concentration of 50 %, 60 %, 63 %, and 70 % by volume, and flume gradients of 10°, 15° and 20°; Table 1 reports the characteristics of the performed tests with the runout and the average angle of deposition in the direction of the maximum runout.

Table 1. Parameters and measured data for experimental tests.

Test	Flume slope (°)	C_v (%)	Average deposit angle (°)	Runout (cm)
7	10	50	4.3	70
1	15	50	5.0	130
2	15	50	4.0	130
3	15	60	9.1	90
4	15	60	8.4	80
16	15	63	4.9	80
9	20	50	3.1	150
10	20	60	6.1	110
12	20	50	5.4	150
13	20	60	5.7	130
15	20	70	22.2	50

5 RESULTS AND DISCUSSION

The results obtained with the presented laboratory apparatus show that the deposits shapes are very sensitive to the flume slope and the solid concentration of the mixture.

Example of the longitudinal profiles obtained along the centre line of the deposition, are shown in Figure 7.

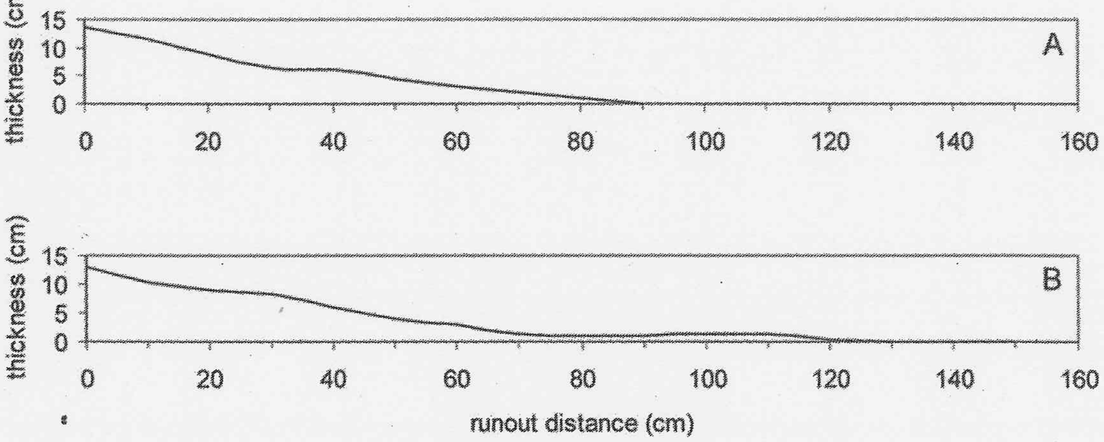

Figure 7. Longitudinal sections of obtained deposits for tilting plane slopes of 15° (A) and 20° (B) respectively, obtained for solid concentration of 60 % by volume.

Some of the test was repeated in the same conditions (flume slope and concentration) and a fair to good reproducibility has been found, as regards the maximum runout and the average deposition angle. The average coefficient of variation for the deposition angle was 11.4 %, while it was 3.6 % with regard to the maximum runout.

In general, lower solid concentrations result anyway in higher mobility and, so, in longer runout (Chau et al. 2000), as can be observed from the diagram runout distance versus solid concentration by volume (Fig. 8b). The average angle of deposition increases with the solid concentration from 3° to 9° (Fig. 8a), but there is not an apparent significant difference as regards the flume slopes of 15° and 20°; this angle seems to depend much more on the characteristic strength of the material than the slope of the flume. At the present stage of the research it is possible to relate these results to the field for one case only (event of June 30, 2001).

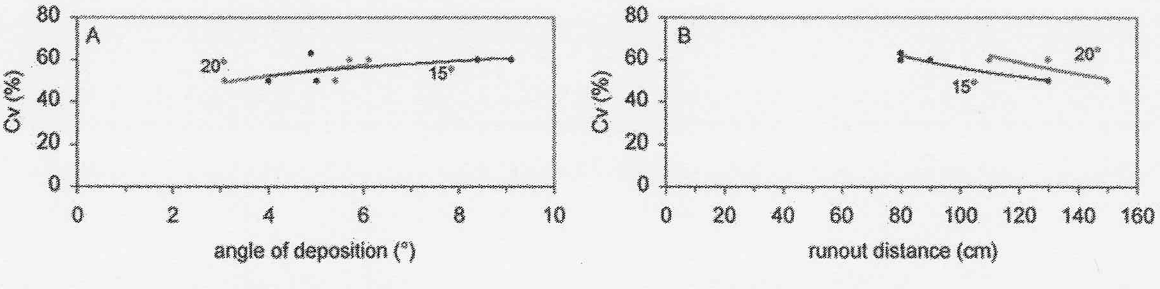

Figure 8. Volumetric solid concentration (*Cv*) versus angle of deposition (A) and runout distance (B) with flume slope of 15° and 20°.

For the geometry of the deposit formed after this event, it is possible to observe that its shape is comparable to that of the deposits obtained in laboratory with a solid concentration of 60 %; the field average deposition angle of 7.3° is equal to the average deposition angle measured in the laboratory tests conducted with $Cv = 60$ %; being the deposition angle dimensionless it is assumed that it is not affected by scaling from laboratory to field. Presently there are no data available about the solid concentration of the flowing debris flow material at Acquabona, but the monitoring station 5 has been recently equipped with a load cell buried under the debris basin floor, its pressure data, together with stage data will give some information about the material density and concentration.

With regard to the field maximum runout the comparison between small-scale experiments and field deposits is less easy, involving scaling investigation; for the June 30, 2001 event (the only field datum on deposit runout presently available) there is a flume to field factor of about 115 (90 cm to 104 m).

With a slope of 10° only a test with a solid concentration of 50 % formed a deposit on the horizontal plane, while with higher solid concentrations the material stopped directly in the flume.

In some tests we noticed a tendency of the clay and silt fraction to form a small lobe over the wider and coarser fan. The same feature is not generally observed in the field at Acquabona: Even if boulders and blocks are found in the frontal part of the deposition lobes (the finer material being behind), the fine fraction result to be always well mixed with the water in the debris flow matrix. The aspect, observed in laboratory experiments, comes probably from a not complete mixing of the material and the water in the feeding tank.

6 CONCLUSIONS

In the paper we reported the results of a series of laboratory experiments with a small flume, carried out with the aim to reproduce the natural debris flows deposition process, and particularly to investigate the dependence of flow runout distances and of deposition angles on the solid concentration and on the driving slope.

The angle of deposition is a function of only the solid concentration; a concentration of 60 % and a flume slope of 20° give the closest value of the average deposition angle to that observed in the deposition basin of Acquabona (7.3° for June 30, 2001 event).

The lower the concentration the lower the slope needed to fully develop a debris flow; for the tested material a maximum solid concentration of 50 % can result in a debris flow on a flume slope of 10°.

The observed segregation tendency between fine and coarse material can be probably overcome with a more accurate mixing of the initial mixture of the material with water, for instance using a small concrete mixer.

As a general conclusion, obtained results show that simple deposition tests, carried out with small flumes or tilting tables, can be useful to get a characteristic and sufficiently reliable deposition angle in confined and unconfined conditions (debris basins, open fan), that is a key parameter in debris flow countermeasures designing.

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