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CASE STUDY – DELTA RESTORATION AT A STEEP RIVER MOUTH

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ABSTRACT

The mouth of the Baye de Clarens torrent in Switzerland is currently constrained by lateral training walls, sequent sills and a bridge with a low hydraulic capacity. Due to a bed load trap upstream, few sediments reach the mouth. To improve flood protection and reestablish a natural dynamic mouth, a project of a delta with restored bed load was designed. In order to ensure that this newly formed delta guarantees flood protection and results in a sustainable sediment management, a physical model has been built at a scale of 1:25. Tests have been performed with several flood hydrographs and corresponding bed load volumes. Two opening angles for the left training wall have been taken into account for the delta evolution. For all cases tested, the newly formed delta does not hinder free flow. No significant backwater effect could be observed. Deposition of sediments occurs on the block ramp at the end of floods, but these deposits are quickly washed out at the beginning of each new flood.

Keywords: *Delta restoration, Lake, Physical model, River mouth, Sediment management*

1. INTRODUCTION

The ecology of river deltas is very dynamic and the deposited sediments provide a natural habitat for many species. Because of the great morphologic changes that can occur during floods, deltas can induce flooding of nearby areas. Thus, regulation structures were often built to protect human infrastructures without considering the loss of natural habitat.

The Baye de Clarens torrent is located close to Montreux in Western Switzerland and flows into Lake Geneva. In the rectilinear section before it enters the lake, lateral training walls have been built to protect the surrounding urbanized area from flooding. The bed is 7 m wide and the walls have an average height of 2.5 m with a batter of 10%. In addition, the presence of sequent sills reduces the bed slope to an average of 3%. The mouth of the river finishes with a bridge above a sill which reduces significantly the hydraulic capacity of the river. Delta evolution is restrained due to the lateral training walls, to the presence of the upstream bed load trap configuration and to the maintenance of the mouth for security reasons.

In order to improve flood protection and the ecological value of the river, reactivation of the delta by reducing the bed load trap maintenance is wished. A project was designed by Stucky Ltd and includes two major modifications. First the existing sills at the mouth are replaced with a 33 m long block ramp with a slope of 10.9%. Secondly, the river bed is widened in its downstream part by building new lateral training walls (Figure 4). On the right bank the new wall has an angle of 20° with the axis of the river, and on the left bank the angle is either 5° or 14°, the smaller angle allowing to preserve an existing building. The existing bridge has to be rebuilt with a greater hydraulic capacity and the significant increase in the span requires placing a pier in the block ramp.

Little literature exists on torrents flowing in lakes and forming a delta (Taylor 1904). The mouth of Baye de Clarens is similar to an alluvial fan (Lowey 2002) with partially submerged.

The objectives of the current study were to assess the performance of this new project:

- Verify the behavior during the floods given in Table 1. The morphogenic flood Q_{morph} has a return period of about two years and is considered to define the bed. The floods Q_{100} and Q_{300} are respectively floods with a return period of 100 and 300 years. Finally Q_{extr} is the extreme flood. For flood Q_{300}, no intervention should be necessary during the flood and no overflowing should occur in the channel upstream of the ramp;

- Define where the sediments will deposit with the new geometry to guarantee short and long term safety.
- Define if and when the delta should be scraped to maintain safety for flood Q_{300}.

Table 1. Floods characteristics

Flood	Q_{morph}	Q_{100}	Q_{300}	Q_{extr}
Discharge [m^3/s]	30	65	74	121
Sediment volume [m^3]	500	4'680	5'680	13'230

2. EXPERIMENTAL SETUP

To study the behavior of the new delta, a physical model (Figure 2) was built at the Laboratory of Hydraulic Constructions (LCH) of École Polytechnique Fédérale de Lausanne (EPFL)(LCH 2013). The model was operated in accordance with the Froude similarity at a scale of 1:25. It reproduces the last 30 m of the Baye de Clarens channel upstream of the ramp, the 33 m long ramp and the bathymetry of Lake Geneva on a length of 85 m and width of 67 m.

