# Erodability of hydraulic structures foundations EDF needs

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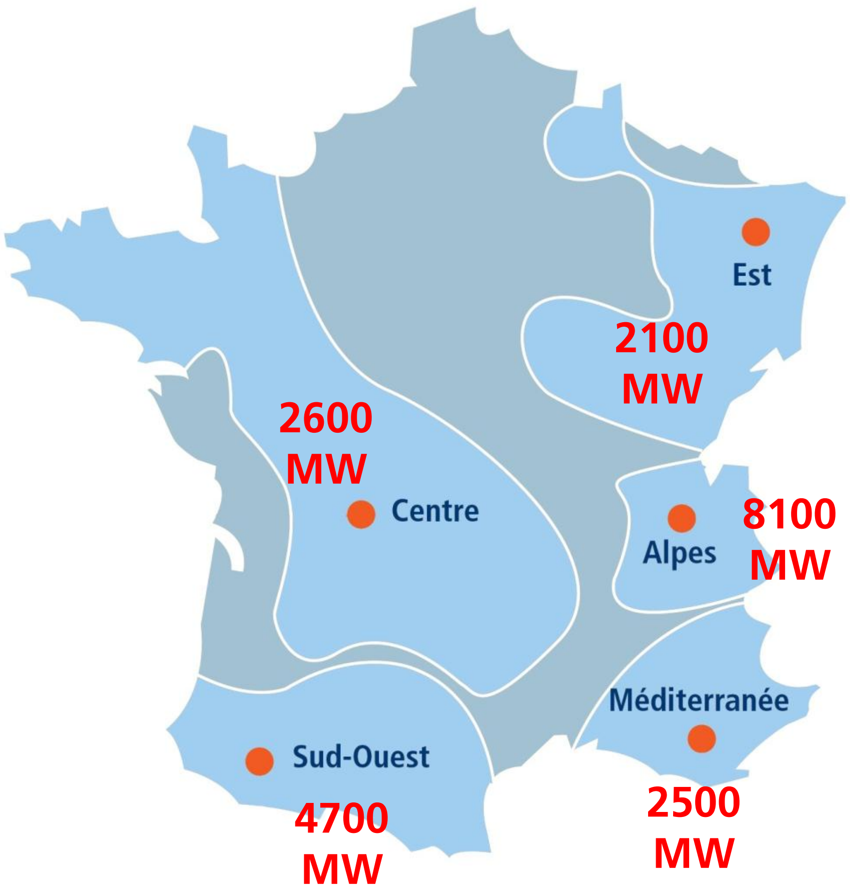
**International Workshop on overflowing erosion of dams and dikes**

***11 – 14th December 2017 - AUSSOIS, FRANCE***

# CONTENT

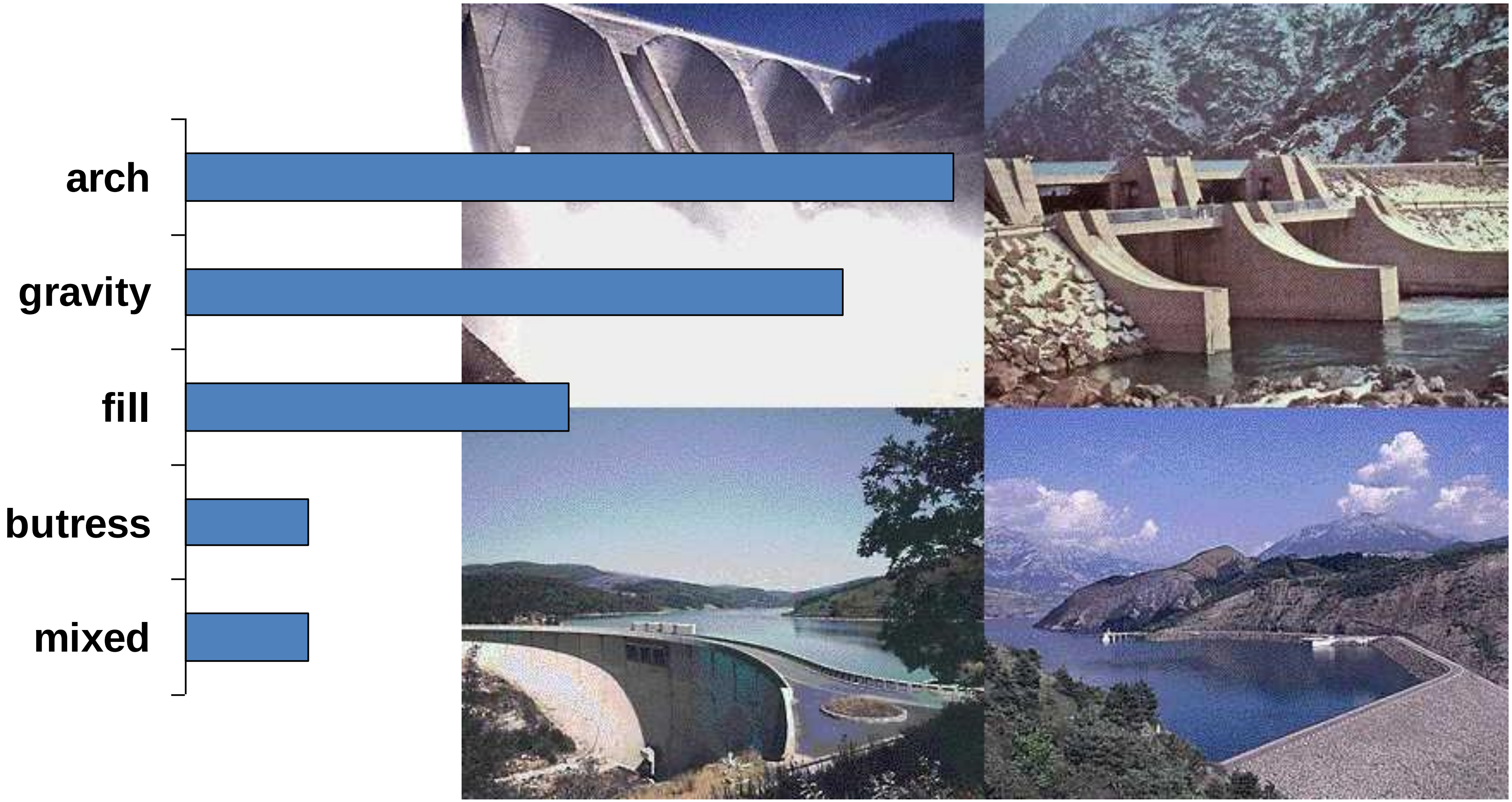
# 1. EDF Hydro

- 450 powerplants
  (100 kW to 1800 MW)
- 20 000 MW – 44 TWh/an
- 220 large dams – 1400 gates
- 1500 km of tunnels – 270 km of penstocks
- Age > 65 years!

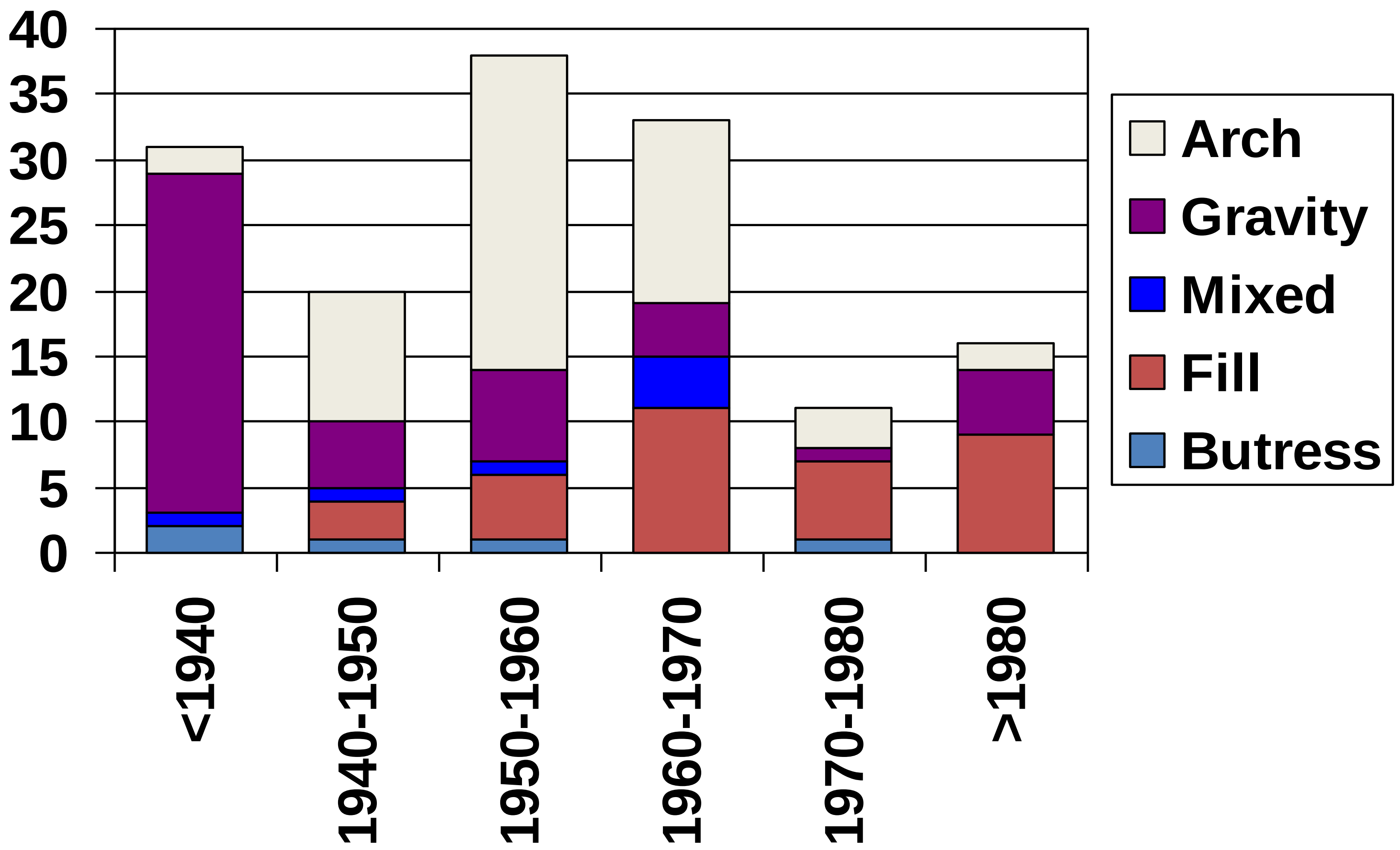


# Dam Portfolio by type

150 class A dams (H > 20m)



# Dam Portfolio by commissionning date



# 2. Hydraulic Design Criteria

- Currently : No « official » regulation in France

  *NB : But Risk analysis required since 2007 without hydraulic criteria*

- Historical « good practices » :
  - Design Flood Q1000 (concrete dams) – Q10 000 (embankment dams)
  - No Safety flood
  - Design with (n-1) gates for large run-off schemes only !

- FrenchCold guidelines for spillway (2013)

# 2. Hydraulic Design Criteria

- « Near » future => « official » regulation in France being discussed since 2013
  - Design Flood ?
  - Safety flood ? (100 000 years ?)

