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Discussion of the Conceptual Model of Debris Flow and Flexible Dikes in the Caracachra Creek

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Abstract **-** In this paper, the first analysis of the conceptual model of this non-Newtonian flow, poses the first challenge of proposing an initial discussion of the geometric, kinematic and dynamic characteristics of this flow that each water cycle converges in the Carachacra stream in Peru, it has been identified in the field that this mixture reaches a sedimentation bank greater than 6 m, and as support to validate and compare the Flo-2d computational tool was used, which has allowed us to obtain not only the maximum draft but also the velocity and the resulting impact forces.

Therefore, by means of the previous results, we projected the imperative need to contemplate flexible dikes in three strategic zones, such as Agua Salada Creek, Antioquia Creek and the lower part of Carachacra Creek.

After the discussion of the conceptual flow model and the technical characteristics of the flexible levees, it was suggested the implementation of the UX 120-H6 model with a height of 6.8m, a fill length between 42 to 70 m, and a variable width between 24 to 42m, this geometry would be adequate to contain the volume of this mixture for a 500-year event, obtaining a height of 4.5m, velocity 2m/s and impact force of 63KN/m.

Keywords**:** Non-Newtonian flow; flexible dikes, Flo-2d, conceptual model, Carachacra Creek.

1. Introduction

The huayco flows are a common problem for the population located in the lower part and edge of the Carachacra Creek in the district of Santa Cruz de Cocachacra-Province of Huarochirí, the destruction and loss of lives caused by this natural phenomenon has not been solved by the authorities so far, because they have not implemented alternative solutions based on science and particularly in civil engineering.

In this sense, the objective of this research is the design of dynamic barriers based on the results obtained from Flow-2d, and the strategic location of these barriers according to factors such as speed, depth and impact force of the huayco flow.

Francisco de Jesús Chacón García (2012) "Barreras Dinámicas a Base de Materiales Convencionales para el Control de Caídas de Rocas", the general objective of this research is to develop a rational methodology applicable to design guidelines, generalized plans, construction specifications and optimization of resources in dynamic barriers to control rockfall on slopes.

In the research conducted by Carol Delgado and Guiliana Tamayo (2020) "Comprehensive management plan to reduce damage caused by landslides, El Pedregal stream, Chosica", where the aim is to reverse the existing situation through the implementation of structural and non-structural correction and prevention measures being formulated in a Comprehensive Management Plan that allows the reduction of vulnerability, which in turn will reduce the risk.

In this regard, L. Zhao (2020) "Coupled numerical simulation of a flexible barrier impacted by debris flow with rocks at the front", where a two-stage coupled modeling technique that can account for debris mobility, nonlinear behavior of a flexible barrier and dynamic interaction between flexible barriers and debris flows is developed, firstly, based on the Arbitrary Lagrangian-Eulerian (ALE) method using LS-DYNA.

Also, Dao-Yuan (2020) "Experimental study on the impact and deposition behaviors of multiple debris flow surges channeled into a flexible barrier", in which, three continuous debris flow impact tests were conducted to investigate the performance of a flexible barrier affected and overflowed by multiple debris flow surges. In this study, a parameter called

Initial Block Rate (IBR) is introduced to describe the initial condition of a flexible barrier filled by previous debris flow surges.

Finally, the research we have presented on dynamic barriers has provided everything from methodologies to optimize this technology to tests to investigate its performance.

2. Dynamic barrier analysis

2.1. Data collection

The braking elements made it possible to contain debris flow displacements with energy dissipation by the simultaneous work of friction. It was the first time braking elements were used with steel cable nets for rockfall mitigation. Bolliger and Heierli were able to apply for a patent for these rope brakes in 1975. Different braking elements with various forms of execution were introduced on the market: 1979 there are reports that in France, they were used as braking elements; 3 steel plates arranged on top of each other. At a braking distance of 6 m for almost a linear energy absorption of 160 kJ over the braking distance. It should be noted that from that time to the present they have been improving in their design and performance, their components being the following:

- Perimeter cable: Horizontal cable whose function is to keep the net upright and to transmit the forces of the net to the posts.
- Energy dissipator or brakes: Elements in charge of absorbing part of the energy caused by rock impact, transforming the kinetic energy into elastic deformation. These dissipators of various types such as: friction, shear, deformation or fracture.
- Capture network: Supports the rock impact through elastic deformation and/or plastically transmitting the stress to the rest of the barrier.
- Support structures: Posts anchored to the ground that allow the catchment net structure to remain upright or in its design position.
- Anchorage:

They are elements that work under tension, their objective is to increase the resistance of the massif, joining the discontinuities by associating the weight of the surrounding soil to the whole. Normally they are constituted by metallic reinforcements that are lodged in perforations in the ground, at the bottom of which they are fastened or anchored by means of injections or expansive mechanical devices, the exterior being fixed to the structure whose stability is to be improved or to plates that are directly supported on the surface of the ground.