The level of Lake Geneva hardly changes during floods, being a large lake with a surface of 680 km^2. On the model the level is controlled by a 2.7 m large weir. To guarantee the stability of the lake level during the experiments, it was chosen to supply the model with a constant discharge. The required discharge to reproduce the Baye de Clarens flood hydrographs (Figure 1a) was taken from the main supply pipe with a programmable butterfly valve and introduced in a 1 m^3 supply reservoir. The remaining discharge was introduced at the bottom of the Lake Geneva tank, just under the weir.

A transition section long of 1.5 m and with the same section and slope as the Baye de Clarens channel was created between the supply reservoir and the modelled area. It allows the development of the short drawdown curve between the reservoir and the supercritical flow of Baye de Clarens. Sediments are manually introduced in this section. The prototype bed load has a 20%, 50% and 90% fraction of respectively 0.012 m, 0.088 m and 0.285 m. A geometric scaling was used for the sediments. The Shields diagram (Figure 1b) in the channel shows that the largest fraction is in motion for discharges higher than 16 m^3/s. The bed of the channel upstream of the ramp was made with bed load sediments and fixed with mortar. The block was made of carefully placed gravel settled with mortar. For the bridge, only the pier was modeled to be able to measure the water level on the ramp at every location.

The bathymetry of the delta (ramp and lake) was measured with a Leica laser distancemeter, before and after each test with a spatial grid of 0.1 m resolution on the model, giving approximately 550 points. Eight ultrasonic sensors for Baye de Clarens and one for Lake Geneva were used to measure the water level during the tests.

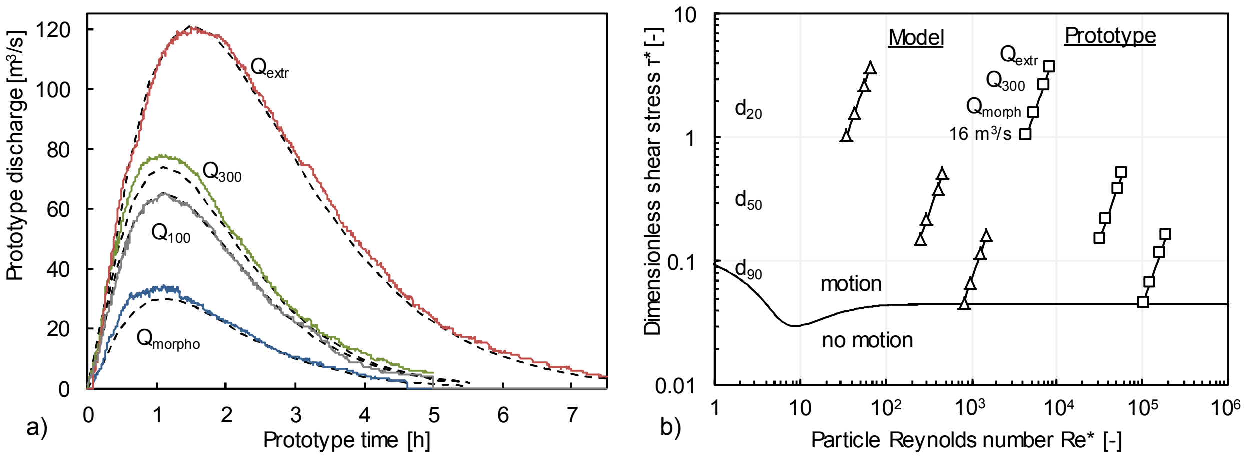

Figure 1. Validation of the reproduced flood hydrographs (a) and granulometry (b).