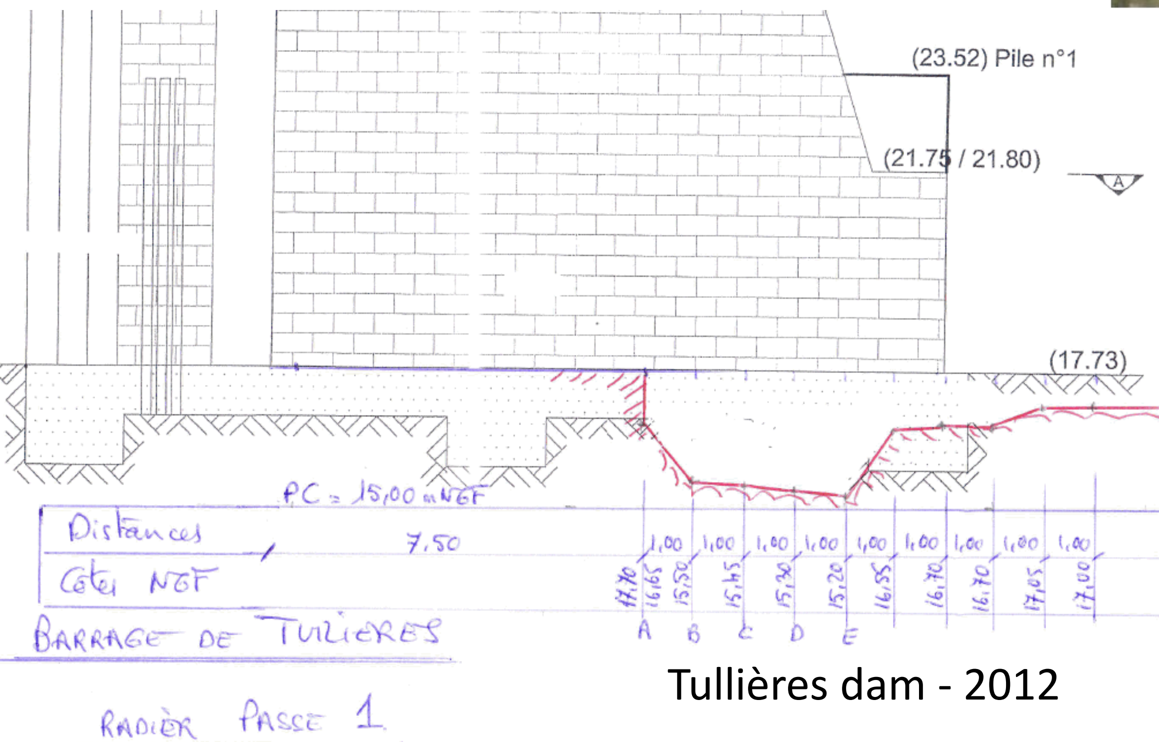
# 3. Examples of erosion issues

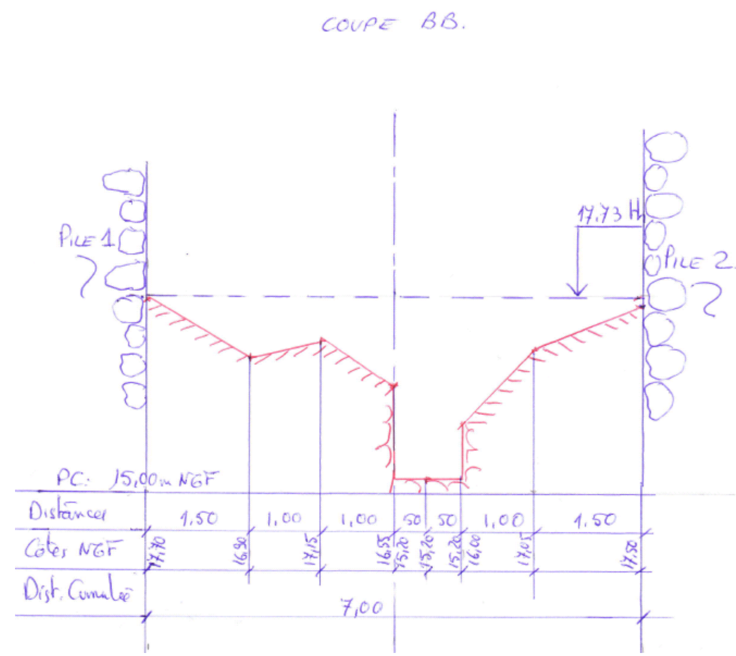
Small power (H = 10 m) / Long duration

**2m deep erosion**

Modification of gates operation process (fish)

Coffer dam




Tullières dam - 2012

# Examples of erosion issues

Small power (H = 10 m) / Short duration

Lac d’Oo dam – 2013 - Before overtopping

# Examples of erosion issues

Small power (H = 10 m) / Short duration – 60 cm head overtopping

Lac d'Oo dam - 2013

# Examples of erosion issues

Small power (H = 10 m) / Short duration – 60 cm head overtopping

Lac d'Oô dam - 2013

# Examples of erosion issues

Small power (H = 10 m) / Short duration – 60 cm head overtopping


Lac d'Oo dam - 2013

# Examples of erosion issues

Small power (H = 10 m) / Short duration – 60 cm head overtopping


Lac d’Oo dam - 2013

# Examples of erosion issues

Small power (H = 10 m) / Short duration – 60 cm head overtopping

Lac d’Oo dam - 2013

# Examples of erosion issues

Grangent dam - high (H = 70 m – Q = 3000 m3/s )

Q100 - Average duration > 1 day

# Examples of erosion issues

grangeant dam - high (H = 70 m – Q = 3000 m3/s )
Q100 - Average duration > 1 day

Before 1966

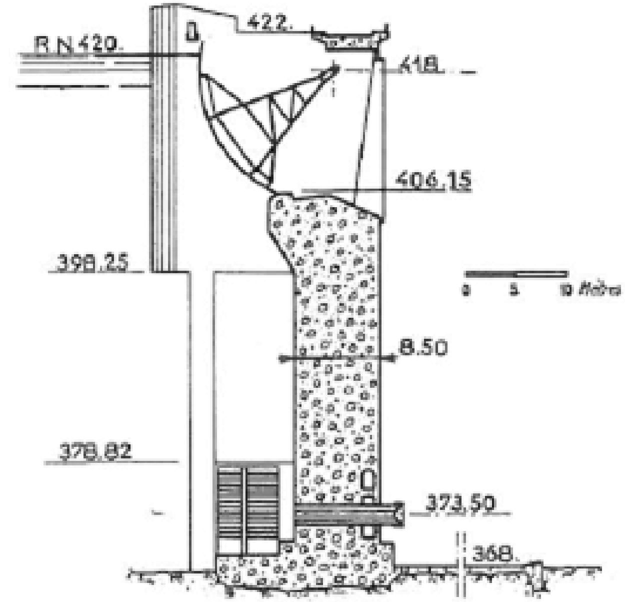
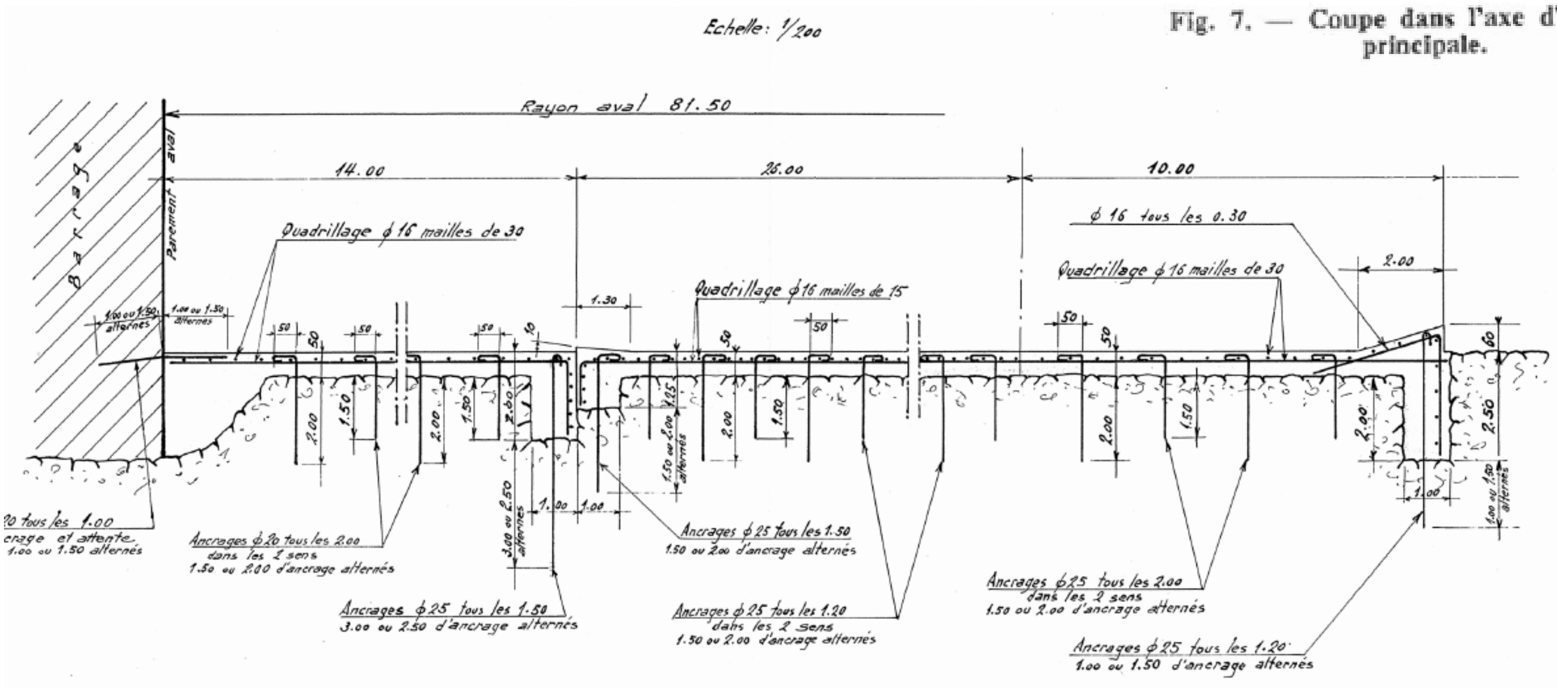


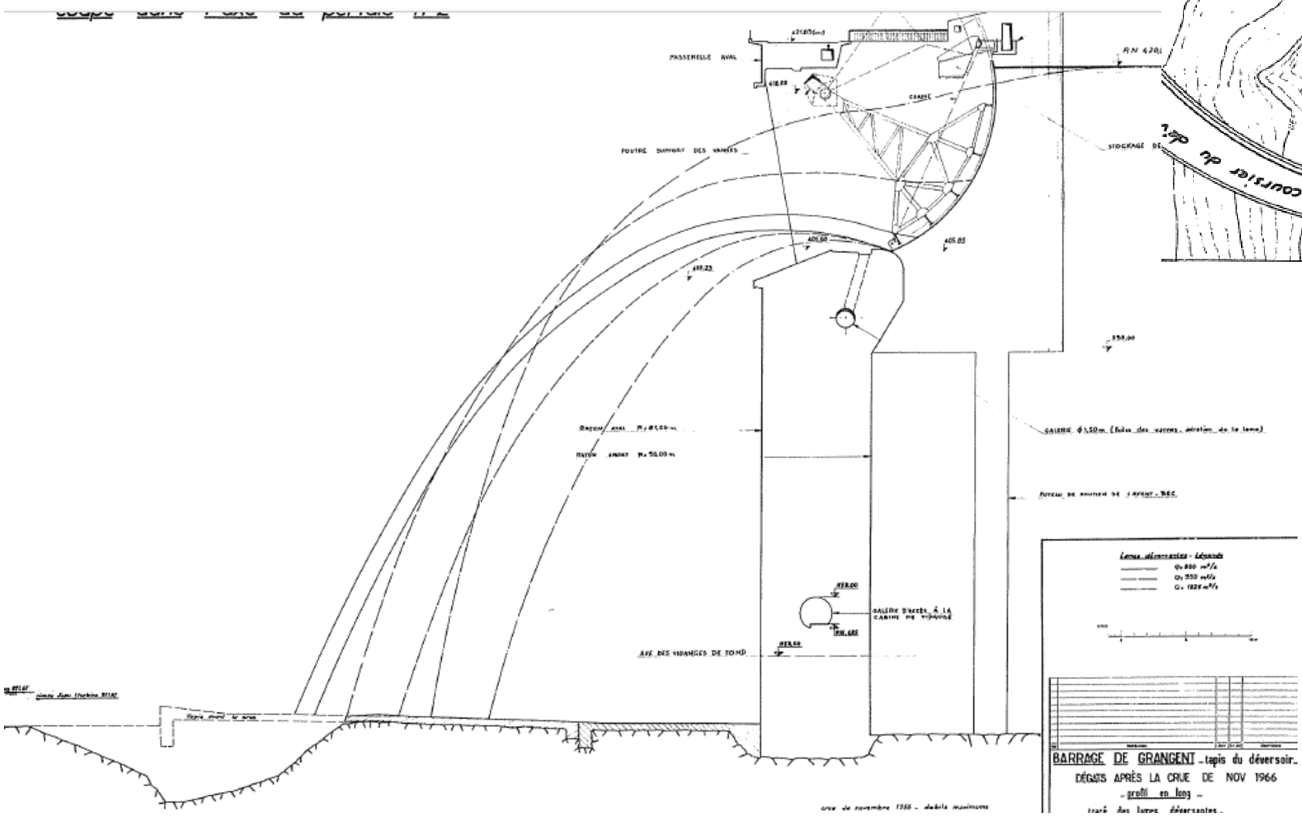

Fig. 7. — Coupe dans l'axe d'une passe principale.

