ÉRosion INterne dans les OuvragesHydrauliques

Internal Erosion in Hydraulic Works

Essais de laboratoire

(CEMAGREF)

Nadia Benahmed

Contexte

1993 Camargue dikes, France

- 12 breaches in December 1993 and 4 breaches in January 1994

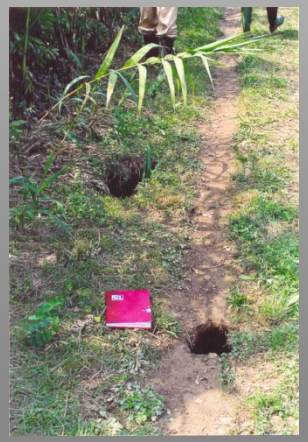
- The Ouches Dam, 2001 (200 years old)

Saint-Gilles flood, 2003

- Breache of Fourques, Petit Rhône Rive Droite

Rupture of Aramon dike, 2002

- 3 total breaches
- 3 partial breaches
- 5 fatalities



- Sinkholes

Rappel

On sait depuis quelques années qu'il y a environ 8000 km de digues de protection contre les inondations en France :

- **8700 km* au dernier recensement**
- **… dont 2500 km* dans les régions Provence-Alpes-Côte d'Azur (1890 km : 1/22) et Languedoc-Roussillon (650 km : 4/22)**

… mais depuis peu de temps que :

- **2700 km* de digues (existantes) de classes A et B doivent faire l'objet d'une étude de dangers d'ici le 31/12/2012**
- **3200 km* de classe C d'ici le 31/12/2014**

* Sources : logiciel BarDigues (R Tourment, M. Wolff – Cemagref)

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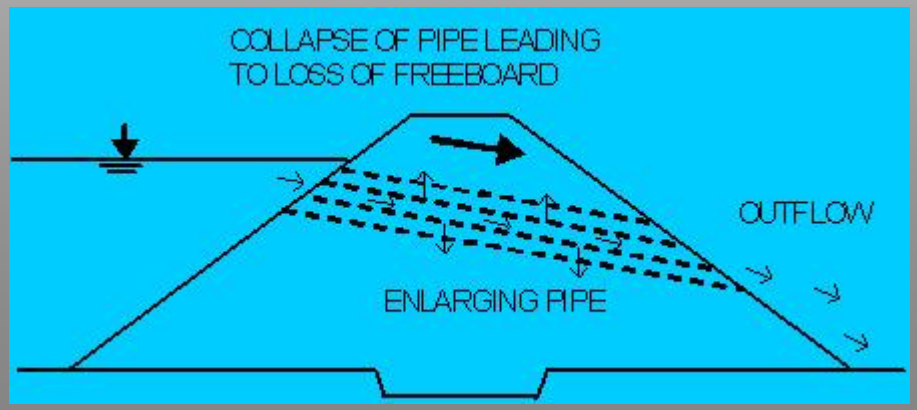
Internal erosion : complex phenomenon which affect stability of hydraulic works (earth dams, dykes,…) ⇨ Failure

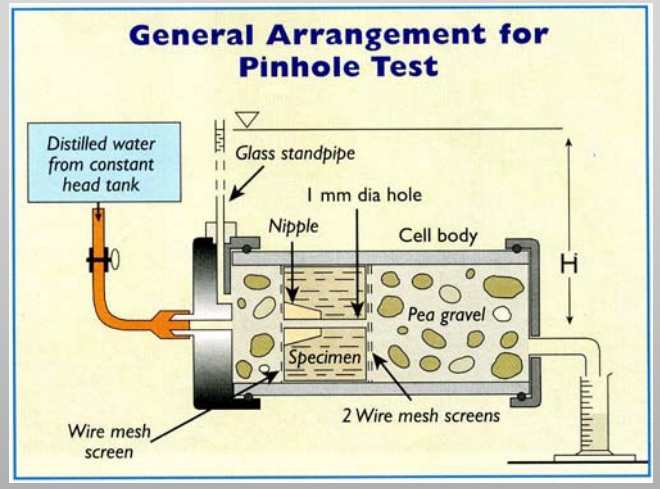
ERINOH 2008 ➡ Four types of internal erosion:

- **Regressive erosion**
- **Contact erosion**
- **Suffosion**
- **Piping flow erosion**

