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Chapter 36
The 1915 Mud-Debris Flow at San Fruttuoso Di Camogli: Modeling the Collapse Effects in the Portofino Pilot Area of the H2020 Reconect Project

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Abstract In mountainous areas during intese rain events shallow landslides are often triggered adding their effect and enhancing the damaging consequences of flash flood. Many coastal area of the Mediterranean are exposed to such events, as recently largely happened in Italy, France, Spain and Greek. Large portions of the coastline mountainous territories have been settled and modified since ancient times with agricultural terraces, in order to practice the subsitence cultivation. This kind of anthropogenic modification of the slopes may be considered as an artificial immobilization of debris cover along steep slopes and, particularly after their abandonment, they can turn into sources of shallow landslides. Then terraces from belonging to soil and water conservation measures may represent a source of hazard if not properly mainteined. Considering the intense rain event that hit the Portofino promontory in 1915 causing strong damage to the Medieval monk Abbey in the iconic small San Fruttuoso village in northern Italy, a numerical modeling has been applied basing on historical testifying and the available evidences. A possible terraced area has been highlighted as a source area for the debris/mud flow that hit the Abbey and

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the model has been applied to assess its effect. This reconstruction allows to test the modeling technique in order to furtherly assess possible risk scenario even in other areas and in the framework of the H2020 RECONECT project, where recovering ancient terraces is considered in the framework of the Nature Based Solutions to riduce geo-hydrological risk.

Keywords Shallow landslide · Debris flow · Portofino · Terraces · Numerical modeling · Tsunami square

36.1 Introduction

In the past, agriculture was the most important source of livelihood for the population. In areas with a favorable climate and rich in water, a very flourishing agriculture developed, especially in the floodplains. The search for suitable areas subsequently pushed the inhabitants towards sloping areas in order to transform even steep terrains as suitable for cultivation. In Italy, terraced cultivation was thus adopted in many hilly and mountain locations since the Middle Ages in north-eastern Italy, in Lombardy, Piedmont and Liguria [1].

The terraced slopes can be taken as an example of the admirable best application of the anthropic cultivation techniques [2]. Transforming slopes with terraces required strong efforts and considerable skill [3, 4].

In some regions, due to a great cultural and environmental value, numerous planning strategies have been undertaken with the aim of obtaining an optimal management of the most sensitive terraced slopes [5, 6]. Terracing can be considered an effective measure either for soil protection or for its conservation [7]. It is now well established that agricultural terraces reduce soil erosion [8, 9]. Considering therefore the crucial role of the soil system in the sustainable management of terrestrial ecosystems, terracing represents one of the best ways to prevent soil degradation in hilly and mountainous landscapes.

Terraced slopes and terraces represent an alteration of the natural morphogenetic system: if subjected to constant maintenance they can guarantee conditions of equilibrium, but if abandoned they represent a possible source of debris for shallow landslides and they can be subject themselves to collapse [10, 11]. These landslides on steep slopes can originate either from high intensity and short duration thunderstorms in the summer season, or from prolonged rainfall of moderate intensity, especially in the autumn period [11–14]. These processes can often cause damage to infrastructures and human losses, especially in areas characterized by the widespread presence of land cover and prone to heavy rainfall [15–17].

The mass moving on the water-saturated slope can easily reach the valley floor where it may even form ephemeral dams that can subsequently be broken through: thus creating dangerous pulsations of solid–liquid material induced by gravity [18–20].

In the Mediterranean coastal areas, where terraced areas are one of the most characteristic features of the landscape, it appears very important, for the purposes of public safety and the protection of assets, being able to foresee any processes of mass movement, which in recent decades seems to be considerably increasing in frequency. In Liguria, since the beginning of the century, numerous events with high destructive power have occurred due to the collapse of terraced areas, often causing serious economic damage and sometimes even the loss of human lives, as in 2011 in Val di Vara and Cinque Terre [21], and in 2014 in Gazzo di Leivi [22].

The socio-economic changes that have taken place in recent decades have led to a reduction in attention to the processing and maintenance of terraced slopes and, in some cases, their abandonment. Lack of maintenance is one of the possible causes of slope failures.

