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2022 05 28 Workshop - Embankment Dam Committee E

Compaction of Earthfill Dams

(Introduction to a new technical bulletin)

J-J Fry





Overview of the presentation

1. Objectives of the bulletin
2. Lay out of the bulletin
3. Some relevant issues
4. Definition and approach
5. Functions and targets
6. Site application
7. Quality control



1 - Objectives of the bulletin

1. To draw up awareness on some relevant issues occurring in earth compaction
2. To emphasize the earth functions improved by compaction
3. To show the current possibilities of new equipment
4. To underline the efficient methods of control



2 - Bulletin layout

- Focus on fine soils ompaction (core of zoned dams, homogeneous earthfill)
 - Relevant issues
 - Main functions
 - Specifications
 - Methods statement
 - Quality Control



3 - Some relevant issues

- orniérage
- surcompactage
- feuilletage
- matelassage
- rutting
- overcompaction
- lamination
- quilting

3.1– Rutting

■ Loading capacity & workability

- M1: mass of roller
- L: Length of the drum
- Cu : undrained cohesion

$$C_u \text{ (kPa)} > M1/L \text{ (kg/cm)}$$

Bull extra Light : 15 - 20 kPa

Dumper: 40 - 50 kPa

Scraper: 70 - 80 kPa

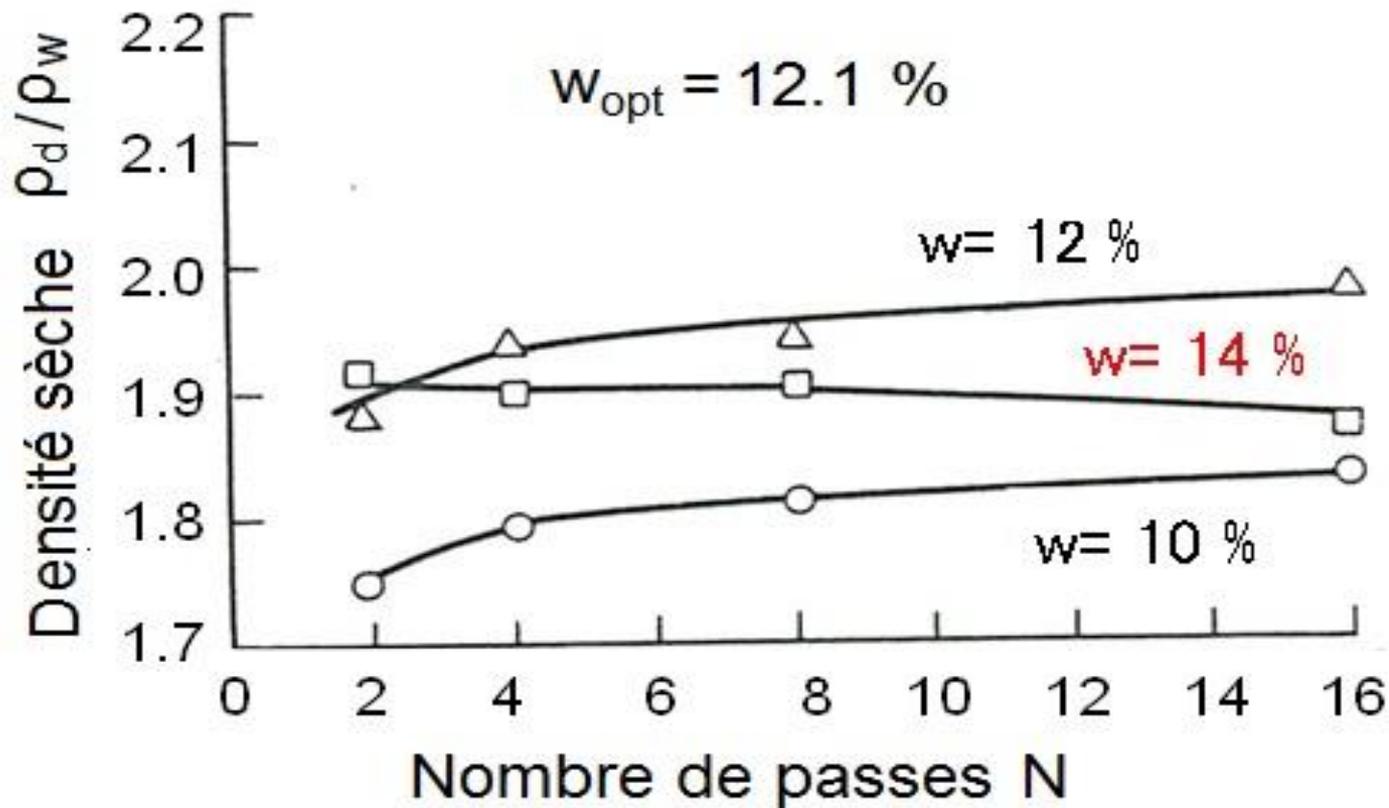




3.2 – Overcompaction

- **Warning: three definitions**
 - 1. Strain softening** beyond an energy compaction threshold
 - 2. Decreasing of density at top of layer** with increasing energy of compaction
 - 3. Economical losses** : too much energy without any positive change.

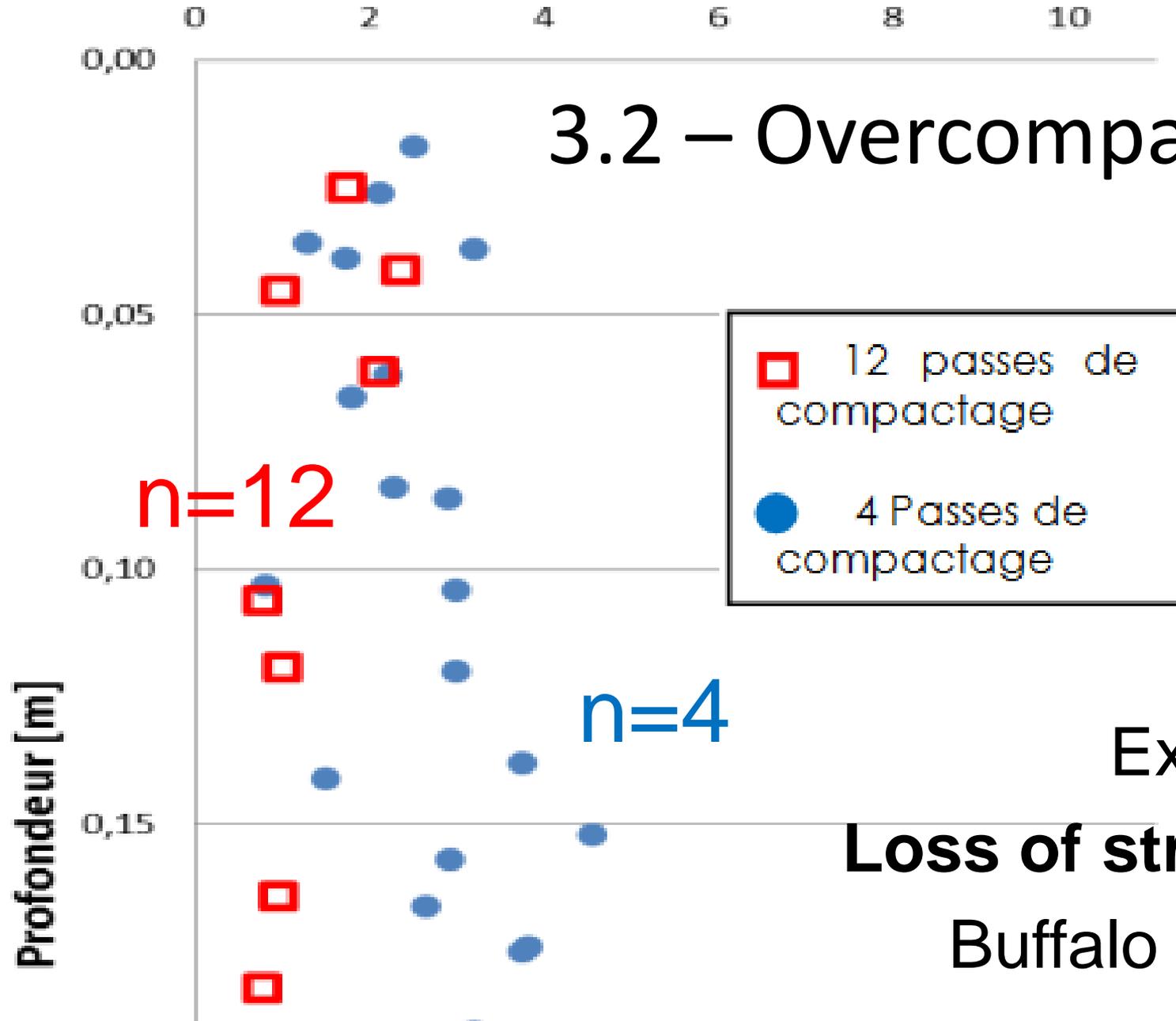
3.2 – Overcompaction



Example of loss of density (Tatsuoka 2015)

Résistance en pointe Qd [MPa]