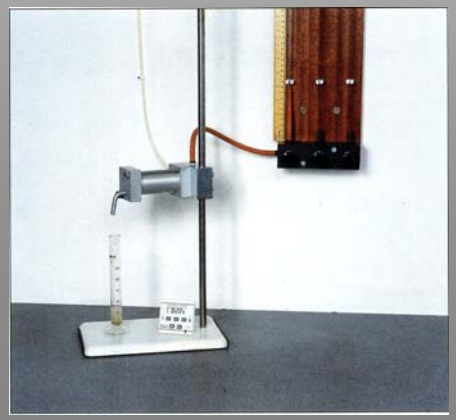


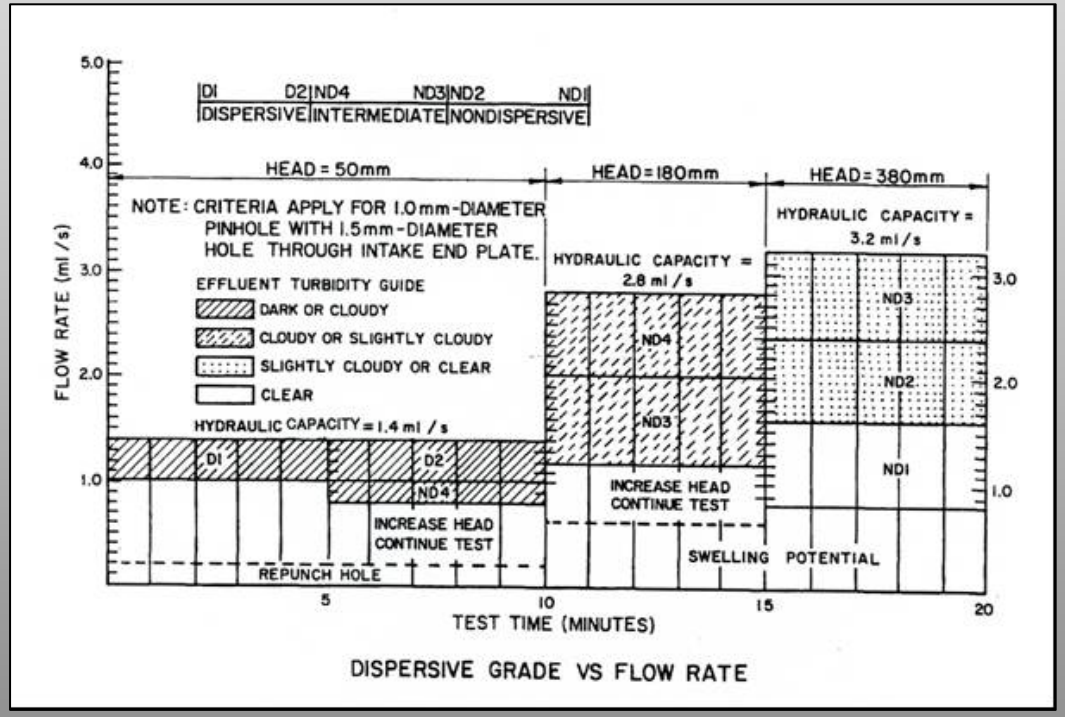
Brief review…

Sherard et al. 1976:



Pinhole Test Apparatus





Lack: Qualitative test, no quantitative data!

Brief review…

Other references :

- ***Hole* Erosion test (Christensen & Das, 1973)**
- ***Leakage* Erosion test (Hjeldnes & Lavania, 1980)**
- ***Drill* Erosion test (Lefebvre, 1986) (Canada)**
- ***Crack* Erosion test (Sanchez & al., 1983; Maranha das Neves, 1987)**
- ***Surface and Internal* Erosion test (Reddi, Lee & Bonala, 2000)**

Constat :

- **Several experimental procedures**
- **Dispersion and different interpretations of experimental results**
- **Nonexistence of appropriate theoretical model to fit the experimental data !!!**

Hole Erosion Device (CEMAGREF)

