Landslides (2004) 1:83–90
DOI 10.1007/s10346-003-0005-x
Received: 9 September 2003
Accepted: 24 November 2003
Published online: 3 March 2004

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Assessing debris flow hazards associated with slow moving landslides: methodology and numerical analyses

Abstract Clayey slow-moving landslides are characterized by their capability to suddenly change behaviour and release debris-flows. Due to their sediment volume and their high mobility, they are far more dangerous than those resulting from continuous erosive processes and associated potential high hazard magnitude on alluvial fans. A case of transformation from earthflow to debris-flow is presented. An approach combining geomorphology, geotechnics, rheology and numerical analysis is adopted. Results show a very good agreement between the yield stress values measured by laboratory tests, in the field according to the morphology of the levees, and by back-analyses using the debris-flow modelling code, *Bing*. The runout distances and the deposit thickness in the depositional area are also well reproduced. This allows proposing debris-flow risk scenarios. Results show that clayey earthflows can transform under 5-years return period rainfall conditions into 1 km runout debris-flows of volumes ranging between 2,000 to 5,000 m^3.

Keywords Slow-moving landslide · Debris-flow · Runout modelling · Rheology · French South Alps

Introduction

Large landslides are often characterized by a complex style of activity. This is particularly true for clayey flow-like landslides which can translate from a typical structural slide to a slow moving earthflow (0.01 to 0.40 m.day^{-1}) which itself can transform into a cohesive debris-flow, characterized by high velocities (1 m.s^{-1} to 15 m.s^{-1}) and runout distances of several hundred of meters.

An unclear point is that not all earthflows produce debris-flows (Iverson et al. 1997; Ancey 2002). In most cases, an earthflow experiences a significant creep behaviour (Picarelli 2001), then decelerates and finally stops flowing after achieving a new hydro-mechanical equilibrium. However, in a limited number of cases the earthflow accelerates suddenly and gives rise to a debris-flow. In recent years many situations have occurred in Europe, often as a result of the increase in soil moisture, following long rainy events or a combination of rapid melting and thawing of the frozen soil. Typical examples include La Valette in France (Colas and Locat 1993), Vallcebre in Spain (Corominas and Moreno 1988), Alverà in the Italian Dolomites (Gasparetto et al. 1996), or some earthflows in the Basento valley (Southern Italy, Pellegrino et al. 2000). In the black marl of the French Alps, also called "Terres Noires", three large earthflows (Poche, Super-Sauze and La Valette) have initiated mudflows or debris-flows in recent years (LeMignon and Cojean 2002), with volumes ranging from 5,000 m^3 to over 60,000 m^3 at La Valette in 1988 (van Beek and van Asch 1996).

In this paper, two debris-flow case histories of the complex Super-Sauze earthflow, representative of black marl landslides, are presented and their runout is modelled. It is important to notice that at this date, only small volumes were released (from 5,000 to 10,000 m^3) from the Super-Sauze earthflow (750,000 m^3). Nevertheless, morphological evidences and numerical simulations suggest that the release of larger volumes is a realistic option, under specific climatic and hydrogeological circumstances. The main objectives are to:

1. assess the rheological properties of the material in the debris source area for various total solid fraction;
2. model the runout of these debris-flows, assuming a Herschel-Bulkley flow type, and to calibrate the model on the observed events; and
3. simulate hazard scenarios to identify the volumes of sediment and water necessary to reach the alluvial fan.

The Super-Sauze landslide and its debris-flow events

Geomorphological features of the Super-Sauze earthflow

The Super-Sauze earthflow (Alpes-de-Haute-Provence, France) has developed in a gullied basin that is located in the upper part of the catchment basin of the Sauze torrent, a tributary of the Ubaye River in the Barcelonnette basin (Flageollet et al. 1999; Malet et al. 2002a; Maquaire et al. 2003) (Fig. 1a). The torrent covers a surface of 4.8 km^2 for a length of 5.8 km, and extends between 2,685 and 1,140 m in elevation. The Super-Sauze earthflow is located in the headwater basin between 2,105 m (crown) and 1,740 m (toe of the flow) for an average slope of 25° (Fig. 1b).

Geotechnical investigations and geophysical prospecting (Flageollet et al. 2000) indicate that the earthflow is structured in two superposed layers (units). The upper unit, 5 to 10 m thick, is a very active and wet viscous formation, whereas the second, with a maximum thickness of 10 m, is a stiff, compact, impervious, stable formation. The total volume is estimated as 750,000 m^3 and velocities lie in the range from 0.01 to 0.40 m.day^{-1}. Sudden groundwater table rises facilitate accelerations of the flow (Malet et al. 2002a). The upper unit can under specific circumstances trigger rapid flow-like phenomena, such as in May 1999 where two debris-flows and a dozen small mudflows occurred.