3.2 – Overcompaction

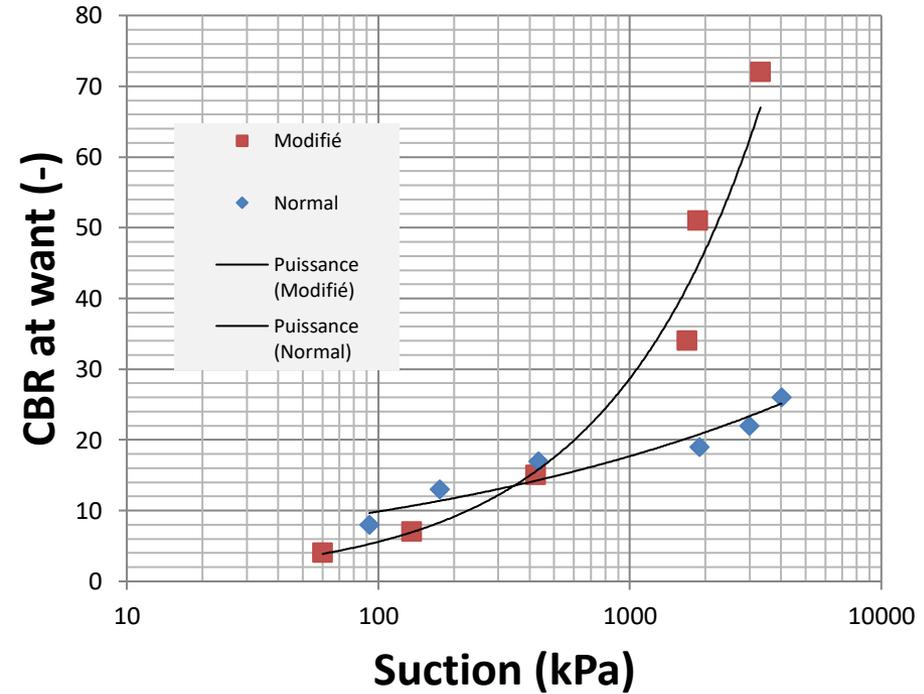
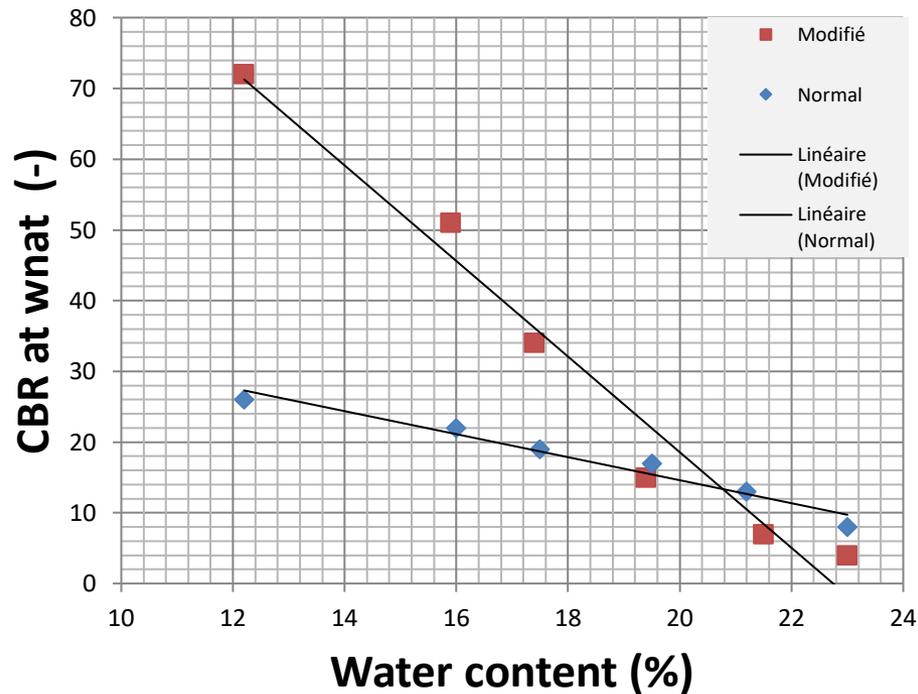


Example

Loss of strength

Buffalo (2015)

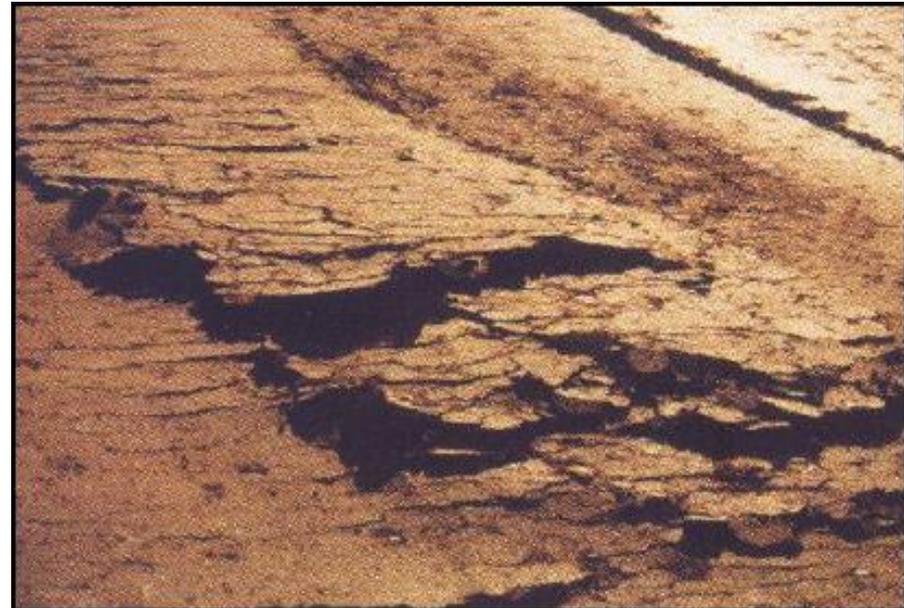
3.2 Overcompaction



The loss of strength is related to the loss of suction

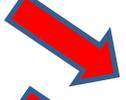
3.3 – Lamination - foliation

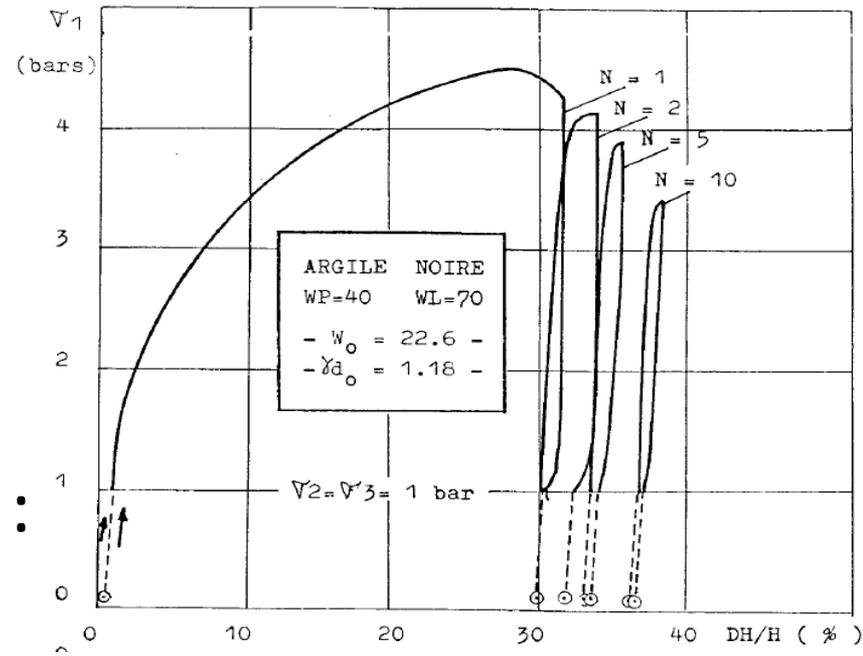
- Kind of overcompaction where the loss of strength is caused by localization of large strains and shearing under the drum



3.3 – Lamination

■ Consequences :

- C' : $C(\text{pic})$  0
 - ϕ' : $\phi'(\text{pic})$  $\phi'(\text{min})$
 - θ_a air: max  min
 - u_w : max  min
 - C_u : max  min
- For instance on plastic clays :
- C_u :  $C_u/2$

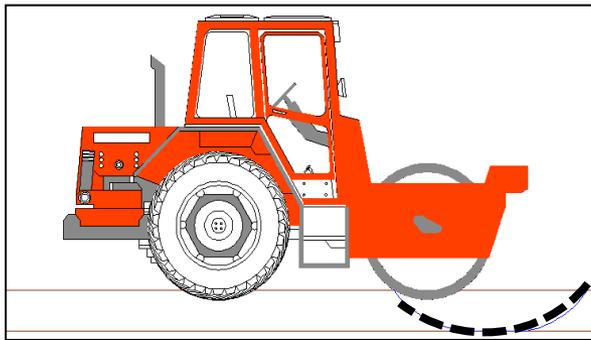


Cyclic triaxial test on plastic clay $IP=30$

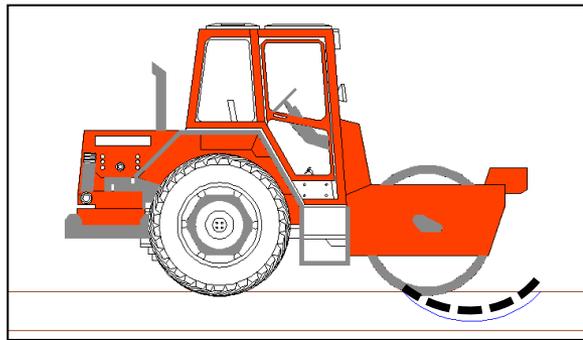
3.3 – Lamination

■ Depth of laminated area

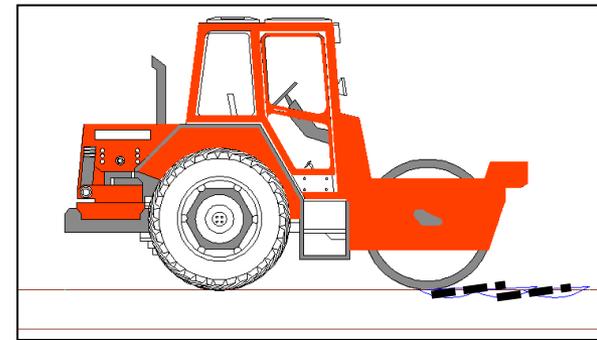
Increases with water content $w(\%)$ &
soil compressibility ($1/E$)