3. RESULTS

All the tests performed showed similar behavior. Before the peak of a flood, flow has a great sediment transport capacity, erodes all deposits on the ramp and a hydraulic jump forms at the deposits front or at the foot of the ramp. The flow takes the whole width of the ramp but most of the discharge enters the lake in the axis of the river (Figure 2a). An erosion pit is created by the hydraulic jump and adequate protection measures have to be taken to protect the foot of the ramp. Some splashing is produced by the hydraulic jump. All the sediments are transported to the foreset bed of the delta.

After the peak, the transport capacity decreases. Two branches following the training walls start to appear, the right side one being more important. Deposits start to form on the delta topset and the ramp. At the end, solely fine particles are transported and only the two branches along the walls remains in the ramp (Figure 2b), which is a situation that is already observed at the current mouth.

Tests were done considering the current bathymetry of Lake Geneva, with few sediment deposits, to reproduce what will happen during the first few floods after construction. The only exception is the final test with flood Q_{100} which used a bathymetry based on the results of the extreme flood to understand what will happen at the long term. This bathymetry used a topset slope of 4.4% and a foreset slope of 45% (Figure 4). Results of this test are presented here at prototype (1:1) scale.

Figure 3a shows the final bathymetry. The two beds of the side branches are visible with their lower elevation in the ramp. The highest deposits in the ramp occur in the middle, around the pier. The topset of the delta has a fairly regular slope with some irregularities created by channels. The foreset has a constant slope corresponding to the angle of repose of submerged sediments. When looking at the bathymetry difference before and after the flood (Figure 3b), part of the erosion occurring at the flood peak in the ramp and in the axis of the river remains at the end. Minor depositions are present in the topset and most deposits occur in the foreset. It was observed that deposits were formed on the left side in the beginning and progressively moving towards the right.

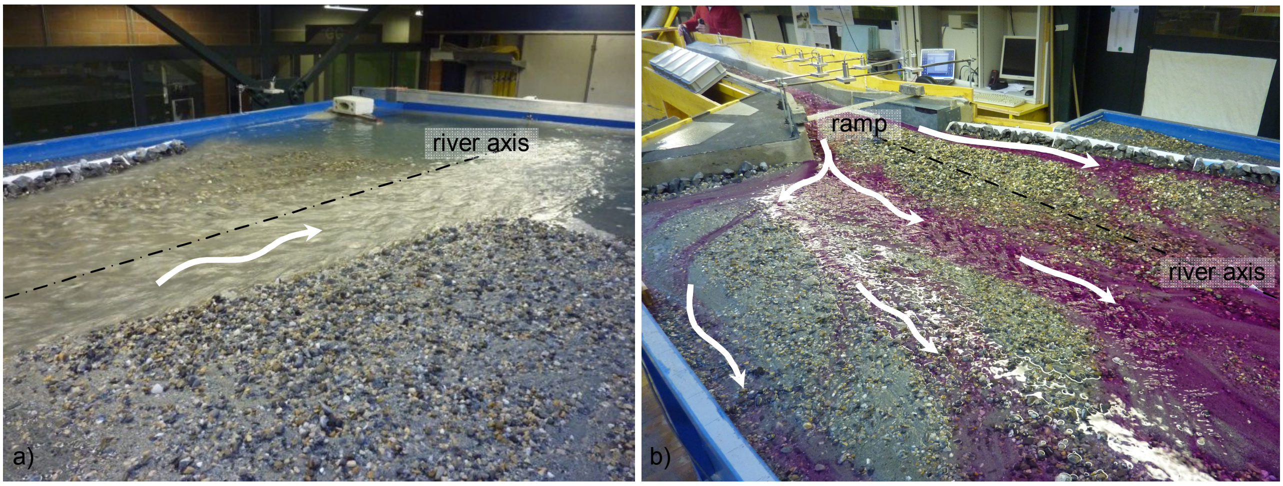

Figure 2. Flow on the physical model for the Q_{100} flood (a) flow along river axis at flood peak, (b) lateral branches at the end of the flood.

