Debris Flow Characteristic along the Main Channel with Structures in the Arenal de Mejicanos, San Salvador, El Salvador.

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ABSTRACT

El Salvador is a vulnerable country to water/sediment related disasters. Arenal de Mejicanos is considered historically as one of the hazardous basin due to debris flows. In order to mitigate the disasters induced by debris flow it is important to focuses on two main points 1) to define the debris flow capacity of the main channel, and 2) to understand debris flow characteristic in the main channel. This study applied a 1D numerical model for debris flow simulation based on the governing equations of mass/momentum conservation of water/sediment mixture flow and mass conservation of bed sediment. The simulation results indicates that channel has enough capacity to carry the sediment of debris flow in the upper part. In the downstream part, the capacity of the channel decreases by the structures e.g. bridge and underpass and debris cannot pass through the channel. Subsequently, inundation by the flood water takes place around upstream side of the bridges. Therefore the objective of this study is to propose a systematic countermeasure, in order to prevent damages by debris flow event.

Keywords: Debris, capacity, management, sediment, structures.

INTRODUCTION

Arenal de Mejicanos, is one of the basin involving the San Salvador Volcano which historically has been vulnerable of debris flow. The largest disasters are related to Debris flow event due to heavy rainfall e.g., the first one occur in 1934 with 2,125,000 m3 of debris volume; the other event occur in 1982 with 425,000m3 of debris volume (Kiernan y Ladru) that buried many houses, and caused casualty of almost 500 people. (USGS). Recently the structures like bridges and underpass constructed along the channel of the basin, but not property designed concerning about hydraulic capacity. Actually, when the debris flow occurred, those structures (bridges) cause the clogging of the debris flow. Based on this the authors thought magnitude of the recent debris flow diminished.

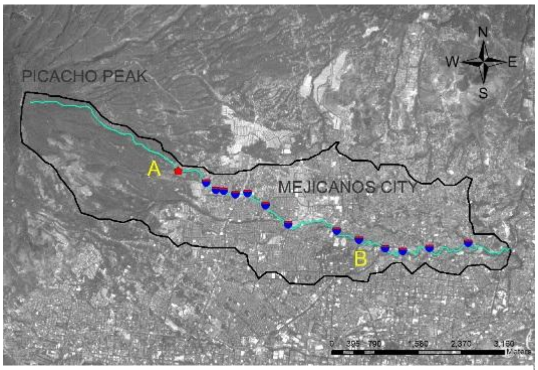

Figure 1 Basin Arenal de Mejicanos and the Structures along the main channel.

METHODOLOGY

Using a 1D numerical model based on the governing equations are employed to compute the debris flow characteristic. Mainly applying 4 inputs: 1) the discharge calculated for 10 and 200 years return period, 2) several grain size (0.1, 0.2 and 0.4 m) including mud flow 3) Natural riverbed profile, and 4) erosion depth of 5 m.

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Mass conservation equation for debris flow is divided into water-sediment mixture, and sediment:

$$\frac{\partial h}{\partial t}+\frac{1}{B}\frac{\partial \bar{u}hB}{\partial x}=\frac{E}{c_*} \qquad (1) \qquad\qquad \frac{\partial \bar{c}h}{\partial t}+\frac{1}{B}\frac{\partial \gamma\bar{c}\bar{u}hB}{\partial x}=E \qquad (2)$$

Where h is flow depth, $\bar{u}$ is averaged velocity, B is the channel width, E is erosion rate or erosion velocity, C_* is the sediment concentration of the stationary sediment layer, $\bar{c}$ is the spatial average sediment concentration, and γ correction parameter for the sediment transport rate.

The momentum equation is

$$\frac{\partial h\bar{u}}{\partial t}+\frac{1}{B}\frac{\partial \beta h\bar{u}\bar{u}B}{\partial x}=-gh\frac{\partial H}{\partial x}-\frac{\tau_b}{\overline{\rho_m}} \qquad (3)$$

And

$$H= z_b + hcos\theta \qquad (4)$$

Where t is time, x is the coordinate along the flow direction, h is the flow depth, θ is the bed slope, $\bar{u}$ is the spatial average velocity, B is the flow width, z_b is the bed elevation measured from a datum line, g is the acceleration due to gravity, E is the erosion rate or erosion velocity, τ_b is the bed shear stress, $\overline{\rho_m}$ is the mass density define as $\overline{\rho_m} = (\sigma\text{-}\rho)\ c + \rho$, σ is the mass density of sediment particle, ρ is the mass density of the water including fine sediment, and β is the momentum correction factor and H is the elevation of the free surface of the flow body.