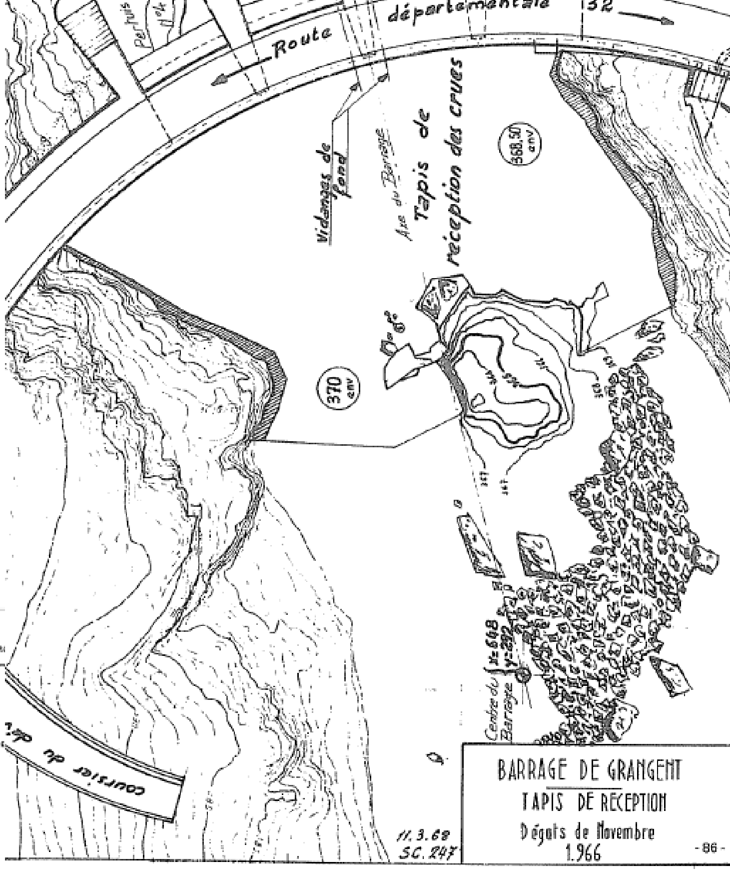


# Examples of erosion issues

grangeant dam - high (H = 70 m – Q = 3000 m3/s )
Q100 - Average duration > 1 day

Before 1966



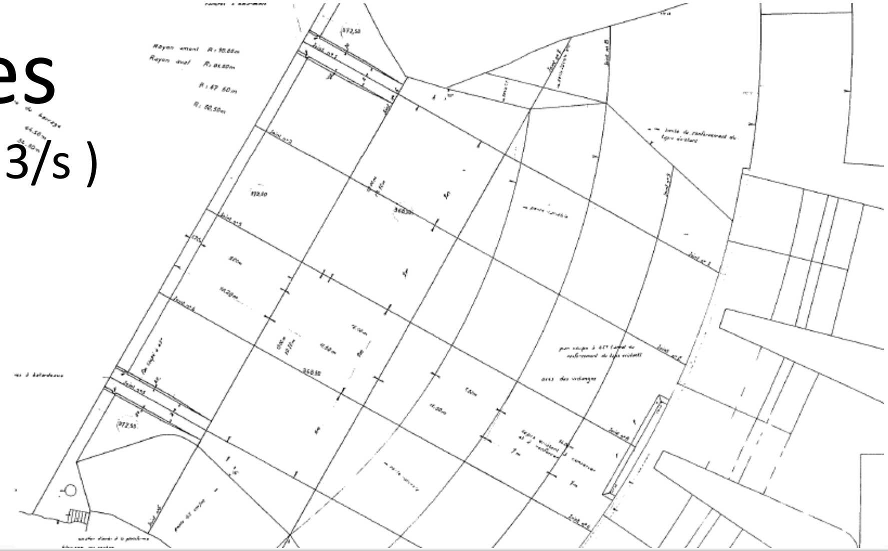



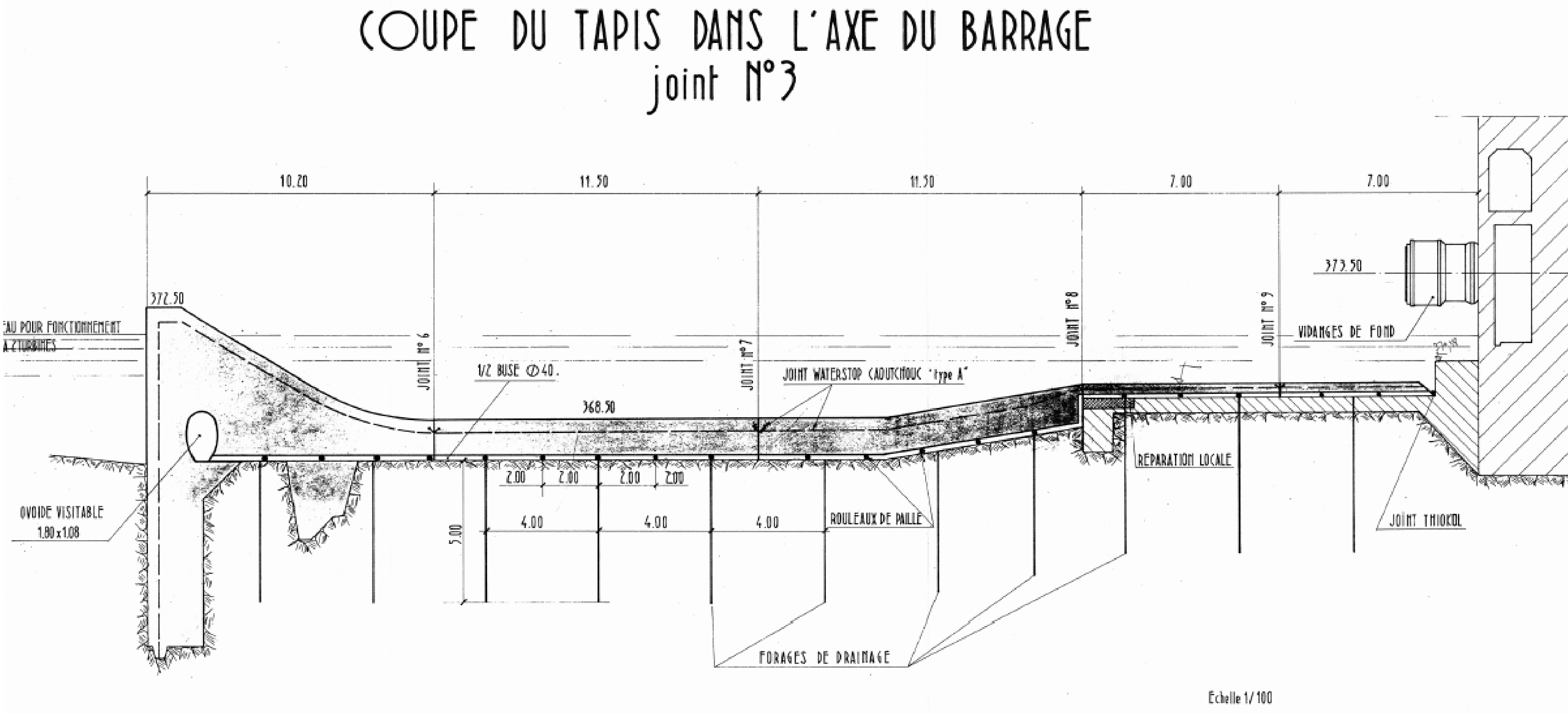
# Examples of erosion issues

grangeant dam - high (H = 70 m – Q = 3000 m3/s )
Q100 - Average duration > 1 day

Repair works – 1968

*Thicker 50 cm => 1,5 m – Improved joints*
*Longer anchor*
*Better drainage*





# Examples of erosion issues

High power (H = 170 m) / Long duration

(India) - 2015

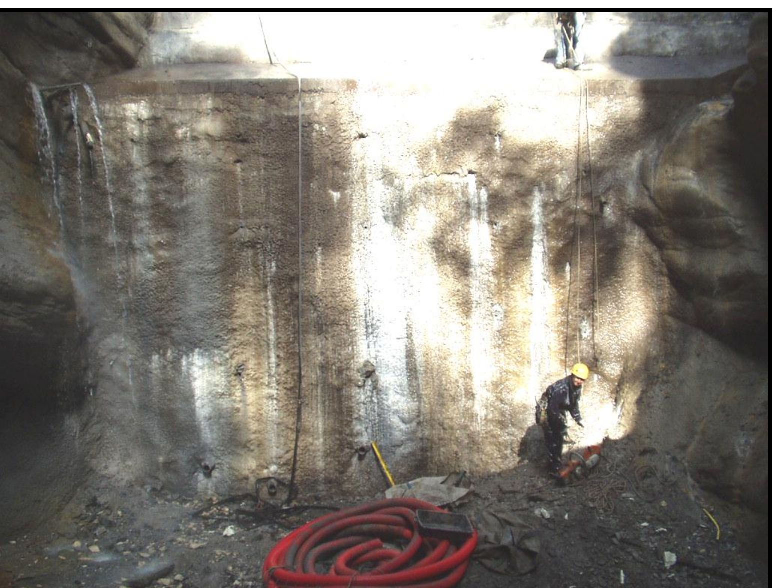
# India- 2015

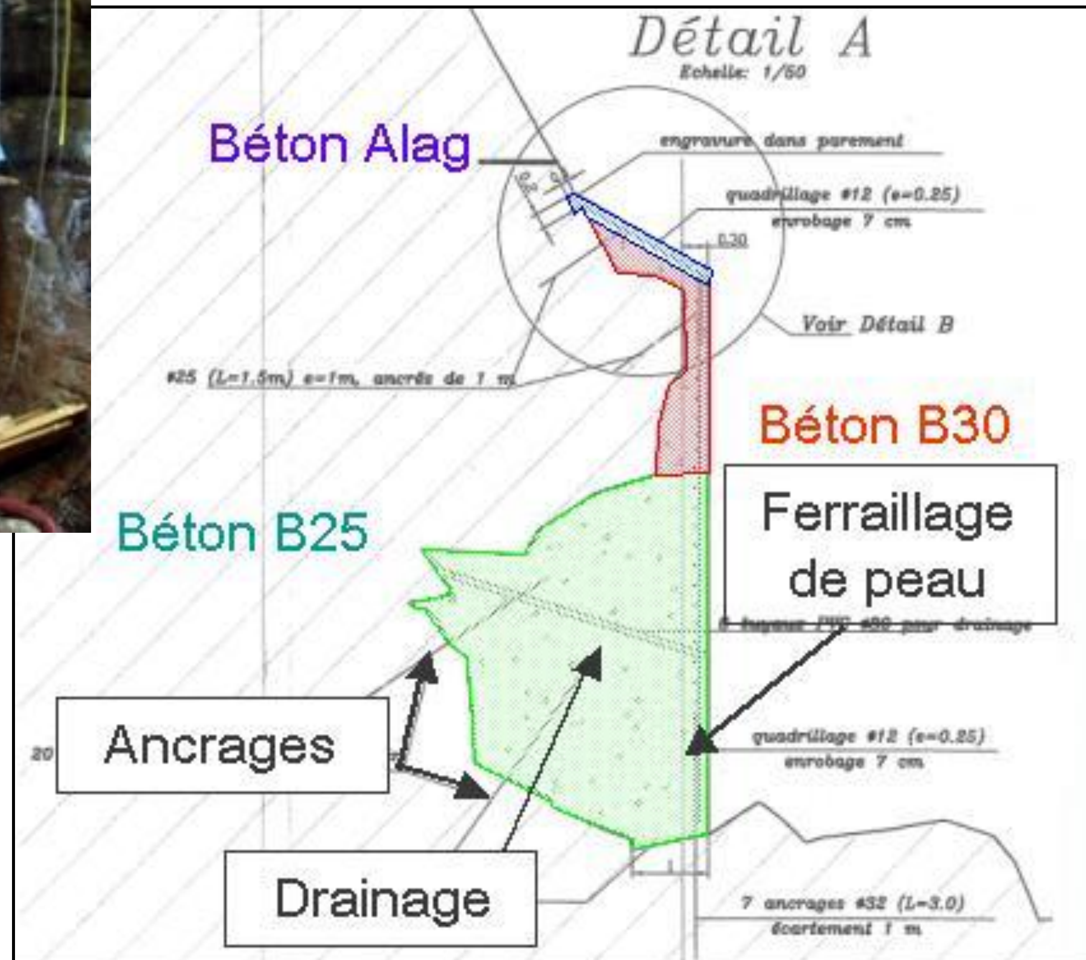

Re-circulating flow downsream

# Particular Examples of erosion issues

Balme de Rencurel – Pot hole


# Balme de Rencurel – Erosion repair works





# Balme de Rencurel – Erosion repair works

- 3D hydraulic numerical model
- Demolition of downstream dam
- Removal of boulder blocks

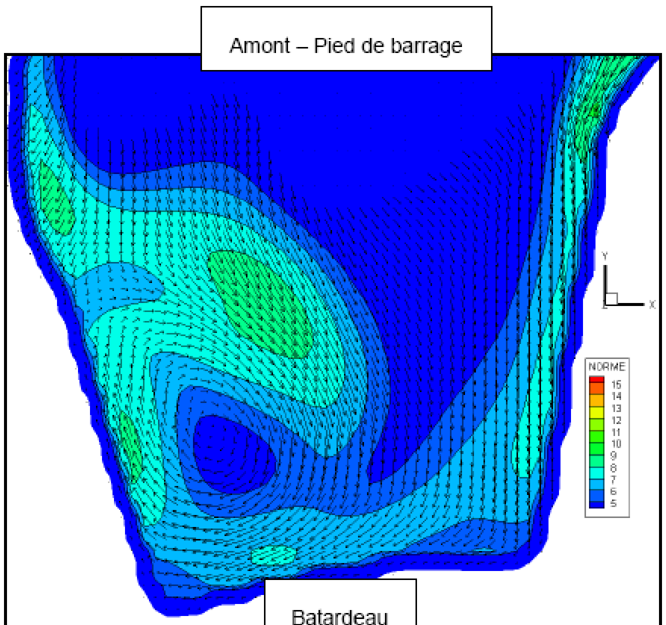



*Figure 8 : Coupe horizontale en 603 NGF*

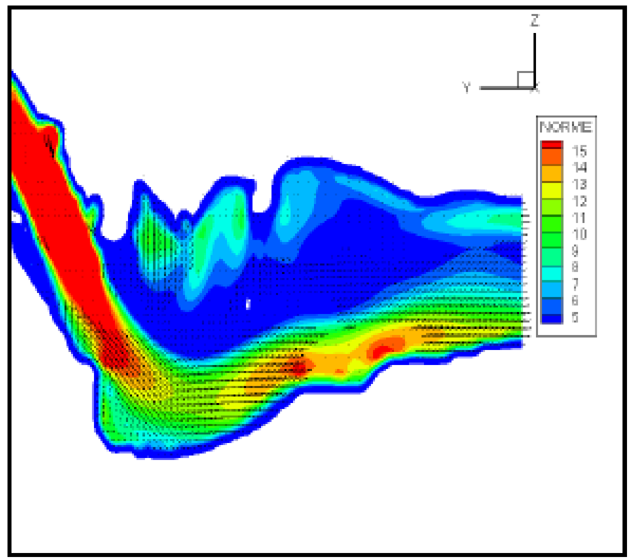



*Figure 50 : Coupe verticale sans batardeau $T_{1000}$*

# Unprotected downstream dam toe

« Good rock… »

Pareloup dam

# Unprotected downstream dam toe

« Good rock… »

Choranche dam

# 4. A bit of history - EDF old lessor

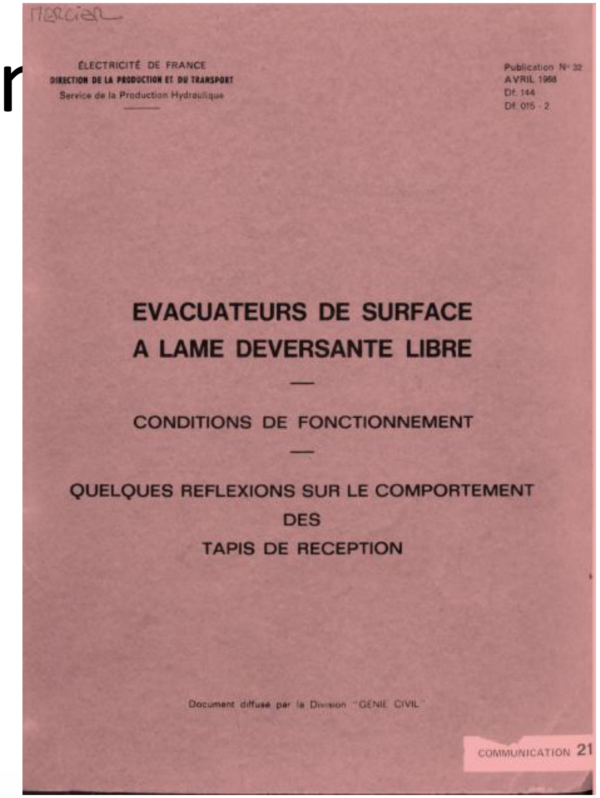
- EDF guideline [1968]
- ICOLD report 1979 Q50.R38

40 arch dams – 20 protected / 20 un-protected

« basic » lesssons

- $P_u$ < 4 000 KW/m² → Few damages
- $P_u$ > 10 000 KW/m² → Important damages (rock / concrete slab)
- Guidelines to dissipation basin design

$$P_{jet} = \frac{\gamma Q H}{A}$$



ÉLECTRICITÉ DE FRANCE
DIRECTION DE LA PRODUCTION ET DU TRANSPORT
Service de la Production Hydraulique

Publication N° 32
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Df. 144
Df. 015 - 2

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QUELQUES REFLEXIONS SUR LE COMPORTEMENT
DES
TAPIS DE RECEPTION