The debris-flow events of May 1999

On May 5th, 1999, a volume of material (*DF1*) failed suddenly from the ablation zone, flowed rapidly on the hillslope and reached the eastern torrent flanking the earthflow (Fig. 1b, area $DF1_d$). The peak velocity, calculated by the forced vortex equation (Johnson and Rodine 1984) on five cross-sections (Fig. 1b) reached velocities, from upstream to downstream, of 3.8 m.s^{-1}, 4.9 m.s^{-1}, 5.1 m.s^{-1}, 4.7 m.s^{-1} and 4.1 m.s^{-1}. During the night of May 12–13th, 1999, a second larger volume of material failed (*DF2*) in the same area of *DF1*. The material flowed along the same path and chan-

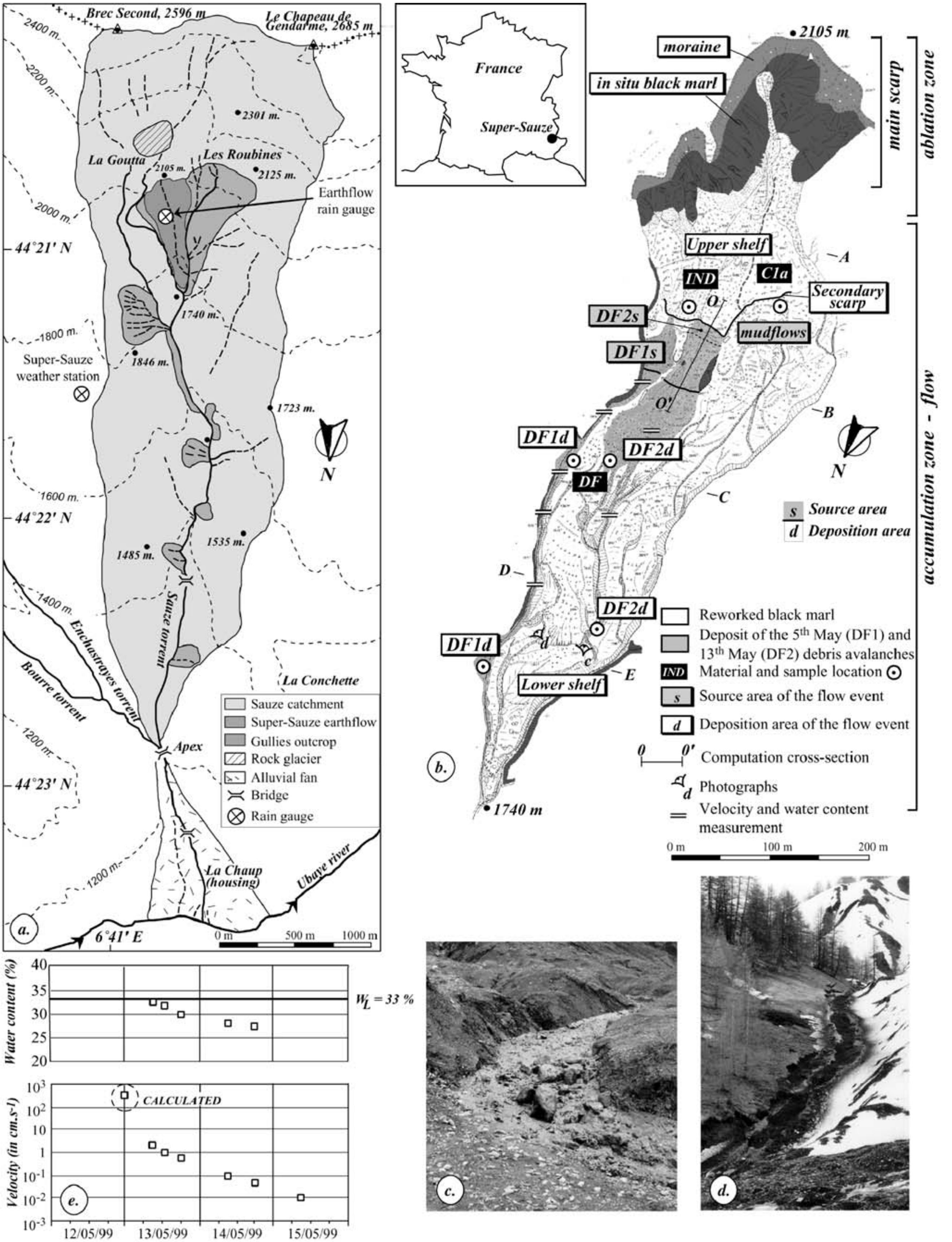

Fig. 1 Morphological map of the Sauze catchment (**a**) and of the Super-Sauze earthflow (**b**). Photographs of the debris-flows DF2 (**c**) and DF1 (**d**). Variation of water content (average value over a depth of 0.80 m) and velocity with time for DF2 event (**e**)