Pressure in

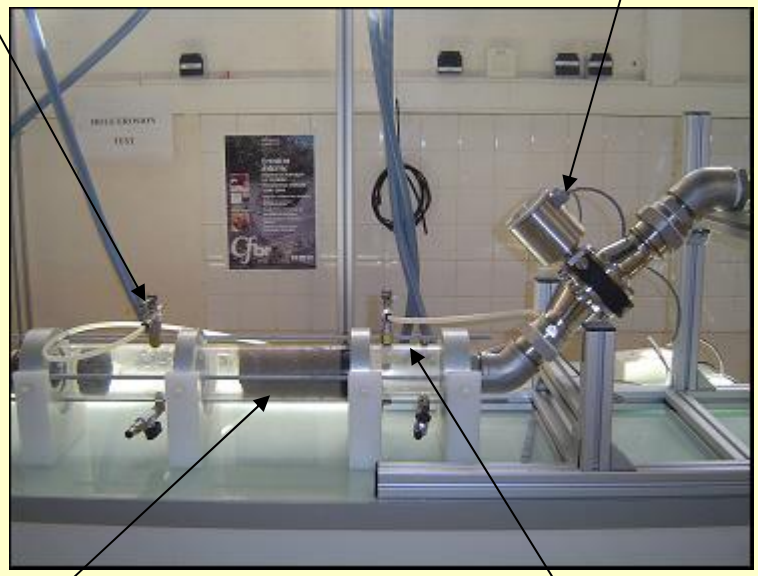
Turbidity meter

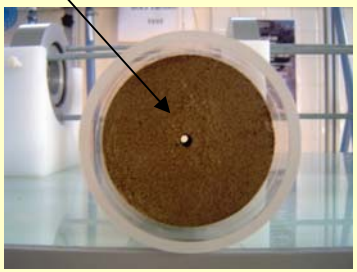
Flow out

Flow in

Sample

Pressure out



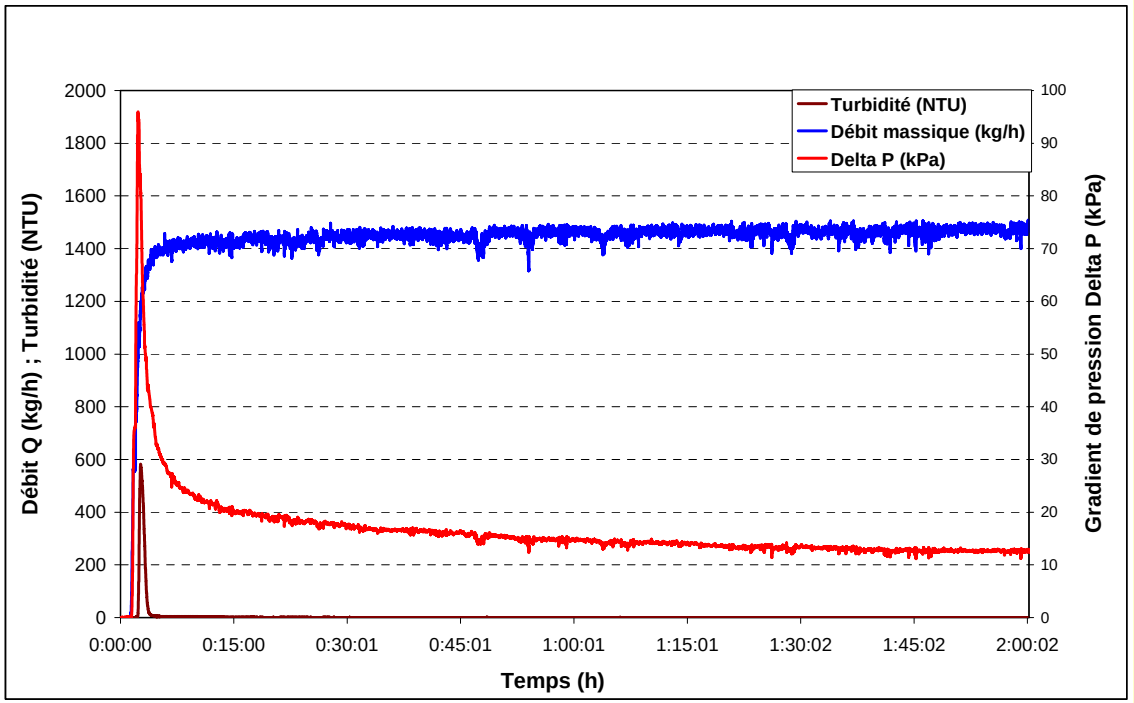


Flowmeter

Pressure transducers

Turbidity meter

Experimental results



Loi d'érosion à seuil :

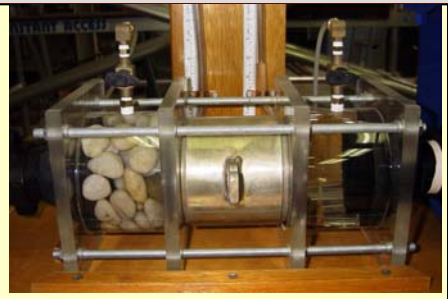
$$\dot{m} = \begin{cases} k_{er}\left(|\tau_b| - \tau_c\right) & \text{si } |\tau_b| > \tau_c \\ 0 & \text{sinon} \end{cases}$$

Paramètres d'érosion :

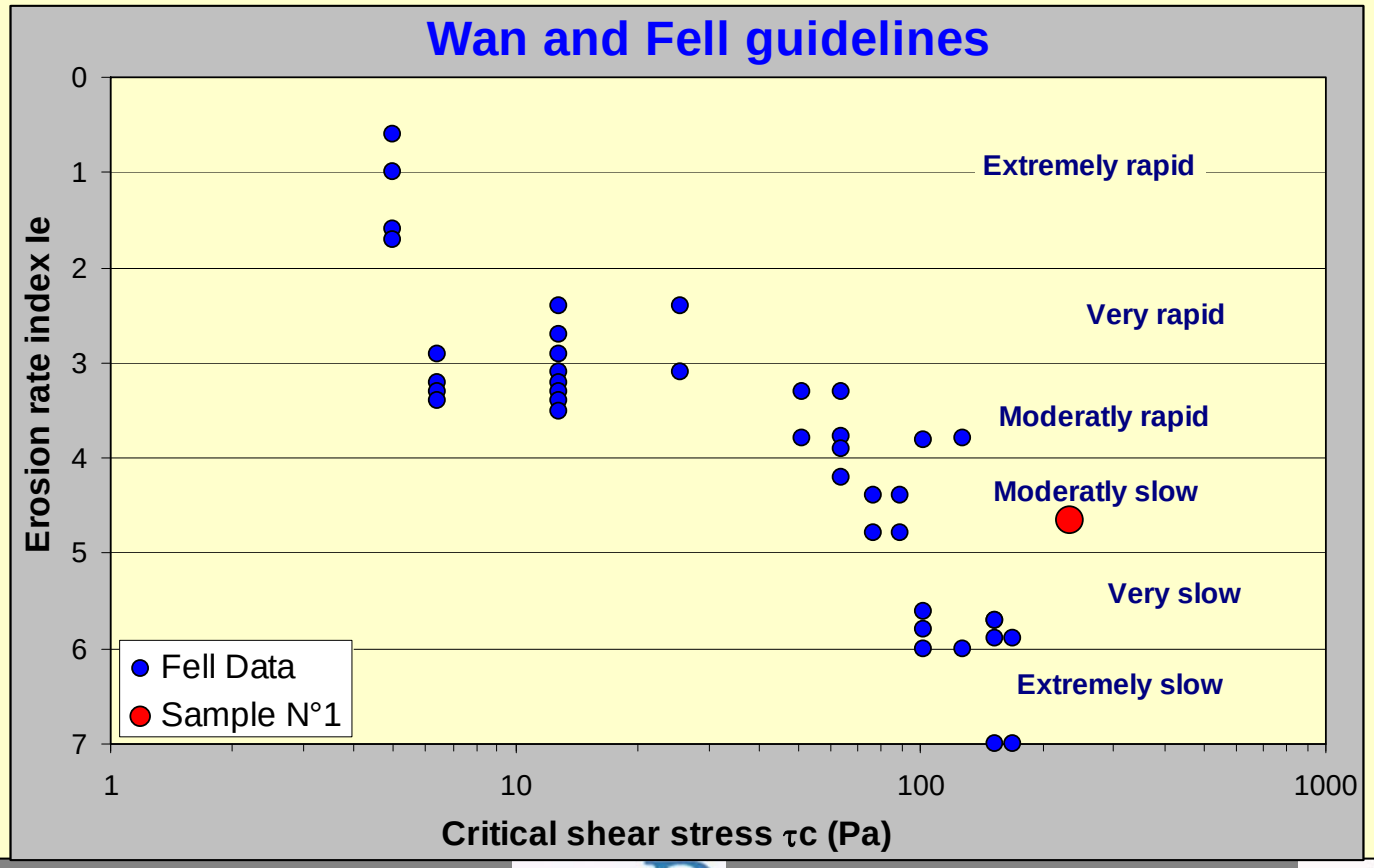
- Seuil d'érosion τ_c
- Coefficient d'érosion k_d

