Integrated approaches in Torrent Hydraulics and Debris flow assessment using physically-based modelling

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In the study of river hydraulics today must take into account many important factors judiciously tools in computational fluid dynamics (CFD). It is no longer acceptable to solve an engineering problem or conduct prevention and rural-urban planning in valleys with rivers and creeks by using empirical formulas in general cases, therefore it has to be carried out a detailed study of morphological processes in rivers and determine deposition patterns, hydrodynamic details, erosion and sedimentation in a pragmatic way and integrating physically-based modelling and empirical relations.

Most of the flash floods and debris flows (Huaycos) occur during the rainy season, between December and April in peruvian slope and coast. In years of El Niño, the number and magnitude of these mudflows increases, due to the intense rains that fall on the coastal basins, putting into activity many streams and torrents, and in some cases damming the river to which they discharge its flow. The huaycos devastate homes and crops, destroy stretches of roads and sanitary infrastructure.

The first case study is the Hualapampa river, tributary of the Huancabamba river by its right margin, in which the hydrological analysis and the contribution of sediments will be carried out. Through hydrodynamic modeling, the flow conditions (water levels and discharges) will be studied in the Hualapampa stream for different hydrological scenarios and under existing topography conditions. For protection purposes, it is planned to know the hydraulic scenarios of the riverbank protection alternatives, performing simulations by placing gabions in the margins, and raising possible modifications to improve the flow conditions.

In the numerical modelling part, the case aims to the use of CCHE2D model to simulate the hydrodynamics of the Hualapampa river in the vicinity of New Hualapampa city and Federico Belaunde Terry highway to flow generated by exceptional events. The elements to be included in the study area are riverbank defenses on unstable slopes serving as protection in the vicinity, as well as the piles and abutments belonging to the bridge of that road. Sediment transport of non-uniform mixtures of sand and gravel by using SEDTRA module was simulated in order to assess possible areas of sedimentation and lowering the level of the background to determine adequate hydraulic capacity or imply riverbed-cleaning works.

Fig.1 – Hualapampa Rivers and tributary streams, as well as F. Belaunde Highway and its bridge.

The area to be simulated was established according to the topographic survey carried out during the development of the project, comprising a section of 1km of the creek in the town of Hualapampa. For the representation of the geometry of the bed and banks was taken as information base topography (basically x,y,z coordinates). The representation of the geometry of the bed in the environment of the CCHE2D model consists of the creation of a quadrilateral finite element mesh that allows to adequately approximate the solutions of the governing equations of the two-dimensional flow. The process begins by building the bottom of the bed. This is done through the module CCHE2D MESH, after discretization of the domain with a suitable mesh with which the interpolation is executed to generate the initial background or ground level.

We must keep in mind that the sub-basins to be analyzed mostly correspond to streams with little hydrological activity and that in the presence of extraordinary phenomena such as the phenomenon of "El Niño" they show great activity. It is taken into consideration that the estimation of maximum flows by different methods is in accordance with what was observed in the field evaluation.

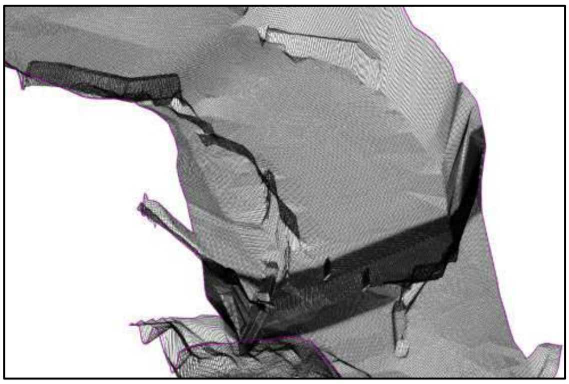

Fig. 2 – Computational mesh of the studied river reach and tributary creeks, with riverbank protections.