Soft soil
large contact area

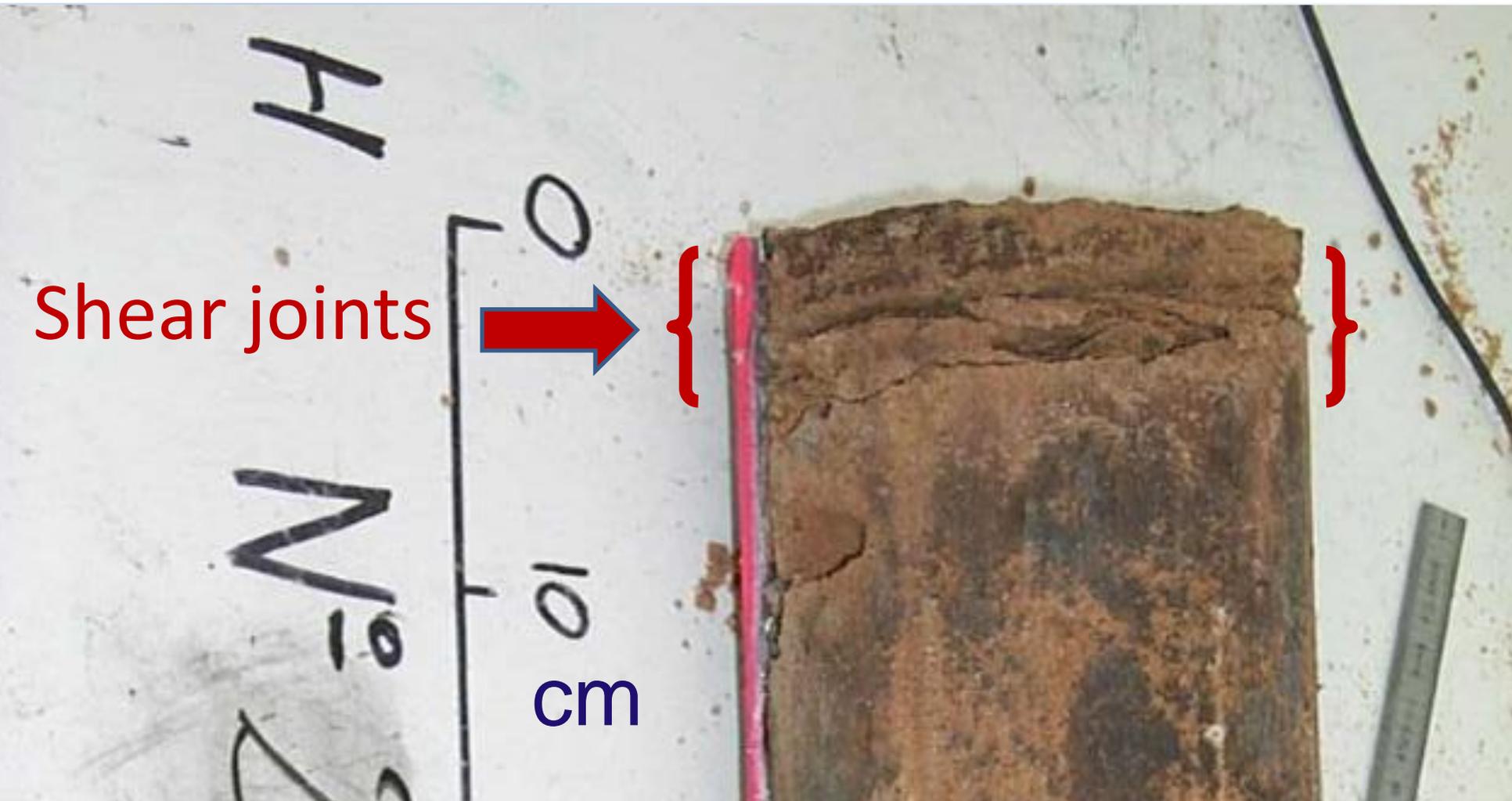


Intermediate soil
compressibility



Hard soil (treated)
Small contact area

3.3 – Lamination



2.3 – Lamination

■ Critical compactors

Still drums



polle





3.4 – Quilting

- **Definition**
 - Elastic rebound of compacted soils just after roller passing
- **Conditions of occurrence**
 - Degree of saturation at optimum $< 80\%$
 - Air permeability = 0
 - Negligeable water permeability



4 - Definition of Compaction

■ Objective

- Compaction consists in **improving** soils mechanical and/or hydraulic **properties** thanks to hardening caused by **irrecoveral déformation** of their skeleton, in order to use them for specific **functions**

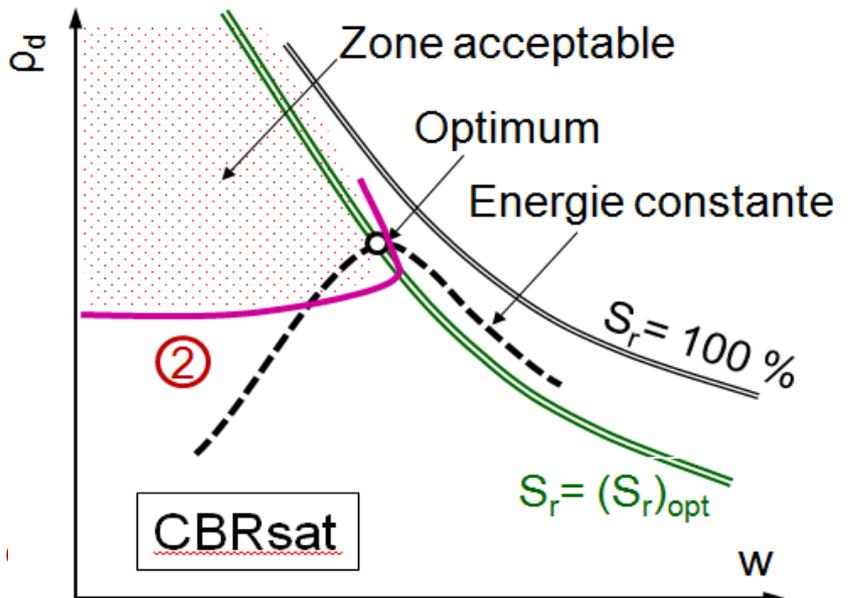
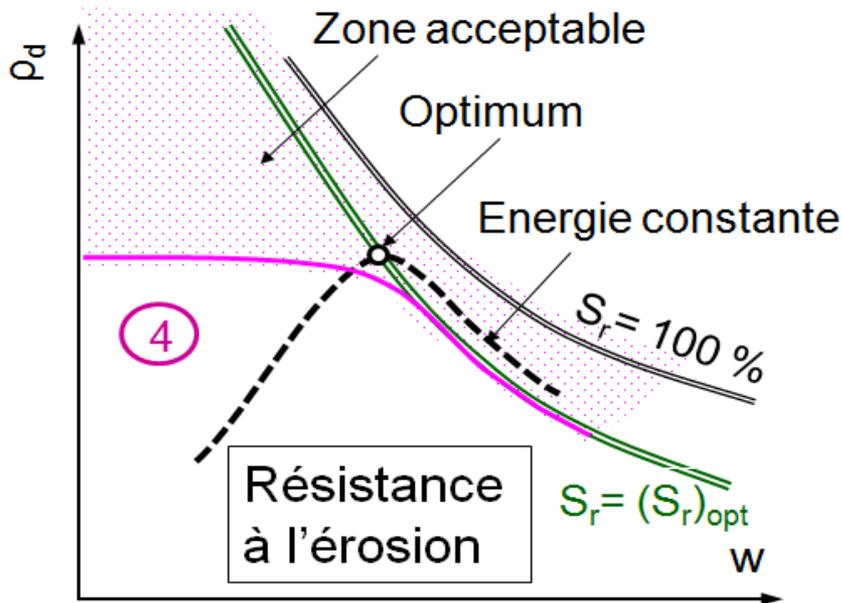
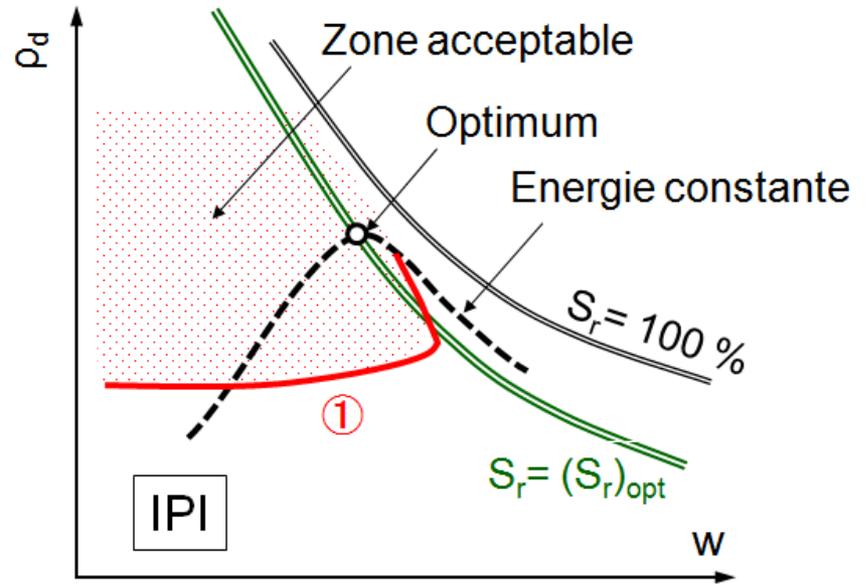
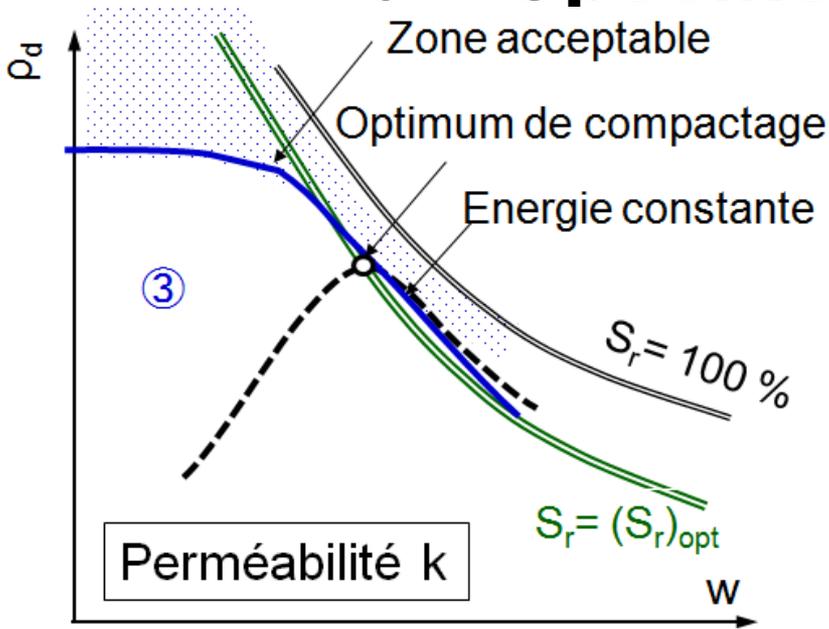
■ Approach

- What **functions**?
- What **properties**?
- What **improvement**?
- What **irrecoveral deformation**?

