

Application of an innovative, low-maintenance weir to protect against debris flows and floods in Ottone, Italy

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Abstract

The need of a low-maintenance and easy-applicable apparatus against debris flow led Maccaferri Innovation Center and the Politecnico of Milan to a new hydraulic-based approach that was focused on the application of a special weir called Mini Skirt Check Dam (MSCD). After a three-years research on applicable equations, a construction site in Ottone (Italy) was identified to have been affected by destructive debris flow in the past years. The site is characterized by the presence of an underground pipe that collects the stream flow rate flowing under the village square. The purpose of this work is to design a MSCD, able to prevent a pressure driven flow in the underground pipe and to avoid the related risk for the inhabitant of the village. MSCD is a special weir, which consists in large wings to slow the flow and a ring net to block boulders and logs, as to become a sifting filter of the debris. As to design the best performing apparatus, materials and type of anchoring are crucial; for this reason, an analysis of the impact pressure was performed. The case study has considered several different aspects: hydrology, size of the material and its characteristics and previous events to have a complete analysis of what could happen in the next events. The result of this collaboration is the complete design of a MSCD, ready to be installed.

Keywords: debris flow; management of the hydraulic risk;

1. Introduction

Ottone is a town in the province of Piacenza, in the Emilia-Romagna region of northern Italy, with an important extension (98.96 km²) which is compared to a small resident population of only 495 inhabitants (ISTAT, 2017). The town is capital of the municipality and it is located at an elevation of 510 m above sea level, while the hamlets are located at higher altitudes and they are a major tourist destination especially in the summer.

The village of Ottone is located in the Alta Val Trebbia, on the Ligurian Apennines. Some of the numerous hamlets that make up the territory are in the Val Boreca. The territory includes the Trebbia and Aveto basins, the main tributary of the Trebbia. The main course of the Trebbia river develops in SW-NE direction for 116 km, from the source on Mount Prelà on the Ligurian Apennines (1406 m), up to the outlet in the river Po near Piacenza. The portion of the basin close to Ottone drains approximately 207 km². The municipal territory develops from a minimum elevation of 344 m to a maximum of 1667 m above sea level, and the average slope of the area is 53%. The inhabited nucleus of the Capital is set on an alluvial fan that has stabilized over time and overlooks the river bed of the Trebbia on the hydrographic right.

The hydrology of Ottone town is characterized by the waters of Rio del Montone and Rio della Ghiossa flow underneath the old town (see Fig. 1), in particular they join below Piazza Vittoria and then continue flowing towards

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the river Trebbia, draining a total area of about 40 hectares. This peculiarity has caused several problems to the population and the purpose of this project is to permanently solve this problem with a lower maintenance weir.

1.1. Problems occurred in Ottone

The main risk for the municipality of Ottone is given by the hydraulic security of Piazza Vittoria. Originally, in the urban plan, the inhabited nucleus was placed outside the path of the two streams Rio della Ghiossa and Rio del Montone. Around the second half of the 1800's, the two streams started to be covered because in the urban planning the area was intended as a market square.

The covering of the last segments of the two streams was completed between 1873 and 2000. The sewer is in masonry with sections of 1.30×1.40 m or 2.00×1.50 m and with vaulted roof. The drainage disposal capacity, assessed with a maximum filling level of the sections equal to $2/3$ of the available height and considering clear water, is $8 \text{ m}^3/\text{s}$, equivalent to a multisecular flow rate. However, the flood events regarding the two streams are characterized by a strong presence of solid transport that can plug the sewer system. This scenario of occlusion made by massive solid transport has occurred more than once in recent history and the events of considerable importance are:

- 19 September 1953
- 13-16 October 2000
- 13-14 September 2015

The most recent event had a particularly high intensity that led to the complete obstruction of the eastern channel of the sewer of Rio del Ghiossa and the current situation of inadequacy of the network that puts at risk the appurtenances of the square. In the period immediately following the September 2015 event, works were carried out to try to restore the flow of Rio del Ghiossa by bypassing the blocked section to canalize the waters up to Trebbia through the western channel. The image in Fig. 1 makes it possible to appreciate the situation following the first interventions for restoring the transport capacity: the black section is out of service due to the clogging caused by the debris carried by the flood, while the green section is the bypass.

