The Case of Ischia Underwater Debris Avalanche (Italy, Tyrrhenian Sea) and Its High Mobility

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Abstract

Ischia volcanic island is one of the few cases in the Mediterranean where a clear relationship between constructional volcanism, volcano-tectonic uplift and cyclic multi-scale gravity failures is evident. One of these collapses involved the island's southern flank and led to the emplacement of a submarine debris avalanche spreading over an area of 150 km^2 with an estimated volume of 1.5 km^3. C^{14} stratigraphy suggests that it may have occurred during pre-historical times or even during the Greek colonisation of the island (around 7th century BC). This very large mass movement i.e. the "Ischia debris avalanche" is still apparent on the seafloor with a mega-blocks field detectable until 40 km from the island along the lower continental slope. Its high mobility is proved by the very low H/L ratio when compared to other submarine debris avalanches. Here we report the preliminary results of a back-analysis in which we modeled a land-sea collapse based on some simplified assumptions. The implemented code used in this study assumes a fluid-solid mixture with given rheological behaviors and was already used for simulate the mobility of some terrestrial debris flows in volcanic areas.

Keywords

Ischia volcano • Debris avalanche • Back-analysis

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43.1 Introduction

Ischia island is located to the west of the Bay of Naples (Fig. 43.1) and is considered an active volcano based on the wide range of magma-related phenomena like shallow seismicity, ground uplift/subsidence and diffuse hydrothermal vents all suggesting the occurrence of a magmatic reservoir at relatively shallow depths.

Volcanic activity dates back to 150 ky and mostly consisted of medium-scale explosive eruptions with emplacement of pyroclastic deposits and lava domes (Gillot et al. 1982). A major ignimbritic eruption occurred 55 ka with the emplacement of the Mount Epomeo Green Tuff deposit and possibly caldera formation. The latest volcanic event occurred in historical times (AD 1302) as a small lava flow emplaced in the island's eastern sector. A peculiarity of this volcano is the great extent of volcano-tectonic and co-seismic uplift of Mt. Epomeo, the central relief of the island, presently

Fig. 43.1 Digital Terrain model of the Naples bay and dispersal axis of Ischia Debris Avalanche (*dashed line*)
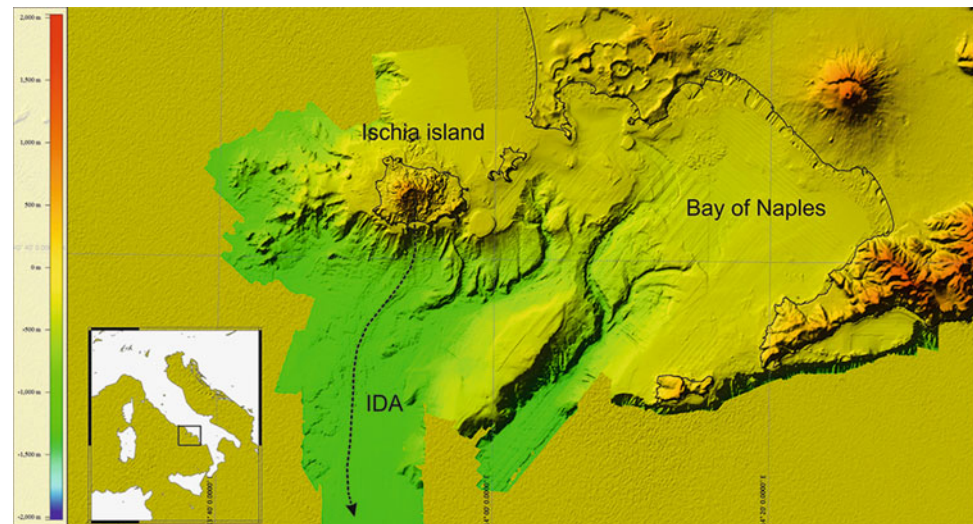
attaining 785 m asl. Geological data indicate that this block has risen at least 800 m in the past 30 ky at an average rate of 20 mmy^{-1} but likely higher over shorter time spans. A clear correlation exists between uplift and gravity failures as confirmed by the abundance of subaerial landslides over Mt. Epomeo slopes also favoured by the strong hydrothermal weathering. These mass movements include debris slides, debris flows, mud flows and rock falls with volumes in the order of 10^3 m^3.

