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INNOVATIVE AND LOW COST CONTINUOUS EVACUATION OF SEDIMENT THROUGH THE INTAKE STRUCTURE USING MULTIPLE JETS AT THE RESERVOIR BOTTOM[*]

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1. INTRODUCTION

Reservoir sedimentation is worldwide a significant long term problem and requires in view of the current mitigation measures an alternative and more sustainable solution. This challenge motivated the present study with the purpose to develop an alternative efficient method to release sediment out of a reservoir. The concept is based on the release of sediment through the headrace tunnel and turbines whereby a special focus was set on the fine sediment in the area in front of the power intakes. Specific jet arrangements should provide the energy and generate the optimum circulation needed to maintain the sediment in

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[*] *Système innovant et économique d'évacuation continue de sédiments à travers la prise d'eau à l'aide de jets placés au fond du réservoir.*

suspension and enhance its entrainment into the power intakes during turbining sequences. The study was mainly based on physical experiments.

2. EXPERIMENTAL INVESTIGATIONS

2.1. EXPERIMENTAL SET-UP

The physical experiments were carried out in a rectangular tank with vertical walls [1]. Different jet arrangements as well as reference tests without jets were performed. Since it is a priori assumed that the influence of the proposed jet arrangements on the flow is locally limited, the tank only represents a limited part of the reservoir located upstream of the dam. It has an elongated shape with a total inner basin length of 4 m, an inner width of B = 1.97 m and a total basin height of 1.50 m. The front wall of the tank is considered to represent the dam, and the two lateral walls confine the reservoir volume in analogy to near vertical valley slopes (Fig. 1).

When preparing the experiment a water-sediment mixture was spread on the bottom of the empty tank. Thereafter, the tank was slowly filled with laboratory water from the back wall, while the sediment is maintained in suspension by pressurized air injection from the bottom in order to achieve a uniform sediment concentration within the tank for initial conditions.

During the experiments clear water is fed by jets (jet experiments) or through the back wall (reference experiments without jets), respectively, while sediment laden water of equal flow rate is drawn out of the tank through the water intake. Thus, the water level in the tank is kept constant.

The position of the jets as well as the nozzle diameter could be varied (3, 6 and 8 mm). Equal flow rate on each of the jets is guaranteed by the use of four identical rotameters.

The perforated plate tranquilizes the water flowing into the tank during reference experiments. Measurements are only executed within the basin part downstream of the perforated plate.

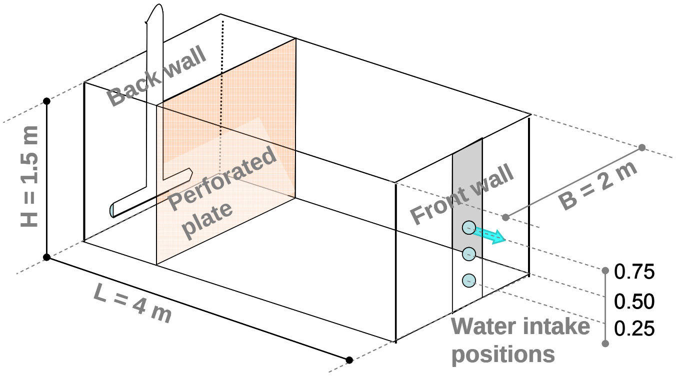

Fig 1.
Sketch of the experimental tank, water intake height indications in [m]
Schéma de l'installation expérimentale, indications de la hauteur sur le fond de la prise d'eau

2.2. EVACUATED SEDIMENT

2.2.1. Definition

The sediment release (evacuated sediment ratio, *ESR*) is defined as the evacuated sediment weight P_{out} divided by the sediment weight initially supplied P_{in} and represents the normalized temporal integral of the released sediment amount: $ESR = P_{out}/P_{in}$. Analogously, the settled sediment ratio is the settled sediment divided by the sediment weight initially supplied P_{in}.

2.2.2. Experiments without jets

Experiments without jets as reference configuration showed an almost linear relation between the sediment release and the discharge within the tested range: the higher the discharge, the higher the evacuated sediment ratio. For a constant discharge the ultimate sediment release as well as the settled sediment ratio was easily estimated by a simple physical approach taking into account the settling velocity and the flow field generated by the discharge through the water intake and the back wall. For the tested discharge range the sediment release ESR was between 0.09 and 0.37 for reference configuration.

2.2.3. Experiments with jets

Jets are effectively mixing; after around half an hour the standard deviation of the suspended sediment concentration was approximately 5 *%*, what in chemistry is considered as homogeneous. Consequently, less sediment was settled and, hence, the sediment release was higher than without jets and reached *ESR* = 0.73f or the highest tested discharge (ΣQ_j = 4050 *l/h*).

Moreover, contrary to the experiments without jets, with jets resuspension of settled sediment was observed. Resuspension started once steady state conditions for the circulation were reached. It has been detected for discharges higher than an experimentally determined threshold. The observed evolution of the resuspension rate suggests that for a final stage all of the initially supplied sediment can be evacuated.

The circular jet arrangement was identified as the most efficient configuration regarding sediment release. Additionally, the normalized optimal geometrical parameter combination was determined as follows: non-dimensional off-bottom clearance of the jet arrangement C/B = 0.175 (C being the height above the bottom of the jets, B the inner width of the tank), water intake height h_i/B = 0.25 (h_i being the water intake height above the bottom), distance of the jet arrangement to the front wall d_{axis}/B = 0.525, distance between two neighbouring jets l_j/B = 0.15, jet angle θ = 0° and water height in the tank h/B = 0.6. Under optimal conditions and with the highest tested jet discharge (ΣQ_j = 4050 *l/h*) after four hours a sediment release of *ESR* = 0.73 was achieved. Without jets and with the same discharge through the water intake the sediment release reached *ESR* = 0.37.

