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A simplified design method for plunge pools scour control downstream of large dam spillways, and its applications

Dr Etienne FROSSARD

Technical Director - Dams & Hydropower

TRACTEBEL Engineering
GDF SUEZ

COYNE ET BELLIER
Ingénieurs Conseils

SCOPE

I- Introduction

II – Hydrodynamic rationales

Flat bottom plunge pool

Scour hole configuration

III – Applications in design

Principles for basic design stages

Example for a construction design

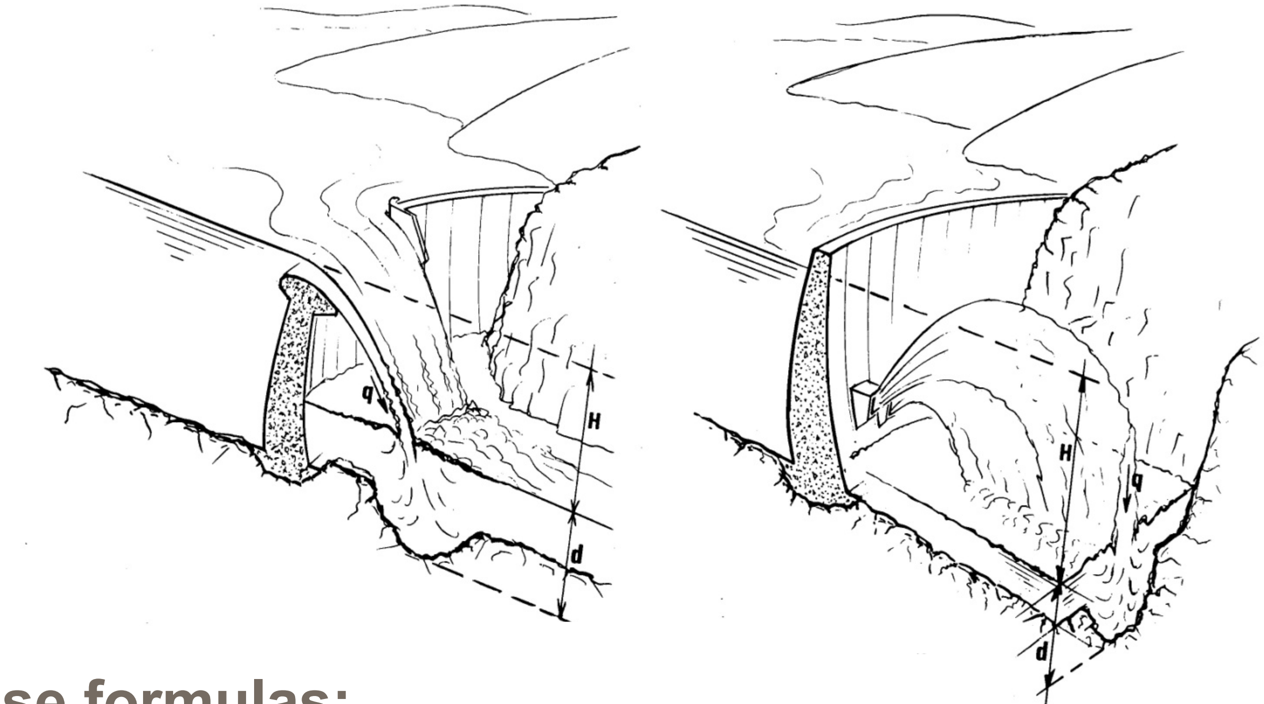
IV - Conclusions

I- Introduction

- As a key concern for long term stability of downstream dam toes *(eg Kariba),* scour development process has been widely investigated since early times of dam engineering.
- Reference state-of-the-art documents on the matter published over last 30 years *(listed in the paper).* The most up to date general methods require parameters delicate to get at early design stages.
- Simplified methods for basic design stages still needed, preferably on the side of lower resistance river beds.

