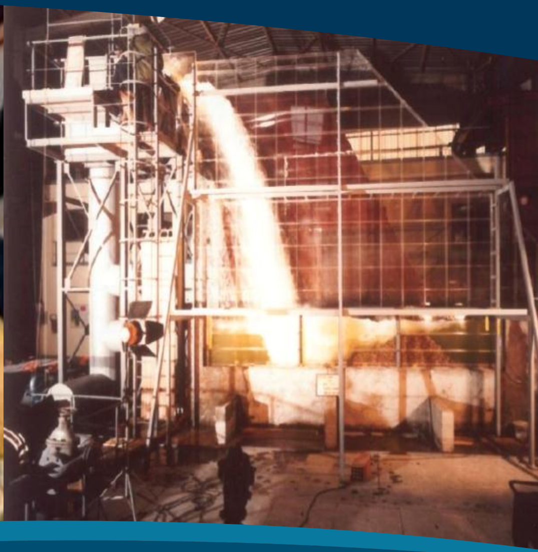
International Workshop on overflowing erosion of dams and dikes

Technical feedback and usual practices of Artelia



EURCOLD

comité français des barrages et réservoirs

Contents

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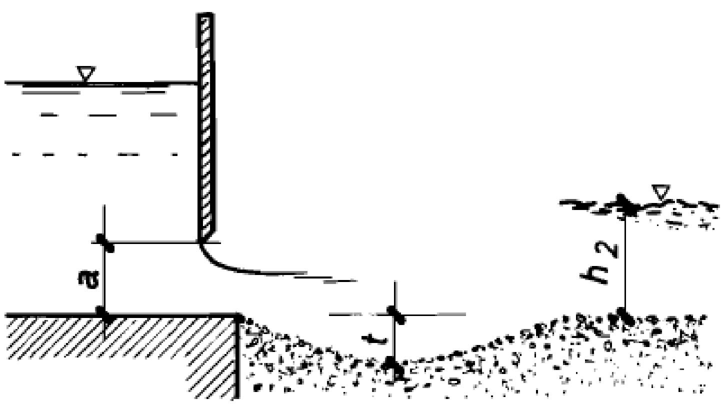
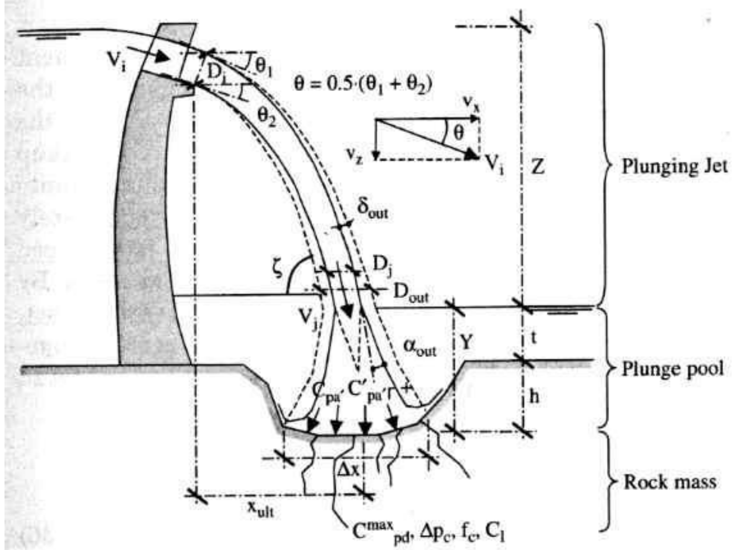
General overview

Downstream of concrete dam – Dissipation of energy

- Comparison between the hydraulic power of the water jet and the resistance of the rock
  - Rock sufficiently resistant?
  - Do we need a concrete basin?
  - Do we need a plunge pool with water mattress?





Nomenclature for a jet discharging over an ogee spillway and plunging into a pool (Bollaert 2002).