2.3. FLOW PATTERN AND EFFICIENCY

The corresponding flow pattern in the transversal plane was similar to an axial mixer, which in the literature is reported as favourable for suspension [2]. In the longitudinal flow patterns resulting from higher discharges, a single rotor was found between jets and water intake (axial flow pattern), whereas for smaller discharges the flow pattern was similar to a radial mixer.

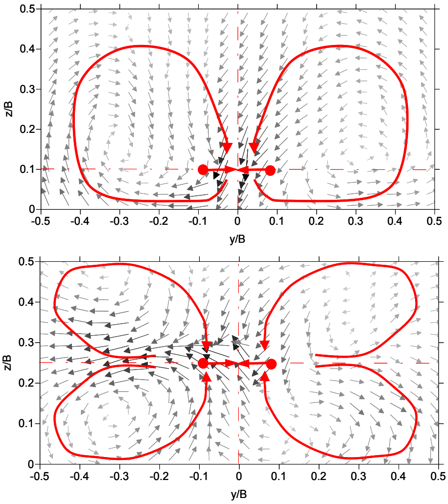

Fig. 2
Typical axial (above) and typical radial (below) flow pattern in the transversal plane obtained by laboratory measurements
Champ de vitesse typiquement axial (haut) et typiquement radial (bas) mesuré en laboratoire

A variation of a single geometrical parameter within the tested range (i.e. 60 to 200 *%* of the optimal value) caused a sediment release reduction of up to 40 *%*, depending on the parameter and the duration, as well as an eventually different flow pattern.

The linear jet arrangement was found to be much less favourable in view of sediment release. Its results were in the same magnitude as for the experiments without jets (*ESR* between 0.37 and 0.45). This is due to the direction of the induced rotation which is unfavourable regarding sediment suspension: the sediment is drawn to the bottom where it is settled and difficult to be put in suspension again.

The efficiency of the jets was established by comparing the sediment release obtained under different conditions: once when jets were employed, once without jets. The predicted efficiency based on time and discharge independent empirical relationships is around 1.7 for the optimum jet configuration. Using the measured data the efficiency depends on discharge and increases with time. At the end of the transient phase and when resuspension started the efficiency was approximately 1.5. With the highest tested discharge the efficiency reached after four hours almost 2 (ΣQ_j = 4050 *l/h*).

3. PRELIMINARY ATTEMPT OF AN IMPLEMENTATION IN A REAL RESERVOIR

In a first attempt for the Mauvoisin dam case study in Switzerland, the experimentally obtained results were upscaled to the prototype scale. From the experiments it became certain that with a circular jet arrangement a definitely higher sediment amount could be released than without. Moreover, close to the water intake the reservoir will be free of sediment and its clogging can be avoided. With further numerical simulations modelling the real reservoir bathymetry the flow pattern can be defined and the expected sediment output estimated. An economic analysis for the Mauvoisin case showed that even if only 7 % of the yearly incoming sediment amount was released by means of the jets, a circular jet installation is already economical.

4. CONCLUSION

1. For the experiments without jets, modelling the so called reference configuration, an almost proportional relationship between sediment release and the jet discharge was observed: with increasing discharge, the sediment release increases. For the tested discharge range the sediment release ESR was between 0.09 and 0.37.
2. The circular jet arrangement was identified as being the most efficient jet arrangement and showed a very high mixing efficiency, due to its induced axial flow pattern. Consequently, less sediment was settled and the sediment release (ESR = 0.73) at the highest tested discharge (ΣQ_j = 4050 l/h) was almost twice the amount released without jets (ESR = 0.37). In analogy to the case without jets, with the jets the relationship between discharge and sediment release was for the whole experiment duration almost proportional: the higher the discharge, the higher the sediment release. However, contrary to the experiments without jets, with the jets and for a discharge exceeding an experimentally determined threshold, resuspension was observed.
3. For an optimal water jet arrangement a time and discharge independent empirical efficiency of between 1.5 and 2 was achieved.
4. Due to the fine grain size used in the experiments (mean diameter of 60 *μm*) the application focuses on large reservoirs where the sediment is well sized along the thalweg and only fine particles are expected in front of the dam as it is the case for sediments transported by turbidity currents.

REFERENCES

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SUMMARY

Being aware of the sustainability problem induced by reservoir sedimentation, an innovative idea was developed. It consists of maintaining sediment in suspension by a jet induced artificial turbulence and releasing it through the water intake. Therefore, two different configurations with four jets each were investigated in laboratory experiments and numerical simulations. The influence of their geometrical parameters and the jet discharge on the sediment release was analyzed in detail. An optimal parameter set was identified for a horizontal circular jet arrangement having a release efficiency between 1.5 and 2 compared to the case without jets. The corresponding flow pattern is axial.

RÉSUMÉ

Étant conscient de la problématique de durabilité induite par la sédimentation des réservoirs une idée innovante a été développée. Le concept est de maintenir les sédiments en suspension par une turbulence induite par des jets et de les évacuer à travers la prise d'eau. Pour ce faire deux configurations à quatre jets chacune ont été testées empiriquement et numériquement. L'influence des caractéristiques du jet et les paramètres géométriques des configurations a été analysée en détail. Une combinaison optimale de paramètres a été identifiée pour une configuration en cercle ayant une efficacité d'évacuation entre 1,5 et 2 comparée avec le cas sans jets. Le champ d'écoulement correspondant est axial.