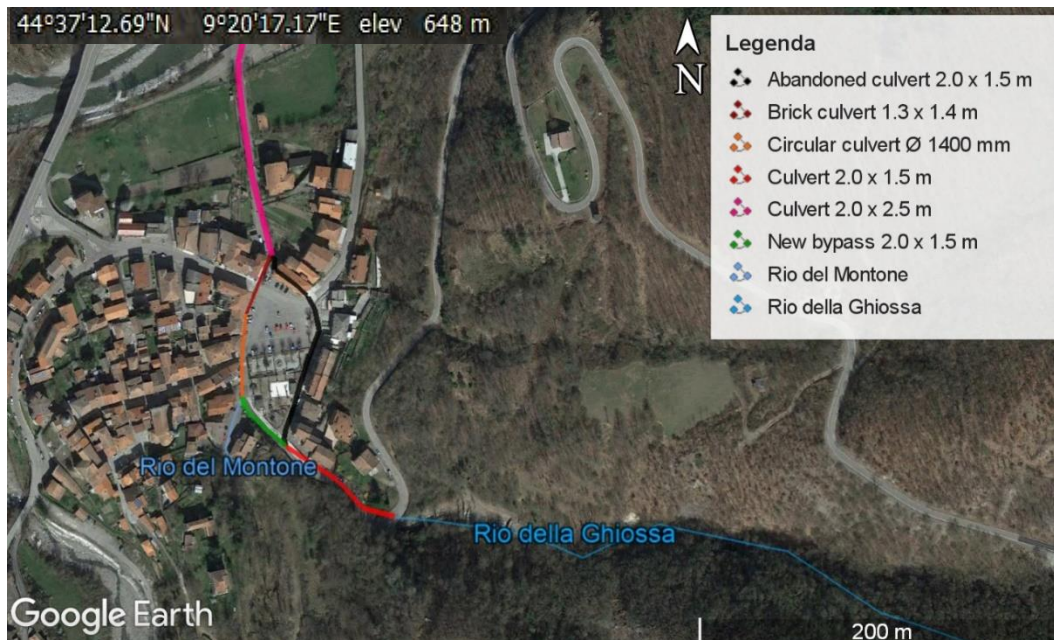


Fig. 1 Representation of the channel system of Rio della Ghiossa and Rio del Montone below Piazza Vittoria after the first restoration: the black section is out of service due to the clogging made by the September 2015 event, while the green section is the bypass made to allow the flow of the waters of Rio della Ghiossa up to Trebbia, following the West channel.

The slopes of the square exceeding 5% allow a good drainage capacity to the underlying sewer. The system is not specifically affected by a possible regurgitation of the Trebbia. To protect the inhabited area, there are four weirs installed upstream of the sewer entrance, at a distance of about 30 meters one to the other (Fig. 2). The structural reliability of these structures should be verified, together with the state of consistency and maintenance.



Fig. 2 Photos of the last two weirs.

1.2. How to reduce the risk

From the past events and from the geomorphological and hydraulic studies of the basin it was noticed that the biggest problem in the case of debris flow comes from Rio del Ghiossa. The measures to reduce the risk of debris flow on Piazza Vittoria are divided into two categories: structural and non-structural.

For the non-structural part, the installation of a monitoring and alerting system designed by CAE S.p.A. in collaboration with the Politecnico di Milano, financed by the Emilia-Romagna region, is about to be completed. Thanks to the study of the precursors to the calamitous event, it is possible to alert the population in advance in order to follow predefined emergency procedures that increase security and reduce material damage. The system logic is based on the correlation between precipitation duration and intensity and the occurrence of debris flow (Guzzetti et al., 2007; Pizziolo et al., 2005).