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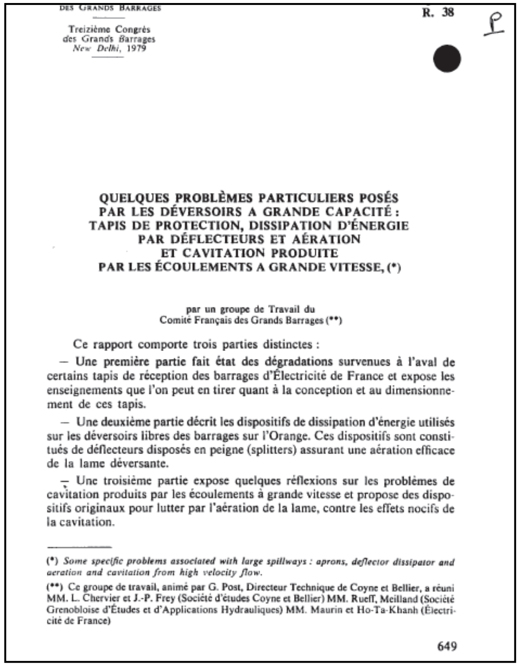

DES GRANDS BARRAGES

Treizième Congrès
des Grands Barrages
New Delhi, 1979

R. 38

QUELQUES PROBLÈMES PARTICULIERS POSÉS
PAR LES DÉVERSOIRS A GRANDE CAPACITÉ :
TAPIS DE PROTECTION, DISSIPATION D'ÉNERGIE
PAR DÉFLECTEURS ET AÉRATION
ET CAVITATION PRODUITE
PAR LES ÉCOULEMENTS A GRANDE VITESSE, (*)

par un groupe de Travail du
Comité Français des Grands Barrages (**)

Ce rapport comporte trois parties distinctes :

— Une première partie fait état des dégradations survenues à l'aval de certains tapis de réception des barrages d'Électricité de France et expose les enseignements que l'on peut en tirer quant à la conception et au dimensionnement de ces tapis.

— Une deuxième partie décrit les dispositifs de dissipation d'énergie utilisés sur les déversoirs libres des barrages sur l'Orange. Ces dispositifs sont constitués de déflecteurs disposés en peigne (splitters) assurant une aération efficace de la lame déversante.

— Une troisième partie expose quelques réflexions sur les problèmes de cavitation produits par les écoulements à grande vitesse et propose des dispositifs originaux pour lutter par l'aération de la lame, contre les effets nocifs de la cavitation.

(*) *Some specific problems associated with large spillways : aprons, deflector dissipator and aeration and cavitation from high velocity flow.*

(**) Ce groupe de travail, animé par G. Post, Directeur Technique de Coyne et Bellier, a réuni MM. L. Chervier et J.-P. Frey (Société d'études Coyne et Bellier) MM. Rueff, Meilland (Société Grenobloise d'Études et d'Applications Hydrauliques) MM. Maurin et Ho-Ta-Khanh (Électricité de France)

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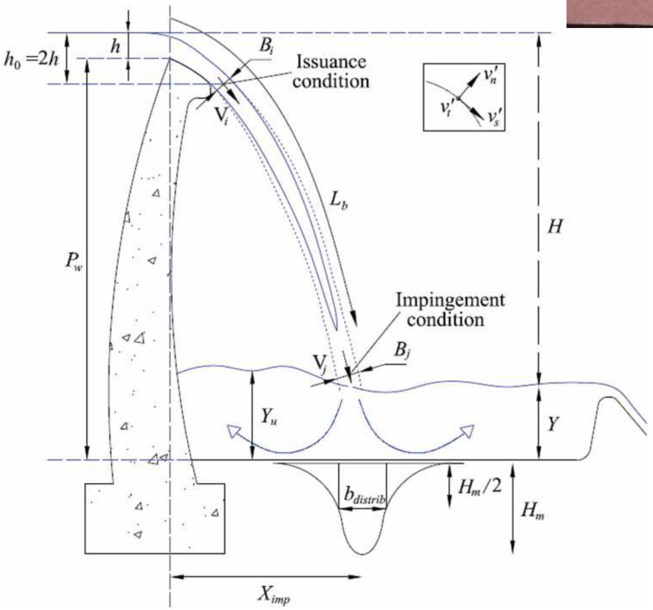


# 4. A bit of history - EDF old lessons

- Few major floods for the past 50 years
  - ✓ A couple of dissipation basins were damaged
  - ✓ Sometimes downstream erosion, but limited extension

BUT..