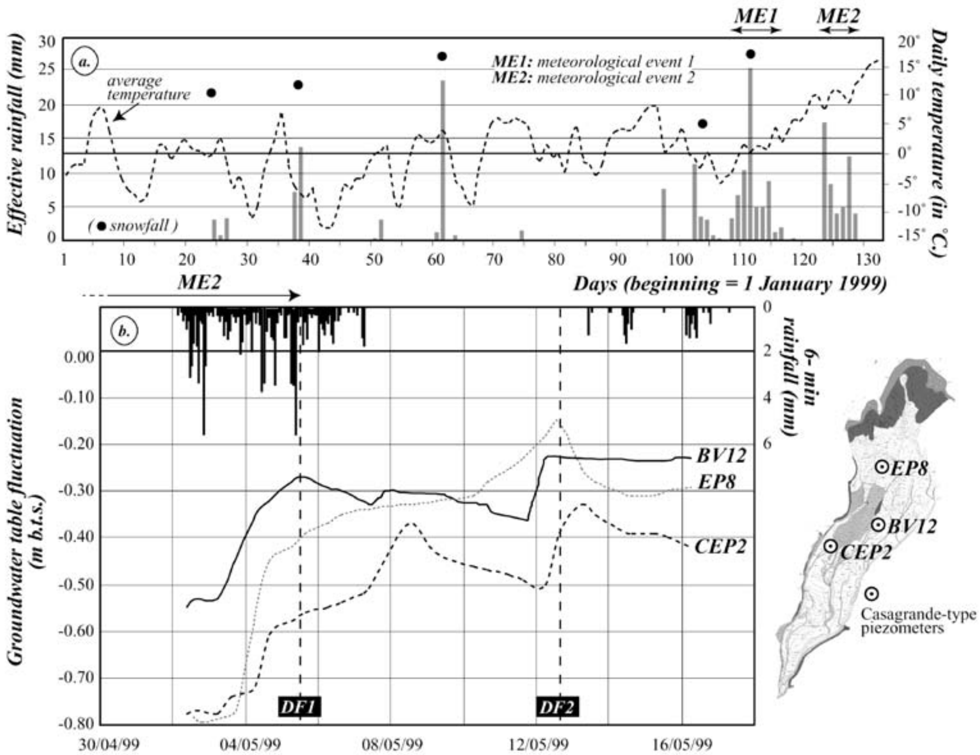

Fig. 2 Hydrogeological conditions leading to the debris avalanche events. Effective daily rainfall and temperature at 1,900 m a.s.l. over the period 01/01/1999 to 13/05/1999 (**a**). Rainfall and groundwater table fluctuations at the onset of the debris avalanches (**b**)

nelized in the main gully of the earthflow. The peak velocity (Fig. 1b, area *DF2* $_d$) reached 3 m.s^{-1} upstream, and 2.8 m.s^{-1} downstream. In both cases, deposits are mainly heterometric levees or small accumulation lobes. Moraine boulders (long axis up to 0.80 m) were only transported by *DF2* (Fig. 1c); for *DF1* only coarse elements (0.20 m) were observed (Fig. 1d). Following Hungr et al. (2001), the phenomena can be classified as a debris-flow (Malet et al. 2003).

In both cases, the material continued as a slow continuous flow to spread for 5 days. Velocity and water content (samples were taken at several locations over a depth of 0.80 m) were surveyed for *DF2* (Fig. 1e). The water contents were quite homogeneous over the depth. The decrease in velocity is correlated to the decrease in average water content. The first day, the average water content corresponds to the liquid limit (W_L=33%). After three days the average water content has decreased only by 9%, and remains higher than the average moisture content observed at Super-Sauze (Malet et al. submitted). A detailed mapping of the deposits and the comparison of two DEMs allow estimating the volumes of the events at 2,500 m^3 for *DF1* and 7,700 m^3 for *DF2*. Morphological evidence suggests that the initial movement was of the slump type. After these two events, mudflows of varying size were observed in the western part of the initiation area (Fig. 1b). These mudflows travelled 100 to 250 m on the surface of the earthflow, with slows velocities (0.5 to 1 m.min^{-1}).

If the effective cumulative rainfall on the period 1 January–13 May 1999 (233 mm) corresponds to the average value (194 mm±37 mm) of the period of 1991–2001, the rainfall distribution over the period January–May is very different. The rainfall falling over the period 15 April – 13 May amounted to more than 50% of the cumulated rainfall since the beginning of the year (Fig. 2a). The exceptional character of the hydrological event is related to the combination of rainfall and quick snowmelt associated with a spectacular rise of temperature observed during 18 continuous days (from 2 °C on 25 April to 18 °C on 13 May). Such an increase has never been recorded in the temperature time series, whose records extend for 50 years.

This combination of high rainfall and temperatures thus explains very significant volumetric water contents (26–27%) before failure in the unsaturated zone (from 0 to −0.30 m) of the source area; that is to say 4–5% more than the other years at the same period. Moreover, the progressive snowmelt involved a significant increase of the groundwater level on the uphill cross-sections (A, B, C) where the average level reaches (Fig. 2b) approximately 30 cm below topographic surface. The failure mechanism can be attributed to a sudden pore-water pressures rise; the failed material is nearly completely saturated. This hypothesis is supported by observations of abundant spring activity within the unstable area during the preceding days.

Assuming that large slope failures can occur in the source area, the generation of large debris-flow events have to be studied by the assessment of (1) the mechanical properties of the involved material, (2) the modelling of the runout of the debris along the Sauze torrent.

Methodology

Three steps of analyses were followed (Fig. 3): (1) characterization of the rheological properties of the material, (2) validation of a debris-flow propagation code on observed events, and (3) estimation of runout scenarios for different failed mass. The rheological properties (yield stress, τ_c, and viscosity, κ) were determined by coupling rheometrical tests and inclined-plane tests (Malet et al. 2002b, 2003). The choice of the model is jus-