5 – Functions (dams/roads)

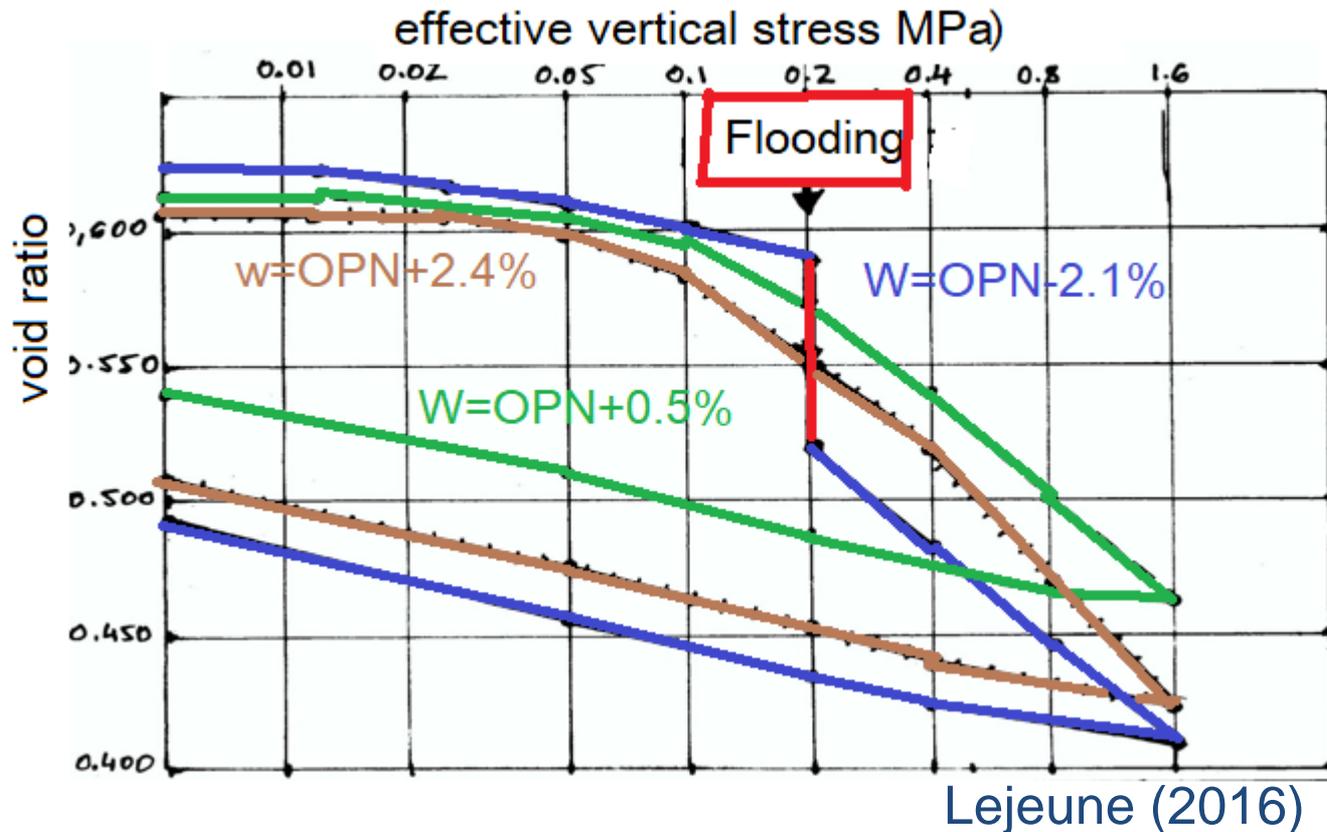
Destination	Roads and train fills	Dams & Levees
Function	High modulus small settlements	Homogeneity water tightness Erosion resistance
Impact of a flaw	Traffic stopped	Failure by internal erosion
Loading capacity	CBR > 20-70	CBR > 5
Settlement	LGV < 1cm/year and <10_cm/25y	Settlement < revanche (> 1m)
Watertightness	-	$K < 10^{-7}$ m/s
Compaction energy	Average to High	Average
Moisture content	Dry to wet	Wet