In order to predict the occurrence of such processes, many attempts have been done in recent decades to establish a correlation between rainfall and surface landslides that can evolve into flows. Although numerous physical models of slope stability have been developed [23–26], the controls that lead to the triggering of slope instability processes caused by precipitation are still not well defined [27], and consequently the improvement of current models remains an important research topic [28].

The main problem of physically-based modeling is the difficulty of collecting basic parameters on areas characterized by complex geomorphological dynamics [28, 29]. However, a possible solution concerns the calibration of the parameter values through a retrospective analysis of previous landslides [9, 30].

This paper proposes to model the mud-debris flow event of 25 September 1915 in the San Fruttuoso di Camogli basin (Parco di Portofino, NW Italy) as part of the studies and research in support of the H2020 RECONECT project (Regenerating ECOsystems with Nature-based solutions for hydrometeorological risk rEduCTion), which aims to contribute to a European reference framework on Nature Based Solutions by demonstrating, upscaling, and replicating large-scale nature based solutions—NBS in rural and natural areas [31].

The Italian case study of RECONECT is the Portofino Natural Regional Park, which represents a unique natural landscape with high ecologic, social, and economic value that is threatened by a range of geo-hydrological hazards, such as flash floods, hyper-concentrated floods, shallow landslides and sea storm surges.

The San Fruttuoso basin is considered highly significant for the modeling of a flow as the source area, based on historical and scientific documentation [32–35], is represented by dry stone wall terraces, similar to the ones described above in Liguria and that look to be related to many shallow landslides in the Mediterranean area.

The mud-debris flow simulation was performed applying the "Tsunami Squares" approach of Ward and Day [36–38], adopting as a base map a Lidar derived DTM. The results obtained verify the quality of the proposed modeling: triggering area, the transport channel and the deposit range all coincide well with ground evidences reconstructed by means of historical-geomorphological sources. The approach is therefore considered encouraging and could be applied to other territorial contexts characterized by potentially mobilizable terraced slopes following significant weather-hydrological events.

36.2 Materials and Methods

36.2.1 General Settings

The study area is part of the Portofino Natural Regional Park, which is located in the Ligurian Region, about 25 km E of Genoa. This is a protected stretch of coast in the western Mediterranean Sea, where the rural and maritime cultures join. The park extends into the areas around the Promontory of Portofino (23 km^2) and include the Municipalities of Camogli, Portofino, Santa Margherita Ligure, Rapallo and the famous settlements of San Fruttuoso (Fig. 36.1).

The Portofino promontory is characterized by steep slopes, in southern and western sectors, and high rocky cliffs; the San Fruttuoso small catchments are settled in the steeper slopes area (Fig. 36.1) in the southern sector of the Promontory. The major relief is represented by Mt. Portofino (607 m), which is the Valle dei Fontanini catchment's head laying about 1 km from the sea (Fig. 36.1). The study area is at the lower portion of this small catchment in the iconic San Fruttuoso bay. The catchment surface is about 0.5 km^2 (Table 36.1) and is characterized by a very high mean steepness, often exceeding 100% (Fig. 36.1). Slopes on the orographic left present a higher steepness and, in the middle portion of the catchment show widespread slope erosion

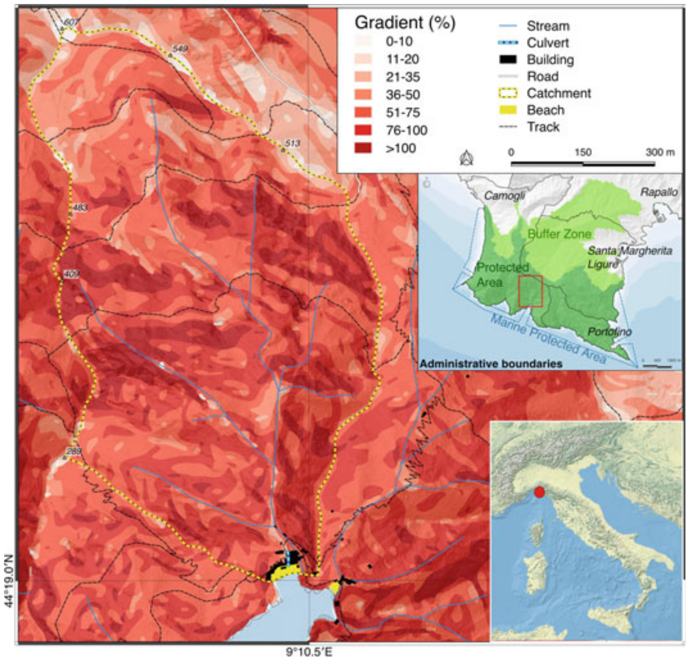

Fig. 36.1 The San Fruttuoso catchment slope gradient, buildings and the culvert under the ancient Abbey, which flows on the small beach