In accordance with the national and international technical recommendations, a 22% admissible risk was considered for the design of protections. Product that this structure directly commits the beneficiary population, even more if there are slopes and unstable channels upstream and downstream of the the bridge found during visits to the area and with the occurrence of extreme events such as the El Niño Phenomenon. the dimensioning a useful life of 15 years and a return period of 100 years which will be the base data for the simulations. The following table indicates the area of tributaries, the liquid flow and unit solid by a width B, as well as the average diameter, bottom slope and energy:

TRIBUTARY	Area (km^2)	Q (m^3/s)	B (m)	q_s ($m^2/s/m$)	D_{50} (mm)	S	$S_{f\,100\,years}$
AGUA SALADA	7.03	84.63	25	3.38	0.41	0.11	0.24
RINCÓN	39.71	58.93	68	0.86	0.49	0.05	0.022
BOQUILLA	0.13	7	5	1.4	1.66	0.14	0.004
RAVIJA	30.11	38.81	65	0.59	2.11	0.06	0.02
CONGOÑA	187.34	259.15	32	8.09	1.86	0.003	0.003

Table 1 – Characteristics of Tributary creeks. Q is discharge, Qs is solid discharge, D50 material in mm, S is slope in m/m, B is average width and Sf is friction slope in m/m.

The results of the velocities in the following figure suggest an adequate protection of the elements to the unstable slopes in the vicinity of the city of Nuevo Hualapampa and near the alluvial fans of the contributing creeks. On the margins near the Hualapampa bridge the speeds they diminish with formation recirculating flow areas, which guarantees the correct functioning of the adjacent defenses, protecting the structure and contiguous slopes.

The defense located on the right side of the outlet of "Ravija" tributary creek has velocities of up to 1.6 m/s being the largest relatively to the other defenses located in other sections of the channel. In front of the "badén" creek, there are the highest values of deposition in the section of the evaluated channel, with localized deposits that are the result of the sedimentary contribution of "boquilla" creek and "agua salada" creek, transported by the runoff of the Hualapampa creek.

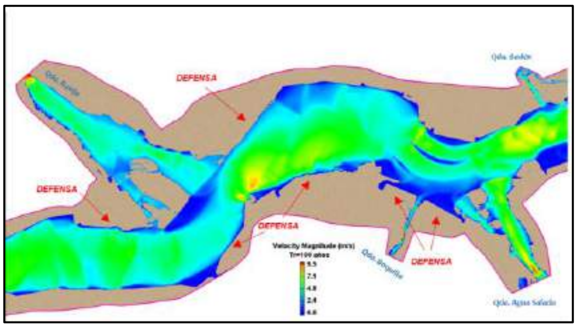

Fig. 3 – Velocity map of Hualapampa River in 100-year flood scenario.

In the left margin and abutment of the bridge, there is a relative increase of deposition with a value of up to 1.6 meters, it would be expected a decrease in the hydraulic capacity of the section of the channel and therefore a decrease in the free edge between the bridge superstructure and the water surface which should be mitigated with the use of sediment control measures in tributary basins or cleaning works in the analyzed river reach.

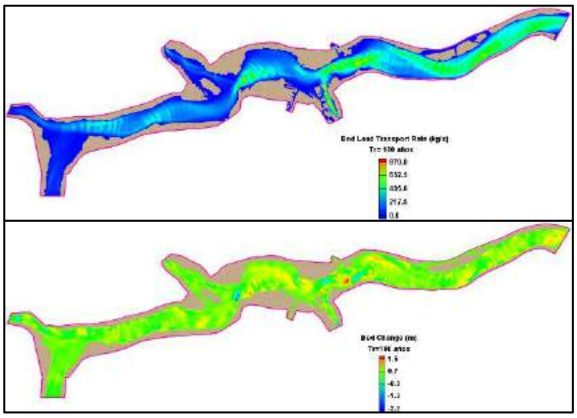

Fig. 4 – Bed load transport rate (Kg/s) and Bed change (meters) maps for the study case in 100-year flood scenario.

The second study case related to debris flow assessment is Sahuanay Creek, located in Chuyllurpata mountains, in the area of the National sanctuary of Ampay specifically on the southern side of a Mountain with the same name in the Vilcabamba Mountain range at the southeast Andes of Peru. Politically, it belongs to Tamburco District, Province of Abancay, capital of the Region of Apurimac.