Experimental results

- Seuil d'érosion τ_c
- Coefficient d'érosion k_d



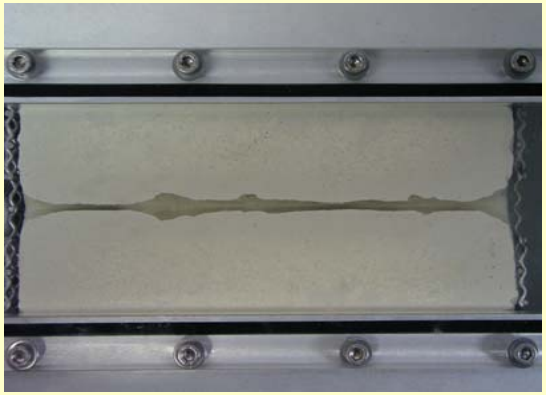
Wan and Fell (2002, 2004)



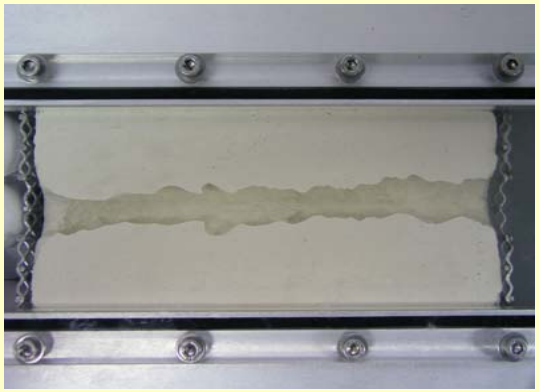
Experimental results

Slot erosion test :

Sample before erosion



Sample during testing



Sample after erosion

Hole erosion test :

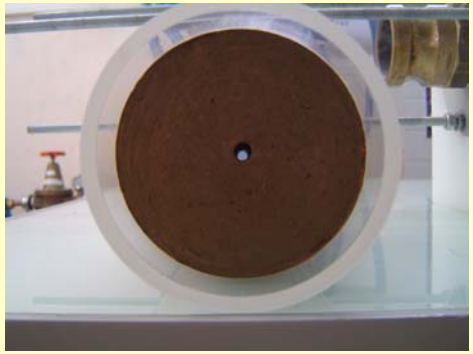
Sample before erosion

Sample after erosion

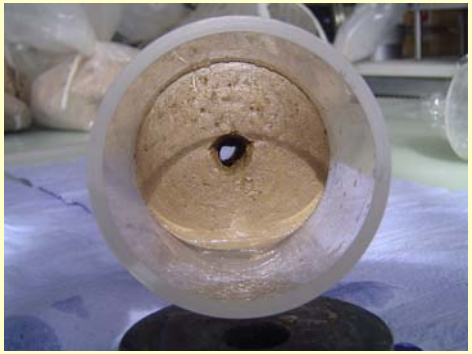
Sample after erosion

Experimental results

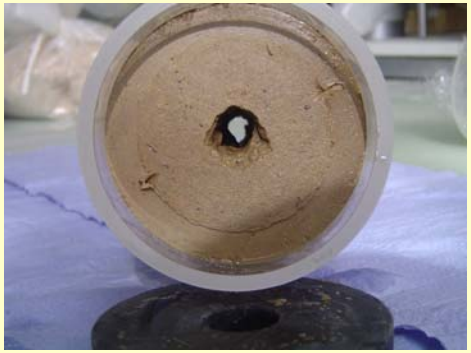
Naturel soil : Silty sand (26% sand, 58% silts, 16% clay)