Marine geophysical surveys all over the island's offshore recently revealed larger mass movements with volume in the order of 10^9 m^3 radiating out from Mt. Epomeo and entering the sea. Over the western and northern continental shelves two debris field with an estimated volume of 0.2–0.5 km^3 show typical features of debris avalanches although their dating and emplacement mechanism are still matter of study (de Alteriis and Violante 2009).

To date the Ischia debris avalanche (Chiocci and de Alteriis 2006), IDA hereafter, occurring along the island's southern flank, is the best known despite its greater depth also due to extensive coring and radiometric datings (de Alteriis et al. 2010). Consequently the litho-stratigraphy of the deposit and its timing are quite well constrained while little is known about its dynamics as for the almost totality of submarine mass movements. A first attempt of modeling the IDA event was made by Tinti et al. (2011) with the main purpose of simulate the propagation of tsunami waves in the Bay of Naples.

In this paper, taking in consideration the IDA runout, we attempt a numerical simulation based on shallow flow equation in analogy with terrestrial high mobility debris flows (Scotto di Santolo and Evangelista 2009) and neglecting, in first approximation, the role of sea water column.

43.2   IDA Morphological Analysis

The entire IDA area can be divided into: (A) a source or failure upper section; (B) a depositional and transit section with relatively low aspect ratio and peculiar hummocky topography; (C) a deeper depositional section with relatively flat topography and less pronounced hummocks. These features are similar although not identical to many other submarine analogues (see Locat et al. 2004).

Direct sampling along the main dispersal axis has shown the occurrence of a very etherogeneous and ethero-metric assemblage of debris, ranging from gravel to boulder embedded in a relatively stiff, clayey-sandy matrix between the toe of slope at 9 km and about 23 km from source. This prevailing matrix area raises 10–15 m above the surrounding seafloor as a low aspect ratio elongated ridge and corresponds to the (B) depositional section. The latter evolves distally and laterally towards (C): a few metres thick, mud supported debris flow including mostly finer, gravel-size debris.

Blocks occur along (B) and (C) sections and have size from metric to tens of metres with several ones attaining a size of 150 m and raising 35 m above seafloor. They are extremely abundant in the (B) matrix section while are generally not embedded into the (C) debris flow.

Presently the sub-aerial slope is 20–12° steep; this slope can be considered only partly representative of the original failure plane due to intense post-collapse erosion. The underwater slope varies from 30–10° downslope according a typical concave profile. These values can be considered as quite representative of the original failure profile apart from modification due to a post-avalanche depositional marine terrace fed by intense erosion along Mt. Epomeo (Fig. 43.3).

