DEPARTMENT OF CIVIL, ENVIRONMENTAL AND MECHANICAL ENGINEERING

Downstream morphological effects of Sediment Bypass Tunnel operations: a 1D numerical study

Matteo Facchini[1*], Robert M. Boes[2], David F. Vetsch[2], Annunziato Siviglia[2]
[1]Dept. of Civil, Environmental and Mechanical Engineering, University of Trento,
[2]Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich

Introduction

Sediment Bypass Tunnels (SBTs) (Fig. 1(a)) have been proven to be an effective countermeasure to reservoir sedimentation (Sumi et al., 2004), but their morphological effects on the downstream reach are still poorly investigated. During flood events, they divert sediment from upstream to downstream around the dam (Fig. 1(b)). Therefore, the downstream reach is subject to repeated releases of water and sediment in form of hydrographs (Q_w) and sedimentographs (Q_b) (Fig. 1(c)). On average, SBTs are operational few times per year, therefore on an engineering or human time-scale they will be operated dozens of times. The <u>overarching goal</u> of this work is to quantify the morphological changes in terms of riverbed slope and grain size distribution (GSD) induced by realistic SBT operations.

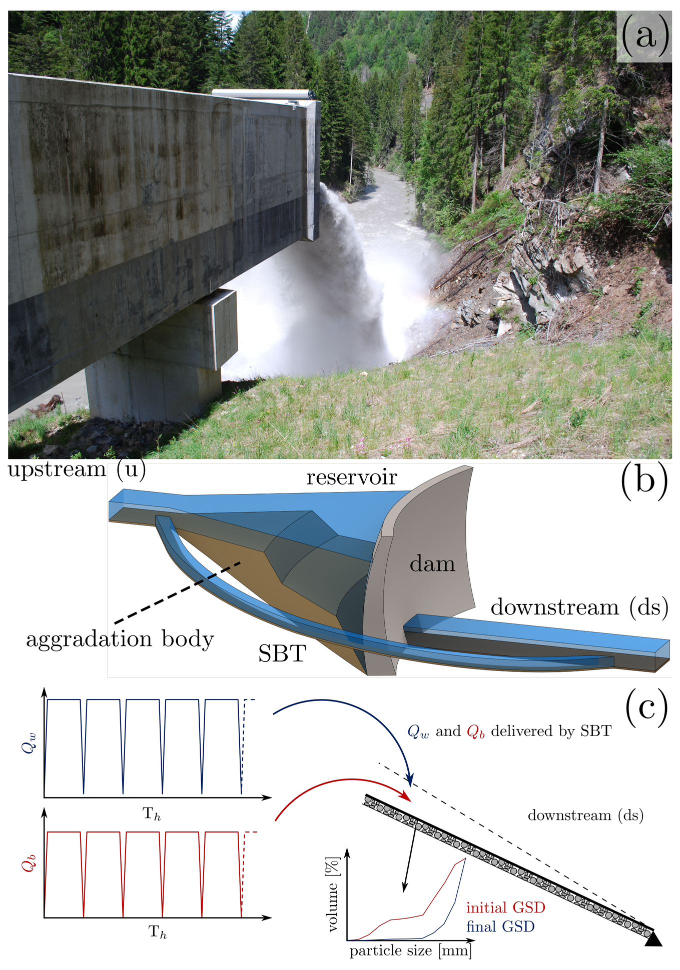

Fig. 1. (a) Solis SBT (Canton Grisons, Switzerland) in operation, (b) sketch of SBT-dam system, (c) 1D numerical study setup.