The structural interventions in the project can be distinguished in interventions for the changing layout of the square and mitigation measures for “debris-flow hazard”. After the September 2015 event, concrete barriers with a jersey profile were laid along the western side of the square in order to preserve the entrance to the shops and create a safe walkway for pedestrians who unfortunately had to be in the area at the time of the manifestation of the landslide event. This floodproofing intervention should be developed in the square renewal project. The hydraulic restoration works in the square were entrusted to a local engineering company, which defined a technological solution that provides the adjustment of the West channel and of the sewage system. The choice to refer to this setting was made on the basis of operational and economic evaluations.

On the other side, the installation of an apparatus called Mini Skirt Check Dam upstream of the entrance of the sewer is planned. It is a slit weir with a central net that is raised with respect to the riverbed, see Fig. 3. This product allows the lowering of the debris discharge, reducing substantially the speed and the highest discharge. The advantage over the traditional weirs is that, with the addition of the net, larger debris and timber that are often the most destructive part of the debris flow can be retained more effectively. Moreover, the presence of the net guarantees the need for a wider slot, which entails a lower expenditure of materials and, in particular, a lower impact on the structure that can be designed with smaller anchorages and greater durability. This weir does not need maintenance at the end of each event and for this reason it is optimal in all contexts where the accessibility of the site is problematic and linked to weather conditions.

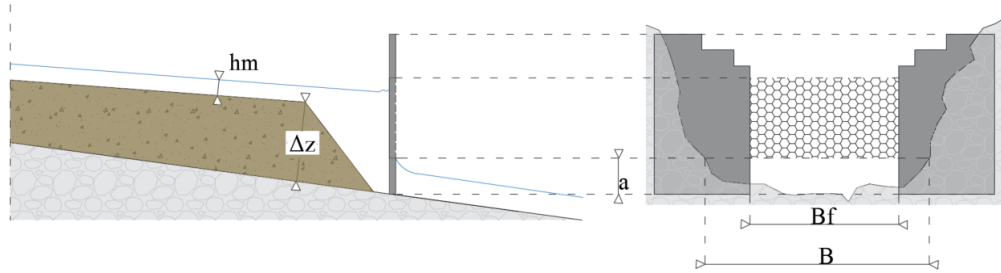


Fig. 3 General hydraulic scheme of a MSCD (University of Trento, 2016). The wings could be made in gabions or concrete and are designed with a specific $R=B/B_f$ for each Froude number and volume of debris. The net in the middle is designed with a specific hm/a parameter, where hm is the flow level in the upper part of the weir.

2. Hydraulic and hydrological modelling

In order to properly design the MSCD, a hydraulic model and hydrological study was implemented. While creating the models, the reference setting has been the “project scenario”, with the new configuration of the sewer that will be completed soon.

2.1. Hydraulic modelling

1D hydraulic modelling has been carried out applying the HEC-RAS model (US Department of Defense, Army Corps of Engineers, 2016), to a series of cross-section, with the aim of identifying the critical section, which is obviously the one with worst debris accumulation. The definition of the geometry has been simple to implement since 88% of the channel is artificial and was constructed using a precast concrete box of defined size. For the remaining part, the reference was to a topographic evaluation received from the technical service of the municipality and to an in situ evaluation carried out with a geologist.

The technical service department of Ottone Municipality had also provided information regarding the elevation of the submerged channel in correspondence to manholes for inspections so that an accurate reconstruction of the submerged part was possible. Since no data was available regarding the elevation of the riverbed upstream of the covered part, an assumption of constant slope (5%) was made.

Considering all the obtained data, the available sections were 41; due to the model structure and function, some of the sections need to be doubled, so that a total of 64 sections were introduced into the model. The junctions among the channels composing the sewer were solved using the momentum equation.

The roughness factor has been kept constant along the whole transverse section, adopting 3 reference values for the main characteristics of sections (precast concrete box, natural open sky section, and open sky section with concrete).

The adopted values of discharge were taken by the previous work from Politecnico di Milano (Menduni, 2016), imposing as an input value that the whole Rio della Ghiossa contribution is channeled in the East segment, as planned in the restoration project. The selected upstream boundary condition was due to the hydraulic jump on the weir. From the output, it has been possible to compute the transport capacity, whose profile is shown in Fig. 4, and identify the critical section.