Fig. 43.2 Plan view of IDA dispersal area. The main source and depositional sections are outlined. Labels indicate coring sites. *Dashed line* is the section along the dispersal axis in Fig. 43.3
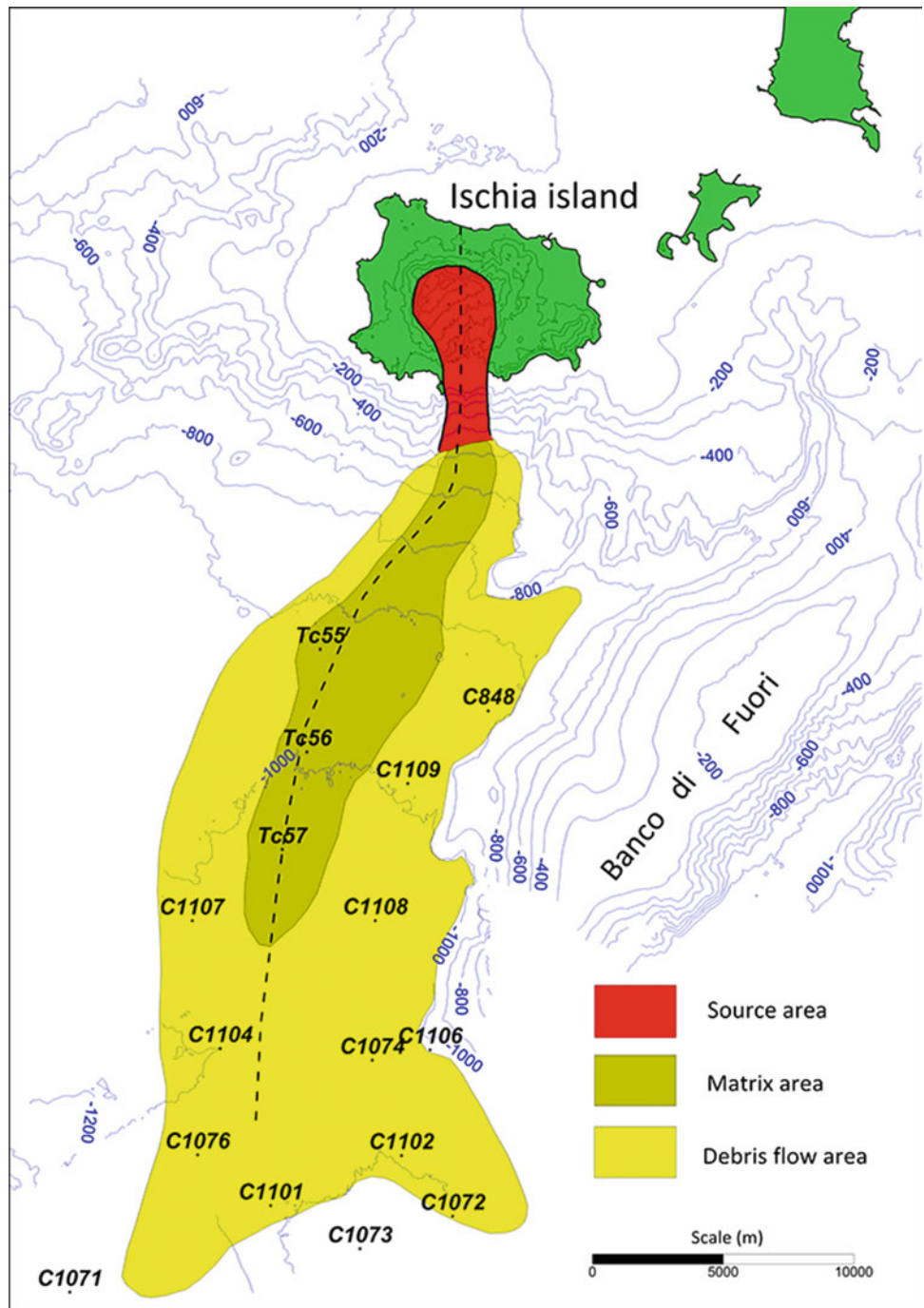

Fig. 43.3 Pre collapse profile reconstruction along IDA main dispersal axis. The *orange area* is the missing volume while *blue area* is the whole deposit including matrix and debris flow
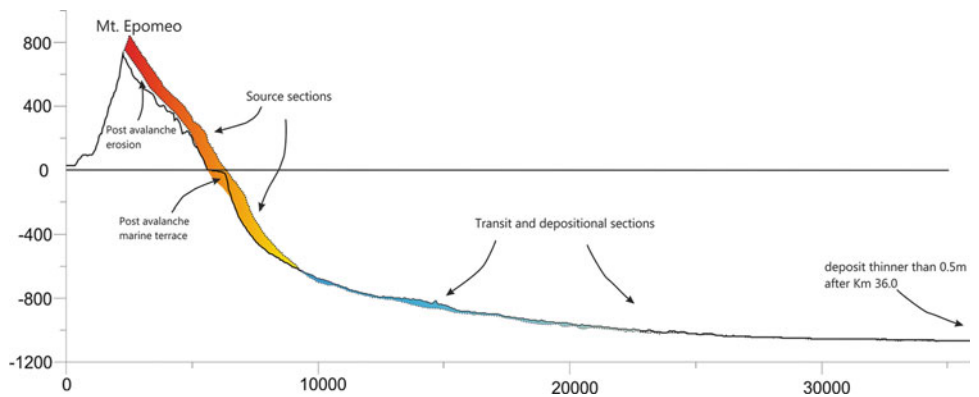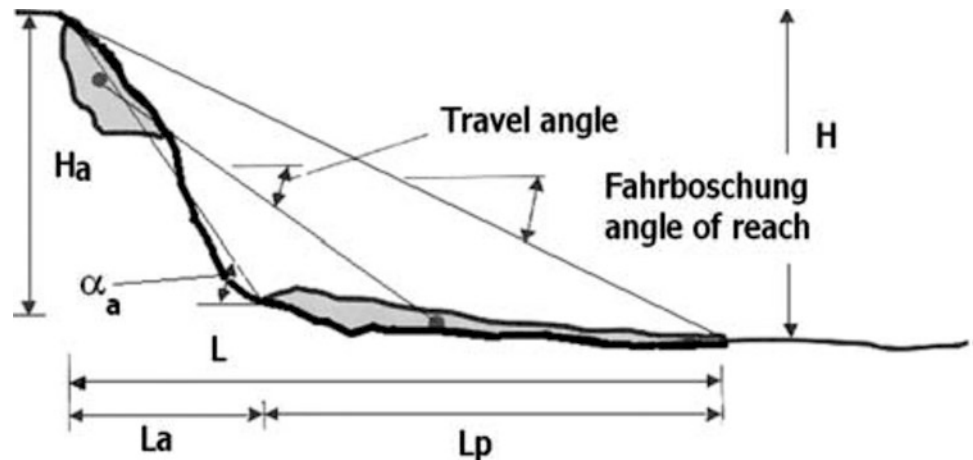
Fig. 43.4 Analysis of the motion: empirical approach (from Scotto di Santolo and Evangelista 2009)