Conceptual framework

To properly work, a SBT must have a higher sediment transport capacity than the river flowing in the reservoir. Therefore, given the slope and the GSD of the upstream river reach, the relationship between the water Q_w and the bedload discharge Q_b (Bedload Rating Curve, BRC) can be calculated for the upstream river reach (BRC_u) and the SBT (BRC_{SBT}) (solid red and blue lines in Fig. 2). SBTs are usually designed according to a given water discharge value $Q_{w,d,SBT}$. Then, we identify four possible SBT release scenarios (see Fig. 2):

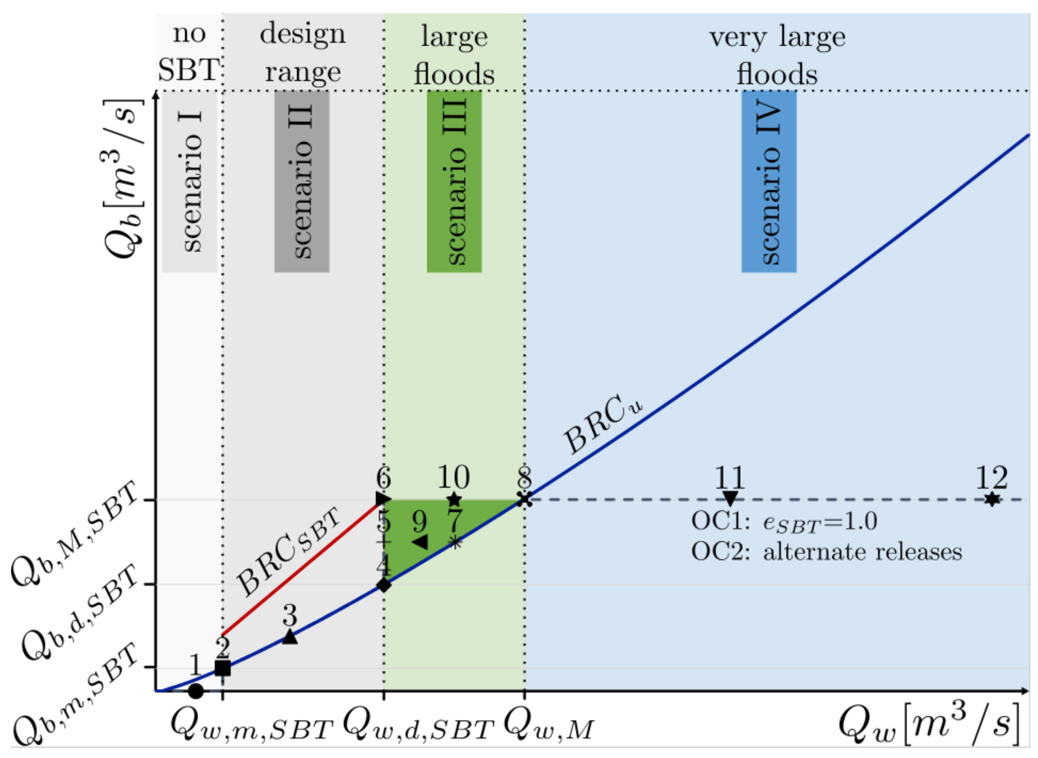

Fig. 2. SBT release scenarios with Bedload Rating Curves (BRC), Operational Conditions (OC), and numbers of numerical runs.

- <u>scenario I</u> (no SBT operation): the SBT is not operated, sediments are stored in the reservoir and water might be conveyed through the dam;
- <u>scenario II</u> (design range): sediment coming from upstream is entirely diverted downstream by the SBT;
- <u>scenario III</u> (large floods): Q_w flowing through the SBT is $Q_{w,d,SBT}$ and the surplus (Q_w>$Q_{w,d,SBT}$) can be either stored in the reservoir or conveyed through dam outlets; Q_b is smaller or equal to maximum $Q_{b,M,SBT}$ that can be carried by the SBT;
- <u>scenario IV</u> (very large floods): Q_b = $Q_{b,M,SBT}$ and extra water (Q_w>$Q_{w,M}$, where $Q_{w,M}$ is the Q_w needed for carrying $Q_{b,M,SBT}$ in the upstream reach) is released from the dam.