II- Hydrodynamic rationales

- For free falling plane water jets, final scour prediction given by numerous available empirical formulas *(ref. list in paper).*



- Key features of most of these formulas:
  - the final scour depth ***d*** appears essentially function of unit discharge ***q*** at impact, total head ***H***, and others (river bed resistance);
  - most often unit discharge ***q*** is given more weight than the head ***H***.

II- Hydrodynamic rationales

Flat bottomed plunge pool

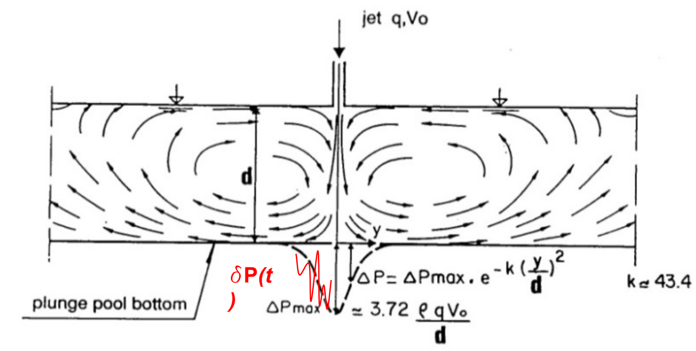
- **Hydrodynamic actions exerted on bottom:**
  - steady average dynamic pressure □P due to deflection of flow lines;
  - instantaneous pressure fluctuations **□*P(t)*** , due to turbulence generated by motion;
  - erosion disintegration of bottom material due to fluctuating forces.

- **Local instantaneous pressure on bottom:**
  P(t) = □g*d* + □P+ □P(t)

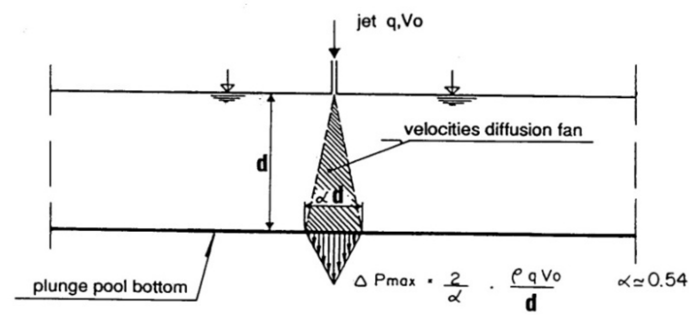
Hydrodynamic data => determination of *d* required to keep fluctuations below a given threshold.

- **Definition of « Jet agressivity depth »**
  = *d* required to avoid cavitation

Resolution: $d \approx 1,4.q^{1/2}.H^{1/4}$ **…+ « jet agressivity sector »**



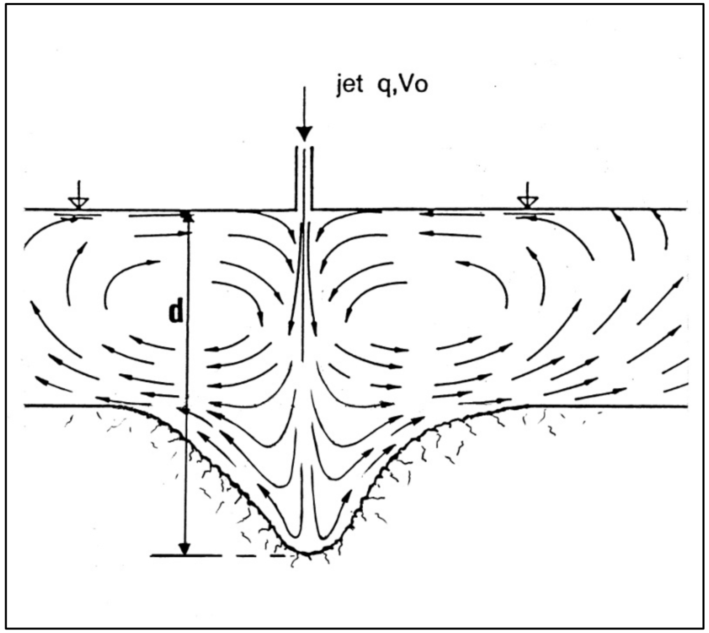
ⓐ Detailed model for flow and average dynamic overpressure
(COLA- 1966 / FRANZETTI- 1980)