5 – Specifications for dams



on

5.1 Prevention of collapse

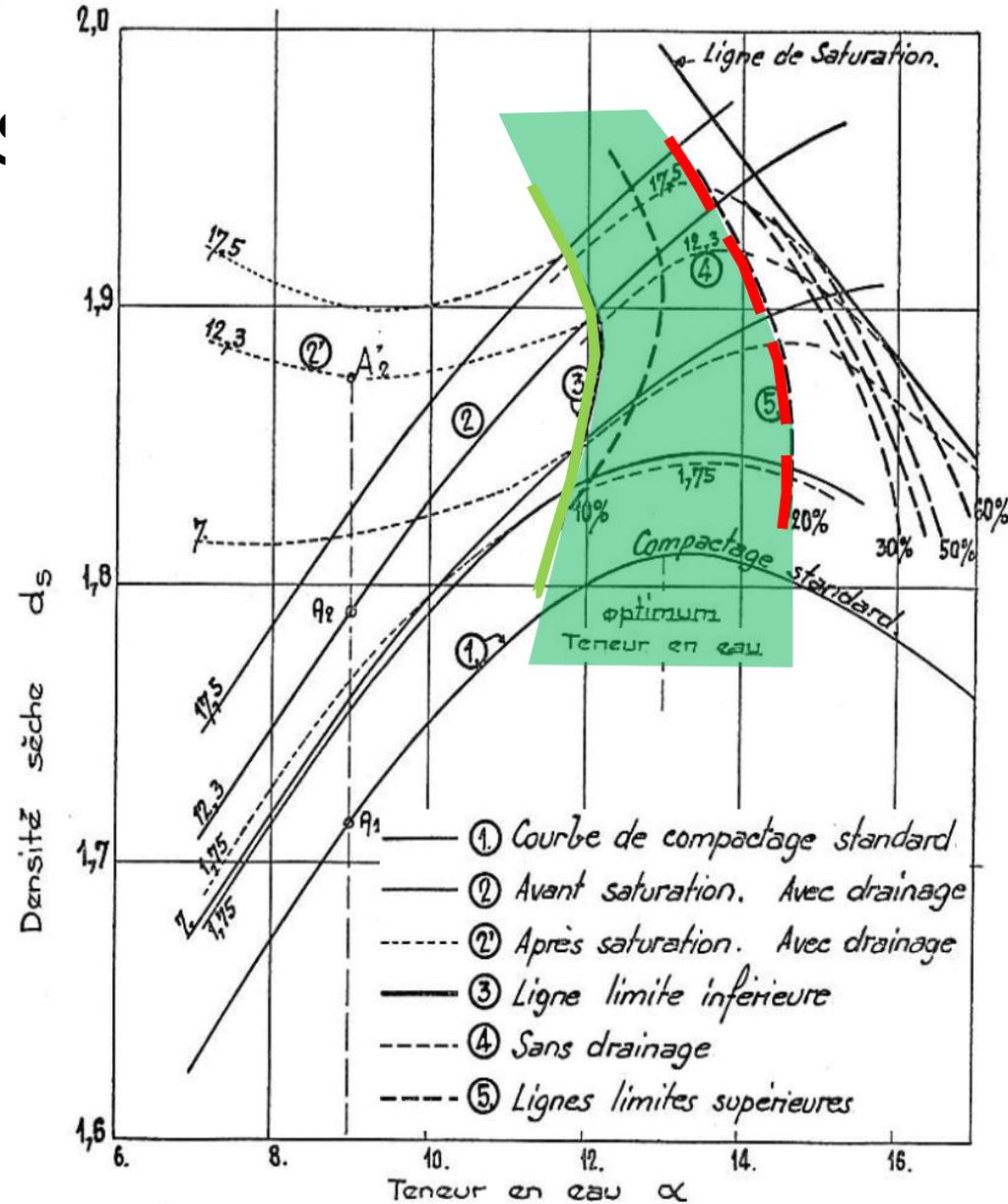


- on the dry side collapse occurs after flooding

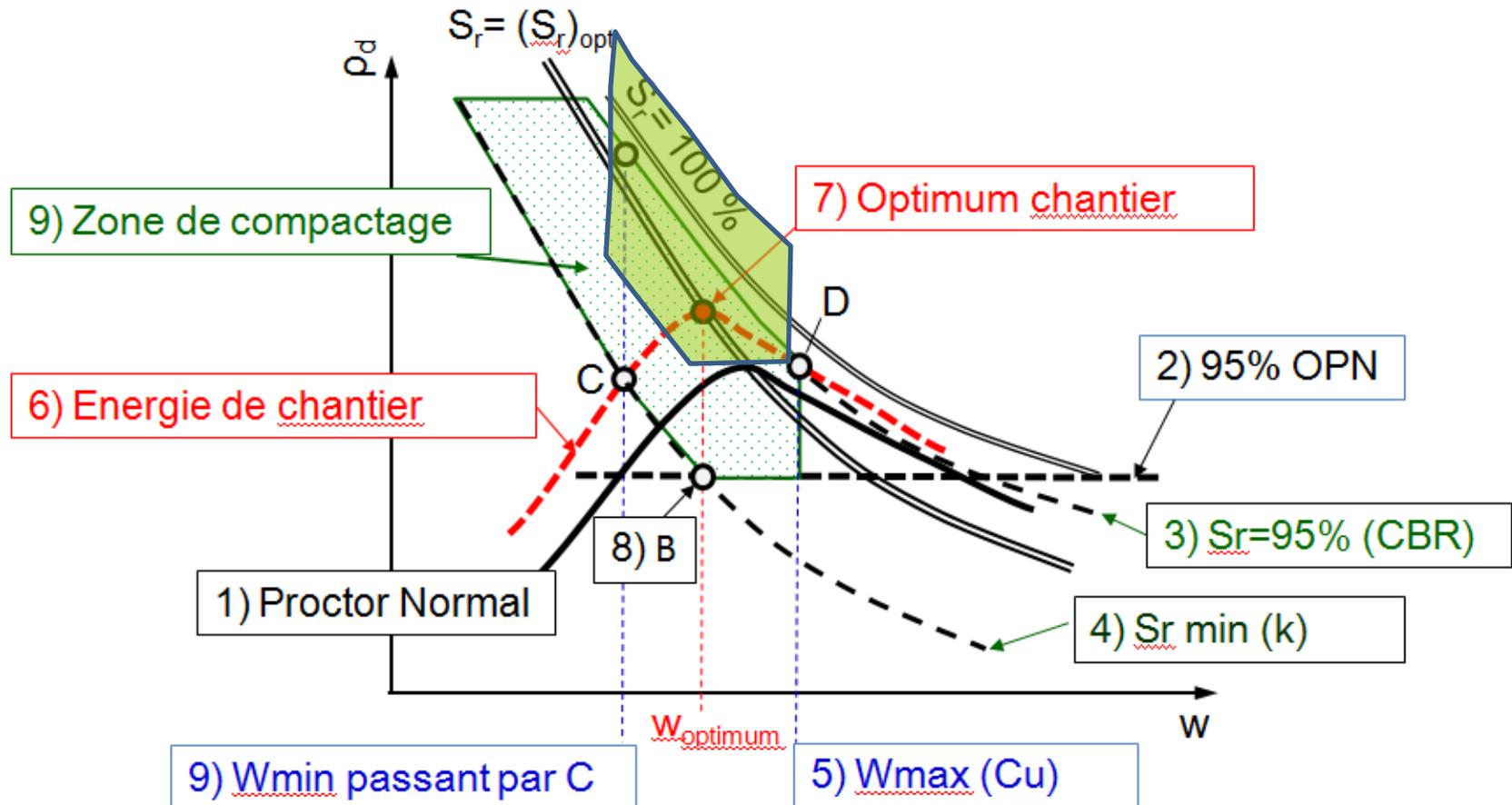
5 - Specifications for dams

- Lower bound of water content for limiting settlement and upper bound for limiting swelling

(USBR 1952)



5 – General specifications



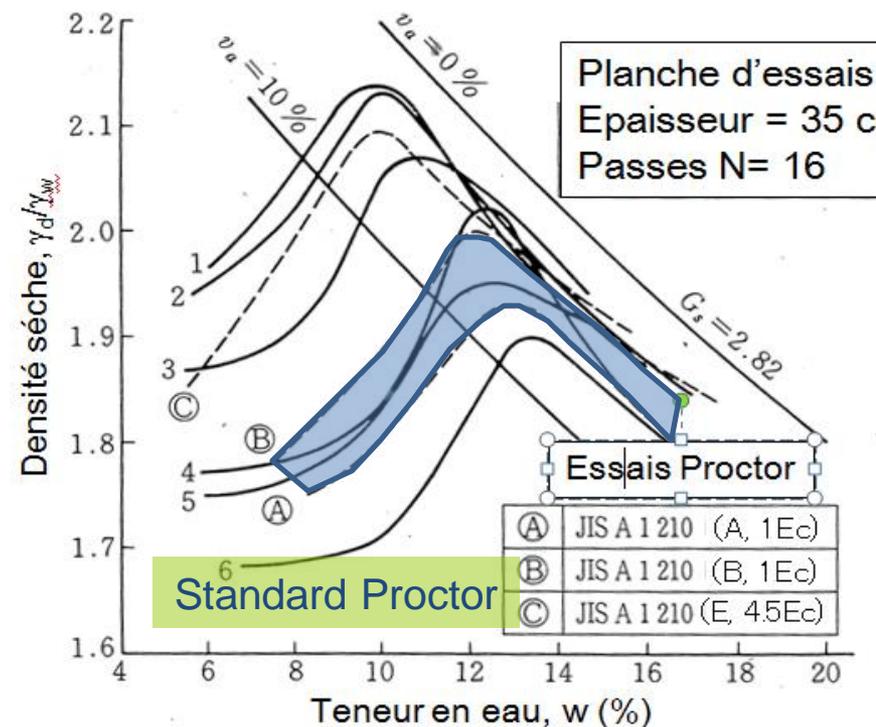
- Adapted from Tatsuoka (2015)

5 – Moisture specifications

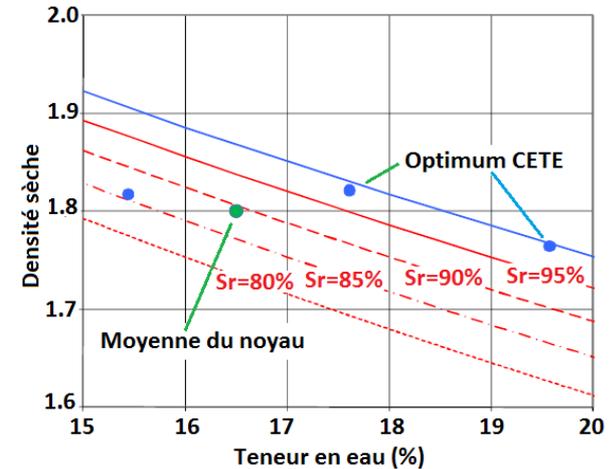
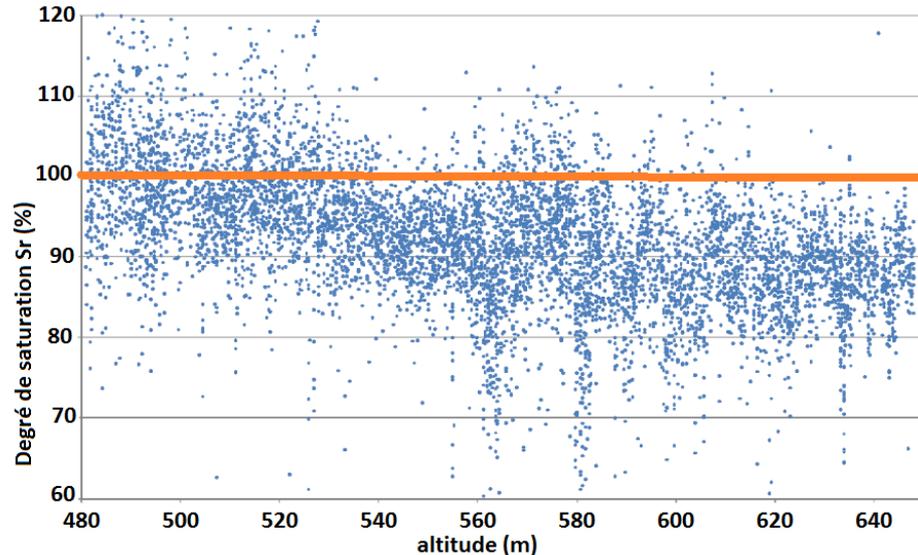
- What is the on site optimum of w ?

The optimum moisture related to the compactor is measured on field compaction tests: for Instance $w_{opt} < w_{opn}$ (Tatsuoka 2015)

N°	compactor	Masse (tonnes)	Masse sur roue
1	Still drum vibrating roller	9.8	-
2		6.5	-
3		4.0	-
4	Tire roller	35.6	5.1
5		17.3	2.5
6		20.0	1.8



5 – Moisture and Sr specifications

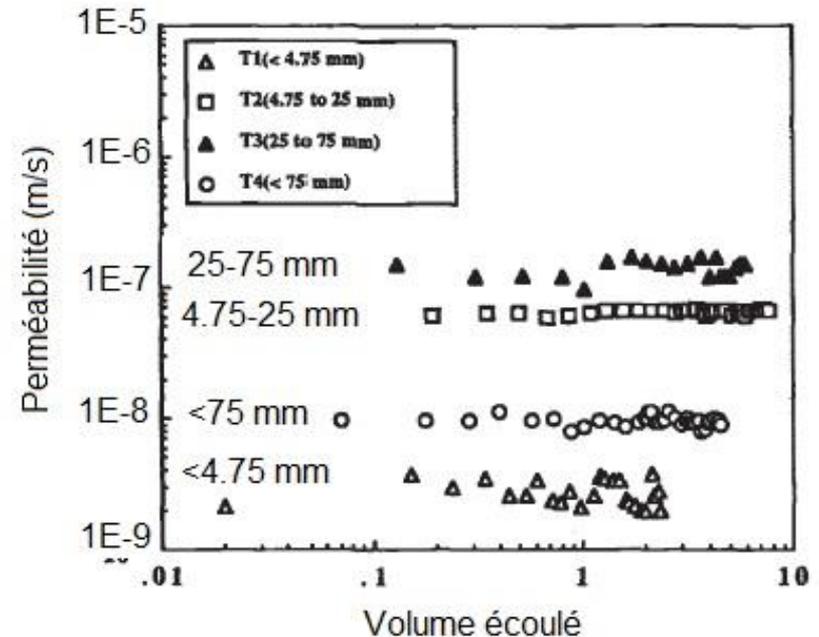
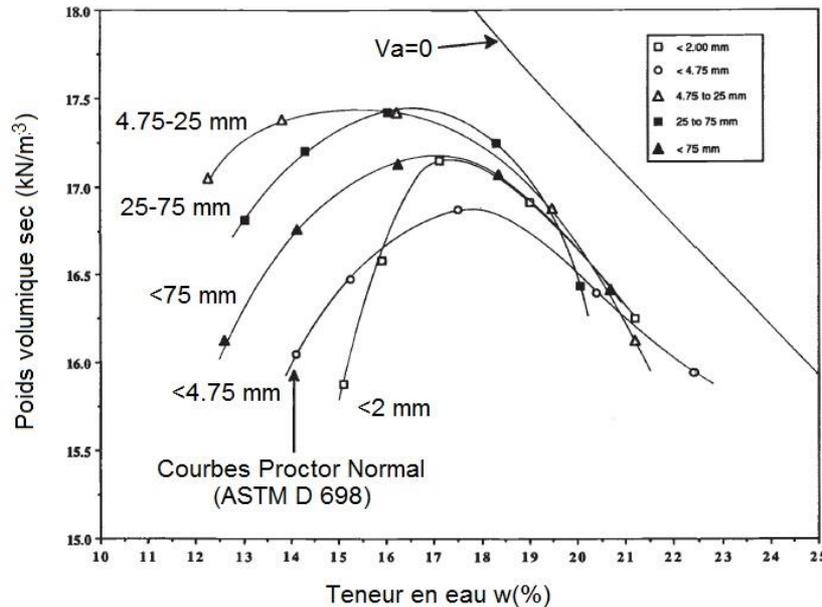