Sample before erosion

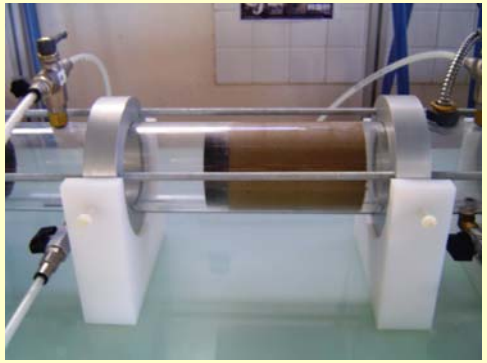


Sample after erosion, upstream side



Sample after erosion, down stream side

Naturel soil : Sandy silt (72% sand, 23% silts, 4% clay)



Collapse of the sample during filling of the testing cell

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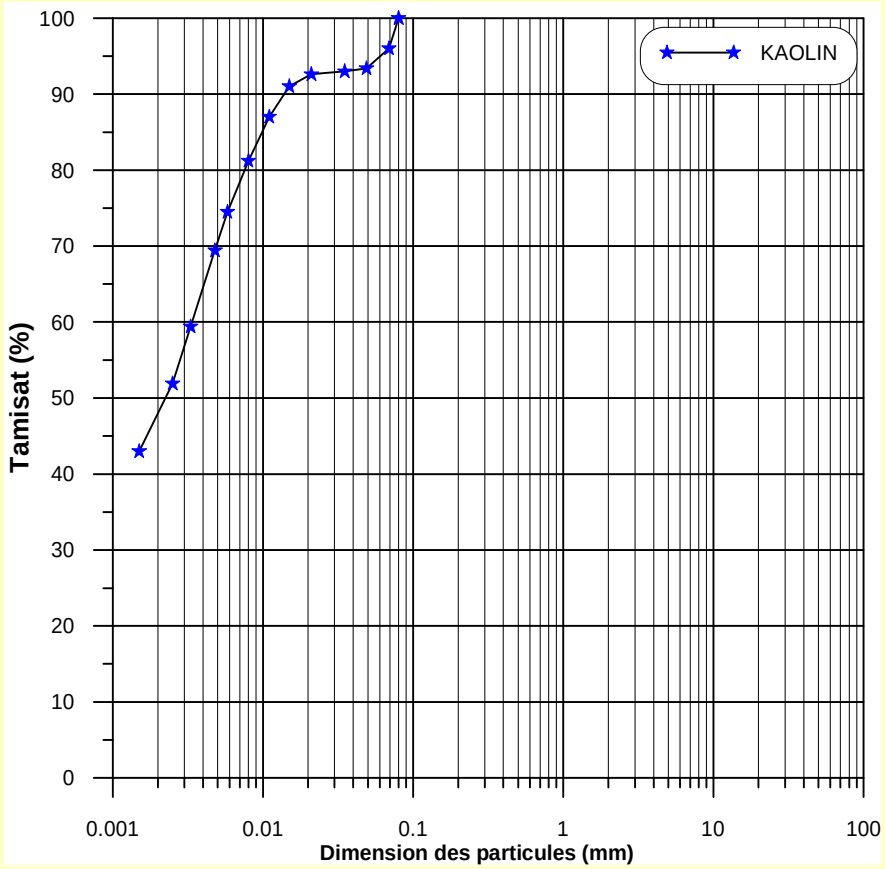
Experimental study