The main objective is to study and interpret the hydraulic behavior of the debris flow occurred in Sahuanay river in order to identify, analyze and make zonification the affected areas along the creek including the urban area involved and areas of expansion that are threatened for possible reactivations and similar events in the river and establish recommendations for prevention and mitigation projects in the entire area of influence. To study the hydraulic behavior of this geomorphological process, the physically-based model FLO-2D will be used to define its advantages and limitations in the development of the work, previously gathering basic information of the basin of the stream and obtaining as results hydraulic parameters in the channel as well as the volume of deposited material. The consequences of possible debris flows in the Sahuanay creek that could affect the city of Tamburco in different hydrometeorological scenarios will be evaluated, from which hazard maps in an integrated approach using empirical relations following the criteria established by Bertoldi et al. (2012).

According to Hampton (1972) the mud and debris flows are the result of some form of collapse in the slope. The debris that falls like a slide collects moisture and moves along the slope, it liquefies or expands as it advances, increasing fluid mobility. According to Iverson (1997) mud and debris flows occur when masses of sediment poorly graded, agitated and saturated with water, fall precipitously due to the pull of gravity. Bardou (2003) characterizes the debris flow through an arrangement of fine sediments in the tail and body of granular material greater than 4 mm, with a head of blocks up to 10 m, after the event the fine material is deposited in the upper part. deep and the granular material is exposed on the flanks.

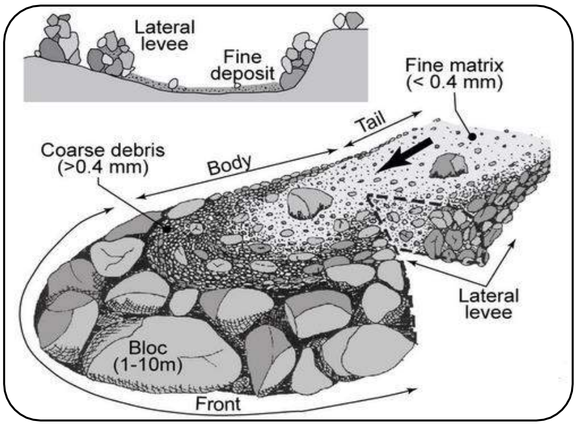

Fig. 5 – Isometric profile of a debris flow and cross section of the creek after its passage according to Bardou (2003).

The debris flow that affected the district of Tamburco, originated in the foothills of the Chuyllurpata mountain due to the generation of a landslide on the right bank of the Sahuanay stream, affecting materials previously removed by the 1951 landslide of the same sector. The event can be considered as a partial reactivation of the old landslide in mention.

Fig. 6 – Sahuanay river basin and some pictures of the debris flow event in March 18, 2012.

The main event was in March 18, 2012. When arriving at the low part, and after affecting some houses, 80% of the transported material was deposited in the depression that constituted the Maucacalle stadium, from there the flow changed its behavior and turbulence to a mass movement type flooding of detritus (INGEMMET, 2012), which went down the narrow channel of the Sahuanay creek affecting houses that were near the channel of the same.

Topographic maps at 1: 50,000 scale and a 1: 10,000 map with curves every 0.5 m have been used. The first plane has been used for the delimitation of the basin and the calculation of the geomorphological parameters, and the second, has been used for the hydraulic modeling of different scenarios of debris flow. The distribution of concentration in volume, the granulometric, plastic characteristics and rheological parameters of the material were introduced derived from soil pits and using the Atterberg (liquid and plastic) limits in comparison with the collected samples of O'brien and Julien (1988). The two-dimensional FLO-2D model was then applied considering a detritus concentration variant of 20% to 45%, average value from the concentrations obtained in the flow during the event. Rainfall hourly hyetograph was obtained from ABANCAY station located near to the Sahuanay River.

The liquid hydrograph obtained from hydrological modelling using HEC-HMS model which reproduced the rainfall event and generate the discharges. Predicting runout using mathematical models typically produce sharp boundaries for flow intensity that may lead to a false sense of accuracy (Bertoldi et al., 2012), so from this moment a sensitivity analysis is carried out and explained for

FLO-2D model changing the rheological parameters and mesh cell size.

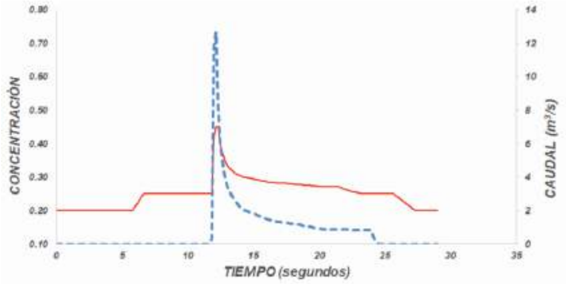

Fig. 7 – Liquid and Solid Hydrograph for 5-year debris flow scenario.