- No major flood on wide catchment areas dams

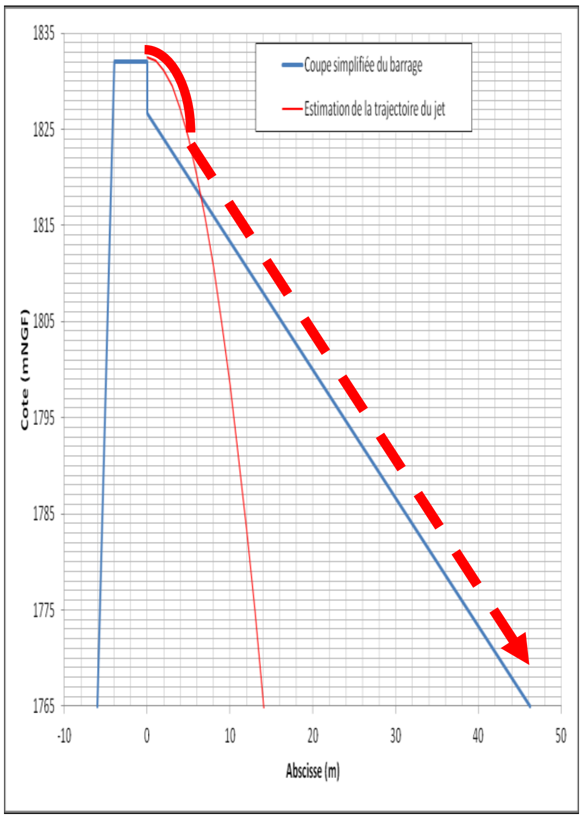
- Some dams rarely spill
  - ⇒ Large dams in mountains – small catchment area peaking effects for average floods

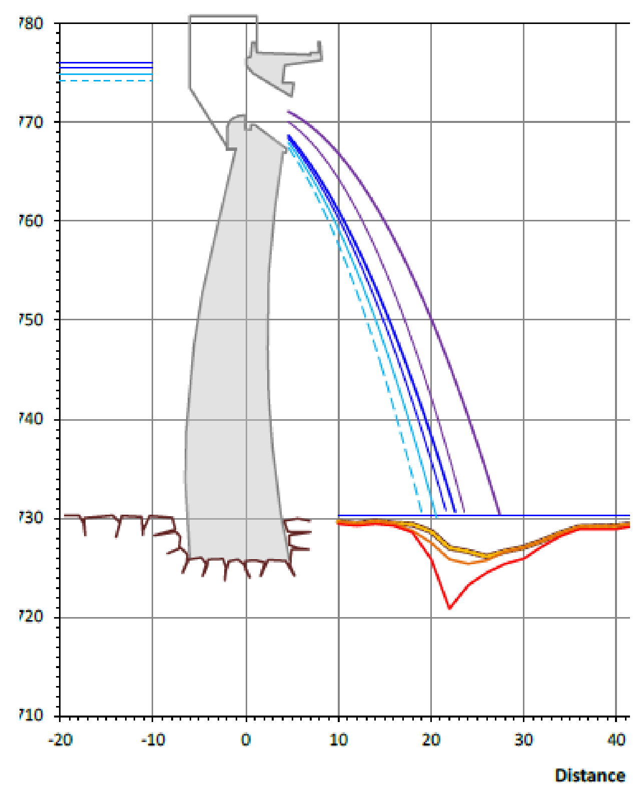
- Difficult to get « historical » information about overtopping and downstream erosion

# 4. A bit of history - EDF old lessons

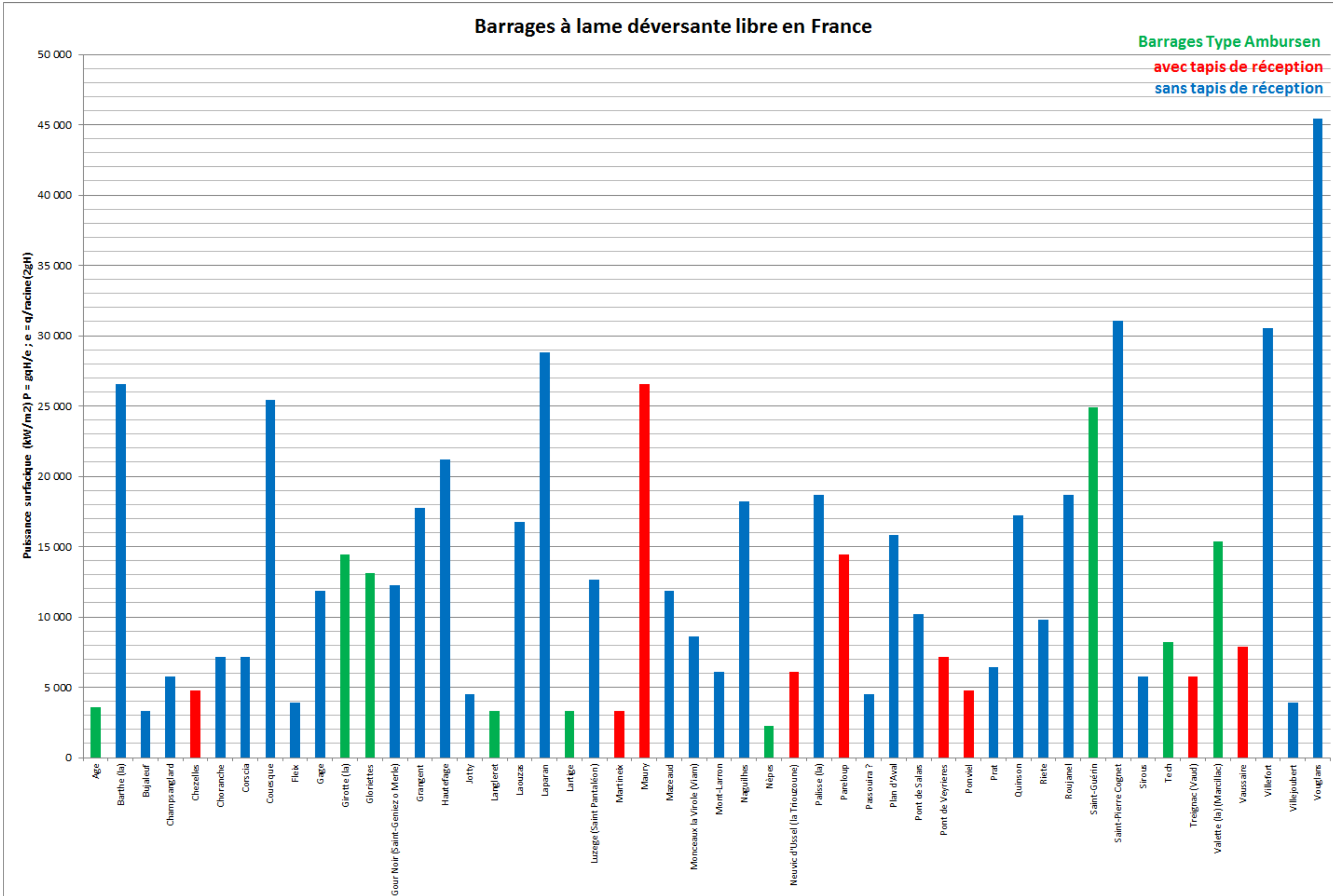
QUESTIONS : SPILL ON ROCK

- How to forecast what will happen for **rare** / unique extreme floods ?
- Time / Short duration



# A bit of history



# 5. EDF current practice
## 3 approaches

- Empirical model (**Veronese**, Mason, Damle, … )
- Semi empirical approach (**Annandale, ...)**
- Theoritical complex approach (**Bollaert, ...)**

# EDF current practice
## 3 approaches

- Empirical model (**Veronese**, Mason, Damle, … )

Time ?

Extent of use – Applicable for rock foundations ?

# EDF current practice
## 3 approaches

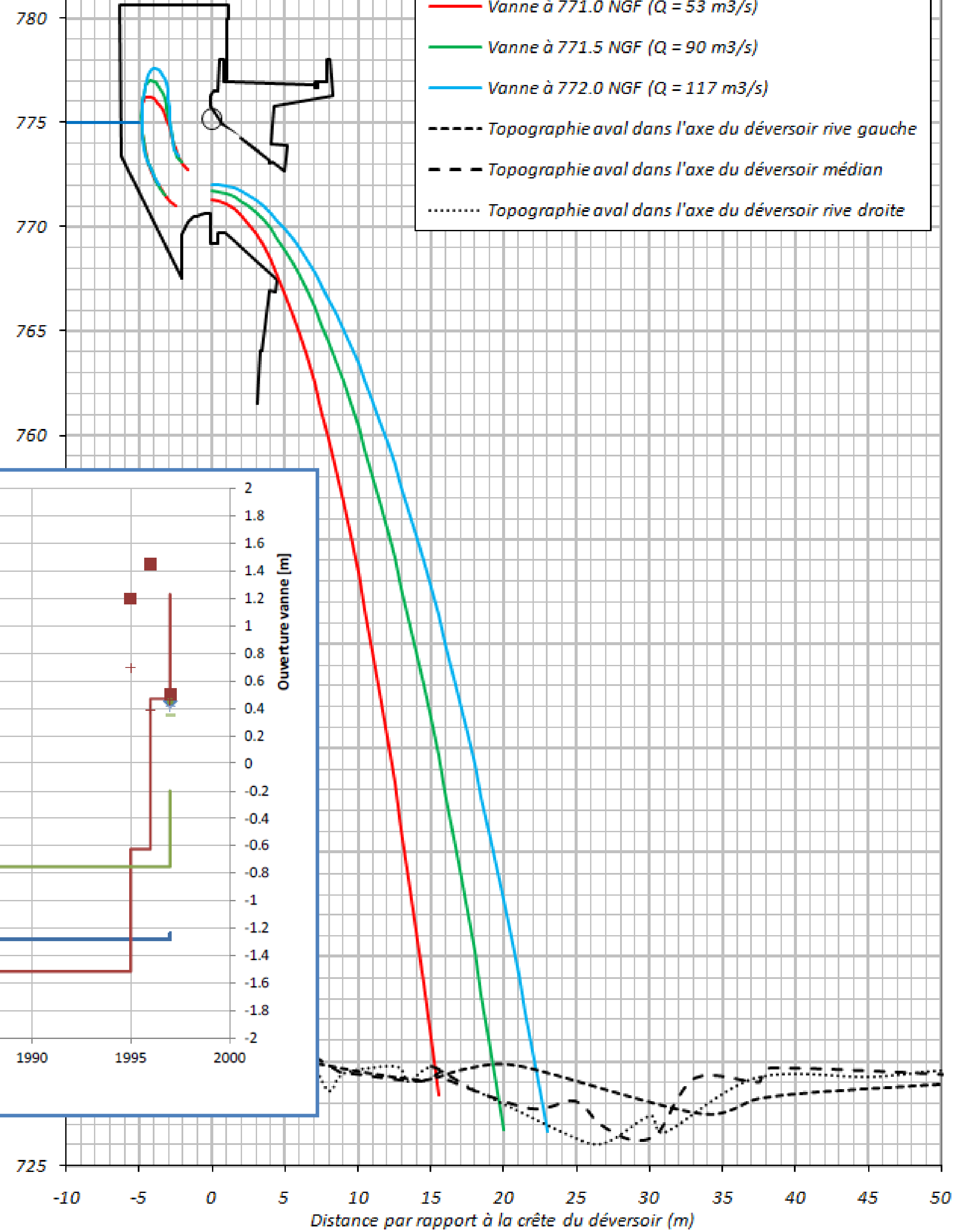
- Theoritical complex approach (**Bollaert, ...)**