Soil : KAOLINITE



Grain size distribution

pH 4 to 9

Density : 2.6 g/cm^3

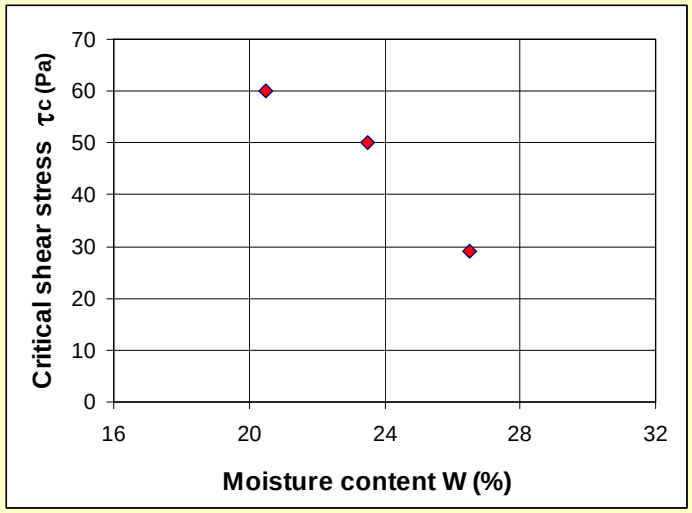
Dry density Opt. : 1.51 t/m3

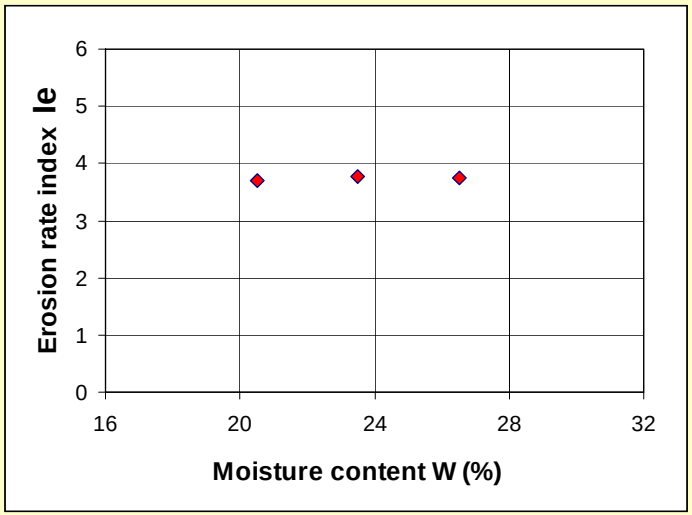
W Opt. : 23.5 %

Wl = 49 Wp = 33 Ip = 16

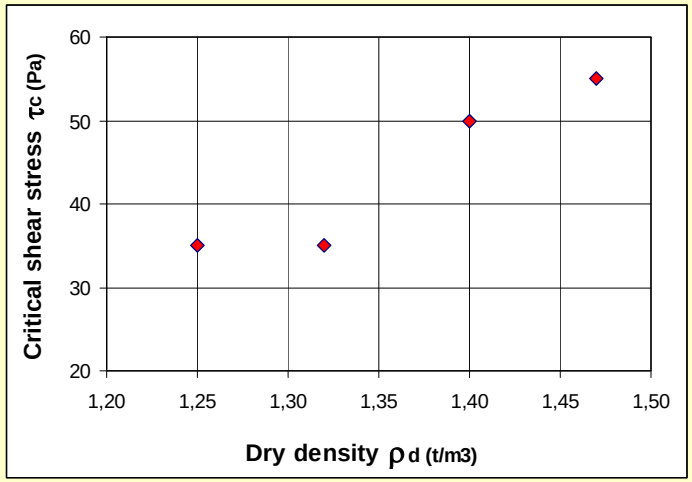
Experimental results

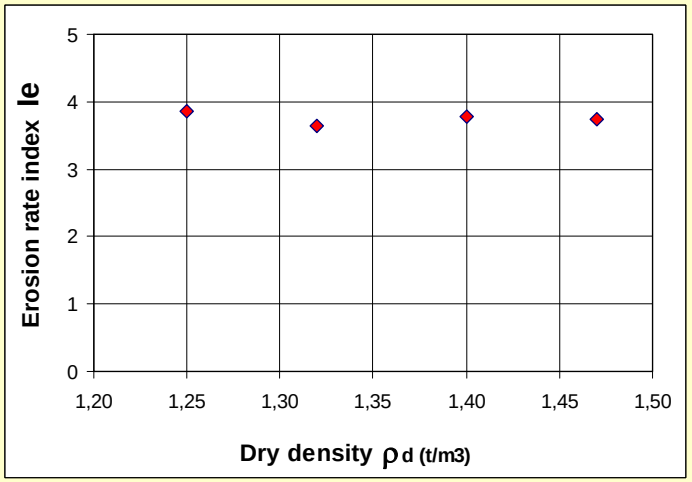
➢ Effect of moisture content on τ_c and Ie (ρd = 1.4 t/m3 (95% OPN))





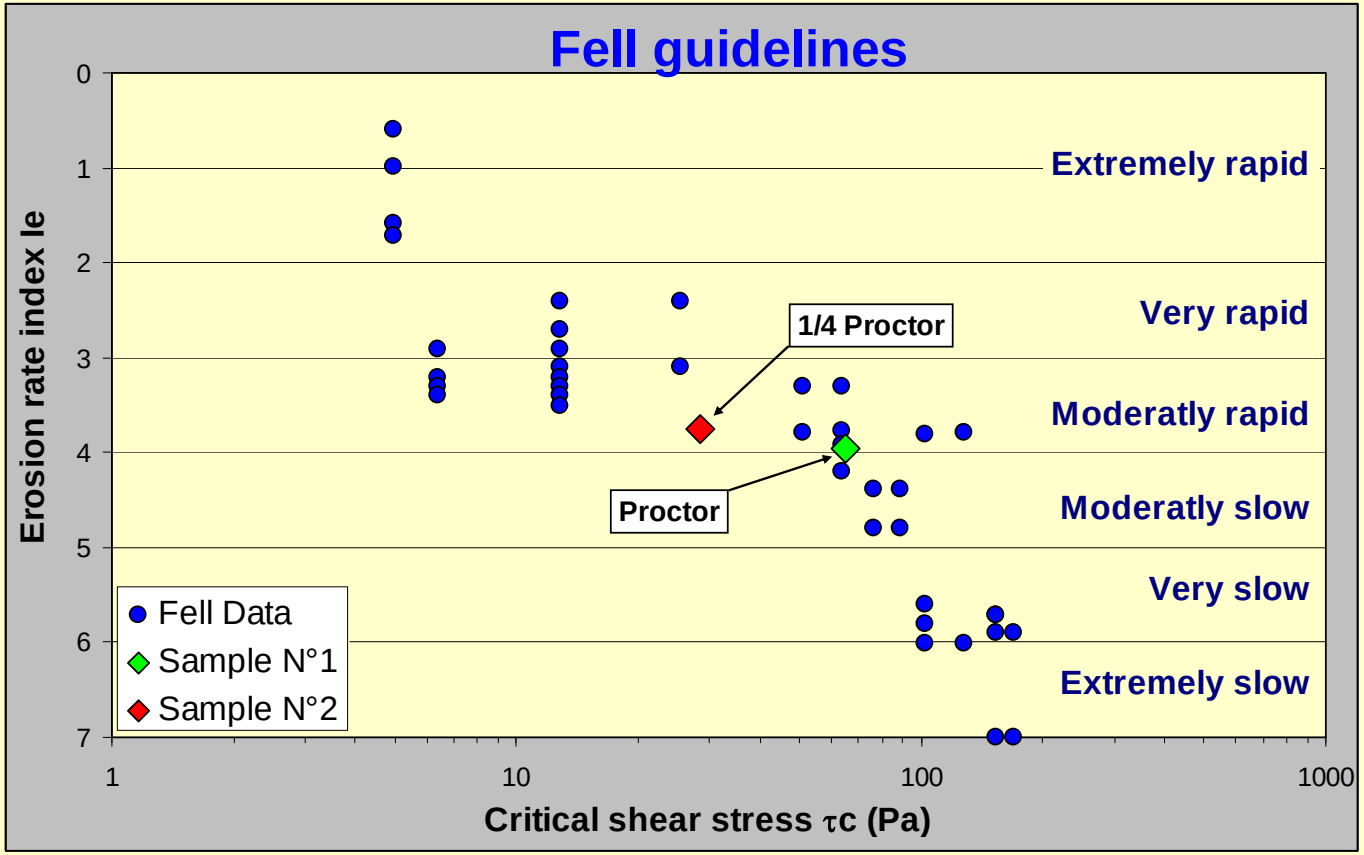
➢ Effect of dry density on τ_c and Ie (W = 23.5 %)