General overview

Dissipation structures

For low and middle head structures (Maximal head: ~ 40 m)

- If the rock is erodible
- And the jet can not be deflected far from the dam

↓

Classical solution : Stilling basin

Standard design
For head > 30 m risk of cavitation

For high head structures

- Sufficient head to deflect the jet far from the dam

↓

Classical solution : plunge pool

Preexcavated into the existing rock or in concrete
The tailwater level can be controlled and raised by an auxiliary small dam

1. Dissipation rates

Definition

$$\text{Dissipation rate} = K = \frac{Power\ of\ the\ jet}{Volume\ of\ dissipation}$$

$$\text{Dissipation rate} = K = \frac{\rho g Q H}{Volume\ of\ dissipation}$$

with :

- Q : discharge (m3/s),
- H : head (m)
- g : 9.81 m/s²

Dimensionnal analysis : [K/ρg] # [velocity]

Froude similitude

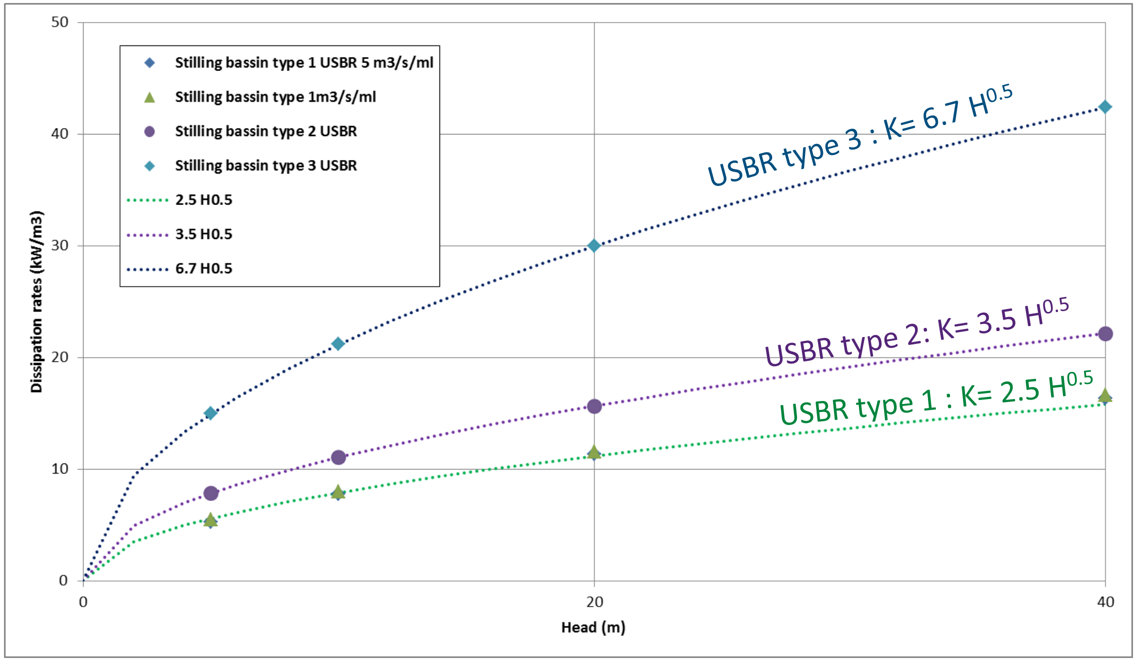
For a similar configuration K varies as $H^{0.5}$

1. Dissipation rates

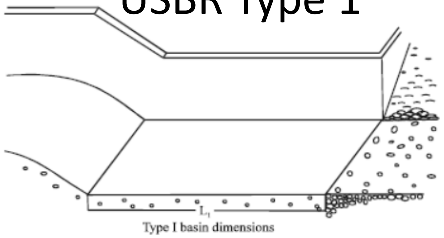
Dissipation rates for stilling basin

For the stilling basin :