Table 36.1 Main features of the hydrographical network in San Fruttuoso

Catchment	Area (km^2)	Perimeter (km)	Mean steepness (%)	Terraced surface (%)	Hydrographical network length (km)	Main stream length (km)
Vallone dei Fontanini	0.585	3.507	70	2.5	2.825	1.142

(Fig. 36.2). Most of the main stream's tributaries are characterized by intense linear incision. Bedrock is made by the polygenic Conglomerate of Portofino (Oligocene) and the hydrographical network is quite well developed, thanks to the diffuse fault and fracture systems that affect the rock mass NW–SE and NE-SW oriented [39, 40]. The main stream is frequently totally dry and presents a high gradient.

During heavy rainfall events, run-off waters may trigger large solid transport despite the low debris and soil accumulation along the steep slopes, as often occurs in the surrounding Promontory areas: the solid transport may evolve into earth-, mud- and debris flows [41, 42].

Climate is Mediterranean, characterized by rather long periods of sunshine, mild winters and rainy autumns, facilitates the coexistence of different varieties of plant species and an interesting assortment of fauna. Local microclimates are strongly affected by altitude, slope gradient and land use; in the southern sector, usually hot and dry, the small and narrow valleys present a humid and cool climate even in summer [39]. Intense rainfall events and thunderstorms in the region are often intense and have short duration, typically less then two hours. Over the last 15–20 years an increase of storms and flash flood events has been observed, severely affecting the stability of slopes in several small catchments in the area [43]. During heavy rainfall events, debris and ead trees are flushed down into the hydrological network and fast accumulating mud and debris flows [31].

The Portofino Promontory has been settled since the Medieval period, when the first San Fruttuoso Abbey was realized: many others heritages are spread in the park area and can be visited along the numerous panoramic paths [39]. The Abbey was built transversally at the mouth of the small stream that originates from the steep slopes of the higher culmination of the promontory. In Fig. 36.3 are shown the stream above the ancient culvert (Fig. 36.3a), its inlet (Fig. 36.3b) and its outlet (Fig. 36.3c, d). The small section of the culvert is capable of draining only ordinary rainfall and may be easly blocked by debris and floating elements that may be transported during intense rain events.

Inside the park there are important historical and architectural testimonies, recognizable along its footpaths. At the mouth of the Valle dei Fontanini catchment the Medieval San Fruttuoso Abbey (Fig. 36.3) lies traversally on the stream.