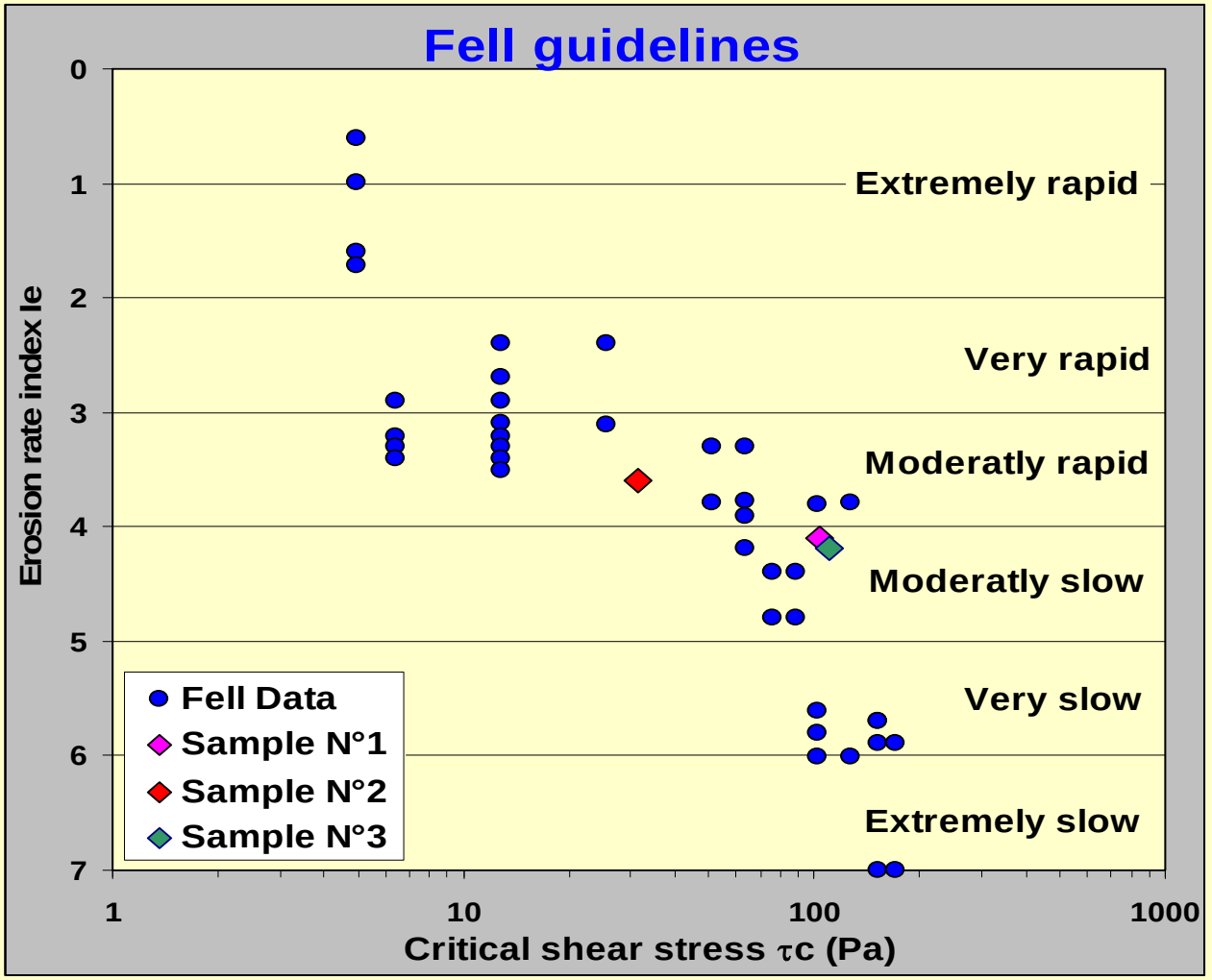
Effect of energy of compaction

	γ_d *(kN/m³)*	W *(%)*	τc *(Pa)*	k_{er} *(s/m)*	k_d *(cm³/N.s)*	Ce *(s/m)*	Ie
Sample N° 1 (Proctor)	**17,9**	**15**	**65,29**	**1,36E-04**	**6,49E-02**	**1,18E-04**	**3,95**
Sample N° 2 (1/4 Proctor)	**17,2**	**15**	**28,51**	**2,01E-04**	**1,00E-01**	**1,75E-04**	**3,76**