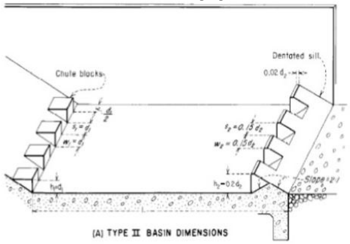
- USBR Type 1 : $K=2.5\ H^{0.5}$
- USBR Type 2 : $K=3.5\ H^{0.5}$
- USBR Type 3 : $K=6.7\ H^{0.5}$



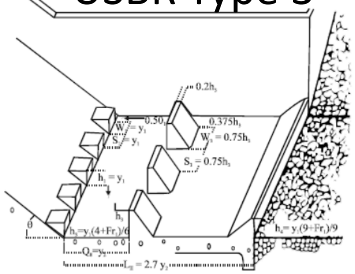
USBR Type 1



USBR Type 2



USBR Type 3



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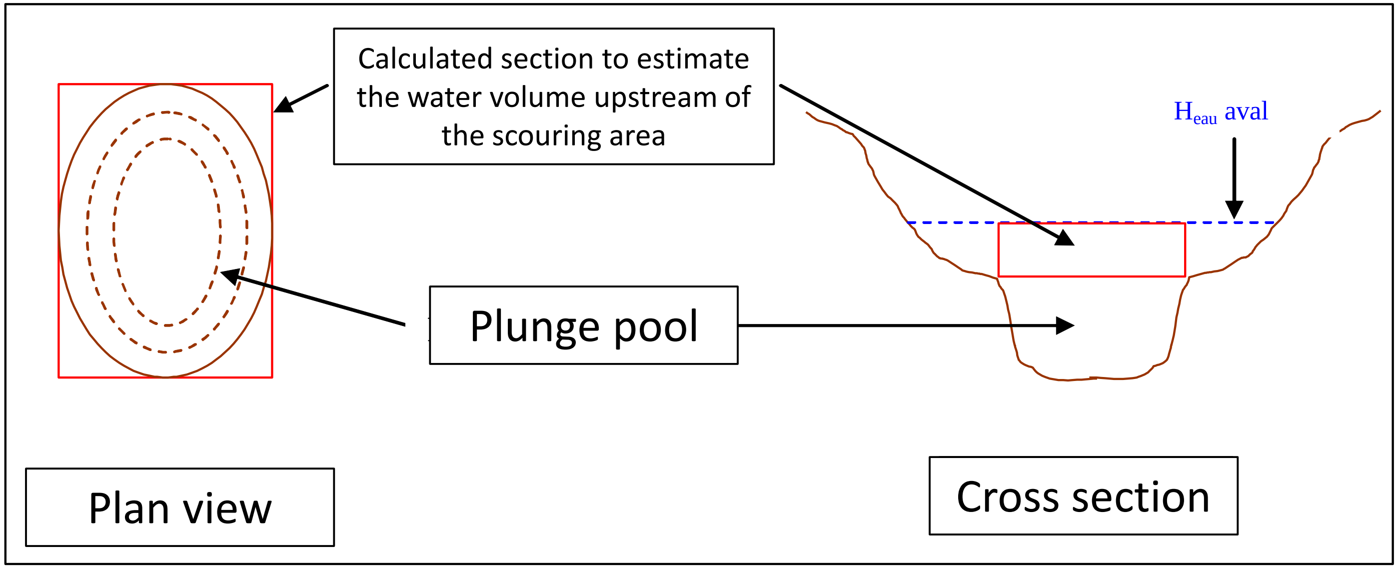
1. Dissipation rates

Estimation of the volume of dissipation for a plunge pool



1. Dissipation rates

The dissipation rates within the plunge pool of 9 spillways (in operation or in the scale model) were estimated (*) :