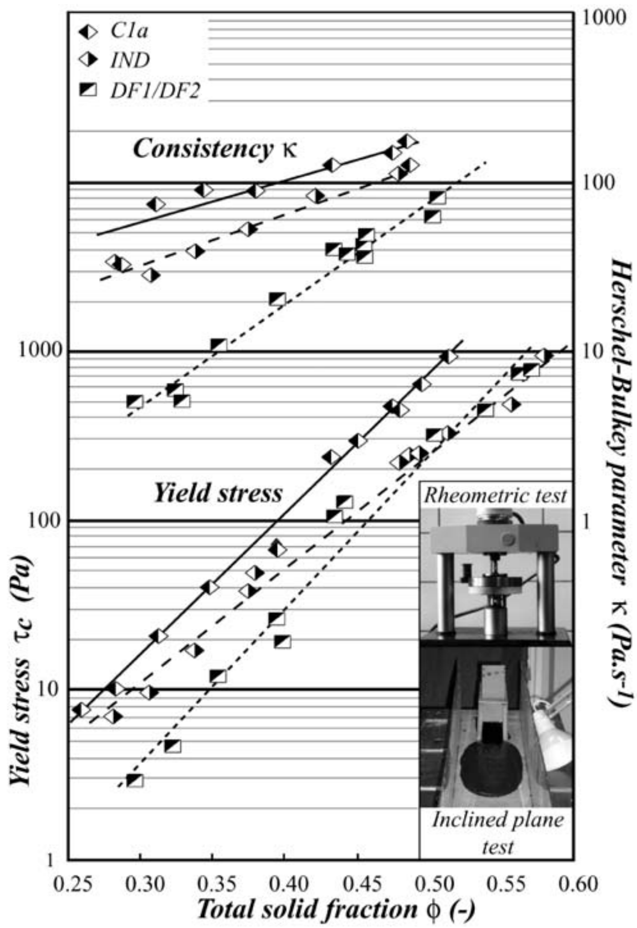

Fig. 3 Variation of the rheological properties (yield stress, τ_c, viscosity, κ) as a function of the total solid fraction ϕ, using the rheometrical tests and the inclined plane tests

tified at section 4 in accordance with the rheological behaviour of the slurry, as well as its description.

Rheology of the earthflow material and the debris flow deposits

Analyses have been carried out on undisturbed samples collected in the initiation area (*IND*), on the western slope area (*C1a*), and in the deposits of *DF1* and *DF2* events (Fig. 1b). A detailed geotechnical analysis can be found in Maquaire et al. (2003) especially to define the grain size distribution of these heterogeneous formations (very fragile marly plates and flakes packed in a fine matrix, and blocks and pebbles) and the brittleness of the marly clasts which required a specific protocol. All matrix samples have a high content of silt and clay (30–40%) and the textural classes range from silty-clay for material *C1a* to silty sand for *IND*.

The grain-size distribution (Table 1) of the two debris flow materials *DF1* and *DF2* cannot be distinguished and are identical to those of the source area (*IND*). Atterberg consistency limits (Table 1) classify the material as inorganic clays with low plasticity (Ip=13–16). The liquid limit is in particular much higher for *C1a* than for *IND*.

Direct-shear strength tests carried out on remoulded samples (fine fraction < 2 mm) indicate a null cohesion and an average friction angle of 28°. *IND* shows a lower friction angle (26–29°) than *C1a* (29–32°). The material of the debris source area exhibits lower strength characteristics than the other part of the earthflow. *C1a* is a very cohesive material, only composed of black marl, whereas *IND* is composed of a mixture of marl and moraine.

Debris rheology is one of the most important parameters of the debris-flow runout models. Numerous studies have demonstrated that the behaviour of the flow is mainly guided by the matrix rather than the blocks or debris carried (Coussot and Meunier 1996), except in the case of dry granular flows (Iverson 1997).

The rheological characterisation was performed through laboratory tests (by parallel-plate rheometry on the < 400-μm fraction and by inclined-plane tests on the < 20-mm fraction). A detailed analysis of the rheological properties can be found in Malet et al. (2002b, 2003).

All the material exhibits a viscoplastic behaviour over the range of shear rates under consideration, and this is well represented by a Herschel-Bulkley constitutive equation (Coussot 1997). Herschel-Bulkley parameters (τ_c, κ) increase with the total solid fraction ϕ. Total solid fraction is the ratio of solid volume to total volume. In practice, the total solid fraction may be determined by weighing a given amount of mixture before and after drying at 105 °C until complete evaporation (Coussot 1997). In our case, total solid fractions ranging from 0.35 to 0.50 correspond to water contents ranging from 70 to 38%.

The yield stress and the pseudo-plastic viscosity varied, respectively, from 3 to 960 Pa, and from 5 to 170 Pa. For total solid fractions between ϕ=0.30 and ϕ=0.60 the yield stress may vary by as much as three times, whereas the pseudo-viscosity varies only by twice as much (Fig. 3). Rheological parameters clearly distinguish the two types of material in the source area; the cohesive silty-clayey matrix (*C1a*) presents high yield stress and viscosity, and the sandy-silty matrix (*IND)*has lower rheological characteristics (Fig. 3). This means that a higher volume of water is necessary to initiate a fluid-behaviour in *C1a* material than in *IND* material.

Model choice and description

Results of grain-size distribution analyses (clay fraction greater than 10% for all material) and rheological tests (shape of the rheometric curves, best-fit parameters with a Herschel bulkey

Table 1 Geotechnical characteristics of the tested material

	Grain-size				Unit weight		Consistency		
Material	Sand	Silt	Clay	Gravel	γ_d	γ_{sat}	W_L	W_P	I_P
C1a	25%	22%	15%	38%	1,760	2,140	32	16	16
IND	31%	29%	10%	30%	1,220	1,790	33	17	16
DF1	37%	21%	8%	34%	1,200	1,700	30	16	14
DF2	32%	25%	10%	33%	1,210	1,680	32	17	15

[a] Unit weight γ_d (dry) and γ_{sat} (saturated) in kg.m^{-3}

[b] Consistency (Atterberg limits): W_L is the liquid limit (%); W_P is the plastic limit (%); I_P is the plasticity index

constitutive equation) suggest the use of propagation models based on a viscoplastic rheology (Bingham or Herschel-Bulkley). Only two numerical models including the Herschel-Bulkley rheology (in simple shear) have been calibrated and validated on laboratory experiments: the *Cemagref 1-D* code developed by Laigle et Coussot (1997) and the *Bing* model developed by Imran et al. (2001). The 1-D flow-dynamics model *Bing*, developed by Imran et al. (2001) for the study of the downslope spreading of finite-source debris-flow, has been chosen for this study. The calibration and validation of the *Cemagref 1-D* model on observed field events is in progress (Malet et al. submitted).