Used for 2 dams so far at EDF

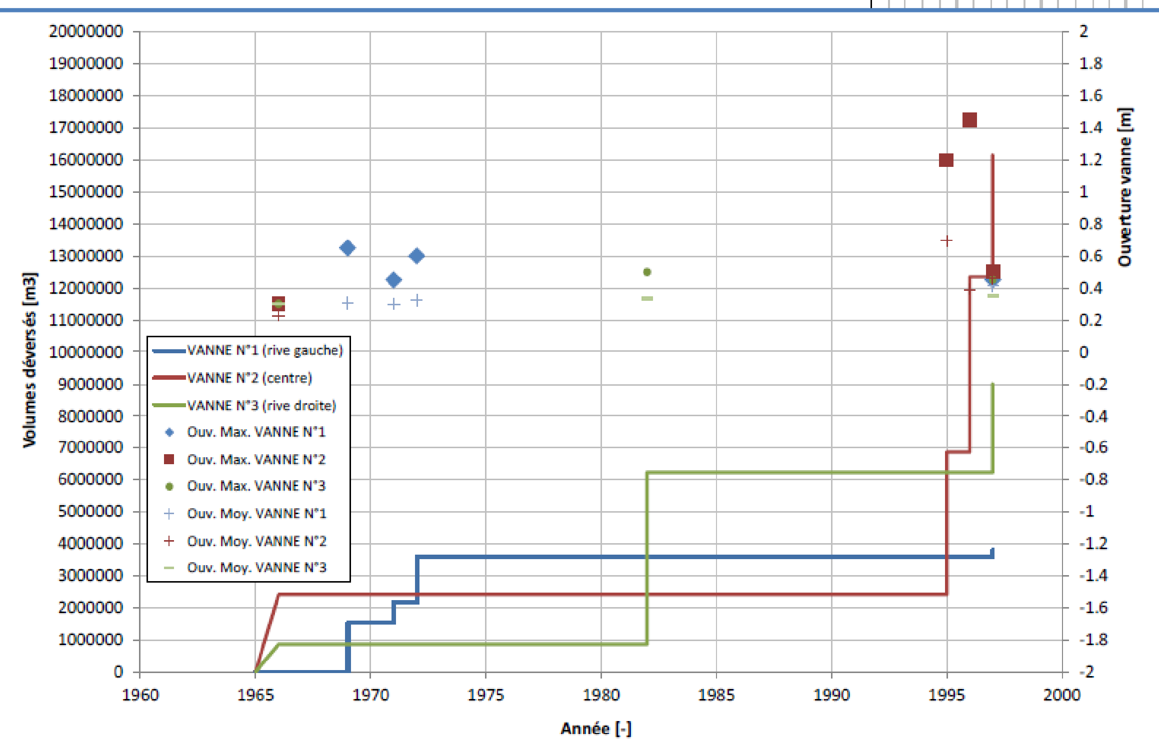
Powerful but « Black box »

- Needs many input data to calibrate the model
- Time dependant – Prediction
- Can take into account efficiency of mitigation measures (rock bolts in foundation..)

- Example :



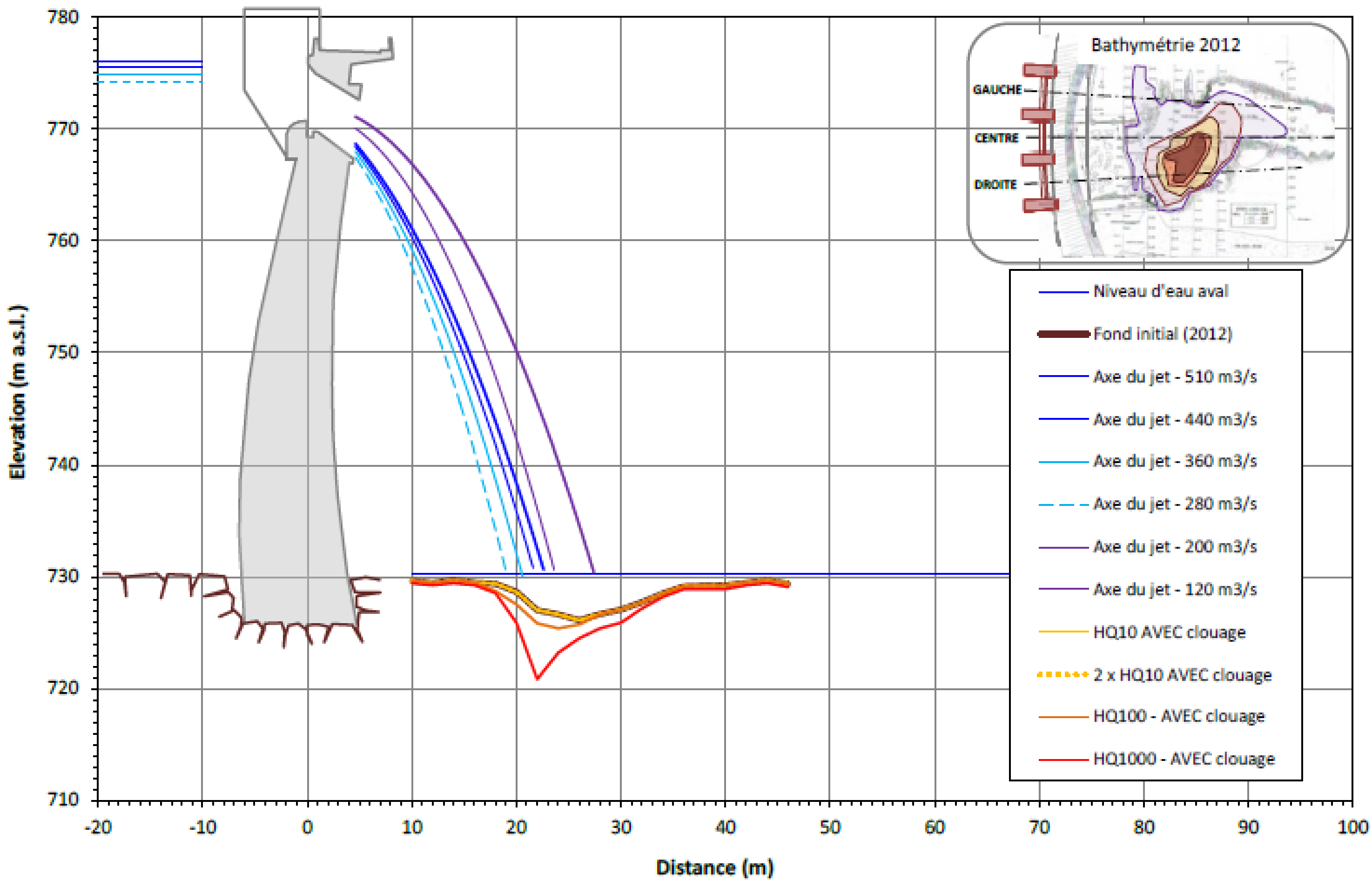
Vanne à 771.0 NGF (Q = 53 m3/s)
Vanne à 771.5 NGF (Q = 90 m3/s)
Vanne à 772.0 NGF (Q = 117 m3/s)
Topographie aval dans l'axe du déversoir rive gauche
Topographie aval dans l'axe du déversoir médian
Topographie aval dans l'axe du déversoir rive droite
780
775
770
765
760
725
-10
-5
0
5
10
15
20
25
30
35
40
45
50
Distance par rapport à la crête du déversoir (m)

Volumes déversés [m3]
20000000
19000000
18000000
17000000
16000000
15000000
14000000
13000000
12000000
11000000
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
Ouverture vanne [m]
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
1960
1965
1970
1975
1980
1985
1990
1995
2000
Année [-]
VANNE N°1 (rive gauche)
VANNE N°2 (centre)
VANNE N°3 (rive droite)
Ouv. Max. VANNE N°1
Ouv. Max. VANNE N°2
Ouv. Max. VANNE N°3
Ouv. Moy. VANNE N°1
Ouv. Moy. VANNE N°2
Ouv. Moy. VANNE N°3

# Bollaert – Prediction Q1000

•



# EDF current practice
## 3 approaches

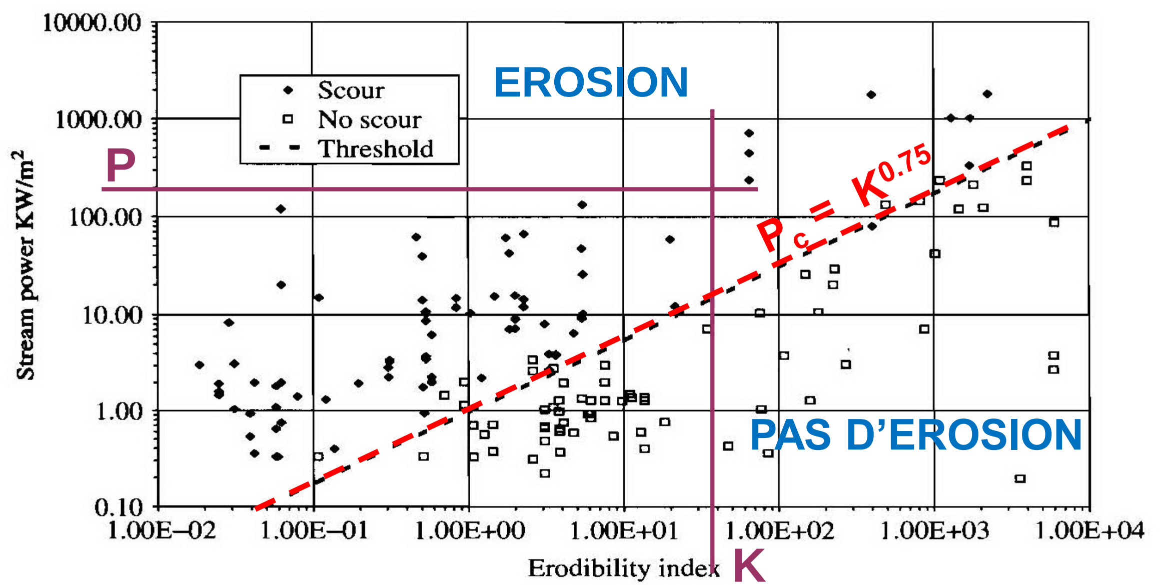
- Semi empirical approach (**Annandale, ...**)

# ANNANDALE method

- Based in « Erodability index » K = Ms . Kb . Kd . Js
- Based on more than 150 observations (soil and rocks)

BUT Low head / power

No Time consideration




Erosion threshold based on the erodibility index and stream power (Annandale 1995).