ⓑ Simplified model equivalent to ⓐ
(FROSSARD-1985)

II- Hydrodynamic rationales

Scour hole configuration



- In case of pitting development on pool bottom, deviation of flow lines on bottom is becoming about 180° instead of 90° => steady average dynamic pressure term increased by a factor about 2.

  Assuming velocity diffusion fan and pressure fluctuation spectrum similar

- Resolution of « Jet agressivity depth » = *d* required to avoid cavitation :

$$d_{Scour\ hole} \approx d_{Flat\ \ Bottom} \cdot \sqrt{2}$$

then

$$d_{Scour\ hole} \approx 2.q^{1/2}.H^{1/4}$$

- Compare to the still used empirical *Veronese limit scour formula (1937)*

$$d_{Scour} \approx 1,9.q^{0,54}.H^{0,225}$$

II- Hydrodynamic rationales

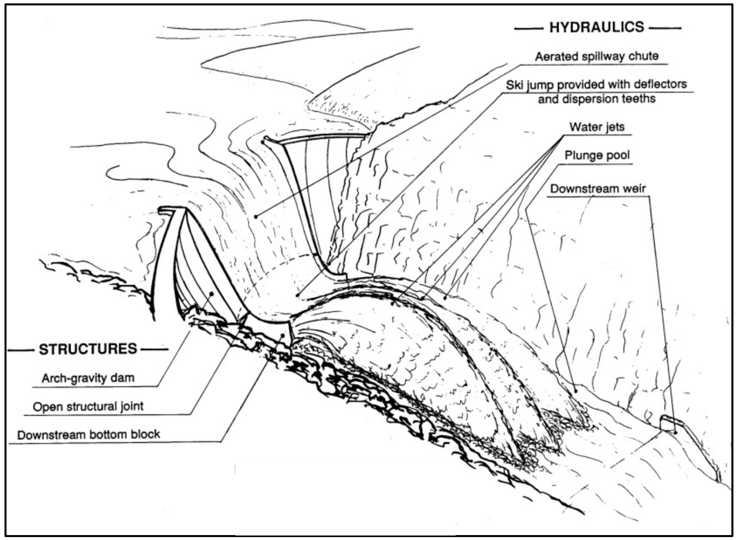
- **Four key comments on preceding results:**
  - **predict inherent instability of flat bottomed plunge pools in case of accidental pitting, as estimated « jet agressivity depths» are significantly greater for scour hole configuration:** $\boldsymbol{d}_{Scour\ hole} \approx \boldsymbol{d}_{Flat\ \ Bottom} \cdot \sqrt{2}$
  - **coincidence with empirical Veronese limit formula provides global experimental basic support;**
  - **In the formula for « jet agressivity depth », the weight of unit discharge at impact *q* occurs to be twice the weight of head *H*:** $\boldsymbol{d}_{Scour\ hole} \approx 2.\boldsymbol{q}^{1/2}.\boldsymbol{H}^{1/4}$
    => so for scour control it will be more efficient to try first to reduce q
  - **as proper resistance and strength of bottom materials are neglected, these simple hydrodynamic rationales are more appropriate for fragile soft rocks or movable granular river beds**