The *Bing* model, developed previously for submarine debris-flows, has been adjusted for subaerial flows by using an ambient fluid density equal to 1 kg.m^{-3}. The layer-integrated conservation equation of mass and momentum balanced are solved in a Lagrangian framework using an explicit finite difference scheme. The flow is assumed to remain laminar throughout the computation. Starting from an initial parabolic shape, the viscoplastic mud is allowed to collapse and propagate on a given rigid impermeable slope. The number of grid cells remains the same throughout the calculation. Each grid node is allowed to move at the local depth-averaged velocity after each time step. As a result, neighbouring nodes can move closer or away from each other.

Mobility analysis

Before predicting the mobility of the debris in the torrent to assess the hazard on the fan, we need to evaluate if the Hershel-Bulkley rheology and the *Bing* code are able to replicate field observations. This has been done by analysing the mobility of a small mudflow initiated in *C1a* material (Fig. 4a, b) and of the debris flow *DF2* initiated in *IND* material. (Fig. 1b, 4b). In both cases, the initial geometry of the debris mass includes the length of the failed mass and the maximum thickness of the initial deposit (Fig. 4c, d). The initial profile of the failed mass is assumed to be parabolic. The channel bed topography is given as input initial condition.

Outputs consist of the front location, the front velocity and the deposit thickness with time. The runout distance and the final deposit depth at stoppage were used to estimate the yield stress and the viscosity of both materials (Fig. 4c, d). As the flow takes place, the initial mass evolves from a parabolic shape into a stretched mass with an average final thickness that is 7 to 8 times less than the average initial value. The *Bing* simulations matched the observed geometry fairly well (error on the shape and the deposit thickness less than 10 cm). Figure 4b compares the results of the simulations with those observed from the deposits. Figure 4e, f shows the runout and deposits thickness as a function of variable yield stress and viscosity from several simulations. The largest runout distances and thinnest deposits are observed at lowest yield stresses. Dynamic viscosity played a minor role in deposit thickness and only affected runout distance at the lowest yield stress, as represented by the large span of runout distances predicted by *Bing*. The best-fit distances and deposit depths are obtained for yield stress and viscosity ranging, respectively, from 290 to 330 Pa and 190 to 230 Pa.s for *C1a* (Fig. 4e), and 170 to 230 Pa and 160 to 185 Pa.s for *IND* (Fig. 4f).

These results verify that the Hershel-Bulkley rheology and the *Bing* code are able to replicate field observations for consistent total solid fractions, and for different movement velocities. The yield stress values and viscosity values estimated by rheometry are lower than those based on field observations, due to both a higher shear rate and experiments carried out on the <400-μm fraction. Finally, if the mobility analysis predicts fairly well the runout distance and the lobe geometry, the velocity of the flow is three orders of magnitude higher than that measured in the field. The computed optimum runout distance is more or less reached after 84 s (more or less 140 min in the field) for the *C1a* mudflow and 2,300 s (more or less 14 min in the field) for the *IND* debris avalanche. This is mainly due to an underestimation of the real viscosity mobilised during shearing, which must be three orders of magnitude greater. Nevertheless, as the model has been calibrated on the runout distances and the deposits thickness, it can be used to define torrential hazard scenarios.

Hazard assessment on the alluvial fan

The evaluation of torrential hazard scenarios on alluvial fans is of primary interest, particularly if the catchment basin is characterised by the presence of large landslides. The relevance of this problem in the Ubaye valley has been demonstrated by the mudflows and debris flows induced by the reactivation of the La Valette earthflow (Colas and Locat 1993). To prepare a hazard zonation of the alluvial fan (in terms of runout distances attained by the debris, and deposit depths), the volumes of debris necessary to reach the apex and/or the confluence of the Ubaye River have been estimated.

Several numerical simulations were performed using (1) the best-fit parameters from the debris avalanche mobility analysis, (2) by changing the volume of released sediment (the volume released at the beginning of the calculation in *Bing* corresponds to a volume of solid debris and water), and (3) the total solid fraction (ϕ=0.35, 0.40, 0.45 and 0.50). The torrent has a length of 3.4 km from the base of the debris source area to the apex, for slopes ranging from 4 to 35°. The distance from the apex to the confluence with the Ubaye River reaches 1.2 km, for an average slope of the fan of 4°. In the first approximation no scouring of the channel and reaches due to the debris-flow was considered.