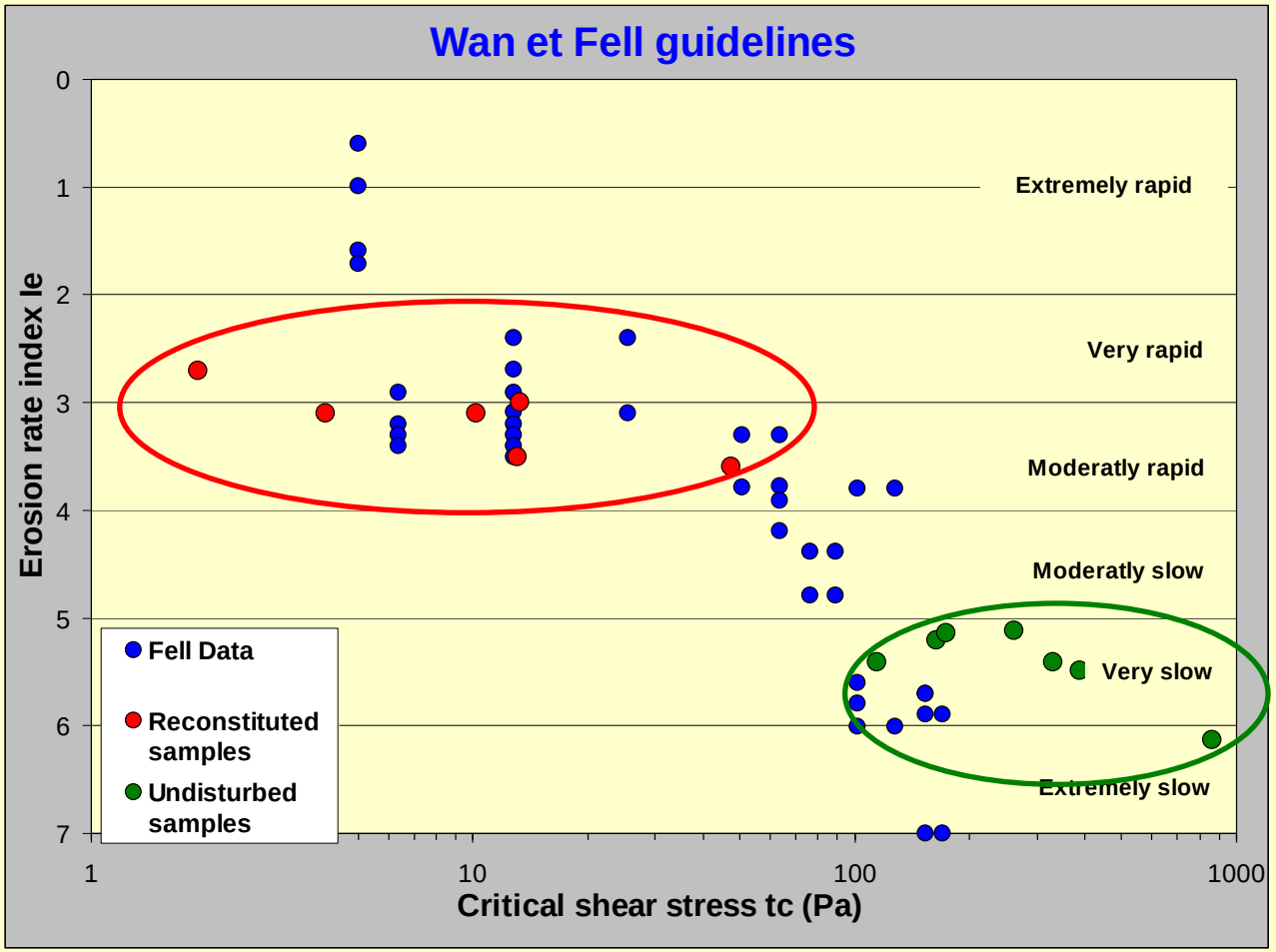
Effect of clay content

	Sample N°1	Sample N°2	Sample N°3
Sand > 50 µm (%)	44	41	33
Silt > 2 µm (%)	30	39	41
Clay < 2 µm (%)	26	20	26
γd (kN/m3)	16,7	16,7	16,7
W (%)	18	19	21
τ_c (Pa)	103,25	31,49	110,75
Ie	4,10	3,60	4,19
kd (cm3/N.s)	4,68E-02	1,48E-02	3,82E-01



Ageing effect ?

HET tests on naturel soils



Merci de votre attention !

Contexte

Failure of Teton Dam by piping

Failure:

On 3 hours only!