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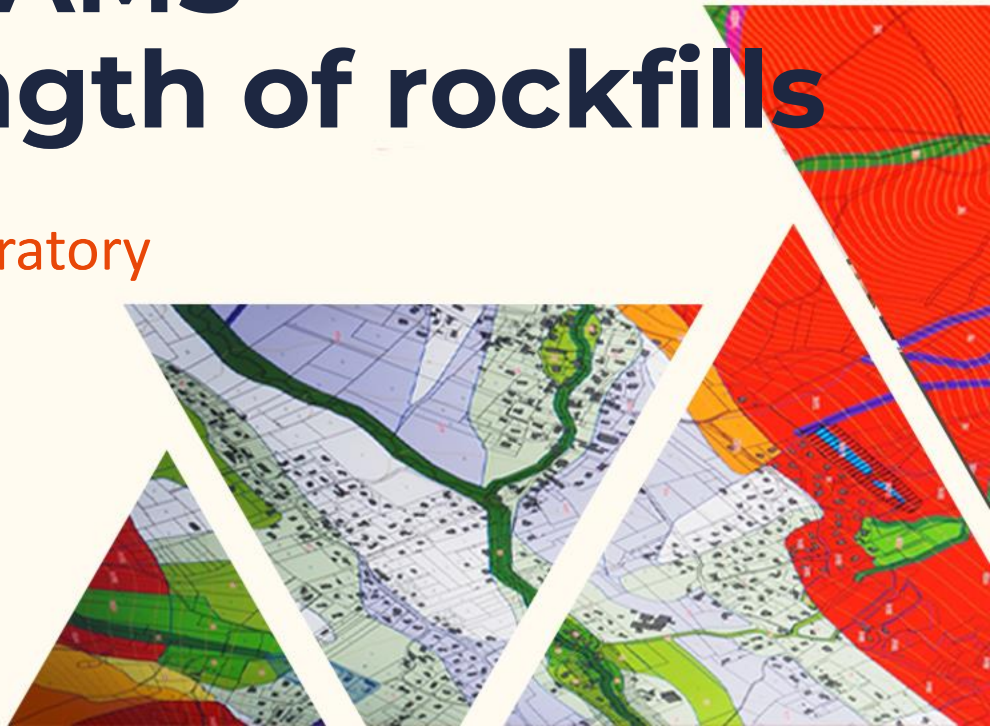
VULNERABILITY OF DIKES OR GRAVITY DAMS

Better estimate the strength of rockfills

Christophe DANO, 3SR Laboratory



3SR

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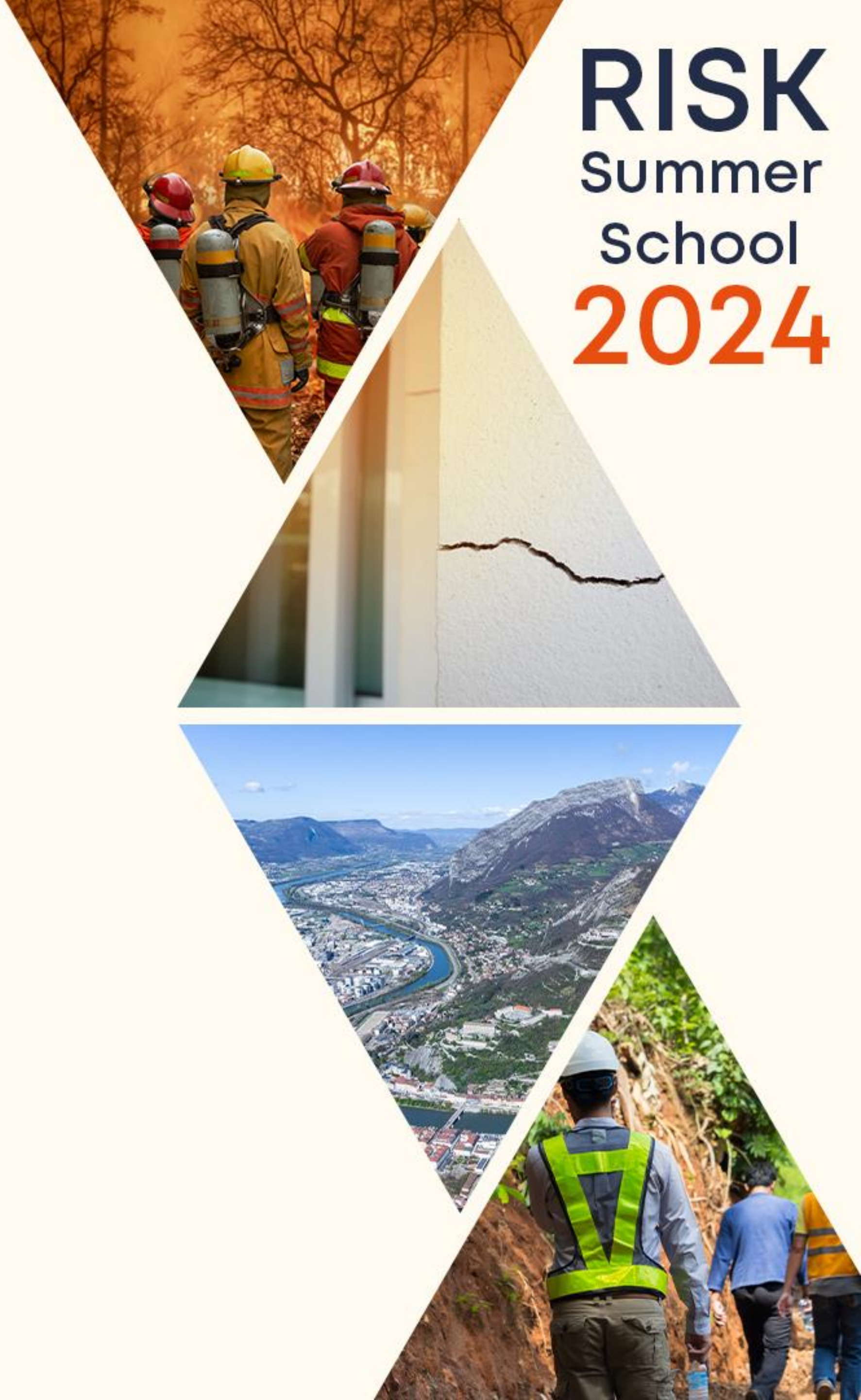
OUTLINE