We adjusted the volume of debris with the assumption that the deposits must be at least 0.50 m thick. Usually, in case of debris flow accumulation, for hazard assessment and mapping (Petrascheck and Kienholz 2003), this thickness corresponds to the minimum value at which the push prompting and damage effect on the exposed structures are effective. Figure 5a shows the results of the parametric analysis. The lower horizontal axis shows the volume of sediment (solid debris+water) that propagated along the channel. The upper horizontal axis corresponds to the volume of solid debris for the different total solid fractions ϕ, assuming a failure of 15-m height and 60-m width in the source area as observed for the *DF1* and *DF2* events. As can be presumed, the runout distance increases with the volume of debris. The same relationship can be found between the total solid fraction and the volume. For total solid fractions consistent with those observed in cohesive debris-flows (Coussot and Meunier 1996), and consistent with those of the Super-Sauze debris avalanches, the volume of debris and water ranges between 30,000 and 50,000 m^3 (Fig. 5a). Figure 5b, c shows the geometry of the simulated events and the thickness of the debris at stoppage. A maximum final deposit thickness of 0.55 and 0.40 m, respectively, are predicted by the model respectively on the apex and at the confluence. The model results allow mapping the location of the front of the debris-flow at stoppage (Fig. 5d).

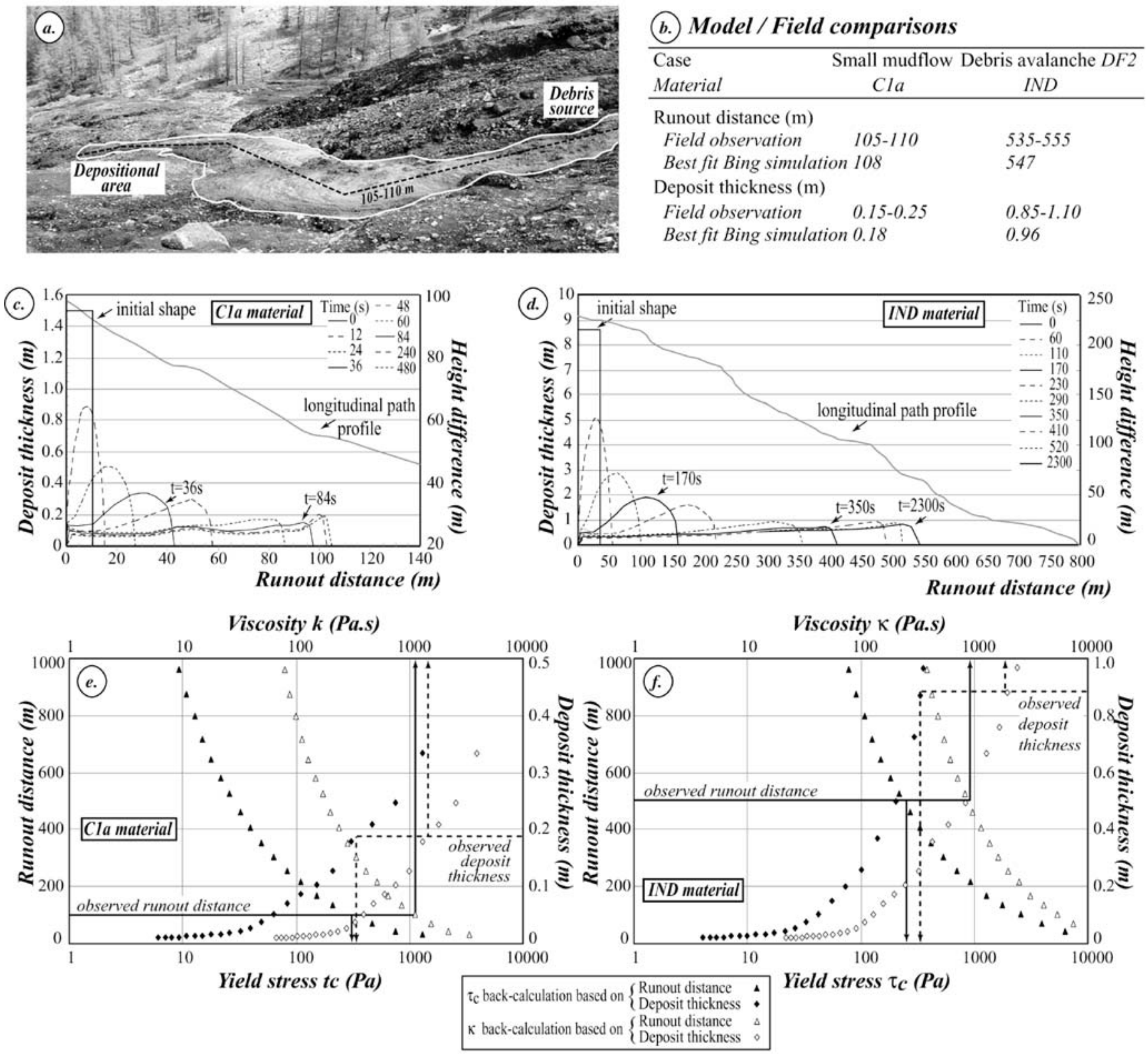

Fig. 4 Mobility back-analysis. Photographs of the C1a mudflow (**a**). Model simulations and field observations (**b**). Evolution of the geometry during propagation and final deposit shape (thickness, runout) for the C1a mudflow (**c**) and the IND debris flow (**d**). Data plots from C1a mudflow (**e**) and IND debris flow (**f**) showing debris runout and thickness as a function of material yield stress and viscosity

Assuming total solid fractions of 0.45, the volume of debris that has to fail in the debris source area ranges between 18,000 and 25,000 m^3. Coupled seepage and stability analyses were carried out to estimate the stability of the earthflow. Conditions in the debris source area are close to failure under natural pore-water pressures and moisture content, and for residual strength (Maquaire et al. 2003). A small excess of water (for instance snowmelt) can therefore initiate failure. Seepage analysis has been used to estimate the volume of debris that can be released for several hydro-climatic conditions. Results of the parametric analyses detailed in Malet et al. (in press) show that hydrogeological conditions able to initiate failures of 18,000 to 25,000 m^3 are attained for a cumulative input of water of 65 mm (over a 3-day-long period), corresponding to a 25-year return period rainfall.