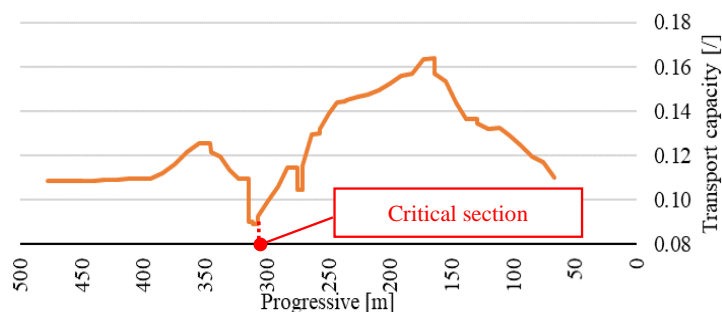


Fig. 4 Transport capacity along the sewer channels based on Hec Ras.

2.2. Hydrological study

Since no hydrometer and rain gauges are present in the basin, calibrating and predicting the peak of flow rate for each return period chosen in the analysis was not a simple task. The total surface of the hazardous basin is less than 0.5 km^2 , so it was extremely inaccurate to use the measuring apparatus installed on Trebbia river to calibrate the model. A simulation based on a GIS tool was preferred to find the water discharge for each return period. A calibration was possible with the data from the previous study (Menduni, 2016), that was calibrated on the amount of rain near the basin and the amount of material accumulated in the village.

The procedure followed consists in different steps:

- GIS analysis to identify the basin and its feature
- Hydraulic manipulation using the Peak Flow model (Rigon et al., 2011) to obtain hydrograph
- Amplification of the obtained curve according to the previous studies (Menduni, 2016)
- Calculation of the solid flow rate

It was fundamental to perform a complete GIS hydrological analysis to identify the basin and some hydraulic characteristic supplied as input data to the Stage tool implementing Peak Flow model and obtain the complete shape of the liquid discharge in time (as it is fully explained in Rigon et al., 2011) an example of the GIS analysis could be found in Fig. 5.

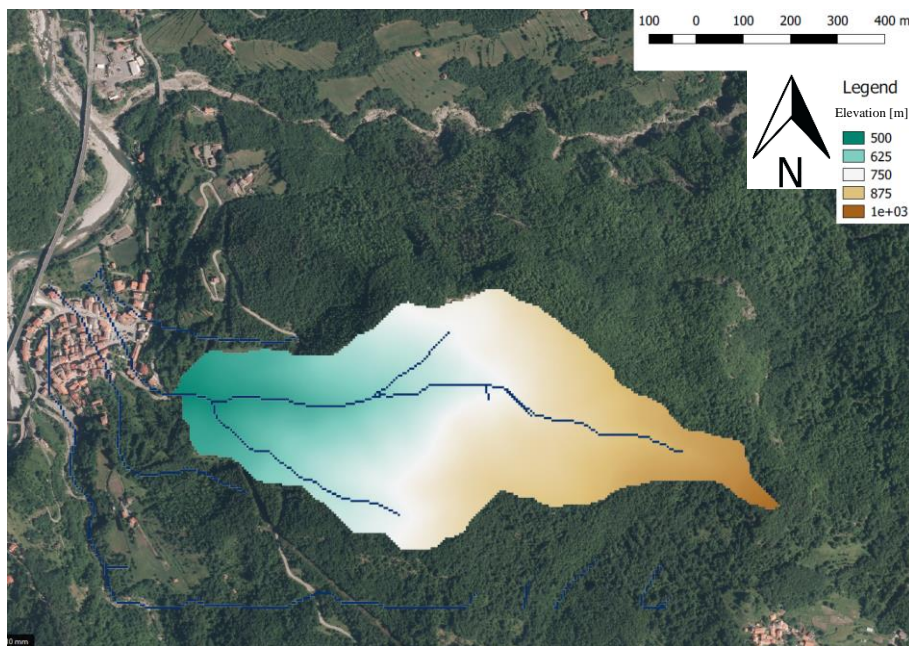


Fig. 5 DTM applied on the reference basin and direction of the main flow carried out with QGIS, each colour correspond to an elevation (in m) above the sea level.