The formula of only fluid type shear stress is employed, with assuming the debris flow is dominated by turbulent flow:

$$\tau_b = \rho f_b(\bar{u}^2+\bar{v}^2) \qquad (5)$$

Where f_b is the friction factor related to the fluid motion. With $f_b = 71\alpha^2$ and where α= Kc/σ

The procedure to obtain the channel capacity is according with the estimated slope, which depends on the critical bed slope θ_c, assuming the sediment is in equilibrium state we can obtain the value considering the bed slope as follow:

$$\tan\theta_c = \frac{\left(\frac{\sigma}{\rho}-1\right)c}{\left(\frac{\sigma}{\rho}-1\right)c+1}\tan Ø \qquad (6)$$

Where σ is the mass density of sediment particles, ρ is the mass density of water, θ is the inclination angle of the slope, Ø is the internal friction angle of sediment particles, and c is the sediment concentration by volume and can be estimated as $\frac{c_*}{2}$

With assuming the uniform flow following equation can be obtained from equation (3).

$$v^2 = \frac{\left[\left\{\left(\frac{\sigma}{\rho}-1\right)c+1\right\}\right] gh\sin\theta-\left[\left(\frac{c}{c_*}\right)^{\frac{1}{5}}\left(\left(\frac{\sigma}{\rho}-1\right)c * cos\theta * tanØ\right)\right]}{f_b}gh \qquad (7)$$

With equation (7), the H-Q relation curves can be obtained at each section as different slope angle as well as the different shape of the section. For example, Figure 2a shows the picture in a section as an open channel with a bed slope of 16 degrees.

	
Figure 2a Picture in Arenal de Mejicanos in a section with bed slope of 16 degrees	Figure 2b Picture in Arenal de Mejicanos in a section with bed slope of 10 degrees

Firstly with velocity of debris flow can estimated with different h. Thereafter, area of the debris flow can be obtained. With combining the velocity and area, debris flow discharge can be obtained with different h. On the other hand, Figure 2b shows a section with the bridge. In this case, hydraulic radius are implemented to estimate velocity for concerning about the pipe flow. Regarding of the types of section, the section from 1 to 4 are mostly open channel, whereas the section from 5 to 8 have bridges and the underpass. Therefore, the calculation of the hydraulic radius are not same with the different types.

RESULTS AND DISCUSSION

In order to create different scenarios of the debris flow, simulation with several grain size (0.1, 0.2 and 0.4 meter and mud flow) with different rainfall return period has conducted. Figure 3 shows the time series of depth and discharge of debris flow, and river bed elevation at the point A as shown in figure 1 which is 1,500 m downstream from the upper boundary with a bed slope of 12° and a grain size of 0.1 m. As this figure indicates, the debris flow reached at this point within 200 seconds. Then celerity of the debris flow can be estimated as 0.93 m/s. After it reached to the point, water depth reached to 2.5 m and debris flow discharge 140 m3/s.

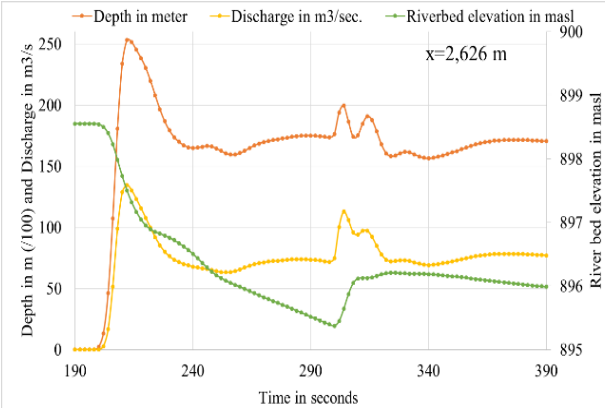


Figure *3 Debris flow characteristic for a return period of 10 years and grain size of 0.1*

Thereafter, water depth increased to 2.5 m and gradually decreases till 1.7 m. The debris flow discharge correspond to the same trend. Concerning about the river bed elevation, initially it is 898.7 (meters above sea level, masl), and starts to decrease because of riverbed erosion take place by the debris flow. Therefore, about 2.3 m of erosion takes place at this point by the debris flow.