# Annandale application to EDF dams

**16 dams on rocks <u>with spilling feedback</u>**

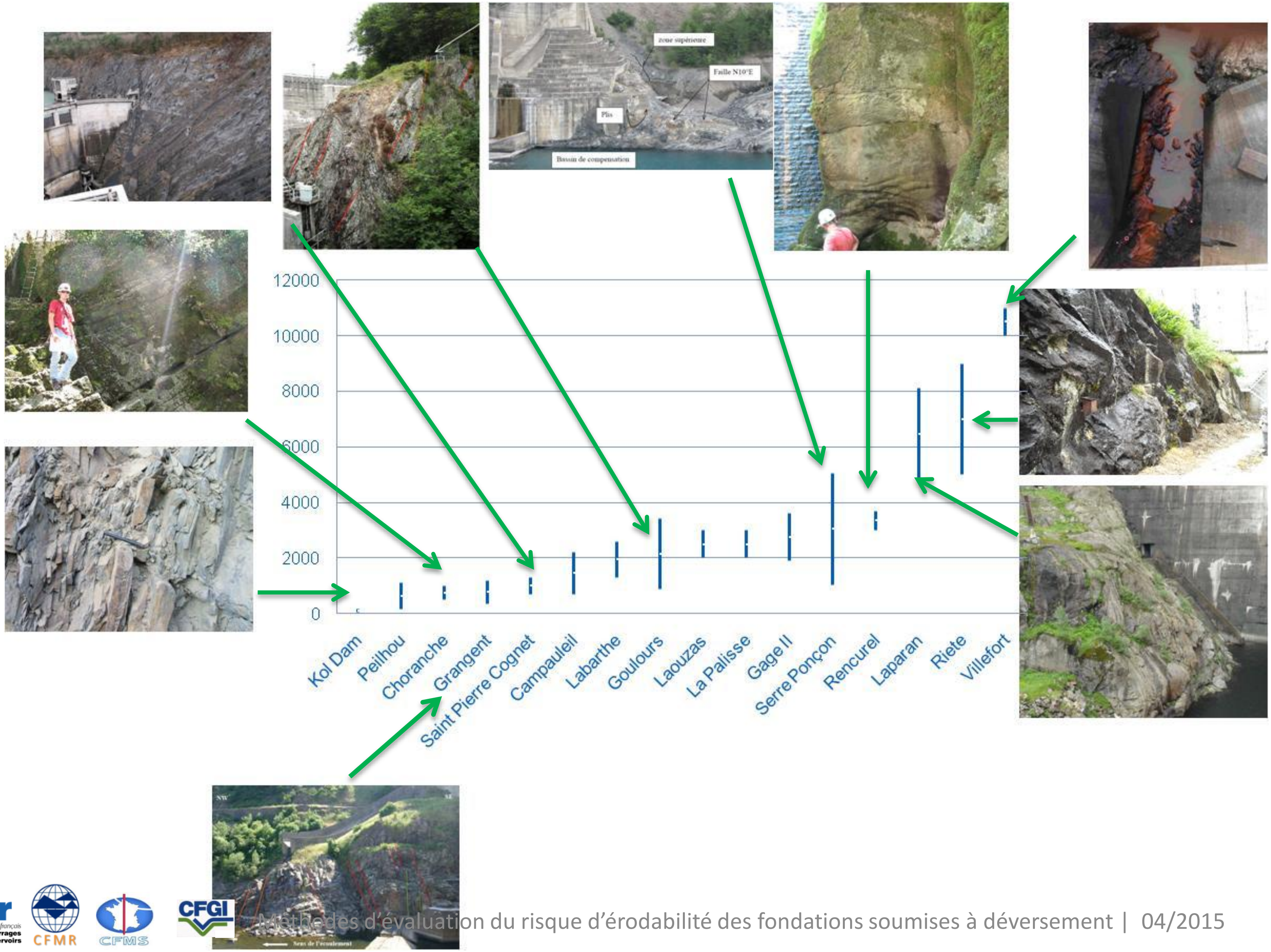
**Riète**

**Campauleil (09)**

**Grangent (42)**

***Flood 2008 ≈ 3200 m3/s***

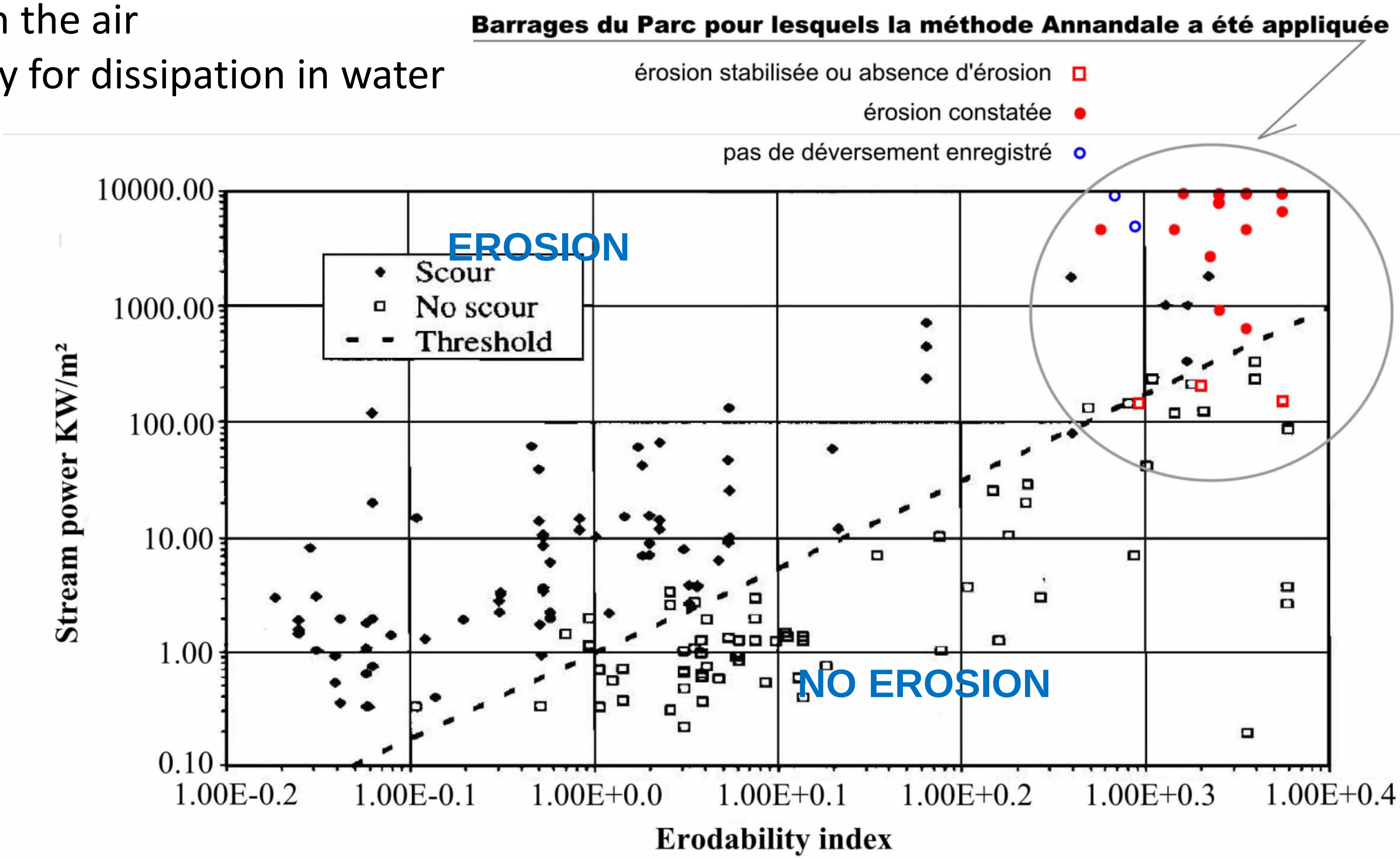
# Annandale application to EDF dams



# Annandale application to EDF dams (2009)

Conservative hypothesis :

- No turbulence in the air
- Ervine and Falvey for dissipation in water

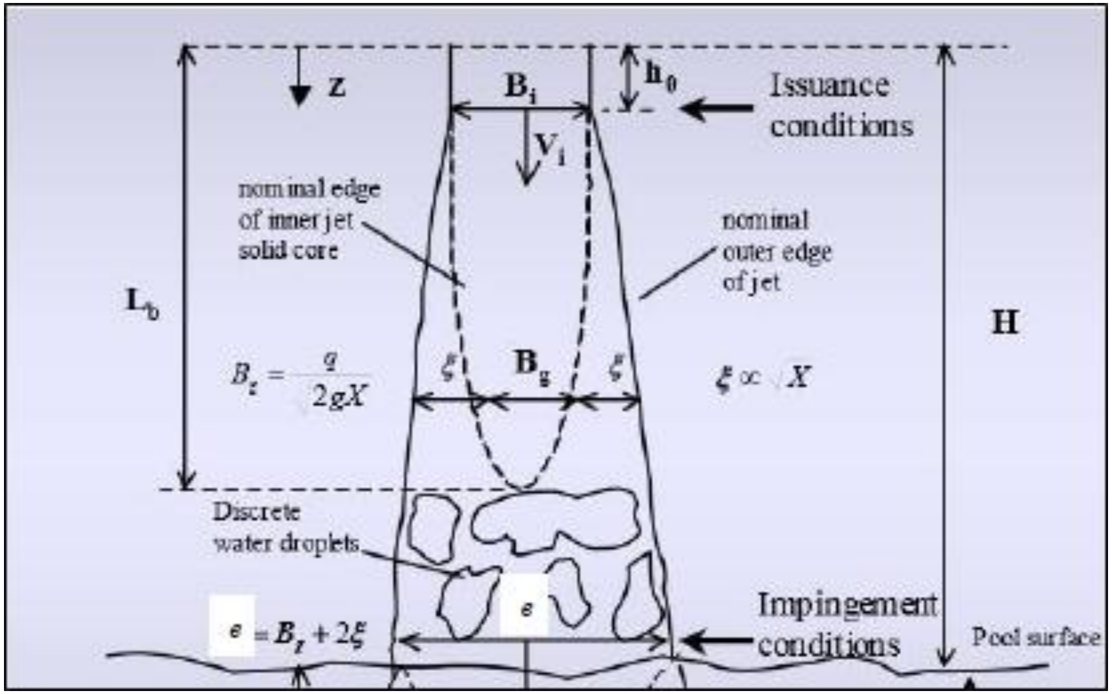



- **Most of EDF dams are in the right top corner ...**
- **Historical observations are consistent with Annandale chart**

**…. Most of times**

# EDF current practice - Hydraulic features – Jet power

## Jet desintegration




- Lateral propagation of jet  $e = B_g + 2\xi$

- Length of désintégration : Castillo

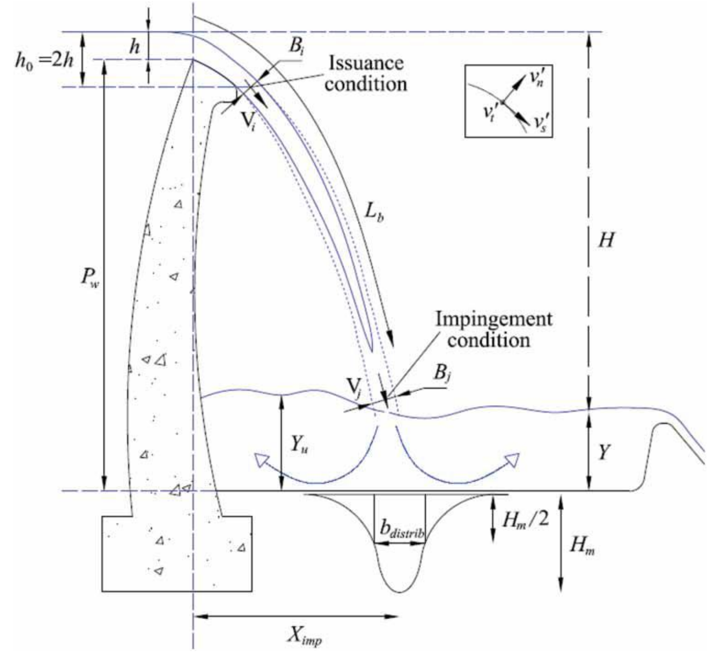
$$L_b = \frac{0.85 \times D_i \times F_{ri}^{\ 2}}{\left(1.07 \times T_u \times F_{ri}^{\ 2}\right)^{0.82}}$$

- Dynamic pressure Coefficient : Castillo $P_{totale} = P_S .(C_p + FC'_p)$

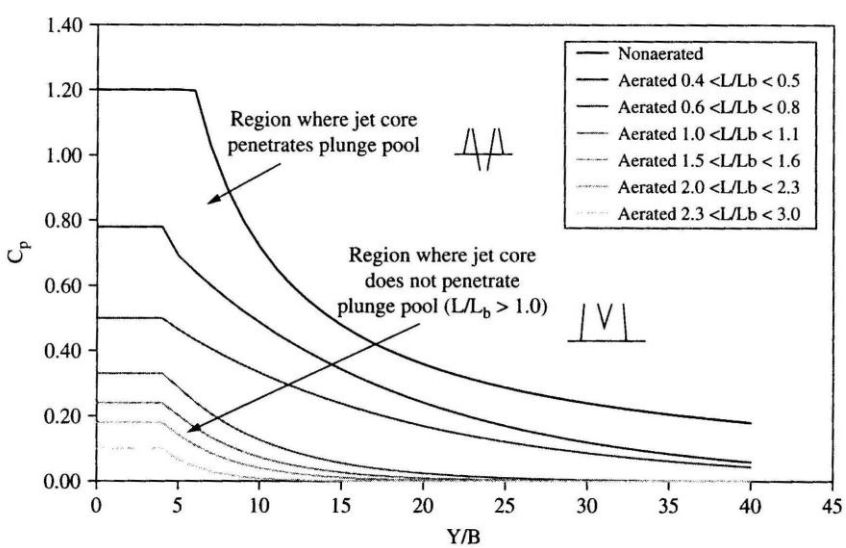
# Diffusion (Dissipation)