Overall, from the results observed for the Sahuanay river, is seen in the upper part a greater presence of flow depths ranging from 4 to 5.6 meters in the scenario of 5 years while in the scenarios of 10 and 50 years has a slight variation to 5.7 and 6 meters maximum. The presence of the Run-Up is also observed at both margins of the channel in all the scenarios and whose braces increase in longitudinal direction. In the lower part of the stream we can see strata of the flow of 2 meters and that decrease as the debris floods up to 50 centimeters.

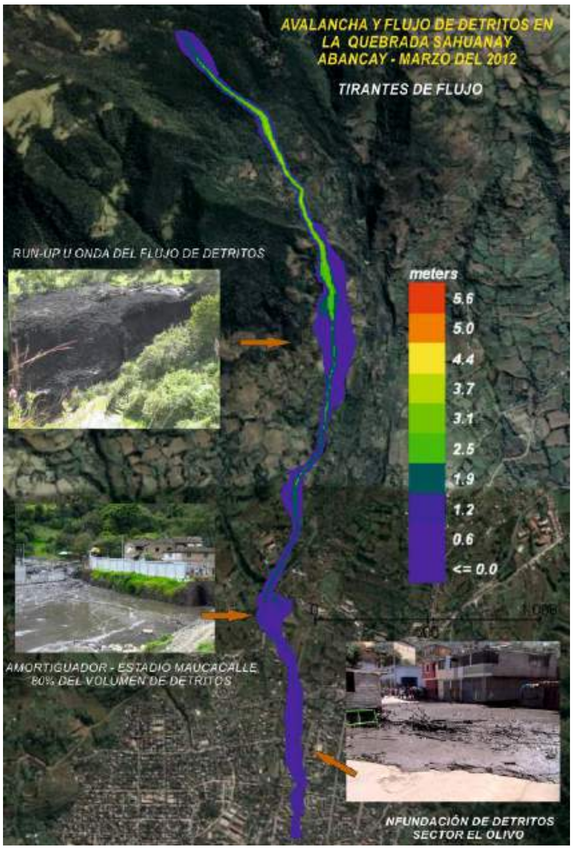

Fig. 8 – Depth map for 5-year debris flow scenario, similar to the occurred event in March, 2012.

The heights of the flow have been compared with the field evidences and the behavior of the simulated flow for the 5-year scenario has been similar to the control points within the stream. On the other hand, in the area of damming the material of the Maucacalle stadium, there is a recirculating area with low speeds. In the realization of the hazard maps High intensity (red color) with flow straps greater than 1.5 meters, medium intensity (orange color) with flow straps between 1.5 and 0.5 meters and low intensity with straps less than 0.5 meters. This methodology is used in different studies of mud and debris flows.

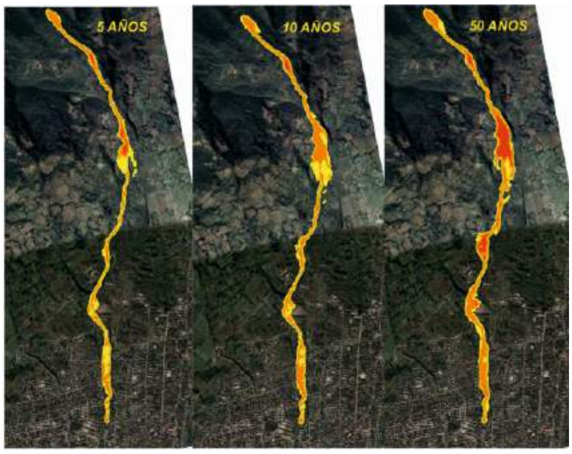

Fig. 9 – Hazard intensity maps for 5,10, 50-year debris flow scenarios.

In conclusion, the results show that the theoretical model regarding debris flow depends in large part on the criteria used to determine data or parameter. The purpose of this work was to delimit the most appropriate criteria for design conditions in similar circumstances. The analysis of debris flows is a subject of current research and has not yet achieved a model that takes into account all the factors involved in the phenomenon, which is why we resort to simple rheological models, such as the two-dimensional model FLO- 2D

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