Figure 4 shows the time series of depth and discharge of debris flow, and river bed elevation at the point B as shown in figure 1 which is 4,000 m downstream from the upper boundary with a bed slope of 8° and grain size of 0.1 m. In this section, debris flow reached at this point within 1,300 seconds. Since the point is, maximum celerity of the debris flow is about 0.4 m/s. Thereafter, water depth increased to 0.6 m and keeps increasing till 3.0 m. Concerning about the river bed elevation, initially it is 711 (meters above sea level, masl), and starts to decrease because of riverbed erosion by the debris flow. Thereafter, about 9 m of deposition takes place at this point by the debris flow.

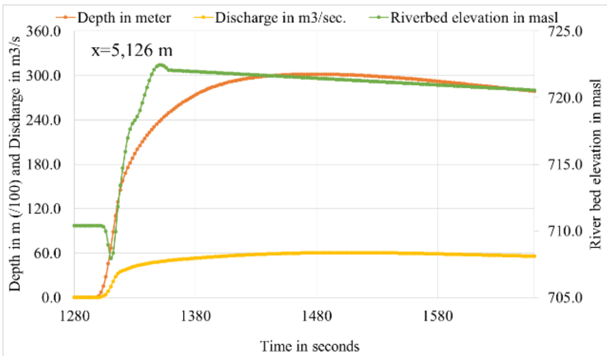


Figure *4 Debris flow characteristic for a return period of 10 years and grain size of 0.1*

Figure 5 shows the comparison between the obtained channel capacity by the equation (7) and the results from the numerical simulation with boundary condition of10 and 200 years. Furthermore each point of the graph is representing a cross section where the river structure locates along the main channel, each section was determine according with the river bed slope, the slopes 18°, 16°,14°, 12°, 10°, 8°, 6° and 4°. Figures shows in the y direction, the value of discharge m^3/s for each return period and for the calculated channel capacity and also in the x direction shows the length and location in meters.

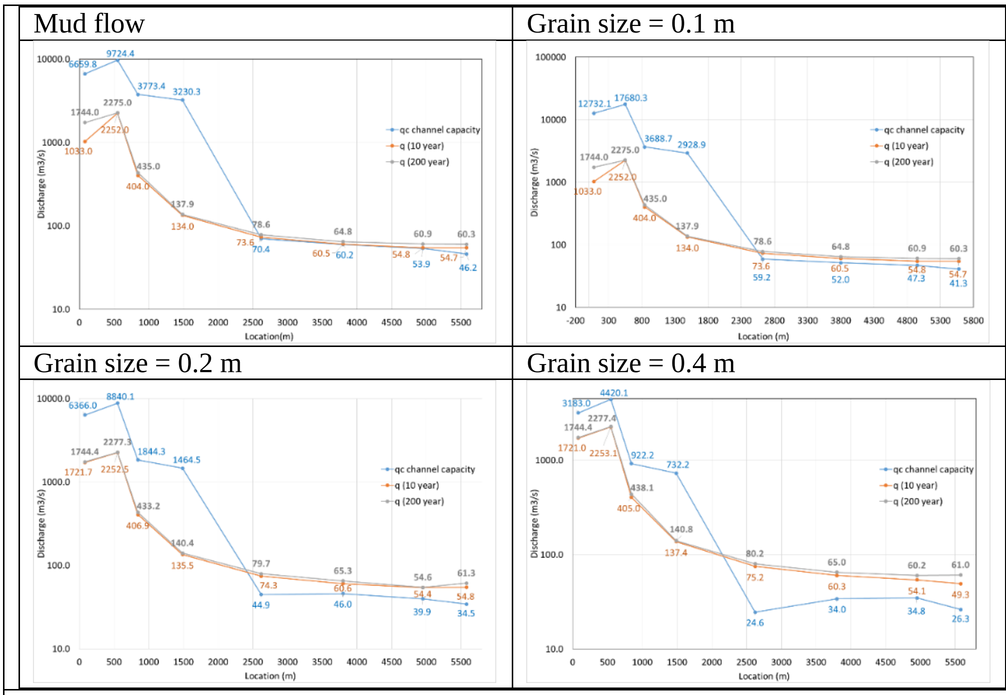


Figure 5 Comparison of the channel capacity vs. Simulation results obtained for 10 and 200 years return period.