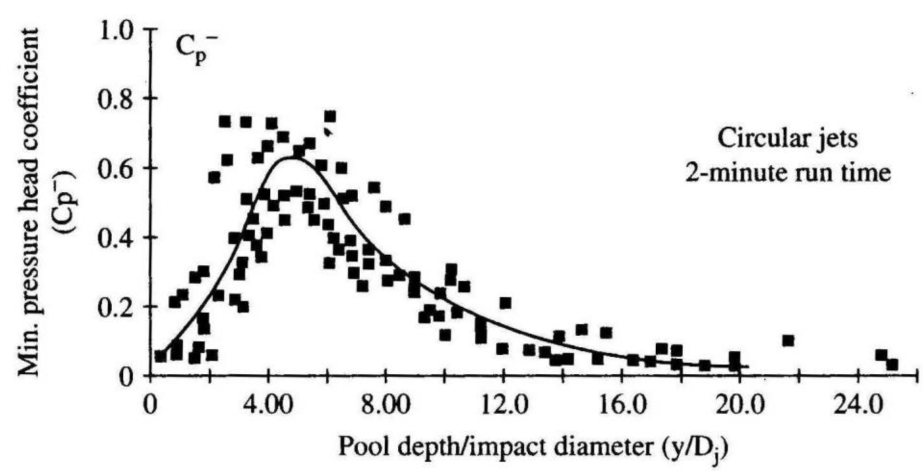
Castillo (2015) :

- Dynamic mean pressure coefficient Cp
  - » Bassin depth Y
  - » Jet thickness $B_j$
  - » Desintegration factor $H/L_b$
  - » …….
- Dynamic fluctuating dynamic coefficient C'p
- Application on « dry » rock




$$P_{totale} = P_S \cdot (C_p + FC'_p)$$

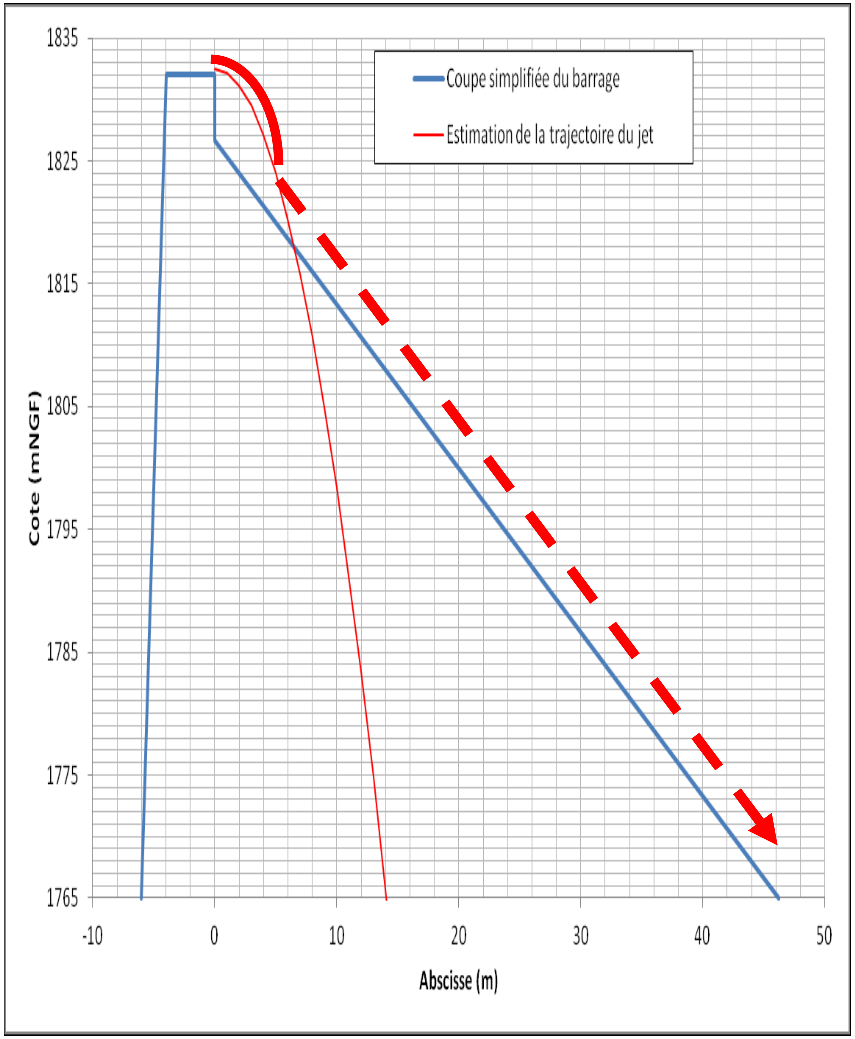


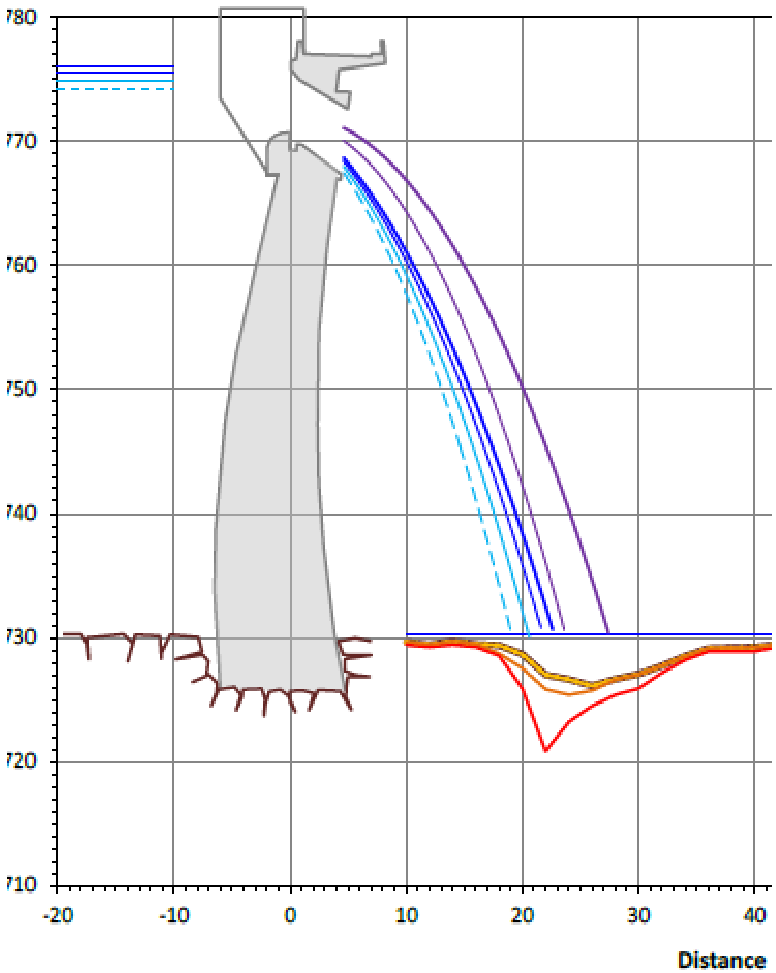




(b)

# Hydraulic Energy at dam toe

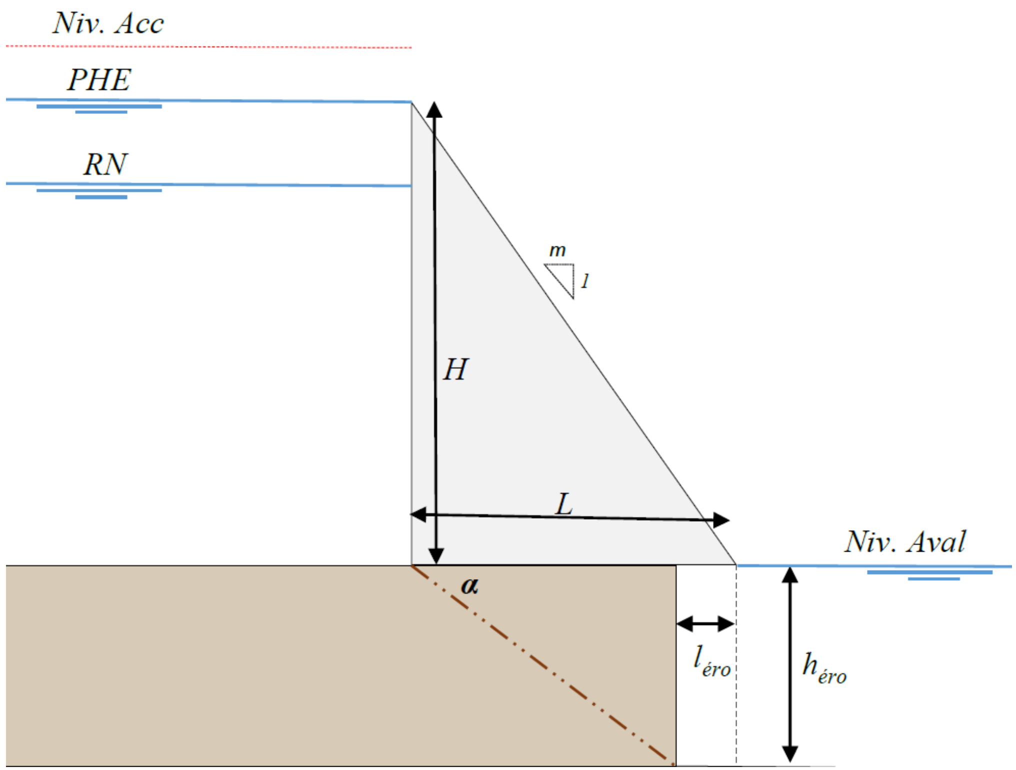
**2 configurations – How different is this ?**



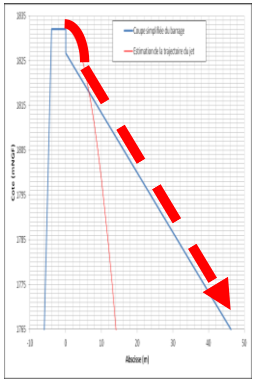



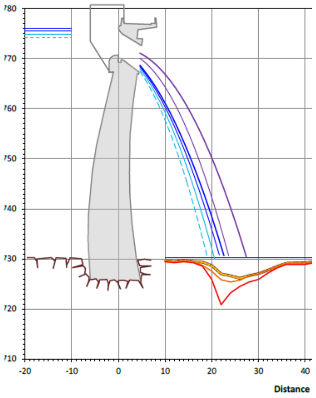
# 6. Impact on dam stability

- Small dam - H = 15 m
- Large dam - H = 40 m



# Conclusion - Questions / Needs






- ✓ 3 Needs
  - ✓ Engineering approach for first estimate
  - ✓ Advanced methods
  - ✓ For Arch and gravity dams

- ✓ **TIME** factor for extreme / short events
  - Short duration
  - Often low linear discharge capacity (20-50 cm over crest.. 1 m sometimes..)

- ✓Convincing Authorities (uncertainties – reliability of methods - Repeatability)

- ✓ Cost efficient solutions to upgrade dam safety

  If overtopping not acceptable :
  - Cost effective mitigation measures (rock bolts, modify jet energy…)

- ✓ Influence on dams stability (which erosion depth is acceptable for concrete dams ?)