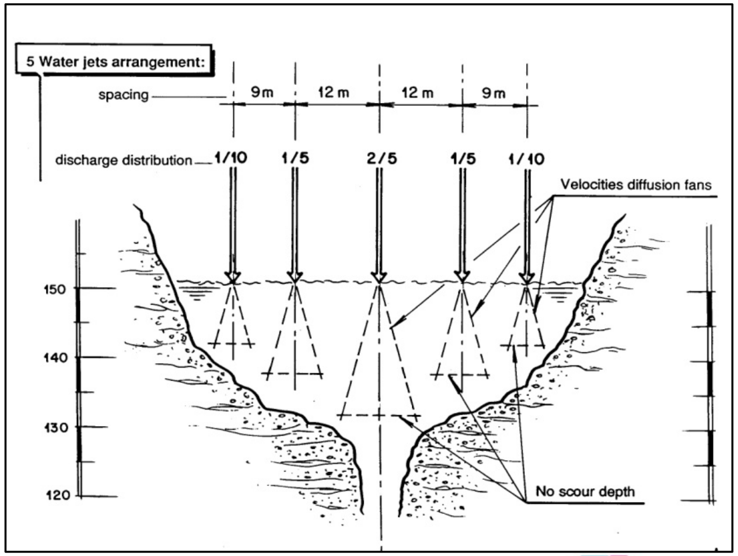
III- Applications in design
Principles

- For a given spillway problem, above rationales, together with aeration concerns, lead to:

  - organize the restitution by dividing total spilled discharge in various water jets more or less parallels, in narrow gorges better achieved by jets distributing water longitudinally;

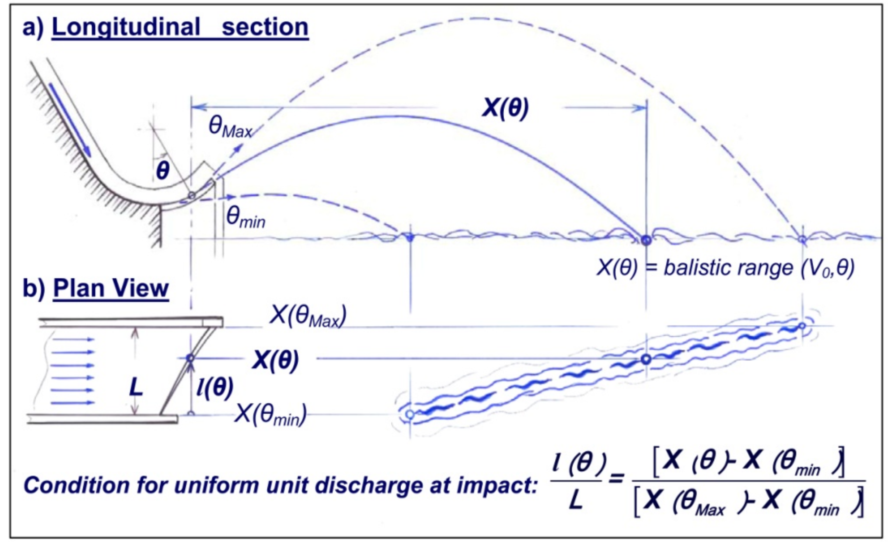
  - Use the concept of « jet agressivity sector» to organize the relative positioning of water jets at impact, by optimizing the distribution of total discharge within the different water jets.





III- Applications in design
Principles

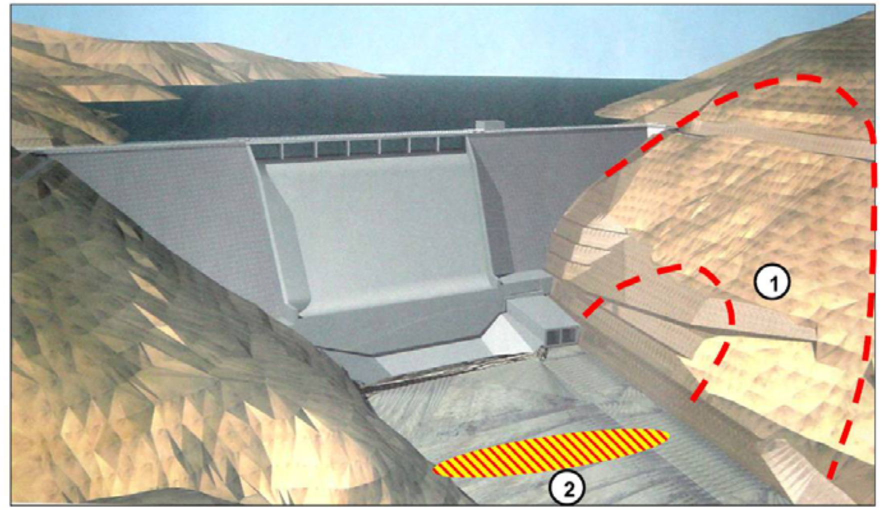
- Restitution features to provide this kind of water jet longitudinal distribution:
  - either dispersion teeths (eg Aldeadavila spillway in Spain, or Karakaya spillway in Turkey);
  - or simpler « longitudinal distribution flip buckets », easy to handle at basic design stages;