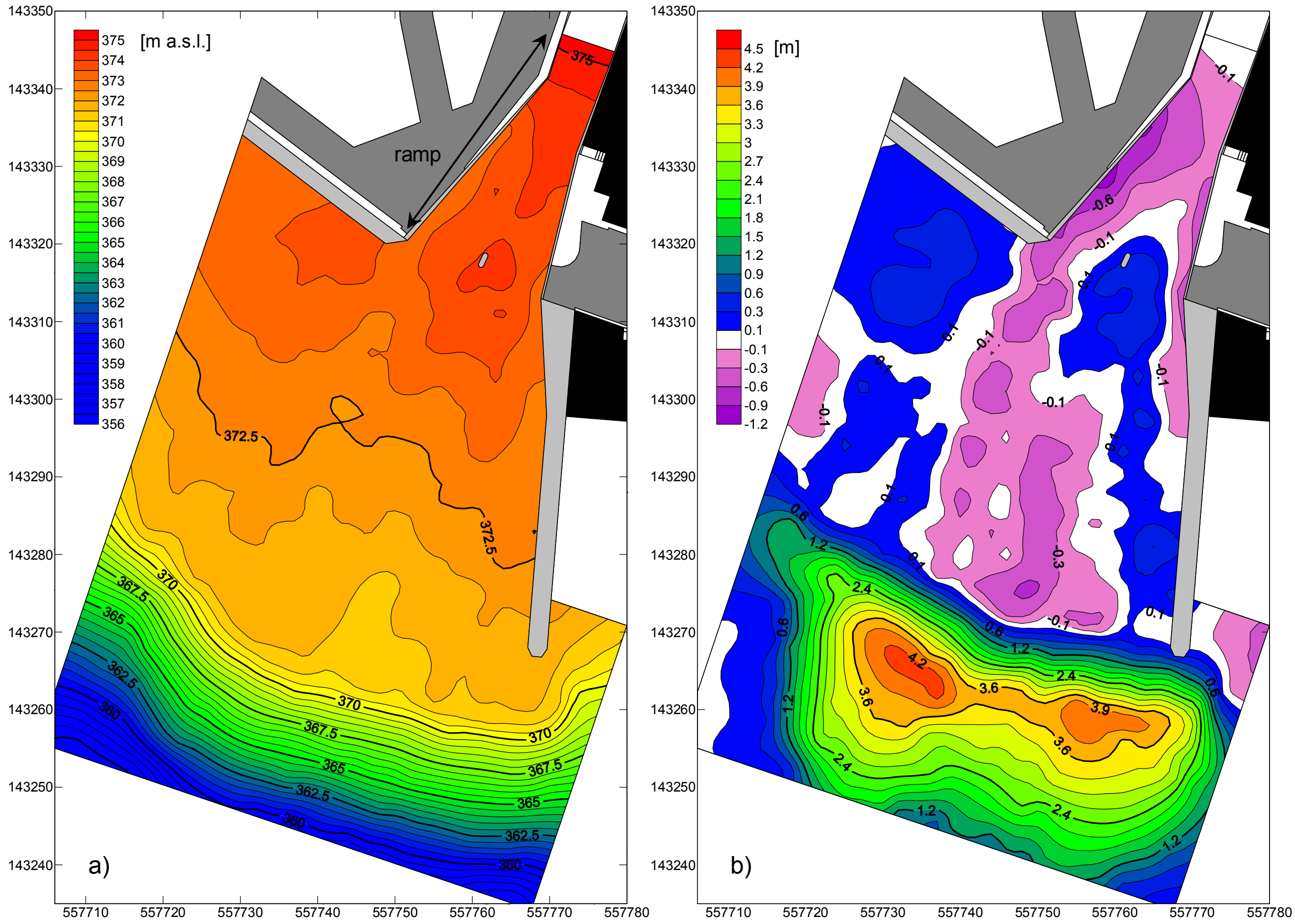

Figure 3. Final bathymetry (a) and height of the deposits (b) after a Q_{100} flood. The numbers on the side show the Swiss coordinates CH1930 in meters.