As figures indicate, those four cases show similar trend, though sediment size is quite different. Those characteristics are following. Q10 and q200 values do not show much difference. They have a maximum discharge values at the second section. The maximum values are about 2,200 m3/s. The values at each point gradually decrease as it goes to downstream. Regarding to qc, they have larger values in the upper section, whereas they have smaller values in the lower section. Compared with q10/q200 and qc, upper sections always enough capacity, though they do not have in lower section. The figures clearly suggests that channel does not have enough capacity for the debris flow, and river structures is main reason for it. It should be highlighted that the clogging by the actual debris flow also occurred at this section.

With this problem in the basin is very important and urgent to propose a Sediment Management System, that consider not only the short time solutions but also the long time, and also it has to consider the structural and non-structural countermeasures, in order to prevent more damage in case of hazard.

Expected Management in Structural Changes

Debris control dams

Sabo's works can stabilize sites, and are a great contribution to all problem and the disasters that occur due to sediment transport, reducing also flooding in downstream areas. The principal objective is to retain certain volume of sediment that is transport since the mountainous area in the beginnings of the river, achieving trapping sediment that could damage downstream infrastructure is achieved also reduce flooding downstream. Sediment deposition of sabo dam should be larger than designed total sediment discharge of debris flow. When the space behind a Sabo dam is not enough large to capture all of the designed sediment discharge of debris flow, several sabo dams should be planned to capture all of the designed sediment discharge of debris flow. In this case, total designed sediment deposition volume of several sabo dams should be larger than the designed sediment discharge of debris flow. (Katsuo Sasahara, 2013)

The shotcrete is one of the most useful techniques in El Salvador in order to control de Landslides movements in the upper part of the basin which is very important and clue part to control the problems downstream, solution for the control of sediment most include this structural countermeasures that in most of the cases are made of concrete or even steel, which make them very expensive to construct or even to give them the maintenance needed to create a good control of sediment.

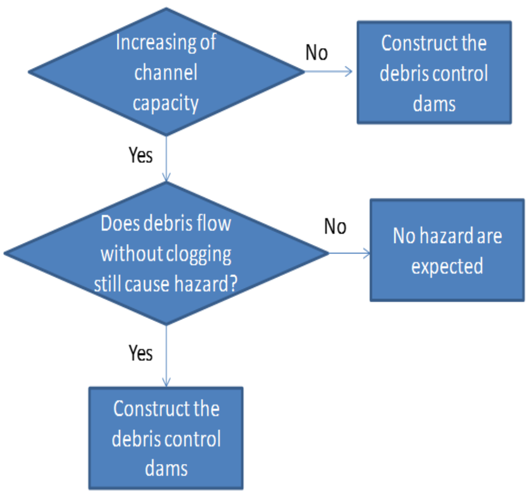
CONCLUSIONS

1) Debris flow characteristic are evaluated along the main channel Arenal de Mejicanos, assuming mud flow and debris flow with several sizes of sediment taking place.
2) Channel capacity are realized in order to obtain information for sediment management
3) Predicted channel capacity is the largest for mud flow, and it decreases with increase of sediment size. The present channel capacity is lower than the expected mud flow, assuming even if sediment deposition does not take place.
4) It is realized that river bed aggradation takes place actively due to sediment deposition in the urban area. Correspondingly channel capacity is much lower than the capacity evaluated in terms of cross section area.
5) When we conducted the sediment management, deficiency of cross sectional area and decrease of channel capacity due to sediment deposition must be taken into consideration.

RECOMMENDATION

For this study, it is clearly understood that the river structures are the main cause of clogging the debris flow, then the clogging induce the inundation. To eliminate this kind of hazard, and with the knowledge is able to propose a systematic countermeasures to decrease the effects of this natural hazard:

- Determine the real size of sediment: as a first step to make a survey in the field is necessary and collect the necessary information to determine the actual size of sediment.
- Conduct a numerical simulation of debris flow with the information based on the field survey.
- Design the bridge opening: next step is to make the bridge opening wider in order to let the sediment pass through.
- Preparation of Debris Flow Hazard Map: it is necessary to make a 2D numerical analysis in order to obtain the affected area of the debris flow with different return period.
- Design of Sabo works or Dams: is better to consider the sabo works for the retention of the sediment in the upper part of the basin.



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