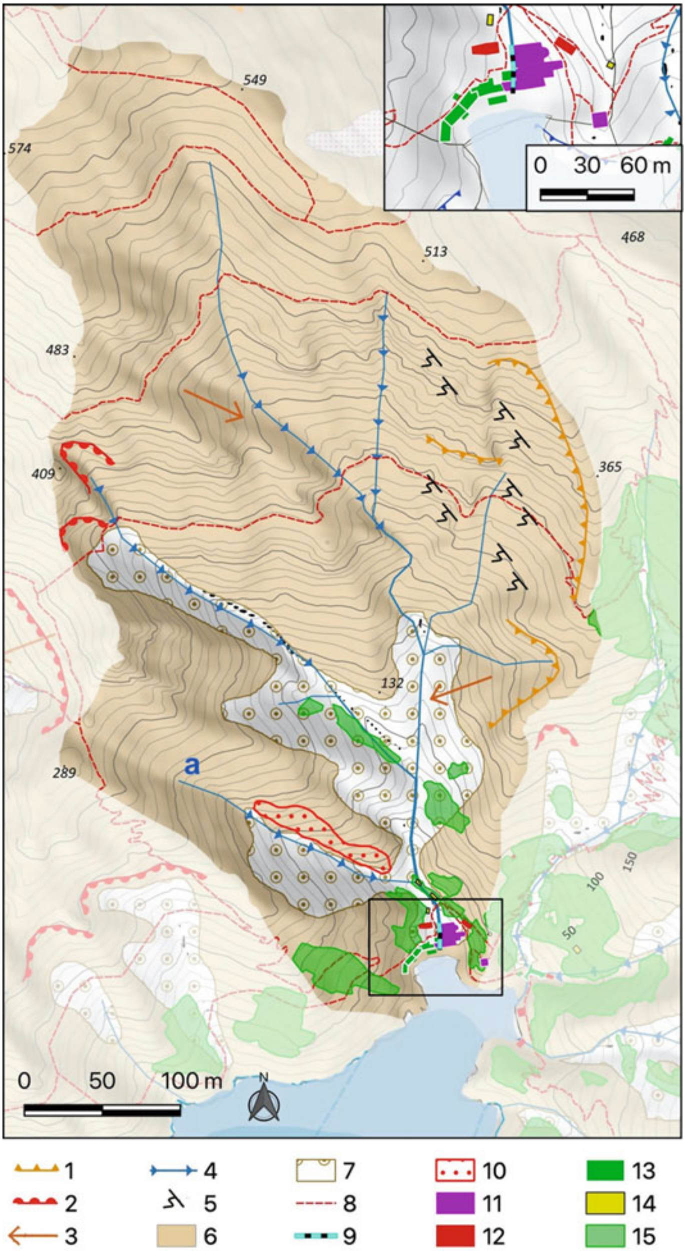

Fig. 36.2 Geomorphological scketch map of the small Vallone dei Fontanini catchment (Turconi et al., 2020) with a possible source area for the debrif flow/hyperconcentrated flow: in a) the Fosso dell'Alluvione creek. (1) Dormant scarp; (2) Active scarp; (3) Slope instability and flow directions; (4) Downcutting talweg; (5) Slope erosion; (6) Conglomerates with sandstone layers; (7) Debris cover; (8) Trail; (9) Culvert; (10) Possible source area for the 1915 event; (11) Religious building; (12) Residential building; (13) Receptive building; (14) Agricultural/rural building; (15) terraces

Fig. 36.3 **a** The stream approaching the culvert running beneath the Abbey; **b** the culvert inlet; **c** the culvert outlet the beach; **d** view of the Abbey with the culvert outlet

36.2.2 The 1915 Event

In 1915 a very intense flash flood event occurred, affecting the San Fruttuoso area and the coastal cities of Camogli, Santa Margherita Ligure, Rapallo (Fig. 36.1) and Chiavari; the last one being about 12 km along the coastline in East direction. Historical data reported that, after relatively light rain during the 24 September night, in the early morning of 25 September, San Fruttuoso hamlet was hit for a few hours (07:00–11:00 UTC) by violent rain that triggered widespread flash flooding [35]; a devastating debris flow demolished part of the San Fruttuoso Medieval Abbey (Fig. 36.4) and deposited a 2 m thick layer of sand and rocks to form a deep beach 20 m wide [44].

Fig. 36.4 A) The actual status after the recovery comparing to the partially collapsed Abbey after the 1915 event B)

Figure 36.4 shows a comparison between the damaged Abbey and its current condition: the partial collapse is clearly visible and involved the church façade and part of the building that laid upon the culvert: its lower part was demolished. In Fig. 36.5 a comparison between the beach before the event and its current status are shown. The beach persisted as the result of the accumulaton of debris and sediments.

Fig. 36.5 The San Fruttuoso bay before 1915 (**a**) and actual (**b**): the beach appeared after the 1915 event

36.2.3 Methods and Data

The debris and sediment flow that occurred during the 1915 heavy rainfall that hit the San Fruttuoso area has been modeled applying the meshless numerical model named ‘Tsunami Squares’. The model has been recently developed and applied to several large landsliding and tsunami generated events [45, 46]. The model is an

Table 36.2 The dataset used and the respective features

Name	Source	Scale/pixel	Date	Type
Administrative unit	Liguria Region	1:5,000	2018	Vector
Digital terrain model	Italian Env. Ministry	1 m	2008	Raster
Hydrographic network	Liguria Region	1:10,000	2019	Vector
Hydrographic basins	Liguria Region	1:10,000	2019	Vector
Regional technical cartography	Liguria Region	1:5,000	2006	Vector
Slope	Liguria Region	1:10,000	2016	Vector

evolution of the previously developed Tsunami Balls [36–38] that allows modeling at a large spatial scales [46], thanks to not needing a specialized computational mesh nor special treatment of dry and wet cells [47]. The computational efficiency of Tsunami Squares allow it to be applied to a wide range of event scales, modeling both landslides and the eventual generated tsunami [48].