Starting from the output of the GIS study, it was possible to perform a further step of analysis using the software Peak flow. The calibration took into account the peak of the flow rate found in the previous studies (Menduni, 2016), so all the curve was multiplied for a factor that gives the same peak. The resulting discharge was amplified to accomplish the values found in previous studies, as shown in Fig. 6.

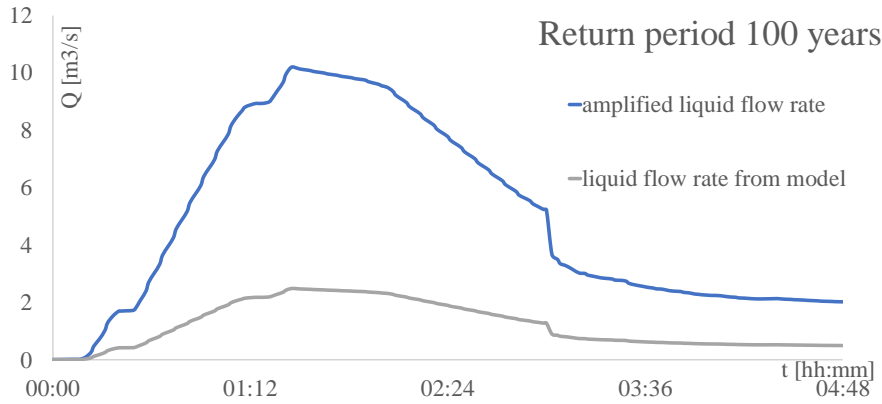


Fig. 6 Example of the amplification of the resulting discharge from the application of the Peak Flow model. For the return period of 100 years the factor of amplification is 4.12, similar factor has been used for the other return periods.

A series of four curves was obtained for four reference return periods. Starting from these curves, the Takahashi criterion (Takahashi, 1978; Lanzoni, 1993) was chosen to obtain the complete curve of the solid and liquid flow rate. An example of the application on the obtained curves is provided in Fig. 7.

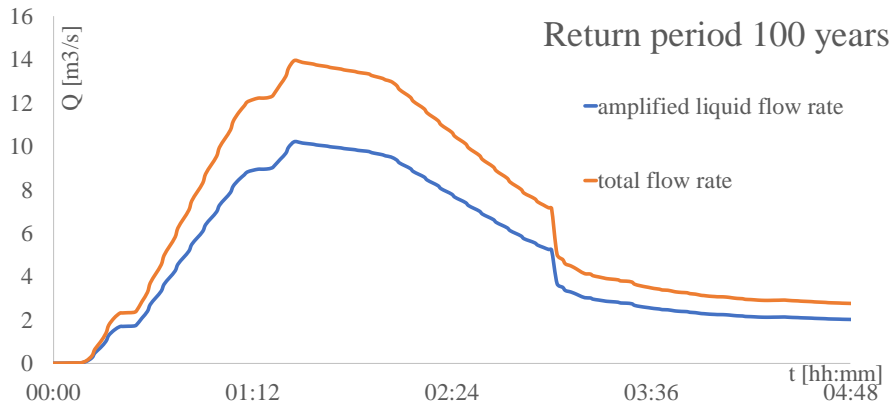


Fig. 7 Example of the amplification of the resulting return period of 100 years event, using the Takahashi (1978) criterion.

Errore. L'autoriferimento non è valido per un segnalibro. shows c and n parameters defining the depth-duration-frequency curves for each return period that were fixed from the local administration and which play an important role in the Peak Flow model (Rigon et al., 2012); $Q_{L\max}$ is the maximum flow rate for each return period and was fixed by Menduni (2016). We call “scale parameter” the coefficient applied to adapt the discharge from the Peak Flow elaboration, to the Peak imposed by the previous studies. V_L represents the total volume of water during the flood event, calculated as an integral of the amplified curve. V_{tot} represents the calculation of the total volume of both sediment and water that flows during the event and is calculated with the Takahashi criterion.