The start of the depositional (and transit) (B) and (C) sections can be set between the toe of upper slope at 600 m down to 1,100 m as far as 40 km from Mt. Epomeo summit here defined as the zero reference point. The IDA deposit spreads over an area of 150 km^2 and is proved until at least 36 km based on the available core stratigraphy (Fig. 43.2). This runout distance increases of 5–6 km when considering the farthest, loose blocks (outliers) detected through multibeam bathymetry or side-scan-sonar records.

43.3 Main Assumptions and Numerical Analysis

In our collapse scenario the summit of Mt. Epomeo, once higher than present, was truncated by the failure plane itself that involved also the underwater upper slope down to 600 m depth. The collapsed material consisted primarily of Mt. Epomeo Green Tuff i.e. a trachytic ignimbrite as the dominant lithotype and secondarily of softer pyroclastic and vulcano-clastic deposits. We firstly assume that this relatively coherent rock assemblage rapidly disintegrated and was channelised towards the south whilst a minor amount might be directed to north. After interaction with sea-water the collapsed mass transformed into a debris avalanche and distally into a debris flow i.e. a flowing solid-liquid mixture with different degrees of interactions between the solid and the liquid fraction. A second necessary, although limiting, assumption is that its behavior can be treated in analogy to terrestrial debris flows of known rheology (Scotto di Santolo et al. 2011). Although core sampling results indicate that the deposit is significantly mixed with hemipelagic sediments suggesting that seabed was likely involved during IDA emplacement we have not considered a changing mass in the model.

IDA landslide was therefore analysed using the DAN-W program i.e. Dynamic Analysis of landslides (Hungr 1995) which can be applied to a wide range of rheological

Table 43.1 Main geometrical parameters used for numerical simulation

Slope angle of failure, αa	12°
Travel angle between source and deposit centres of mass	4°
Maximum runout, L	33700 m
Extent of the deposit section Lp	26700 m
Mean and maximum deposit thickness (locally constrained by core stratigraphy or inferred by seismic data)	5 and 30 m
Difference between the highest source section and the toe of landslide, H	1900 m
Inferred volume of the failed mass (or trigger volume)	1.5–3.0 Km^3

behaviors. Among these the most suitable for solid-liquid mixtures i.e. debris flow-debris avalanche types are the frictional, Voellmy and Bingham described by Eqs. (43.1), (43.2) and (43.3) respectively.

$$\tau = \gamma H_i \left(\cos \alpha_i + \frac{a_c}{g} \right) \cdot (1 - r_u) \tan \varphi \qquad (43.1)$$

$$\tau = \gamma H_i \left(\cos \alpha_i + \frac{a_c}{g} \right) \cdot \mu + \gamma \frac{v^2}{\xi} \qquad (43.2)$$

$$\tau = \tau c + \mu \cdot v \qquad (43.3)$$

In (43.1) and (43.2) γ is the unit weight of the flowing material; $a_c = v_i^2/R$ is the centrifugal acceleration resulting from the vertical curvature of the flow path R; r_u is the pore-pressure coefficient (ratio of pore pressure to total normal stress at base of boundary block); φ is the friction angle; μ is a friction coefficient and ξ is a turbulence coefficient with dimensions of [m/s^2]. In (43.3) τ_c is the constant yield strength and μ is the Bingham viscosity. The sliding mass is divided into a number of discrete blocks that interact each other while sliding according to different relationship (Hungr 1995).