The longitudinal profile (Figure 4) shows the current bathymetry. The initial state for flood Q_{100} was artificially established based on the deposits of flood Q_{extr} over the current state. The final state after flood Q_{100} shows the slight erosion and deposition mentioned earlier in the topset, as well as the large deposit in the foreset. The point of rupture between the topset and the foreset is for every test slightly under the lake level. It is an important point as it defines the amount of deposits in the foreset. A regular slope of 4.5% starts from this point and goes up in the ramp. With time this rupture point will move further away from the ramp. To control the amount of deposits in the ramp, the location of this point must be monitored.

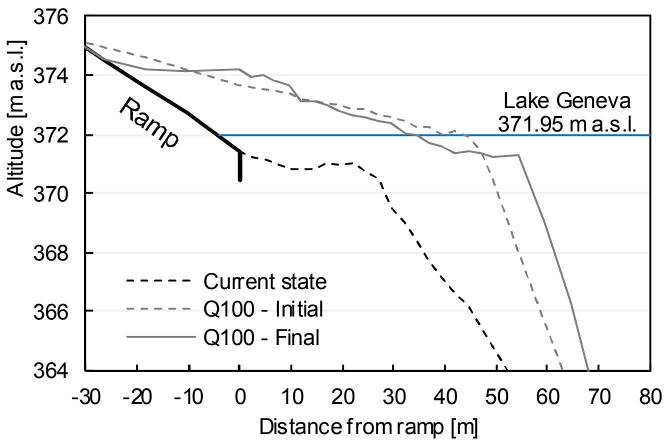

Figure 4. Longitudinal profile in the axis of Baye de Clarens.

Tests with an opening of the left training wall of 5° and 14° were performed for flood Q_{300}. The results show no significant difference in the deposits or the water level in Baye de Clarens. It was thus decided to use 5° for the final angle to maintain an existing building.

The Q_{300} and Q_{extr} floods were compared regarding the deposits. In the topset, the slope is identical, and for Q_{extr} the deposits are 0 to 0.5 m higher than for Q_{300}, with the biggest difference on the right side. The main difference occurs in the foreset where the bed load is transported and deposited. Three zones of deposition occur. The biggest one is in the axis of the river and the two other are on the sides in the continuity of the side channels that forms during the decrease of the flood. The deposit on the right is much more important than the one on the left.

The deposits in the ramp show no influence on the water level in the channel upstream of the ramp. In this channel, a few waves overtop the side walls during the peak of flood Q_{300}. During flood Q_{extr}, a very small fraction of the discharge flows over the side walls on both sides.

The bridge pier on the ramp was designed to be parallel to the flow with a rounded section. Because the flow around the pier is largely supercritical, the flow rises up to a few meters when it hits the pier. The largest fraction of the bed load was also seen hitting the pier above the flow after being projected by bottom irregularities in the ramp. The hydraulic jump can sometimes be on both sides of the pier and the pier has to be designed to resist accordingly.

4. CONCLUSIONS

Investigations on a physical model of the project to restore a dynamic delta at the mouth of Baye de Clarens showed that it was well designed and meeting flood safety requirements. The high sediments transport capacity during the peak of floods washes away the deposits in the ramp and hence the deposits have no effect on the water level in the upstream channel. During the decrease phase of floods, to lateral branches form along the training walls. The majority of the deposits are occurring in the foreset of the delta, and with the naturally steep slope of the Lake Geneva bathymetry, large quantities of sediments can be absorbed.

The key to control the deposits in the ramp is to monitor the rupture point between the topset and foreset. Regarding long term safety, the model allowed to determine the critical deposits elevation from which local dredging is required and in which area. Dredging, currently occurring every two years, will be drastically reduced with the delta implementation. This project will lead to a sustainable sediment management that will permit typical fauna and flora to develop in the delta.

ACKNOWLEDGMENTS

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