Table 1 Final results of the hydrological study

		Tr 20 yrs	Tr 100 yrs	Tr 200 yrs	Tr 500 yrs
c	mm/h	35.99	70.68	77.81	87.2
n	-	0.348	0.335	0.332	0.328
$Q_{L\max}$	m³/s	7.55	10.12	11.2	12.64
Scale parameter	-	3.88	4.12	4.14	4.21
V_L	10^3 m^3	17	23	24	27
V_{tot}	10^3 m^3	23	32	33	37

3. Design of MSCD

The characteristics of the basin and the presence of a sewer portion of the stream, forced the design procedure to install an apparatus like the MSCD, that could dilute the amount of water and sediment but also requiring less maintenance. A section for the installation that is near to the road and easy to access was chosen and at the same time far enough from the bridge to avoid problems related to the pressure in that section. This job site is a part of the whole works in the County to improve safety against debris flow that will occur in the future. This installation, in particular, will ensure a constant amount of flow rate in the channel and thus, avoiding the pressure inside the sewer.

To avoid the sediment to overflow the hydraulic obstacle, all the volume of the debris moved by the 500 years return period flood must be contained in the chosen section in the space upstream, so a check on the available storage capacity was necessary while choosing the position.

With reference to Fig. 3, the design parameters to be determined were:

- a, how much the net is uplifted from the ground: this parameter could be found in the abacus of the design (Morstabilini & Deana, 2018)
- R what is the ratio between B (the width of the undisturbed section) and Bf (the distance between the wings of the MSCD), see Fig. 3.

The considered base section is 4.7 m wide, so two possible Bf: Bf = 3 m and Bf = 3.5 m were chosen leading to two design options: R = 1.57 and R = 1.34. one of the resulting graphics for these options is reported in Fig. 8.

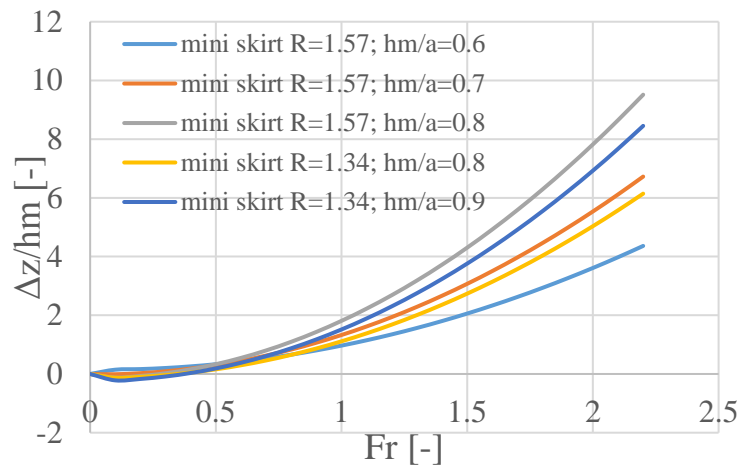


Fig. 8 Example of a resulting design abacus for R=1.57 and R=1.34 and different hm/a parameters

The ability of the MSCD to dilute the debris flow is determined by the ratio $\Delta z/h_m$ which is a non-dimensional parameter that expressed the maximum amount of material that is temporarily blocked by the apparatus. Considering that the maximum height of the weir should be 2 m, the options for the design are in Table 2 the chosen solution is the third, with final drawing of Fig. 9.

Table 2 Final results of the hydraulic model

R	a	h_m/a	h_m	dz/h_m	dz	$dz + h_m$	Fr	U	Q
[-]	[m]	[-]	[m]	[-]	[m]	[m]	[-]	[m/s]	[m ³ /s]
1.57	0.35	0.70	0.25	6.72	1.65	1.89	2.20	3.41	3.42
1.57	0.30	0.80	0.24	7.04	1.69	1.93	1.90	2.92	2.50
1.57	0.70	0.60	0.42	3.61	1.52	1.94	2.00	4.06	8.14
1.34	0.35	0.80	0.28	6.14	1.72	2.00	2.20	3.65	3.66
1.34	0.30	0.90	0.27	6.22	1.68	1.95	1.90	3.09	2.66

