Venting of turbidity currents against reservoir sedimentation

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Reservoir sedimentation

Main consequences

Generation
Equipment
Security
Environment

Bottom outlet partially blocked by sediments at the Jiroft Dam, Iran (Photo by S. Emami)

Sedimentation of Sufers reservoir, Switzerland (photo courtesy of Kraftwerke Hinterrhein AG)
Reservoir sediment management

Mechanical dredging

Hydrosuction Airlift

Removal to downstream side

Turbidity current

Sediment deposits

Suspended sediments

Dead storage level

Dam

Free flow flushing
Pressurized flushing
Venting turbidity currents
Venting of turbidity currents

1. Reservoir
2. Bottom outlet
3. Downstream river
4. Upstream river

Bed load in delta region

ρ<sub>w</sub>

Q<sub>in</sub>

Sediment deposits at the vicinity of the dam

Inflow  Delta  Reservoir  Dam  Downstream river
Objective of the study

How can we improve the efficiency of venting by maximizing sediments released and minimizing water loss?
Experimental set-up

- **Flume:** Total length = 8.55 m; width = 0.272 m; height = 0.9 m
- **Bottom outlet:** width = 9 cm; height = 12 cm
- **Slope from 0% to 5%**

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**Diagram:**
- **Head tank**
- **Main flume**
- **Recirculation pipe**
- **Inlet**
- **Wall**
- **Bottom outlet**
- **Downstream tank**
- **Downstream basin**
- **Venting pipe**
- **Restitution pipe**
- **Mixing tank**
- **Pumping pipe**
Measurements

- A LabVIEW interface was created to run and stop the measurements simultaneously.
- Acquisition frequency (data recorded every 360 ms)

- Flowmeter
- Level probe
- Turbidity probe
- Depositometer
- UVP transducer
- Thermometer
- Camera
A glimpse of experiments

Slope 5%
\[ \frac{Q_{\text{VENT}}}{Q_{\text{TC}}} = 200\% \]
Video 8x faster
Local venting efficiency

\[
LVE = \frac{M_{\text{VENT}}}{M_{\text{TC}}} = \frac{\int_{t=T_{vi}}^{T_{vf}} C_{\text{VENT}} Q_{\text{VENT}} \, dt}{\int_{t=0}^{T_{vi}} C_{\text{TC}} Q_{\text{TC}} \, dt + \int_{t=T_{vi}}^{T_{vf}} C_{\text{TC}} Q_{\text{TC}} \, dt - \int_{t=T_{vi}}^{T_{vf}} m_{\text{dep}} \, dt}
\]

Total outflow sediment mass during venting

\( \dot{m}_{\text{dep}} \) : deposited sediment mass flow rate

\( T_{vi} \): Beginning of venting

\( T_{vf} \): End of venting

\( C_{\text{VENT}} \) and \( C_{\text{TC}} \): outflow and turbidity current sediment concentrations at time \( t \)

\( Q_{\text{VENT}} \) and \( Q_{\text{TC}} \): outflow and turbidity current discharges at time \( t \)
LVE on a horizontal bed

- Parameter varied: Venting degree $\Phi = \frac{Q_{vent}}{Q_{TC}}$
- Horizontal bed: $S = 0\%$
- In-time venting: at arrival of the current to the outlet

Venting on a horizontal bed leads to the highest efficiencies when using $\phi = 100\%$.

$\bar{t}$ : Normalized venting duration
$LVE$ : Local Venting Efficiency
LVE on steeper bed slopes
LVE on steeper bed slopes

The optimal venting degree depends on the reservoir slope in the vicinity of the outlet. Steeper slopes yield higher optimal venting degrees.
LVE on steeper bed slopes

**Steeper bed slopes lead to higher venting efficiencies.**
LVE with different timings
LVE with different timings

The timing or start of venting should be synchronized with the arrival of the turbidity current at the dam.

S = 2.4%; $\Phi = 115\%$

S = 5%; $\Phi = 115\%$
Conclusions

- On a horizontal bed, venting is the most efficient with $\phi = 100\%$. With the 2.4% and 5.0%, venting is the most efficient using $\phi = 135\%$.
- Venting efficiency increases with increasing slopes. Hence, venting should start directly after the commissioning of the dam, in order to maintain the formation of a cone in front of the low-level outlets and avoid the filling of the dead storage.
- Venting is the most efficient when synchronized with the arrival of the turbidity current at the outlet.
- Early venting is more efficient than late venting.
Journal publications


Thank you for your attention

Research funding:
Many factors determine rates of mechanical abrasion. Of particular importance is sediment type and physical characteristics. Angular sediments composed of minerals with a Mohs hardness greater than 5 - such as quartz, feldspar and tourmaline - are problematic. In addition, hydraulic and facility operation parameters such as flow velocity, hydraulic head, turbulence, turbine rotation speed and turbine material affect abrasion susceptibility. Impulse turbines, such as Pelton or Turgo, are more susceptible to abrasion than are reaction turbines. However, runner changes and needle tip/seat ring replacement are much easier with Pelton turbines. Therefore, they may be preferable on the basis of the overall life cycle cost.