Fig. 43.5 Initial and final profile; Voellmy model ($\mu = 0.03$ and $\xi = 2000$ m/s^2). *Dashed line* is the present day profile. *Red line* is the modeled pre-collapse section, *blue line* the post-collapse depositional section
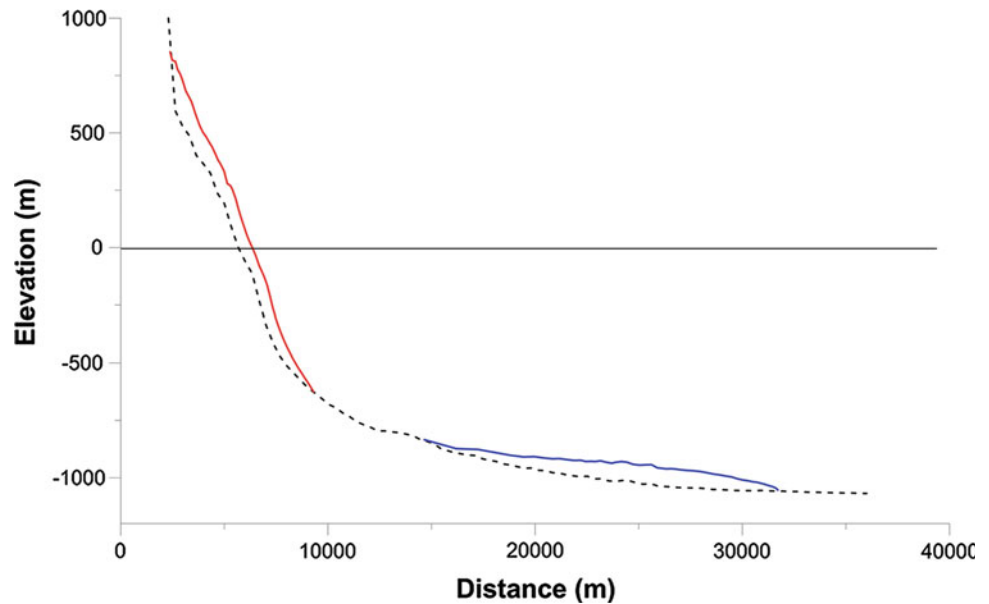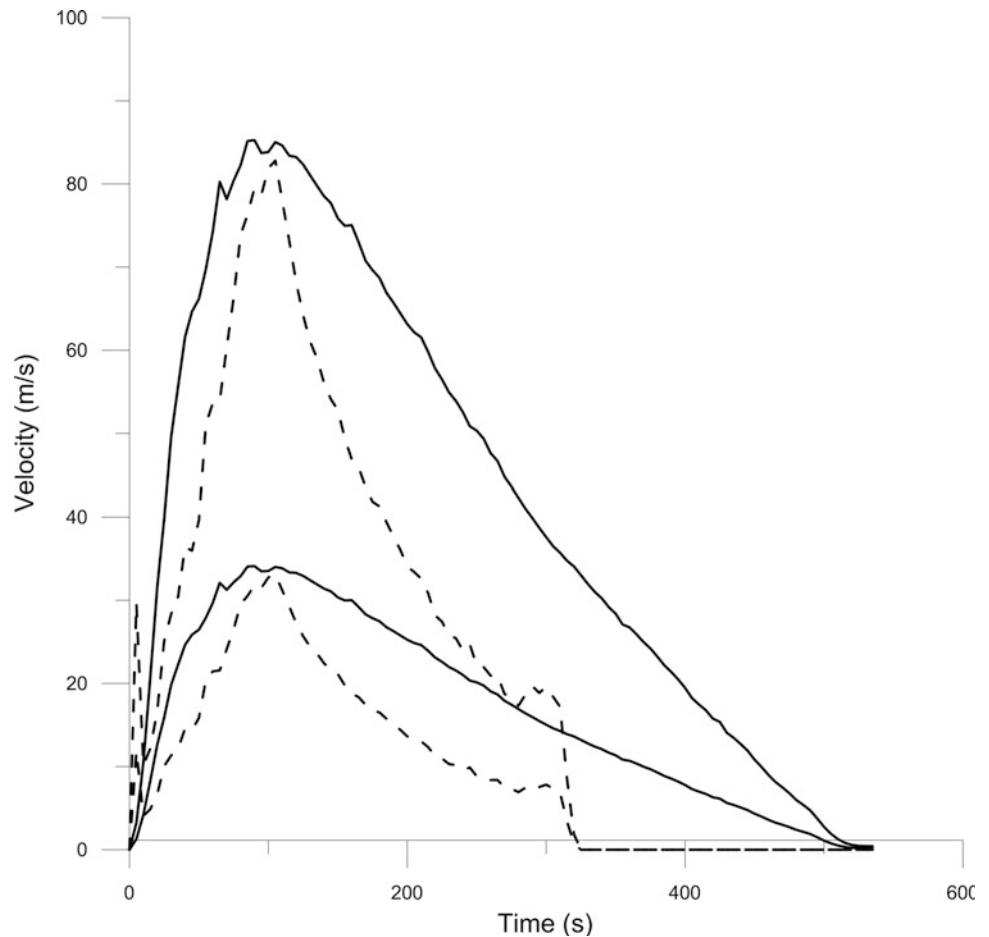
Fig. 43.6 Velocity plot of the mass movement front and rear (continuous and dashed lines respectively) Voellmy model. Velocities were reduced from ~ 85 m/s to ~ 35 m/s by lowering the turbulence parameters of one order of magnitude (ξ from 2000 to 100 m/s^2)