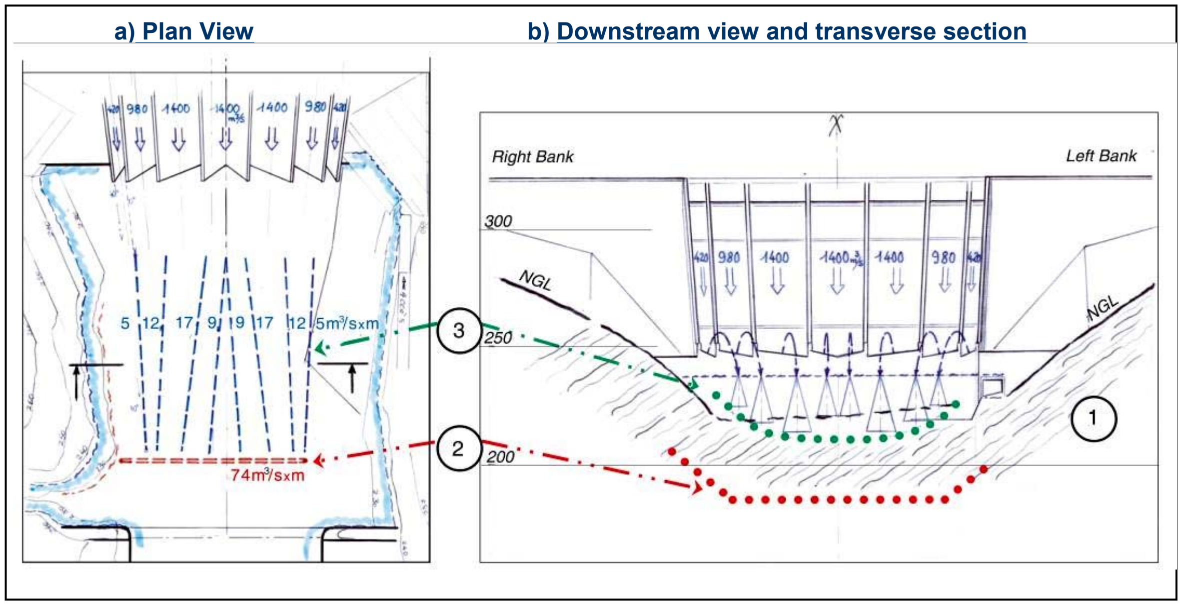


III- Applications in design

Example of implementation 7000 m³/s

- **Gravity dam project 120m high in Algeria, with exceptionally difficult geological conditions revealed during foundations preparation => in-depth reconsideration of the whole project during construction.**





III- Applications in design

Example of implementation

Final configuration of Koudiat-Acerdoune Dam in Algeria *(7000m³/s spillway,120m high)*, commissioned in 2009.

IV - Conclusions

- The method provides original simple design approaches to problems of scour control downstream of large dam spillways.

- More suitable for:
  - heavy discharges to be spilled in narrow valleys;
  - lower resistance river beds.

- Some of the key simplifying assumptions may be refined in future developments.

IV - Conclusions