Kol dam (2014)

- **Warning !** Some soils and some procedures could lead to Sr (OPN) very close of 100% triggering quickly very high pore pressure
- **Good practice** : Sr(OPN) # 90% and Sr < 95%

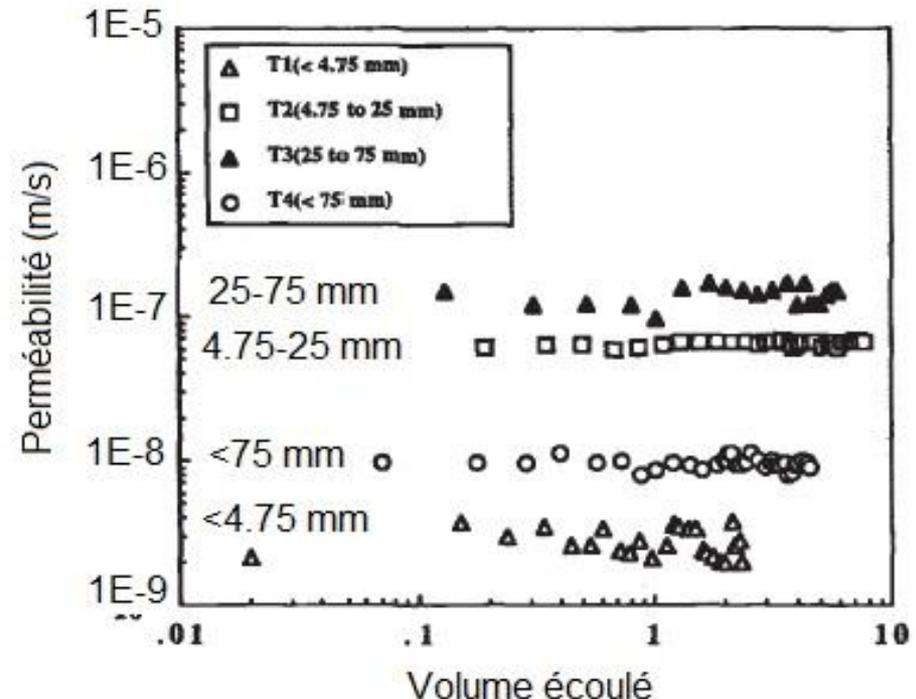
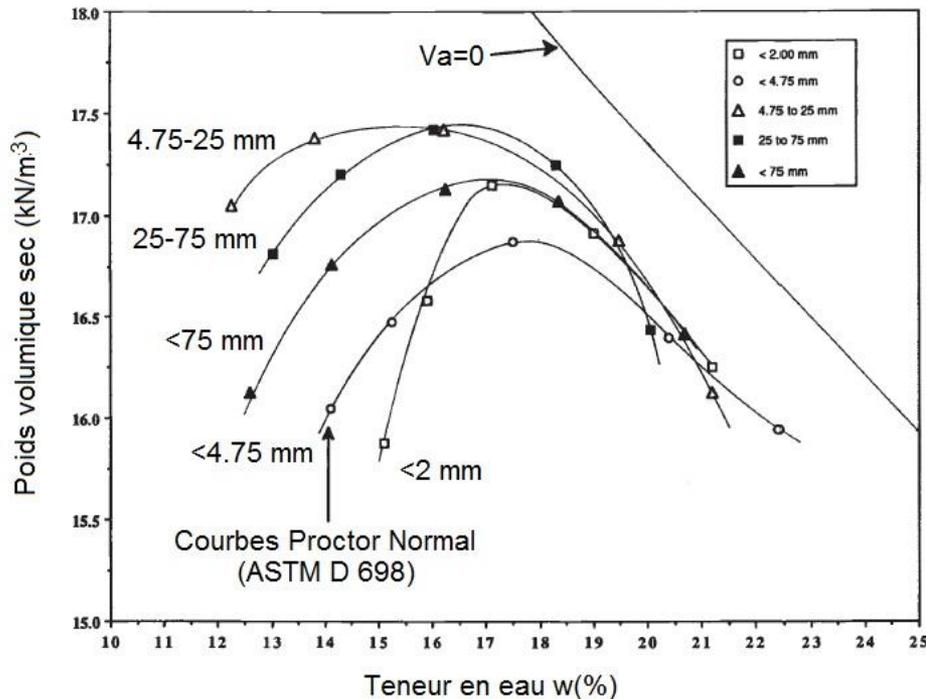
5 – Specification for « milling »

- The finest gradation of soils: no clods
 - Objectives : good watertightness and cracks prevention
- Pulvimixer or crushing station: 0/5 mm



5 – Specification for « milling »

- Objectives :
- good watertightness
 - erosion prevention

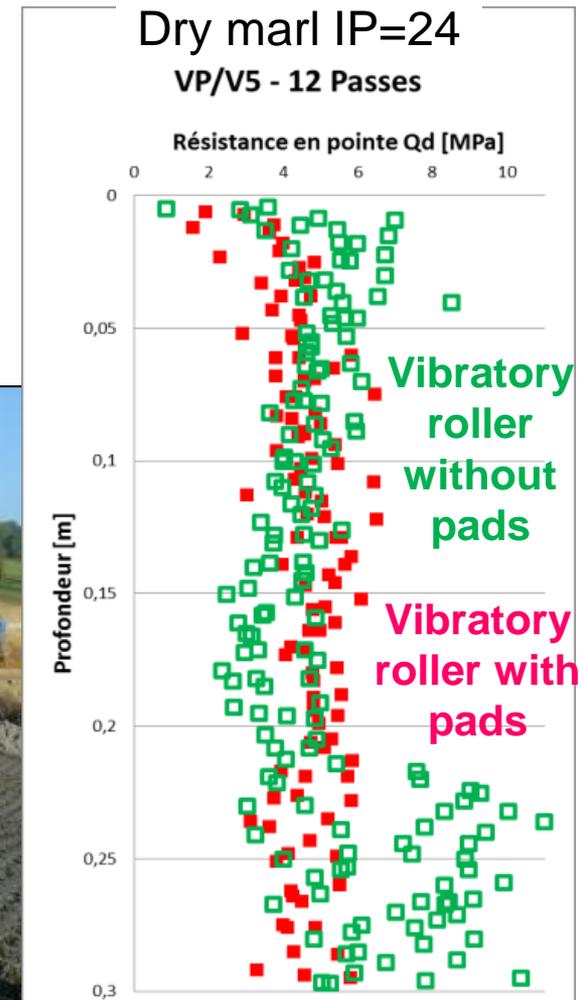


5 – Specification for « milling »

- The finest gradation of soils: no clods
- Pulvimixer or crushing station: 0/5 mm
- Drum with pads



(Photo and data
Mahmutovic 2015)



5 – Homogeneity

- $\gamma_d^{\text{top}} - \gamma_d^{\text{base}} < 2\% \text{OPN}$

Trial tests

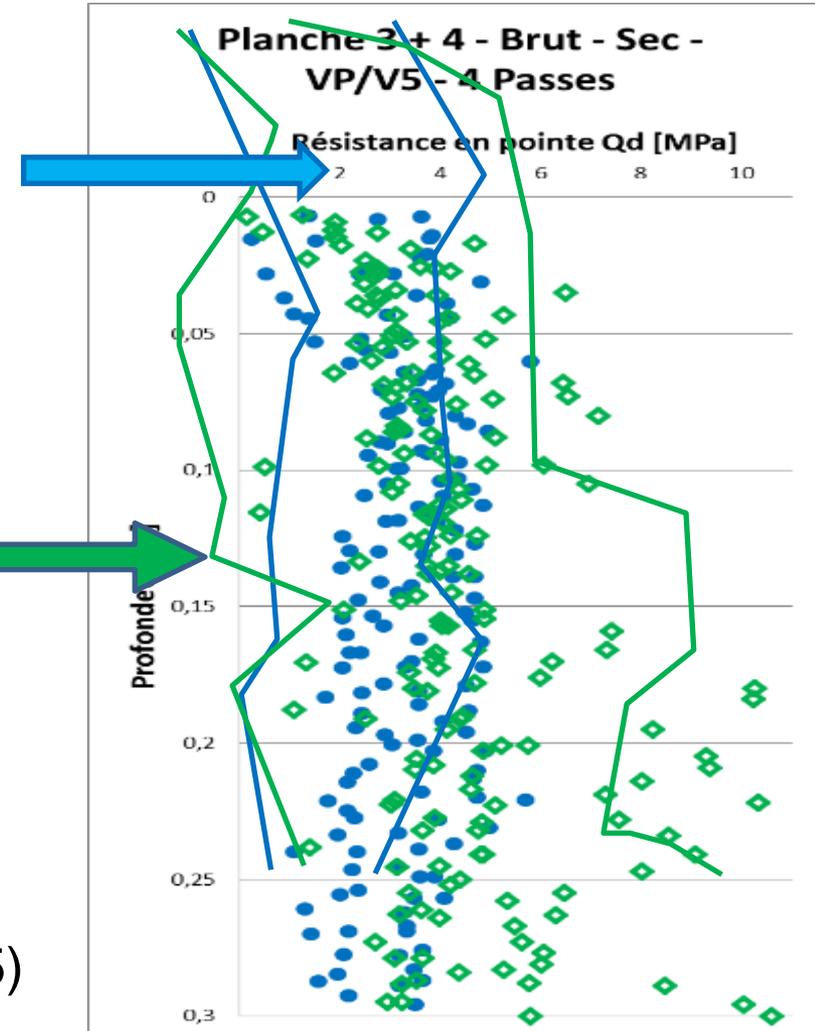
- Marls A2
- IP=24,
- Wopn=21,
- Ds opn=1,83)

Vibrating roller with padfoot

VP5 reaches a more homogeneous material that the smooth drum vibrating roller **V5**