Discussion and conclusion

Large landslides often show their complex nature by sudden changes in behaviour (from sliding to flowing) or in velocities (from less than 0.01 m.day^{-1} to greater than 1 m.s^{-1}). As a consequence, such a phenomenon provides an opportunity to develop a flow-like landslide assessment approach that incorporates failure and post-failure stages. Such methodologies are vital to estimate risk scenarios along a torrent and on an alluvial fan. The Super-Sauze case history outlines significantly the importance of field observations to usefully calibrate the numerical models. The

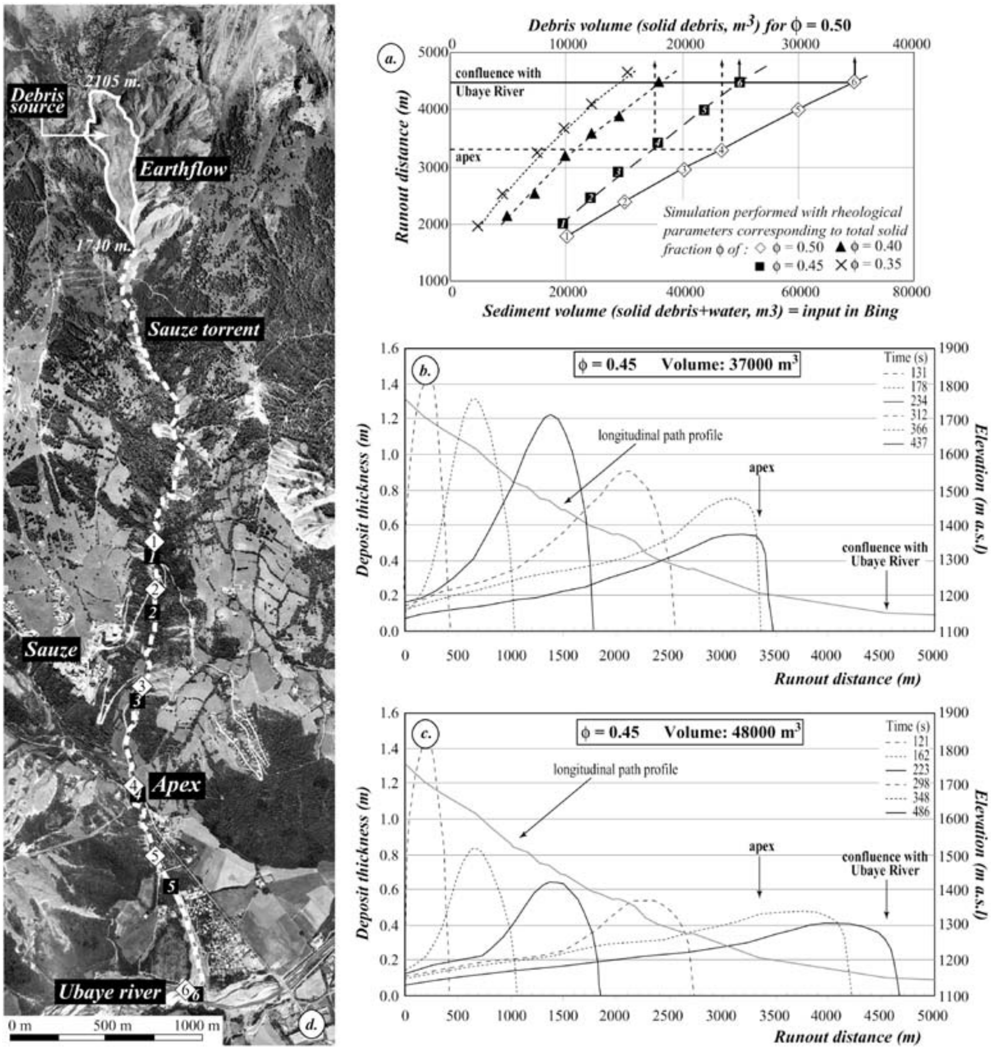

Fig. 5 Hazard assessment for the Sauze alluvial fan. Estimation of the debris volume necessary to reach the apex of the torrent and the Ubaye river confluence for different total solid fraction (**a**). Computed debris-flow geometry to stop at the apex (**b**) and at the Ubaye river confluence (**c**). Location of the front stoppage in the torrent for different simulations (**d**)

proposed methodology allowed the evaluation of realistic risk scenarios for similar instabilities. The study has shown that complex clayey earthflow can transform into 1 km-runout debris-flows (of volumes ranging between 2,000 to 5,000 m^3) under 5-years return period rainfall, and into 4-km runout events (of volumes ranging between 30,000 and 50,000 m^3) under 25-years return period rainfall (Malet et al. in press). Nevertheless major effort should be put in the development of runout models able to take into account channel-bed scouring and two- or three-dimensional spreading models to correctly delineate high, medium and low hazard areas on the alluvial fan.

Acknowledgments

This work was supported by grants from the French Ministry of Research in the ACI-CatNat contract MOTE (MOdélisation, Transformation, Ecoulement des coulées boueuses dans les marnes) and from the Centre National de la Recherche Scientifique under the INSU-PNRN contract ECLAT (Ecoulement, Contribution de LAves Torrentielles dans les basins versants marneux). Contribution INSU N°354. Contribution EOST N° 2003-40-UMR7516.