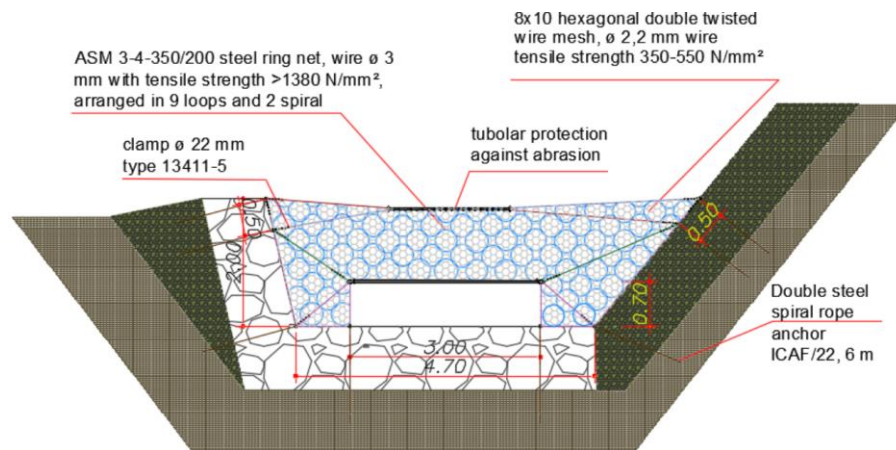


Fig. 9 Final design of the MSCD: in order to be easy to apply, the particular asset of the wire ensure the hole to stay open during the event.

4. Conclusions and future development

The Ottone research was an interesting case study to apply the results of the research on MSCD. In addition, the creation of a work team that involved Maccaferri Innovation Center and the Politecnico of Milano was fundamental in finding the best design solution for this site. During 2019 data load cells will be installed in the clamps which will communicate the tensile strength on anchoring. Combining this information with data coming from the sensor already installed for the early warning system, it will be possible to find a correlation between the rain and the pressure on the barrier, enlarging the knowledge on the phenomena occurring in the area.

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References

Computer Program

Brunner, G. W., 2016, HEC-RAS: River Analysis System: Hydraulic Reference Manual (5.0 ed.): US Department of Defense, Army Corps of Engineers.

Journal article

Guzzetti, F., Peruccacci, S., Rossi, M., and Stark, C., 2007, Rainfall thresholds for the initiation of landslides in central and southern Europe: Meteorology and Atmospheric Physics, v. 98, p. 239–267, doi: 10.1007/s00703-007-0262-7.

Rigon, R., d'Odorico, P. and Bertoldi, G., 2011, The geomorphology structure of the runoff peak: Hydrogeology and Earth System Science, doi:10.5194/hess-15-1853-2011.

Takahashi, T., 1978, Mechanical characteristics of debris flow: Journal of the Hydraulics Division 104 HY8, 1153 - 1169.

Online PDF

Arpa, 2005, Evaluation of the risk of landslides in Appennines in Emilia Romagna [translated from Valutazione del rischio da frana nell'Appennino Emiliano-Romagnolo].

https://ambiente.regione.emiliaromagna.it/geologia/temi/dissestoidrogeologico/pdf/soglie_pluviometriche.pdf/@download/file/soglie_pluviometriche.pdf

Personal Communication

Menduni, G., 2016, Analysis of the hydrogeologic risk in Ottone related to the events of 13-14 september 2015 and residual risk [translated from Analisi del rischio idrogeologico nel Capoluogo del Comune di Ottone con particolare riguardo agli effetti calamitosi del 13-14 settembre 2015, ai conseguenti scenari di intervento e alla gestione del rischio residuo], Milan.

Proceedings from a Symposium or Conference

Morstabilini, C. and Deana, M. L., 2018, Debris Flow: a new design approach: Geomechanics and Geodynamics of Rock Masses. European Rock Mechanics Symposium, vol 2.

Thesis

Lanzoni, S., 1993, Meccanica di miscugli solido-liquido in regime granulo inerte. [ph. D thesis] Padova, University of Padova.