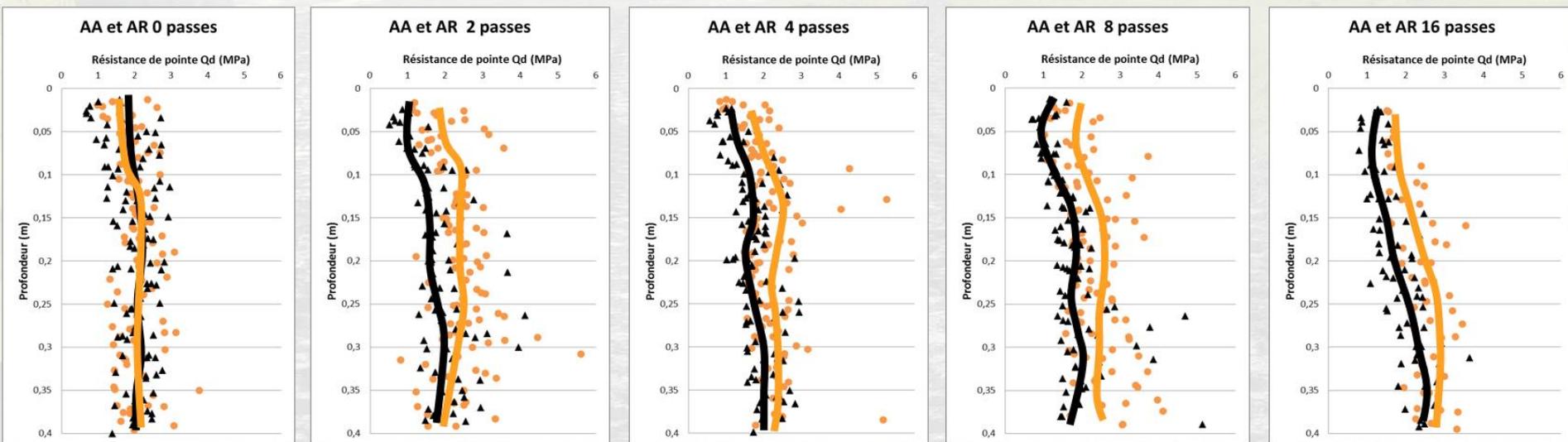
(Mahmutovic 2015)

4 Passes VP5
4 Passes V5



6 Methods statement

- Shallow compaction: low amplitude high frequency
- Deep compaction: high amplitude low frequency
- Bufalo (2016) noticed forward and backward compaction is less effective than forward compaction only



Forward and backward **forward only**



5 – Material based specifications

- Other functions for tricky soils:
 - Chalks : study impact on microstructure
 - Marls: évolutive materials
 - Slakes: stratification/anisotropy
 - Plastic clays: swelling or cracks
 - Silt & loams: collapse settlements
 - Plastic loams : slow drying

6 – Quality Control

- The **uncertainty range** on $(w-w_{OPN})$ is more or less the **specified range**:

Soil type	Number (3 points)	Optimum Proctor (γ_d/γ_w)			Optimum water content (%)		
		Average	Std.	Likely range between 2 points	Average	Std.	Likely range between 2 points
CH	26	1,559	0.026	0.072	22.6	0.9	2.4
CL	26	1.749	0.018	0.048	16.4	0.7	1.8
ML	25	1.701	0.016	0.046	16.7	1.0	2.9

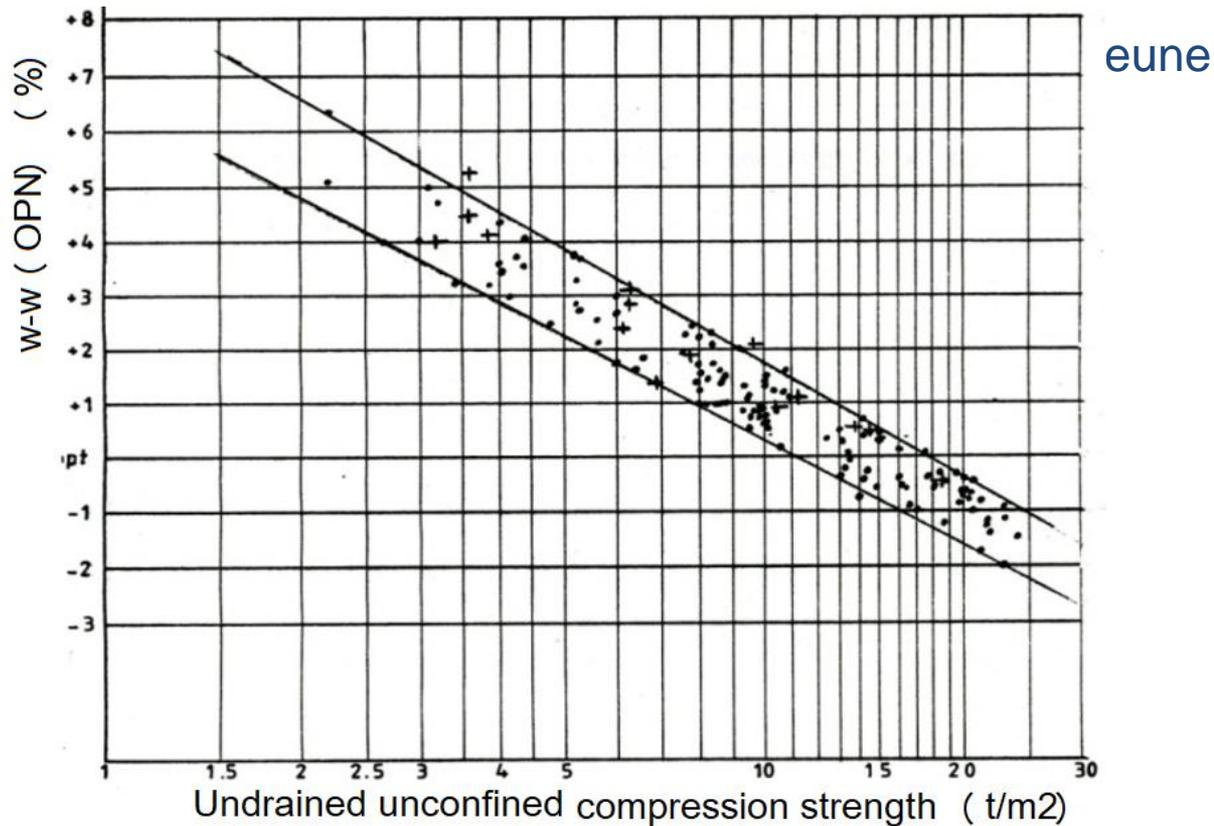
*Reproductibility of Standard Proctor Optimum
(ASTM D698-07)*



6 – Quality control

- Looking for best practice:
 1. Compaction trial test
 2. Hilf method for a quick check
 3. Proctor confirmed 1 day after
 4. Visual inspection in trenches for lamination
 5. Undrained strength:
 - Penetrometer
 - UCS
 - Pocket shear test

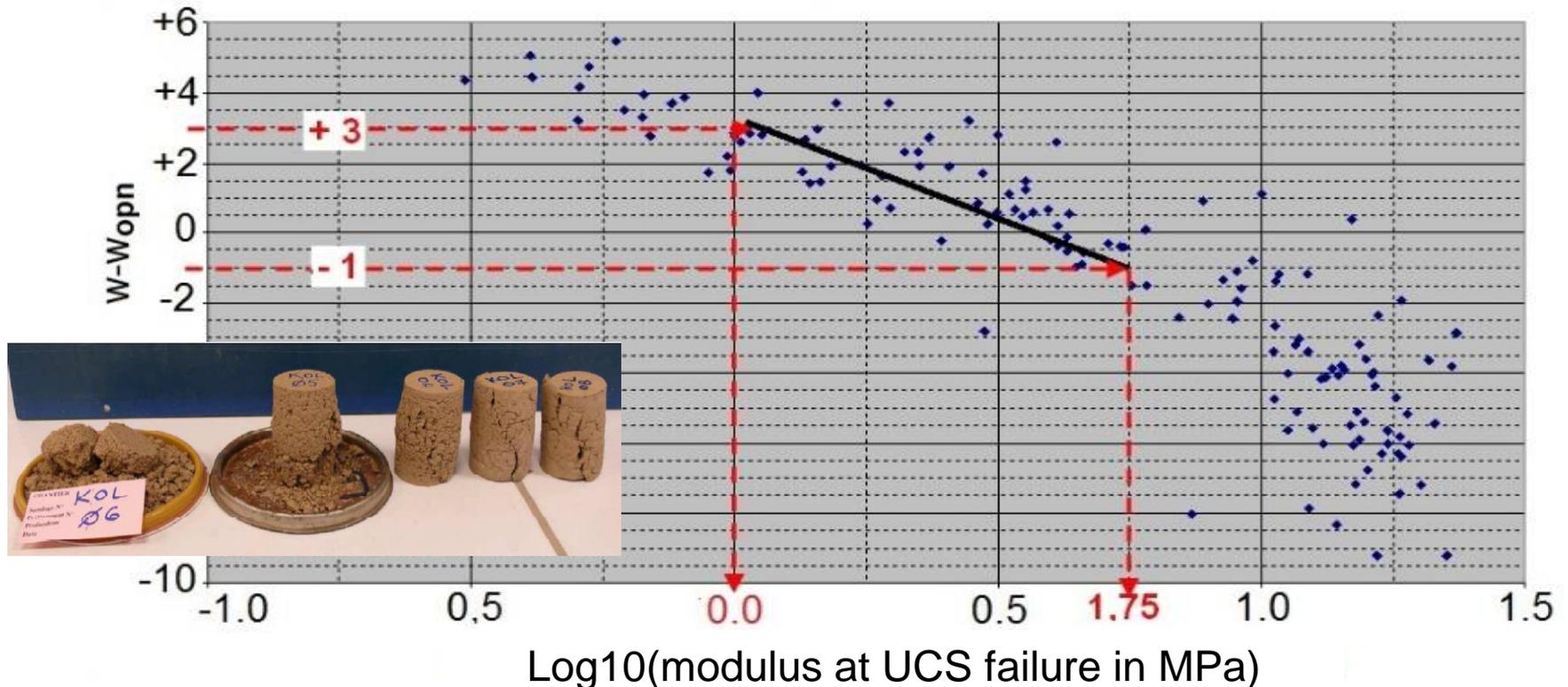
6 – QC Secondary control of $w-w_{OPN}$



$w-w_{OPN}$ versus S_u (UCS, pocket shear test, triaxial 38mm)