Dam	Q (m3/s)	Head (m)	K = (P/V) (KW/m3)
P.K. Leroux (South Africa)	13 000	71	30
Cambambe (Angola)	9 500	60	56
Maguga (Swaziland)	7 000	85	31
Ertan (China)	23 900	165	21
Xingo (Brazil)	16 000	83.5	22
Sidi Saad (Tunisia)	5 400	50	9.3
Katse (Lesotho)	6 040	142	20
Bunji (Pakistan)	21 400	145	30
B72 (Oman)	588	40	22

The only information of the dissipation rate can not represent the whole phenomena but give a global value for comparison

* Paper Jehanno et al. presented at Congress CFBR-SHF (2009) + additional investigations by ARTELIA

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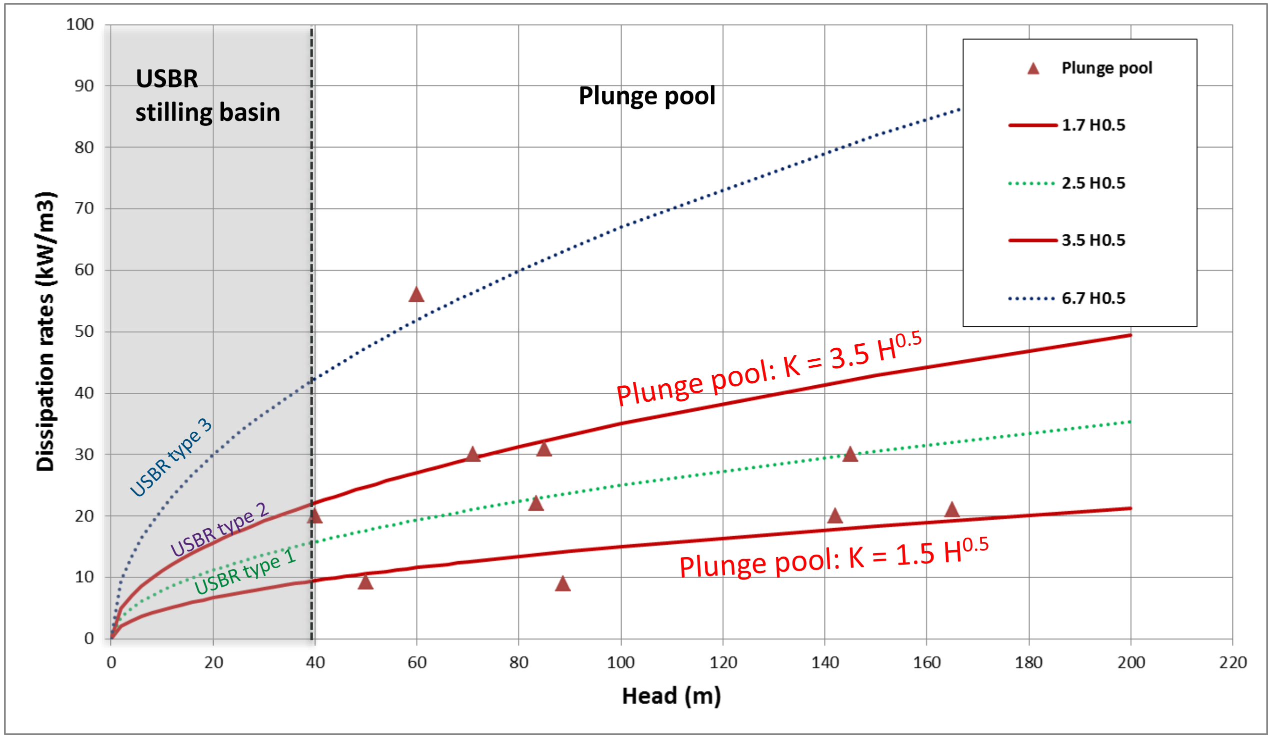
1. Dissipation rates