The main morphological parameters that were input to modeling shown in Fig. 43.4 are reported in Table 43.1. Most of these parameters are relatively well constrained by multibeam bathymetry and marine geophysics although still many uncertainties remain especially as regards the thickness of the deposits which is hardly detectable through geophysical data.

It is widely accepted that a convenient measure of the mobility of subaerial or submarine marine mass movements is the H to L ratio known also as apparent mobility. The results of the 2D numerical simulation were evaluated by matching the calculated vs. observed maximum runout and thickness of the deposit along IDA main dispersal axis. The best fits were obtained with those models based on a Voellmy rheological behaviour with $\mu = 0.03$ and $\xi = 2000$ m/s^2 (Fig. 43.5).

The velocity estimate which is one of the outputs of modeling such type of mass movements is still a very conjectural issue especially for submarine cases. It worth to recall that, to date, the few documented debris avalanches are terrestrial; for instance the peak values in the order of 50–70 m/sec observed at Mt. St Helens 1980 (Voight et al. 1983) occurred in concurrence with a magma-related lateral blast. Such values should be considered unrealistic in the case of purely gravity driven collapse.

In our case peak velocities in excess of 80 m/s were obtained at around 100 s after initiation of failure which is also in good agreement with similar values obtained by Tinti et al. (2011) with a different approach. Such peak velocities seem overestimated however. A more realistic value of 35 m/sec was obtained reducing the turbulence ($\mu = 0.03$ and $\xi = 100$ m/s^2) but at the expenses of lower mobility and thicker deposit (Fig. 43.6).

It also appears that if the parameters for an entirely sub-aerial movement were utilized this results in a lesser than measured run-out. The presence of higher—than—predicted pore water pressures into the sliding mass is therefore necessary but possibly still not sufficient to explain the very high mobility of IDA.

While high mobility for sub-aerial landslides can be explained either with the increase of the pore water pressure or with a solid to liquid transition, in the case of submarine movements the presence of sea-water i.e. of a drag force should decrease mobility but enhance the hydroplanning

(Hurlimann et al. 2000). Our preliminary results indicate the necessity of adopting relatively high turbulence parameters to account for the extreme mobility of such mass movements since yet a conclusive understanding of the phenomenon does not exist despite several working hypotheses.

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