OC1 and OC2 refer to two different Operational Conditions, namely:

- OC1: all sediments from the upstream reach enter the SBT and are conveyed downstream;
- OC2: each bedload-laden SBT operation is followed by a bedload-free SBT operation.

Methods

To quantify the downstream changes in riverbed slope and GSD, we run 1D numerical simulations with BASEMENT (www.basement.ethz.ch). The model describes the hydro-dynamics by the Saint-Venant equations. Friction exerted by flow over a cohesionless bottom composed of mixed sediment induces sediment transport, which is assumed to occur only as bedload. The GSD of the riverbed surface and the development of size stratification are described using the active-layer approach of Hirano (Hirano 1971, 1972).

Numerical model setup

The specific quantification of the inputs to the numerical runs takes as a reference the reach of the Albula River downstream of the Solis Dam and the Solis SBT (Canton Grisons, Switzerland). The length of the channel is 10 km with a slope of 1.5%. The cross-sectional geometry is rectangular with a constant width of 15 m. The channel is discretized using 100 equally-spaced cross-sections. Trapezoidal hydrographs and sedimentographs (Fig. 1(c)) are fed at the upstream end of the domain. They vary sympathetically in time as represented in Fig. 1(c) and are characterized by peak values Q_w and Q_b which are given in Table 1 (values refer to numbered symbols of Fig. 2). The duration of each release is 12 hours and both the rising and falling limb last 1 hour, mimicking real SBT operations.

	1	2	3	4	5	6	7	8	9	10	11	12
Q_w [m³/s]	30	50	100	170	170	170	223	275	197	222	428	623
Q_b [m³/s]	0	0.23	0.55	1.06	1.49	1.92	1.49	1.92	1.42	1.92	1.92	1.92

Table 1. Summary of input Q_w and Q_b for numerical simulations under different OCs.

Results

Figure 3 shows modifications of the riverbed level and composition computed at three cross-sections (0.2, 5, and 10 km far from the upstream end, respectively) after 50 SBT operations under OC1 and OC2. Results are given in terms of non-dimensional elevation difference $\Delta\eta/\Delta\eta_{eq}$ and mean geometric size of the riverbed GSD $d_g/d_{g,eq}$. The reference values ($\Delta\eta_{eq}$ and $d_{g,eq}$) refer to the mobile-bed equilibrium, the state reached after sustaining a defined configuration for a sufficiently long time (more than thousand releases). On the x-axis, a non-dimensional water discharge Q^*_w is shown, which is relative to the SBT design discharge defined in Figure 2. Dashed lines divide the graph following the definition of possible SBT release scenarios given in the conceptual framework. Different symbols refer to the numbered ones in Figure 2 quantified in Table 1. Moreover, filled red symbols are relative to OC1 while empty blue symbols are relative to OC2.