References

Ancey C (2002) Debris-flows and related phenomena. In: Balmforth N, Provenzale A (eds) Geomorphological fluid mechanics. Springer, Berlin Heidelberg New York

Colas G, Locat J (1993) Glissement et coulée de La Valette dans les Alpes de Haute-Provence. Présentation générale et modélisation de la coulée. Bulletin de Liaison des Laboratoires des Ponts et Chaussées 187:19–28

Corominas J, Moreno M (1988) Mechanism of mudflows: a case study in the Spanish Pyrenees. In: Bonnard C (ed) Proceedings of the 5th International Symposium on Landslides, Balkema, Rotterdam

Coussot P (1997) Mudflow rheology and dynamics. Balkema, Rotterdam

Coussot P, Meunier M (1996) Recognition, classification and mechanical description of debris-flow. Earth Sci Rev 40:209–227

Flageollet JC, Malet JP, Maquaire O (2000) The 3-D structure of the Super-Sauze earthflow: a first stage towards modelling its behaviour. Phys Chem Earth 25(9):785–791

Flageollet JC, Maquaire O, Martin B, Weber D (1999) Landslides and climatic conditions in the Barcelonnette and Vars basins (Southern French Alps, France), Geomorphology 30:65–78

Gasparetto P, Mosselman M, van Asch TWJ (1996) The mobility of the Alvera landslide (Cortina d'Ampezzo, Italy), Geomorphology 15:327–335

Hungr O, Evans SG, Bovis MJ, Hutchinson JN (2001) A review of the classification of landslides of the flow type. Environ Eng Geosci 7:221–238

Imran J, Harff P, Parker G (2001) A numerical model of submarine debris-flow with graphical user interface. Comput Geosci 27:717–729

Iverson RM (1997) Hydraulic modeling of unsteady debris-flow surges with solid-fluid interactions. In: Chen CL (ed) Proceedings of the 1st International Conference on Debris-Flow Hazards Mitigation. Am Soc Civil Eng, New York

Iverson RM, Reid ME, LaHusen RG (1997) Debris-flow mobilization from landslides. Ann Rev Earth Planet Sci 25:85–138
Johnson AM, Rodine JR (1984) Debris-flow. In: Brunsden D, Prior DB (eds) Slope instability, Wiley, Chichester
Laigle D, Coussot P (1997) Numerical modeling of mudflows. J Hydraul Eng 123(7):617–623
Le Mignon G, Cojean R (2002) Rôle de l'eau dans la mobilisation de glissement-coulées (Barcelonnette, France). In: Rybar J, Stemberk J, Wagner P (eds) Proceedings of the 1st European Conference on Landslides, Swets & Zeitlinger, Lisse
Malet JP, Locat J, Remaître A, Maquaire O (2004) Triggering conditions of debris-flows associated to complex earthflows. Geomorphology (in press)
Malet JP, Maquaire O, Calais E (2002a) The use of Global Positioning System for the continuous monitoring of landslides. Application to the Super-Sauze earthflow (Alpes-de-Haute-Provence, France). Geomorphology 43:33–54
Malet JP, Remaître A, Ancey C, Locat J, Meunier M, Maquaire O (2002b) Caractérisation rhéologique des coulées de débris et laves torrentielles du bassin marneux de Barcelonnette. Premiers résultats. Rhéologie 1:17–25
Malet JP, Remaître A, Maquaire O, Ancey C, Locat J (2003) Flow susceptibility of heterogeneous marly formations. Implications for torrent hazard control in the Barcelonnette basin (Alpes-de-Haute-Provence, France). In: Rickenmann D, Chen CL (eds) Proceedings of the 3rd International Conference on Debris-Flow Hazards Mitigation, Millpress, Rotterdam
Malet JP, van Asch TWJ, van Beek R, Maquaire O (submitted) Dynamic hydrological modelling of a fast moving complex landslide in the French Alps. Hydrol Proc 18 pp
Maquaire O, Malet JP, Remaître A, Locat J, Klotz S, Guillon J (2003) Instability conditions of marly hillslopes, towards landsliding or gullying? The case of the Barcelonnette basin, South East France. Eng Geol 70(1–2):109–130
Pellegrino A, Ramondini M, Russo C, Urciuoli G (2000) Kinematic features of earthflows in Southern Italy. In: Bromhead E, Dixon N, Ibsen ML (eds) Proceedings of the 8th International Symposium on Landslides. T. Telford, London
Petrascheck A, Kienholz H (2003) Hazard assessment and mapping of mountain risks in Switzerland. In: Rickenmann D, Chen CL (eds) Proceedings of the 3rd International Conference on Debris-Flow Hazards Mitigation. Millpress, Rotterdam
Picarelli L (2001) Transition from slide to earthflow and the reverse. In: Proceedings of Conference on transition from slide to flow—mechanisms and remedial measures, Karadeniz Technical University, Trabzon, 25–26 August 2001
Malet JP, Remaître A, Laigle D, Locat J, Maquaire O (submitted) Cross-calibration of two debris-flow runout models on clay-shale catchments of Southeast France. In: Lacerda W (ed) Proceedings of the 9th International Symposium on Landslides, Balkema, Rotterdam 6 pp
van Beek LPH, van Asch TWJ (1996) The mobility characteristics of the La Valette landslide. In: Senneset K (ed) Proceedings of the 7th International Symposium on Landslides, Balkema, Rotterdam

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