The procedure computes both the mass movement and various features of the movement itself: the flow and height through a cross section, the instantaneous velocity of the flow. Then its computational efficiency allows to obtain precise data from the modeling in a small scale event. Modeling details may be found in [45].

Data used for the model application and for map drawing are shown in Table 36.2.

36.3 Results

The analysis conducted on the 1915 event, first compared historical images and documents with the current conditions, with the aim at identifying the possible source area of the debris and sediments flow that damaged the Abbey. The short creek that meets the main one on the hydrographical right, noted with “a” in Fig. 36.2 was named by the people living in San Fruttuoso after the 1915 event as “Fosso dell’Alluvione” which means “Flood Creek”. This lead us to believe that the 1915 flow originated from that small tributary. The high slope gradient in the whole catchment minimizes debris and soil accumulation along the slopes so, considering the ancient anthropogenic modification of the area, we considered man-made debris and soil accumulation within stone wall terraces as a possible source. In fact, starting from the first Abbey complex settlement in the 10th Century, stone walled terraces were constructed mainly for olive orchard plantations [34]. Many historical terraces are still present in the area (Fig. 36.2).

As a second step, we examined the more favorable slope gradient and aspect conditions and identified a possible source area for the debris and sediments that damaged the Abbey in 1915. We postulated that the source had medium thickness of about 1 m, its surface extent related to the volume of the accumulated debris on the beach. Considering the debris evidence [44], the accumulated volume can be estimated at about 6000–7000 m^3. The bay configuration (Fig. 36.5) does not allow coarse sediments to be washed away by the litoral currents, then even considering the yearly solid transport from the hydrographical network and the effect of more recent but less intense geo-hydrological events and a small percentage of loss, we can consider the current volume comparable to the 1915 accumulated one.

In Fig. 36.8 the possible source area is identified. The lack of ground evidences may be explained by the artificial accumulation of debris and sediment employed for building the terraces. They are man-made landforms [49] and after more than 100 years, no sign of scarps or erosion cuts were left after their washing away. Besides, due to the high slope gradient, terraces in the study area have been often constructed by putting stone walls directly on the bedrock and bringing soil and sediments to constitute the terraces [34, 50]. Then, the collapse would have left the original rocky surface only.

The total volume of the moving mass has been extimated in about 6200 m^3. Even if it is not a large quantity, it would be able to cause the collapse of large portion of the Abbey: both the church façade and part of the building laying on the culvert (Fig. 36.4b).

The performed simulation let us identify two points, named 1 and 2 in Fig. 36.6, where debris flow, velocity and heights were computed: point number 1 is immediately after the confluence of Fosso dell'Alluvione with the main stream, and number 2 is immediately before the Abbey. Results are shown in both Figs. 36.6 and 36.7 and in Table 36.2. The flow develops and runs quickly from the source area to the sea, due to the short path followed by the debris and the high velocity induced by the slope and stream high gradient (Fig. 36.6). The debris quickly hit the Abbey complex and then, after its partial collapse, easily accumulated on the small bay.

The maximum height of debris and sediments during the event, immediately after the stream confluence (1), is supposed to be about 5 m, while a top height of about 3.4 m could have reached the Abbey (Table 36.2). Velocity reached a maximum value of about 4.5 and 3.4 m/s respectively at points 1 and 2. Considering the debris and sediments flow extimated in more than 100 m^3/s, the kinetic energy transferred to the ancient building caused its partial collapse. At point 1 higher flow and velocity occurred due to the different gradient and geometrical cross section.

In Fig. 36.7 the evolution of debris and sediments flow is shown at the six time steps corresponding to data in Table 36.3 across a section in point 2. The top height of about 2 m was reached between 24 and 28 s, when the higher flow and velocity happened: probably at that time the Abbey collapse occurred. A further remark regards the high intensity of a very short event that may be considered as an impulsive one, considering again the combination of the flowing masses and their velocity, and then kinetic energy.