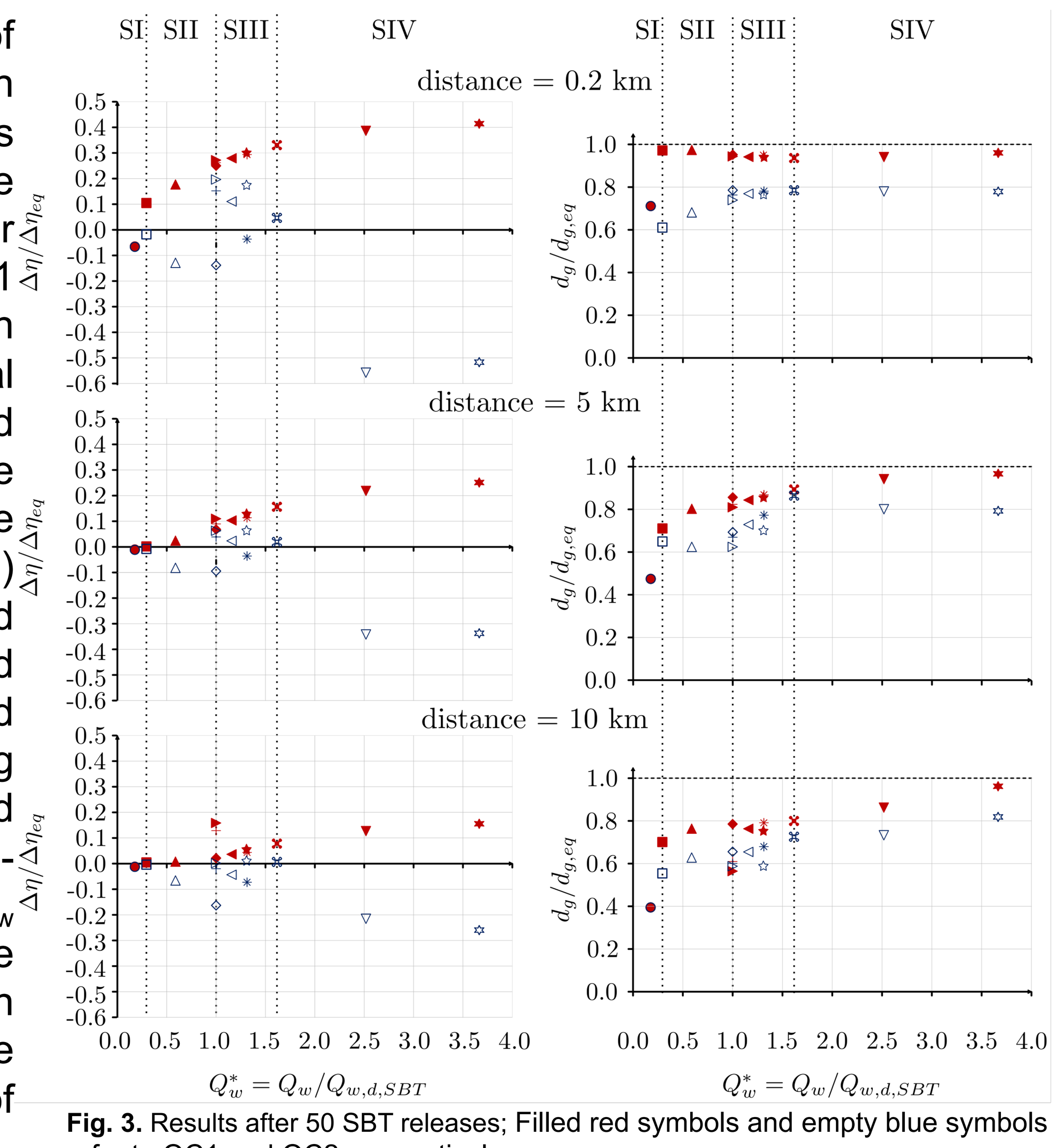

Fig. 3. Results after 50 SBT releases; Filled red symbols and empty blue symbols refer to OC1 and OC2, respectively.

Results at equilibrium (not shown here) predict:

1. an aggradation trend for SII and III under both OC1 and OC2 and for SIV under OC1;
2. an erosion trend for SI under both OCs and for SIV under OC2;
3. the achievement of a mobile-armor state for the riverbed GSD (except for SI).

Results after 50 SBT operations show that:

1. the riverbed level is still far from the equilibrium over the whole reach, while the GSD is close to the equilibrium even at the downstream end (distance = 10 km in Figure 3);
2. the release of bedload-free waters (OC2, empty blue symbols in Figure 3) slows down the achievement of the mobile-bed equilibrium for both riverbed level and composition.

Conclusions

On an engineering time-scale, i.e. after 50 SBT operations:

- the riverbed level is still far from the equilibrium state, while the riverbed GSD is closer to it over the whole reach;
- close to the upstream end of the domain the riverbed level and GSD are both closer to the equilibrium than at the end of the domain;
- the release of bedload-free waters (OC2) slows down the progress towards the equilibrium.

References

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