Fig. 1: Dynamic barrier example.

2.2. Type of dynamic barriers

- **Dynamic barrier UX:**

The UX series offers debris flow barriers for wide channels composed of ring networks that are capable of withstanding high static and dynamic loads. The barriers act against torrential floods by retaining solid, dynamically impact resistant and water permeable materials.

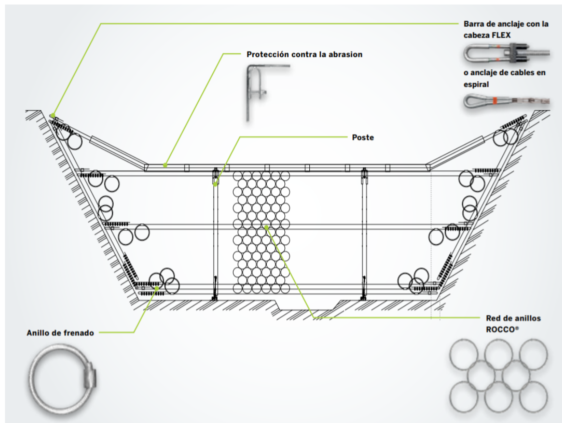

Fig. 2: Components of a UX barrier.

- **Dynamic barrier VX:**

The VX series is used in gullies or narrow channels, where the height of the barrier can be guaranteed without the use of posts. These debris flow barriers are composed of ring nets that are capable of withstanding high static and dynamic loads.

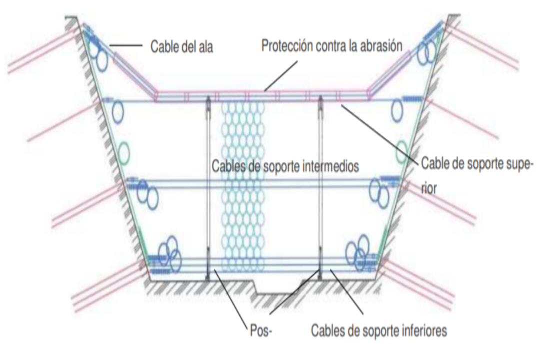

Fig. 3: Components of a VX barrier.

2.3. Conceptual model

According to the characteristics of the non-Newtonian fluid flow of the Carachacra stream, it was determined that the Flo-2d model was the most appropriate method to perform this simulation, which considers homogeneous fluids, but of variable concentration. As inputs to perform this simulation it is necessary to define the rheological parameters such as the coefficient and exponents:

$$\mu = \alpha e^{\beta C} \quad \tau_y = \alpha e^{\beta C} \tag{1}$$

Where:
Cv: Concentration in volume of the mixture
μ: Dynamic viscosity (Pa.s)
τ_y: Yield stress (Pa)

It should be noted that for the results to be accurate, a high resolution elevation model is required, being its most important results the height, velocity and impact force reached by the flow in each of the cells throughout the simulation.

In this sense, taking into consideration the above-mentioned inputs, we have:

Table 1: Yield stress and viscosity.

Source	$\tau_y = \alpha e^{\beta C}$		$\mu = \alpha e^{\beta Cv}$	
	α	β	α	β
Field measurements				
Aspen Pit 1	0.181	25.70	0.036	22.10
Aspen Pit 2	2.72	10.40	0.0538	22.10
Glenwood 2	0.0765	16.90	0.0648	19.90
Glenwood 3	0.000707	29.80	0.00632	19.90
Glenwood 4	0.00172	29.5	0.000602	33.10
Correlations available from the literature				
Lida (1938)	-	-	0.0000373	36.60
Dai etal (1980)	2.60	17.48	0.00750	14.39
Kang and Zhang (1980)	1.75	7.82	0.0405	8.29
Qian etal. (1980)	0.00136 0.050	21.20 15.48	- -	- -
Chien and Ma (1958)	0.0588	15.48	-	-
Fei (1981)	0.0047 0.166 0.0047	19.1-32.7 25.60 22.20	-	-

3. Numerical model results

Taking into consideration each of the parameters of the Flo-2d model, we obtain the following maps as a result:

From the maximum flow depth map (see Figure 4 for a Tr = 500 years), it is concluded that the flow depth in the Carachacra Creek has a variation between 0.5 and 4.5 meters.