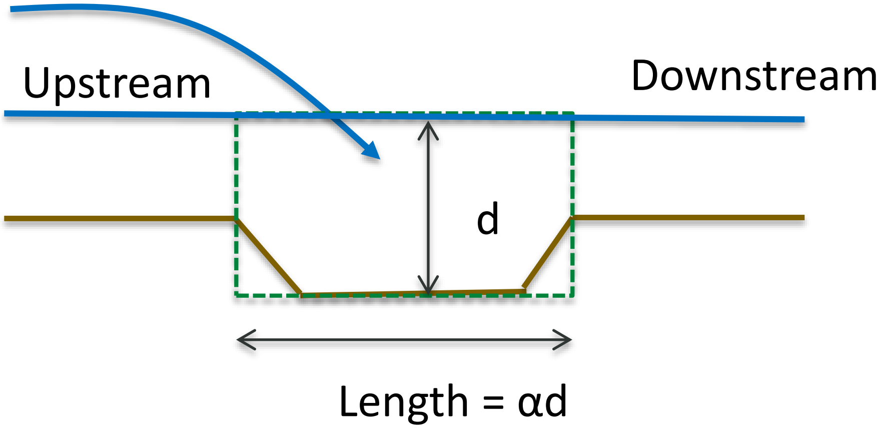


- As we can see :
  - Except for one singular value of 56 kW/m³,
  - K for plunge pools is included :

    - between 10 and 30 kW/m³

    - between 1.5 $H^{0.5}$ and 3.5 $H^{0.5}$

1. Dissipation rates



d: depth of erosion

Veronese : $d=1.9q^{0.54}H^{0.225}$

α = coefficient

Dissipation rate = $K=\dfrac{\rho g Q H}{Volume\ of\ dissipation}$

Per width unit :

$$K=\frac{\rho g q H}{d*length} \rightarrow K=\frac{\rho g q H}{\alpha d^2} \rightarrow K=\frac{\rho g q H}{\alpha(1.9q^{0.54}H^{0.225})^2}$$

for a given geometry of plunge pool

$$K=\frac{\rho g}{\alpha(1.9)^2}\, q^{-0.08}H^{0.55}$$

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1. Dissipation rates

- Advantage : preliminary approach easy for implementation, based on previous experiences
- Limits : Do not take into account the characteristics of soil and rock materials

2. Estimation of the erosion potential

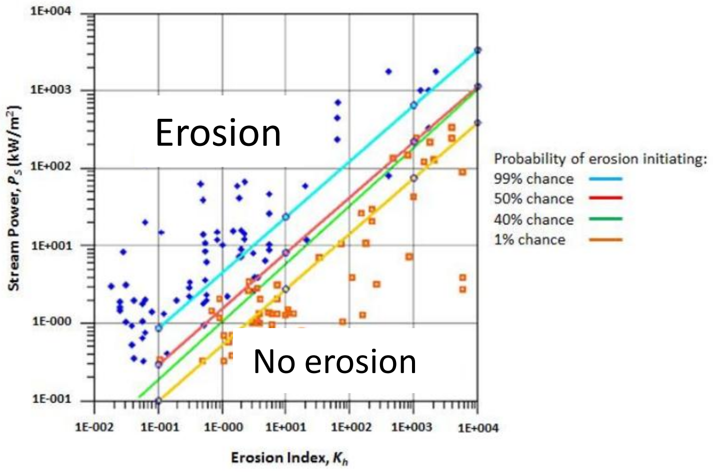
Empirical and semi-empirical approach

- Many empirical formulas were developed to compute the scour depths.

Most commonly used: Veronese, Martins, Mason,….