6 – QC Secondary control of $w-w_{OPN}$

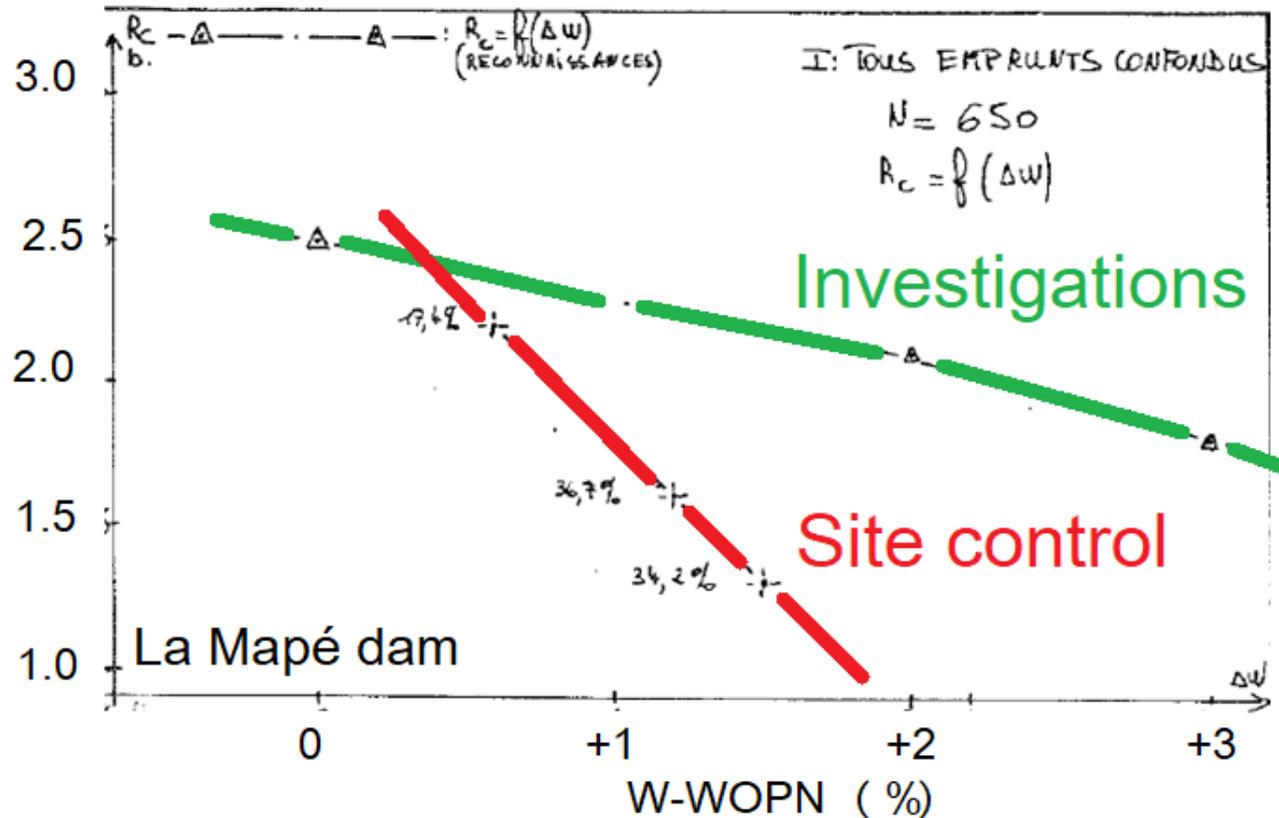
- Unconfined Compression Shear test (Φ 100 mm)



Secondary control of $(w-w_{opn})$ based on $\log_{10}[USC/\varepsilon_1(\text{failure})]$

6 – QC: Secondary control of $w-w_{OPN}$

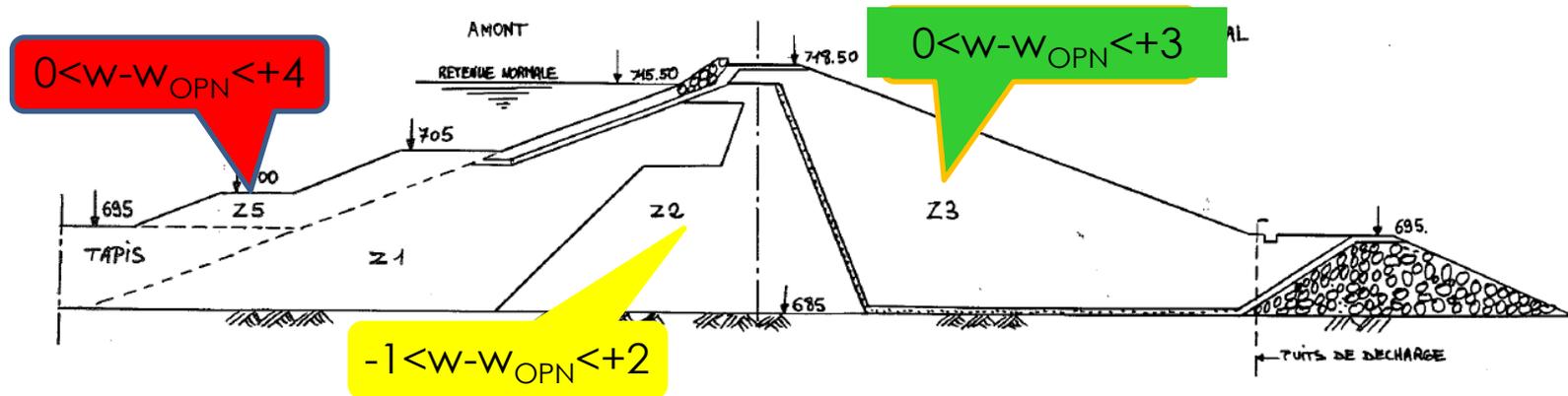
UCS (Bars)



- Wrong values detected by secondary control

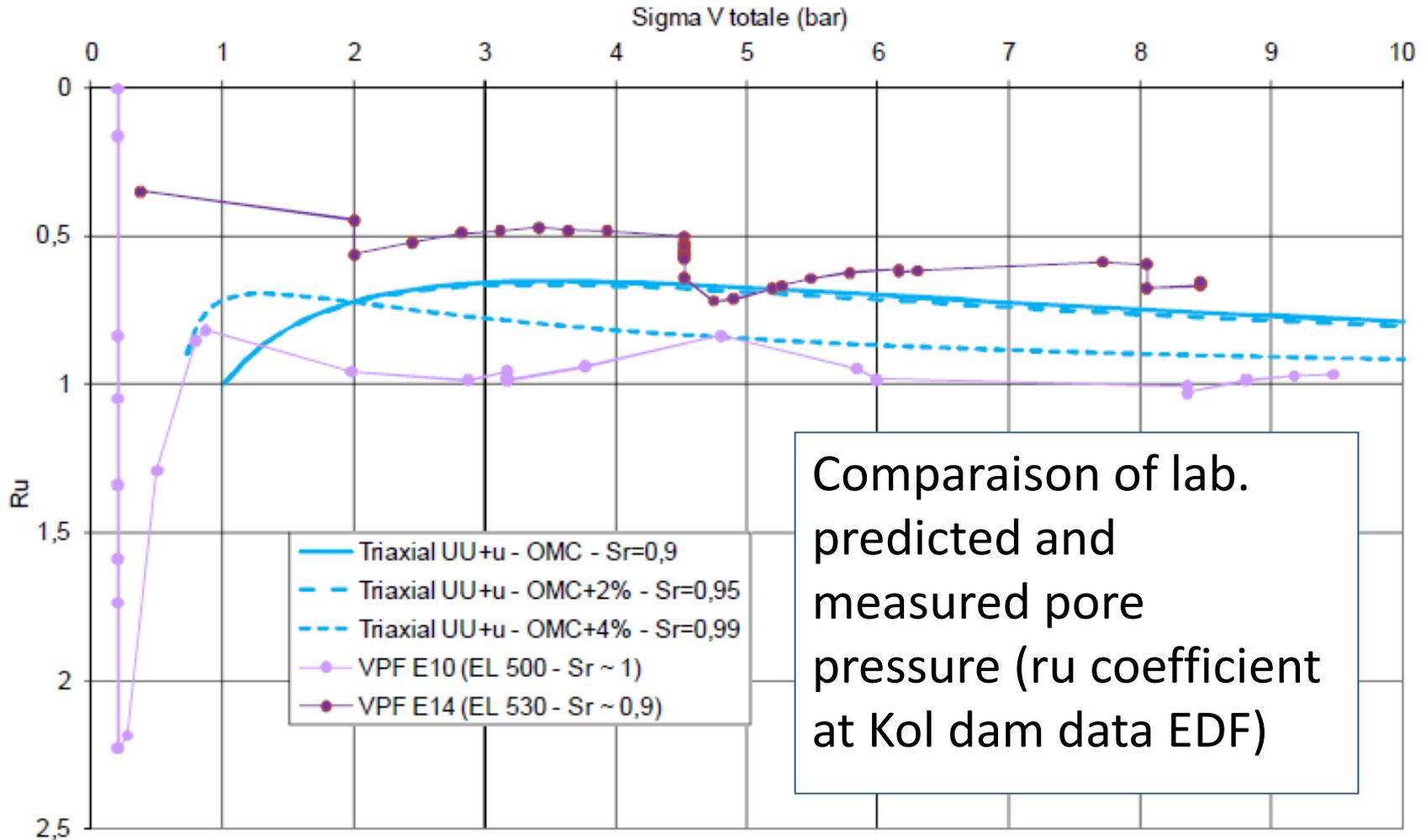
6 – QC: Secondary control of $w-w_{OPN}$

- January : QC required excavation of 270 000 m³ too wet clay



- February :
- New zoning : Z2 clay, Z3 laterite et Z5 excavated too wet material
- New spécifications (voir ci-dessus)
- New borrow pit
- Intensive use of Hilf method

6 – QC and monitoring of pore pressure



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Thank you for your attention

Your experience is welcome