From the maximum flow depth map (see Figure 5 for a Tr = 500 years), it is concluded that the maximum flow velocity in the Carachacra Creek has a variation between 0.2 to 2.0 m/s.

From the map of the maximum depth of the flow (see Figure 6 for a Tr = 500 years), it is concluded that the impact force of the flow in the Carachacra Creek has a variation between 6988.6 to 62897.3 N.

The results for a rainfall event considering 500 years, without the dynamic barriers, are shown below.

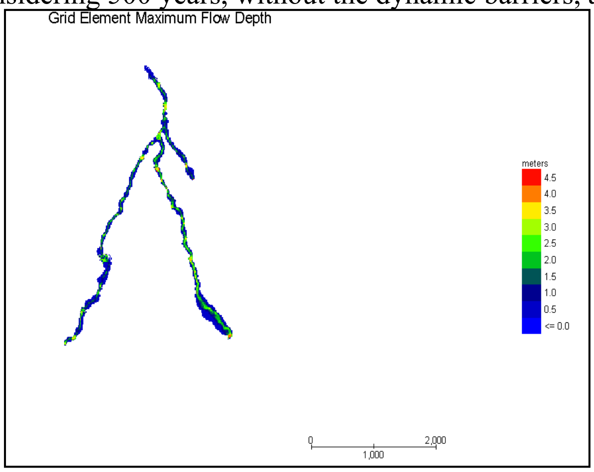

Fig. 4: Map of flow depths for 500 years.

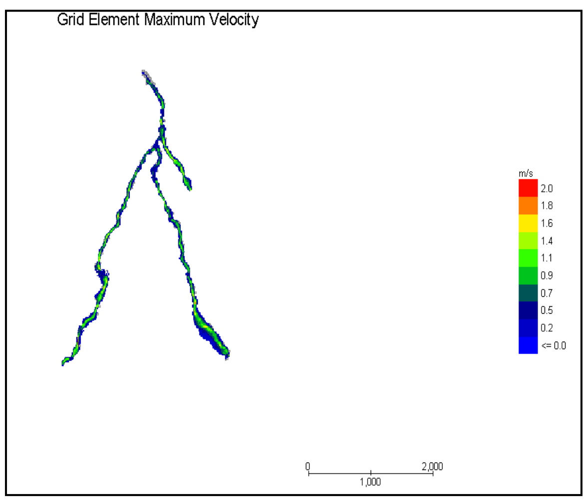

Fig. 5: Map of flow depths for 500 years.

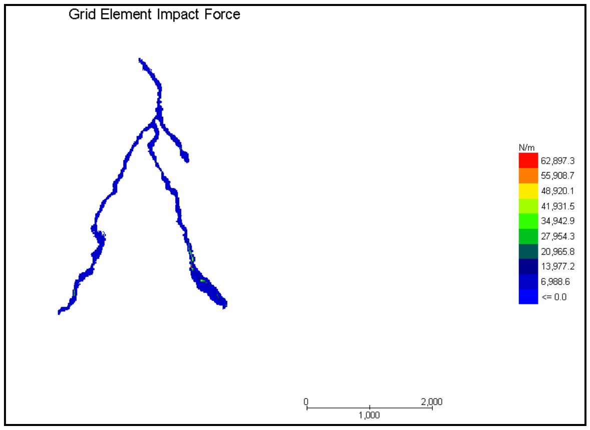

Fig. 6: Map of flow depths for 500 years.

The results for a pluviometric event considering 500 years, with dynamic barriers, are shown below.

The system to be implemented according to the results obtained from the Flo-2d model as height of 4.5 m, speed of 2.0 m/s and impact force of 62,897.3 N, consists of installing 3 Dynamic Barriers against debris flows in the Carachacra Creek in the District of Santa Cruz de Cocachacra Province of Huarochiri in the following strategic areas (see Figure 7 an 8).