36.4 Discussion

The possible reconstruction of the 1915 debris flow event that caused the partial collapse of the ancient San Fruttuoso Abbey and the formation of a new beach,

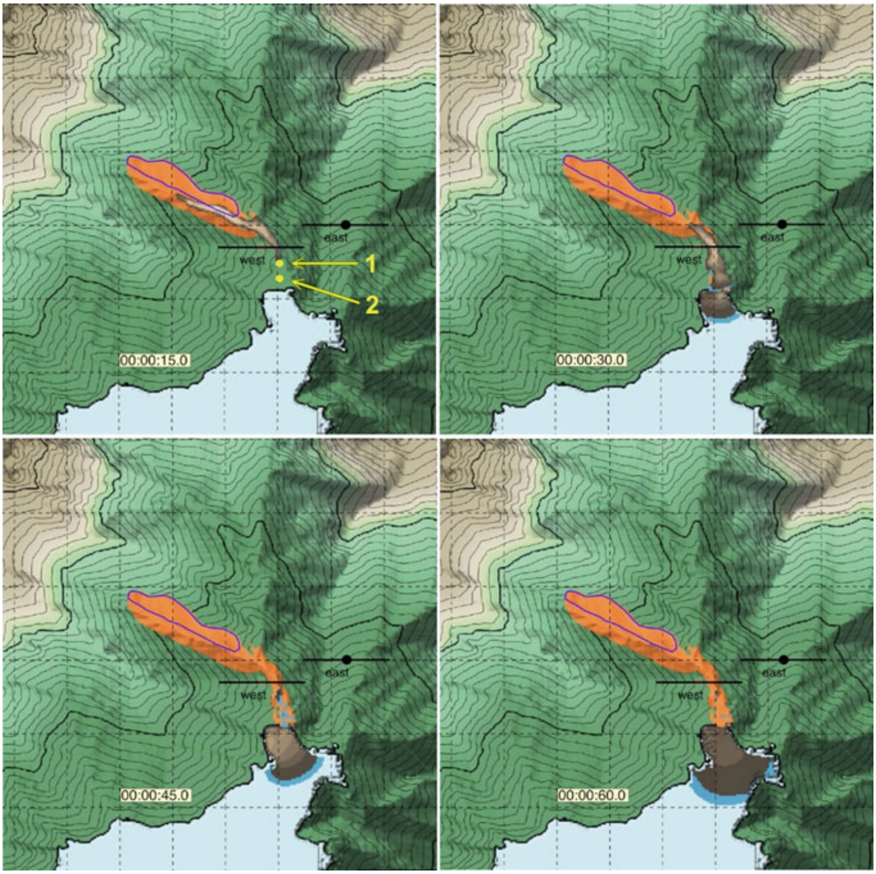

Fig. 36.6 The simulation at 4 different time steps and the location of the section (2) in Fig. 36.7 and in Table 36.2 (1, 2)

allowed us to test the Tsunami Square method to a small but highly destructive shallow landslide. Many assumption had to be made due to the length of time passed since the event and the lack of direct quantitative data. The modelled source area has been identified as the most probable one considering the land use in the area since the first settlements. Perhaps, modifying the source area would not change significantly the results, but only its topographical deployment. On the other hand considering the Fosso dell'Alluvione as the possible source stream due to its name, not many other possible source areas in the little catchments may be found (Figs. 36.5, and 36.8). Because no scarps are evident in the higher part of the small catchment and because slope gradients are higher there, we believe the upper reaches of the stream to be less probable as a natural accumulation source of the 1915 event. Further, the debris cover along the creek could be partly related to the event or to other slope processes that interested the north facing slope.