Semi-Empirical approach (type Annandale)

- Comparison between the erodability index and the stream power
- Almost 150 observations (soil and rock)



Erosion potential – erodibility index versus stream power

Source: USBR standards. Chapter 3: General spillway considerations

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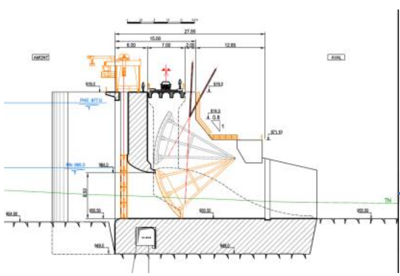
2. Estimation of the erosion potential

These two methods were applied on a wide range of head, discharge, soil and rock materials



Project	Structures	Stage of project	Head (m)	Discharge (m3/s)
Fufu (Malawi)	Ski Jump	Under design	120	4200
Janneh (Lebanon)	Ski Jump	Under Construction	120	1300
Beaumont-Monteux (France)	Gated dam	In operation	1-10	15-4900
Nachtigal (Cameroon)	Downstream of gate	Under design	4-8	650-7500
Antetezambato (Madagascar)	Downstream of gate	Under design	12	14000
Rusumo (Rwanda)	Downstream of gate	Under Construction	9	200
Marege (France)	Overflowing on existing arch dam	In operation	82	1450

- Problematic of erosion : critical issue for a number of projects

- As a first assessment, empirical and semi-empirical methods associated with dissipation rates allow for estimating the risk of erosion downstream of a dam

- These formula do not take into account the duration of the event in particular for extreme event (Q10 000, PMF)

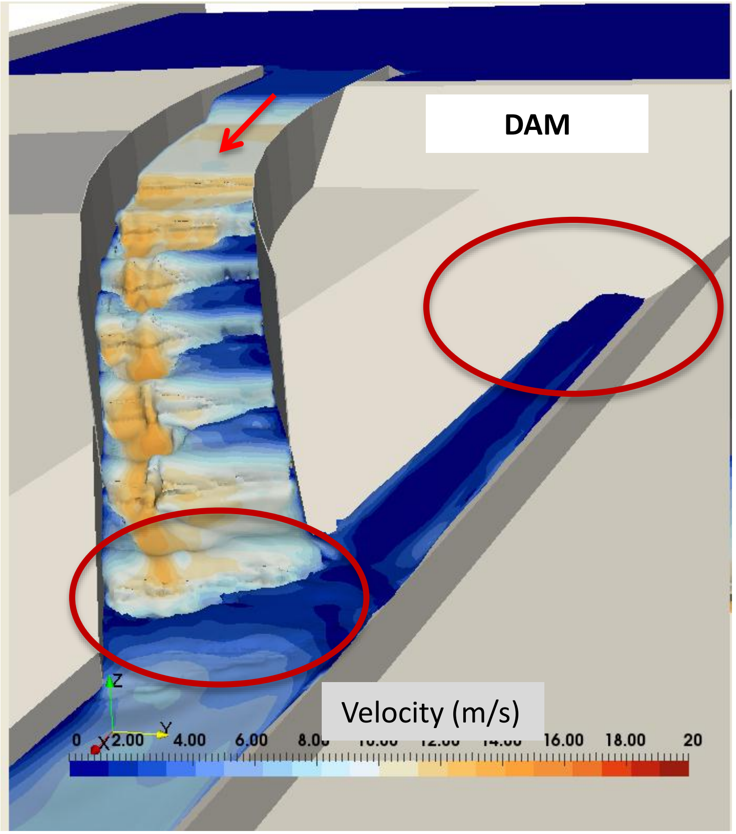
- In order to get a more precise assessment of the erosion risk, a 3D approach is often used
  - 3D numerical model
  - Physical scale model

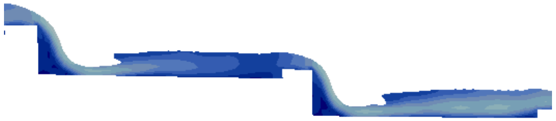
3. Previous experiences with 3D models

- 3D numerical model : case of Bwanje dam in Malawi
- Physical scale model :
  - case of B7.2 dam in Oman
  - case of Katse dam in Lesotho
  - Case of Bunji dam in Pakistan

3. Previous experiences with 3D models

3D numerical model





Project :

- Bwanje dam (Malawi)
- Rockfill dam of 40 m height
- Stepped spillway

Main objectives of the model were to study:

- The flow conditions over the stepped spillway (nappe flow conditions)
- The flow conditions downstream of the spillway : especially to check velocities at the toe of the dam and into the river

Results

- Velocities< 14 m/s
- Verification of the erosion potential with a semi-empirical approach (type annandale)

➢ No risk of erosion of the rock
➢ No risk of destabilization of the left bank

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3. Previous experiences with 3D models

- Model of ski-jump (B7.2 Dam Oman 1:80 scale)
  - Model for 40 m head

Main objectives of the model were to study:

- the conditions of the jet in the air and at the impact
- the risks of scouring in the wadi at the impact area

Results

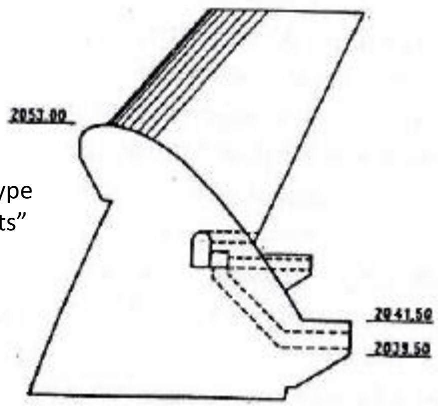
- Part of the lateral nappe flowing straight ahead without jumping → Modification of the design of the ski-jump
- Estimation of 3 m of depth scour for PMF (30% less that the depth scour obtained with empirical formula (Veronese, Martins B).
- K=P/V=22 KW/m^3



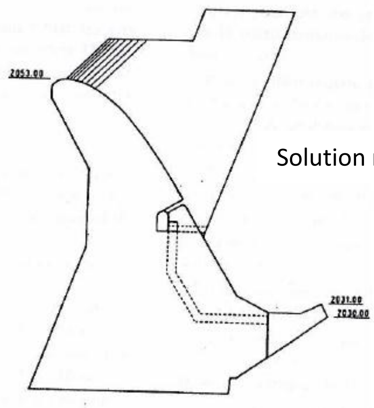

3. Previous experiences with 3D models

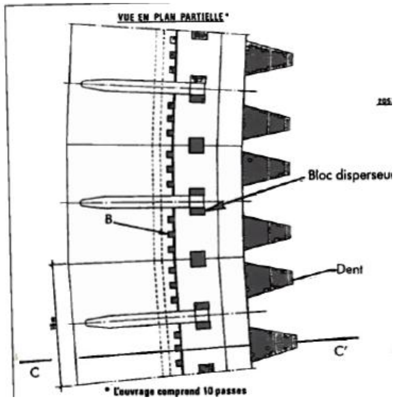
- Model of ski jump (Katse dam – in operation since 1997)
  - Model for high head (185 m of head)

Solution n°1 : type “Colonel Roberts”



Solution n°2





The model have shown a clear advantage for the solution n°2 specially developped for this project (reduction of 7 m of the scour depth. 27 m instead of 34 m)

Reduction of 50 % of the minimum water depth to avoid erosion (27 m instead of 56 m (Veronese))

K=P/V=20 KW/m^3

3. Previous experiences with 3D models

- Model of plunging jet (Bunji dam in Pakistan)

	Head (m)	Water depth (m)
Cylindrical bucket	135	45
Circular lip bucket	141	39
Serrated bucket	144	36

Global conclusion

- Objectives: assess the erosion potential and check the dissipation of energy downstream of a dam

- As a first assessment, empirical and semi-empirical methods associated with dissipation rates allow for estimating the risk of erosion downstream of a dam

- Adopting dispersion teeth or other means to increase the effective length of jet impact, the scour depth will be decreased accordingly.

- In any case, for critical projects, results given by the two methods shall be checked on 3D model.
  - To take into account the aeration of the water jet
  - To check the return of high velocity flows in the river
  - To ensure that no high velocity flow can damage the structures, their foundations or banks stability

Thank you for your attention!

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