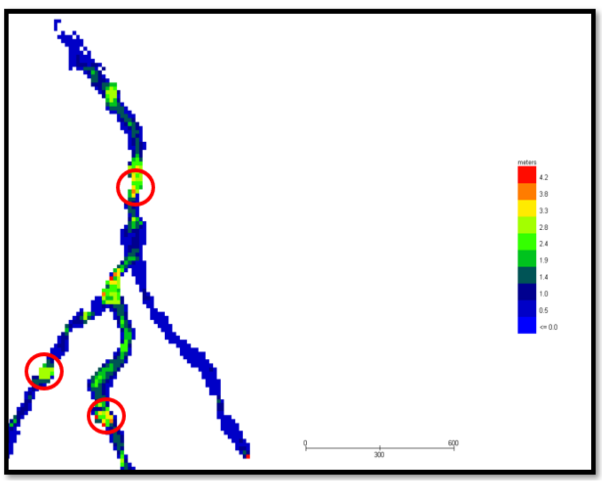
Fig. 7: Results of the model considering the barriers.

Fig. 8: Satellite image location of the barriers.

4. Conclusion

Applying the Flo-2d numerical model in the Carachacra Creek discharge zone for a return time of 500 years, according to the results of depth is 4.5 m, maximum velocity of 2.0 m/s and impact force of 62,897.3 N, the most adequate dynamic barrier model for this type of parameter is the UX 120-H6 model of the Geobrugg company.

According to the analysis developed, the three dynamic barriers will have a total containment of 18,293 m³ in the Carachacra Creek.

According to the height of the debris fluid in the Carachacra Creek and placing a safety factor, the heights of the dynamic barriers should have a height of 6.8 m.

Before being placed, the dynamic barriers should have preliminary studies and information such as: size of the riverbed, soil mechanics study, topography plans, probability of landslides, height of debris flow, velocity.

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References

[1] Dao-Yuan, Jian-Huan Yin, Jie-Qiong Qin, Zhuo-Hui Zhu, Wei-Qiang Feng, « Experimental study on impact and deposition behaviours of multiple surges of channelized debris flow on a flexible barrier» Landslides, 2020.
[2] D. Song, C.E. Choi, C.W.W. Ng, Gordon G.D. Zhou, J.S.H.Kwan, H.Y. Sze, Y.Zheng « Load-attenuation mechanisms of flexible barrier subjected to bouldery debris flow impact» Landslides, 2019.
[3] Song Dong-ri, Zhou Gordon G.D. Choi Clarence Edward, Zheng Yun, « Debris flow impact on flexible barrier: effects of debrisbarrier stiffness and flow aspect ratio» Jounal of Mountain Science, 2019.
[4] Geobrugg. Barrera de protección contra corrientes de detritos UX: La solución efectiva para torrentes anchos. (2009).
[5] Takahashi, T. Debris flow. International Association for Hydraulic Research. Rotterdam: Balkema A. (1991).
[6] Suarez J. Control y erosión en zonas Tropicales Bucaramanga. Colombia: Instituto sobre Erosión y Deslizamiento-Ingenieria de Suelos (2001).
[7] Melo, Raquel; Van Asch, Theo; Zêzere, José L. (2018) Simulación y análisis de agotamiento del flujo de escombros utilizando un modelo dinámico, 555-570p.
[8] Brunkal, Holly; Santi, Paul (2017) Consideración de la validez de los factores de aumento de volumen del flujo de escombros, 291-298p.
[9] Ding, Mingtao; Huang, Tao; Zheng, Hao (2020) Influencia respectiva de la diferencia vertical de las montañas en la ocurrencia del flujo de escombros en el río Upper Min, China, 1-13p.

[10] Zeng, Qing-Yung; Pan, Jian-Ping;Sun, Han-Zheng (2020) Simulación SPH de estructuras impactadas por el flujo de escombros de relaves y su aplicación al análisis del efecto amortiguador de presas de control de escombros, 1-17p.
[11] Ren, Diandong; Leslie, Lance M. (2020) Mejora del calentamiento climático de los catastróficos flujos de escombro del sur de California, 1-10p.
[12] Ding, Mingtao; Heise, Micha; Hübl, Johannes; Fusch, Sven (2015) Evaluación de la vulnerabilidad regional para los flujos de escombro en China: un enfoque de CWS, 537-550p.
[13] Enok Cheon, Seung-Rae Lee y Deuk-Hwan Lee (2020), Evaluación de peligros basada en la combinación del DAN3D y el método de aprendizaje automático para planificación de barreras de tipo cerrado contra el flujo de escombro, 1-24p.
[14] LE, M.H.; HAN, Q.W.; FANG, C.M.; GUAN, J.Z. (2019), Un marco para la evaluación de peligros de las áreas de acumulación de flujos de escombros, 6255-6267p.