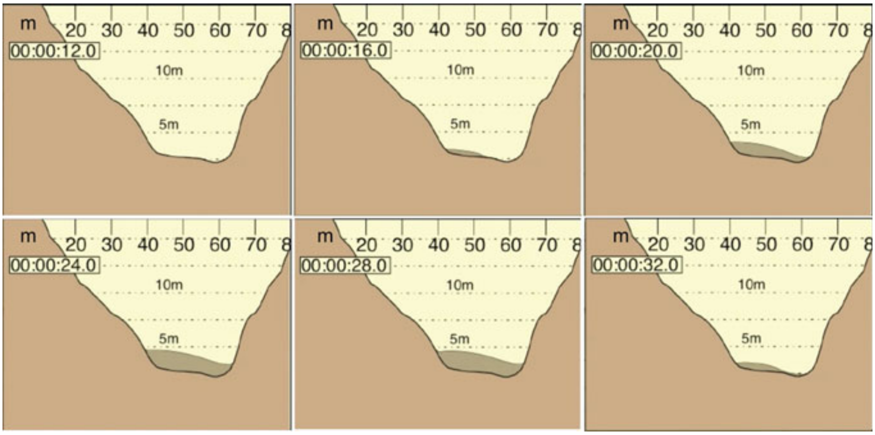

Fig. 36.7 Total height of flowing after 1, 2, 3 and 4 min of simulation at an East–West section in point 1 in Fig. 36.6, close to the Abbey

Table 36.3 Simulation results at point 1 (left) and 2 (right) in Fig. 36.6: Q = sediments flow; v = sediments velocity; h = sediments height

t (s)	Q (m^3/s)	v (m/s)	h (m)	t (s)	Q (m^3/s)	v (m/s)	h (m)
12	13	2.4	1.5	12	0	0	0
16	111	3.5	3.9	16	7	1.6	0.6
20	246	4.5	5.3	20	46	2.4	1.2
24	233	4.4	5.3	24	108	3.3	1.8
28	91	3.3	3.8	28	116	3.4	1.9
32	6	1.6	1.2	32	23	2.2	0.8

Fig. 36.8 The possible debris flow source area (S) along the Alluvione creek

The numberical simulation evaluated the flow, velocity and height of debris along the stream. These values are considered compatible with such a kind of events [51, 52], while the involved volume was assessed considering the current beach condition. Nevertheless, the simulation is affected by uncertainty due to the lack of quantitative and precise data, but the imposed constrains may be considered as the most probabile ones.

After all these considerations, recognizing stone-wall terraces as possible sources for debris and sediment flows appears to be compatible with the conditions leading to similar events that recently happened in the Liguria region. In 2011 a strong and intense rain event, maybe similar to the one in 1915 in San Fruttuoso, hit the Cinque Terre area about 40 km along the coastline in the East direction [21], causing dozens of shallow landslides that originated mainly from dry-stone wall terraces: apart from the different spatial scale of the two events, the effects were similar. In 2014 another similar event happened at shorter distance East from San Fruttuoso in the hinterland of Chiavari city [22]: after heavy rains a single collapse along a slope caused a debris flow that hit a building, which was knocked down causing two people to die.

Such a kind of events frequently strike different parts of Liguria during intense rain precipitation: shallow landslides are triggered, often involving terraces which represent an anthropogenic accumulation of debris and sediments along the slopes [22, 49]. Then it is crucial to model and simulate the possible evolution of these fast evolving shallow landslides and the spatial relationships between the source areas and potentially exposed elements to realize risk scenarios.

36.5 Conclusions

The back analysis of landslides like the 1915 one, apart from the direct reconstruction itself, is crucial for the assessment of the future possible similar events that may happen in similar conditions. The simulation approach allows us to investigate and identify areas possibly exposed to shallow landslides, including cultural heritage sites, buildings, roads, and tourist facilities. Then it allows risk assessment and possible design mitigation measures.

The H2020 RECONECT project aims to reduce geo-hydrological risk through an holistic ecosystem based approach [31], which signifies considering the events development and related solutions at the catchment's scale using natural means. Terraces, particularly where they have been realized about 1000 years ago, are part of the ecosystem due to peculiar vegetation and fauna that populate them. Besides, they are a globally used soil and water conservation measures [49] due to their retaining capacity and soil erosion reduction capabilities.

Identifying terraces and their possible role as a source of fast developing shallow landslides is crucial to point out if they represent a possible hazard and if they need to be maintained, considering their diffuse abandonment [50]. Interventions should focus on risk reduction, in particular in presence of culverted stretches that are often present close to the streams' mouth and that may be easily clogged by the floating material, sediment and debris sweeped away: the consequent waters overflowing can caused hard damage to the surrounding area. Finally, mitigation measures should focus on the precise evaluation of flow path and zones of concentration, which is possible thanks to the high precision LIDAR data that are more and more available.

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