Abrasion can be reduced by selecting metals to increase erosive resistance and/or by reducing the volume of fine sediment that reaches mechanical equipment. Plants often are designed to remove most of the coarse sediment particles. However, even silt can cause significant abrasion if the quartz content and pressure head is high enough. The 1,500 MW Nathpa Jhakri hydroelectric plant in India used four desilting chambers that were successful in removing coarser sediments. However, damage from the finer particles was so severe that parts of the turbines had to be replaced within one year.

Materials used commonly in sediment-prone hydropower plants are stainless steels that are heat treated for hardening and increased protection from abrasion. Protecting mechanical equipment from sediment abrasion can also be achieved with hard surface coatings of ceramic paints or pastes or with hard facing alloys. Research has shown improved resistance to sediment abrasion when tungsten carbide-based composites are used as a surface coating. In undertaking such assessments, it is important to consider the fact that abrasion will increase as the reservoir fills. The Nozaki method can be used to assess turbine repair frequency. The method accounts for the effective sediment concentration, particle size and shape, the turbine material and any coatings.

Turbine designs need to minimize peak velocities to reduce impacts. For a Pelton turbine, fewer jets and larger runner buckets with larger radii reduce centrifugal forces between the sediment and runner surfaces. Regardless of the turbine selected, designs must consider issues such as the ease of runner removal for future maintenance.
# Measuring instruments

<table>
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<th>Parameter</th>
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<td>Camera</td>
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![Diagram of measuring instruments setup](image)

- The setup includes a **Flume**, a **Mixing tank**, a **Downstream basin**, and a **Camera** for photos and video recording.

- Measuring instruments used include:
  - **Electromagnetic flowmeter** for discharge measurement.
  - **Ultrasonic level probe** for water level measurement.
  - **Turbidity probe** for concentration measurement.
  - **Depositometer** for deposition thickness measurement.
  - **UVP transducer** for velocity profiles.
  - **Thermometer** for temperature measurement.
  - **Camera** for photos and video recording.
Global view

$$VE = \frac{M_{VENT}}{M_{TC}} = \frac{\int_{t=0}^{t=T} C_{VENT} Q_{VENT} dt}{\int_{t=0}^{t=T} C_{TC} Q_{TC} dt}$$

Erosion?
Deposition?
Water entrainment?
**Venting efficiency indicator**

When considering water losses:

- For $\phi = 115\%$ and $125\%$, curves shifted below $\phi = 100\%$ and very similar to $\phi = 80\%$

- $\text{VEI}$ is closely similar for $\phi = 30\%$ and $50\%$

$\bar{t}$ : Normalized venting duration

$\text{VEI}$ : Venting efficiency indicator

**Venting on a horizontal bed leads to the highest efficiencies when using $\phi = 100\%$.**
Venting efficiency indicator

\[
VEI = \frac{\int_{t=T_{vi}}^{T_{vf}} C_{VENT} Q_{VENT} dt}{\int_{t=T_{vi}}^{T_{vf}} C_{TC} Q_{TC} dt - \int_{t=T_{vi}}^{T_{vf}} m_{dep} dt} - \int_{t=T_{vi}}^{T_{vf}} V_{VENTsed} dt}
\]

Total outflow sediment volume during venting

\[
\int_{t=T_{vi}}^{T_{vf}} V_{VENTsed} dt
\]

Total outflow water volume during venting

\[
\int_{t=T_{vi}}^{T_{vf}} V_{VENTwat} dt
\]

\[
V_{VENTsed} = \text{Volume of sediments evacuated during venting}
\]

\[
V_{VENTwater} = \text{Volume of clear water evacuated during venting}
\]
Venting efficiency indicator

When considering water losses:

- For $\phi = 115\%$ and $125\%$, curves shifted below $\phi = 100\%$ and very similar to $\phi = 80\%$
- VEI is closely similar for $\phi = 30\%$ and $50\%$

$\bar{\tau}$: Normalized venting duration

VEI: Venting efficiency indicator

Venting on a horizontal bed leads to the highest efficiencies when using $\phi = 100\%$. 
Experimental results

Combined effect of venting degree and bed slope on venting efficiency

Chamoun, S., De Cesare G., and Schleiss A.J. (201X) "Venting of turbidity currents on different bed slopes.", Journal of Environmental Management (under revision)