- Rockfill ?
- Brief history of dikes and rockfill dams
- Geotechnical investigation
    - Mechanical part
    - Hydraulic part
- Erosion



Rockfill ?

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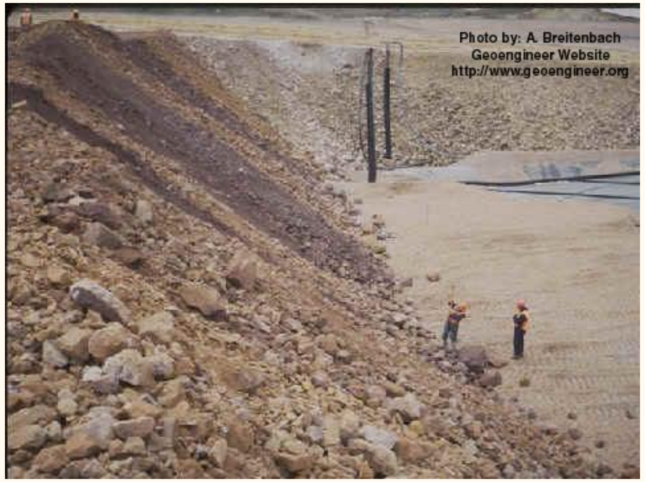

- Collection of rock particles : purely frictional, non cohesive
- From some mm to meter in civil engineering applications
- Usually placed in dense conditions

railway

dam

coastal dikes

river dikes

Brief history of dikes and dams

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PERIOD 1 – From ancient times (> 2000 years) to Middle Age

Agriculture, flooding mitigation, water ressource

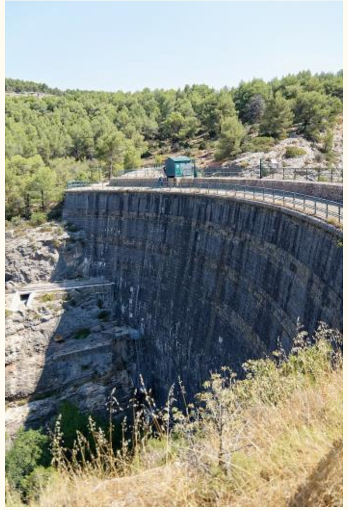
Small and massive dams (< 25m)

Engineering point of view : double need of STABILITY / WATERTIGTHNESS

Figure 1 : Barrage de SADD-EL-KAFARA (-2650 av JC) d'après SCHNITTER

PERIOD 2 – Industrial revolution (19th – beginning of 20th century)

Technical improvements : concrete, arch technology (thinner dams)



« Zola » dam (France)

Brief history of dikes and dams

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PERIOD 3 – Post 2nd world (1950 – 1970)

Higher and higher structures (> 250m)

Objectives : energy production, irrigation

Location : Europe / North America (USA, Mexico)

2 main catastrophic events on concrete arch dams

Malpasset (France), 1959,

Quality of the abutment

Vajont (Italy) 1963,

Landslide in the reservoir

Brief history of dikes and dams

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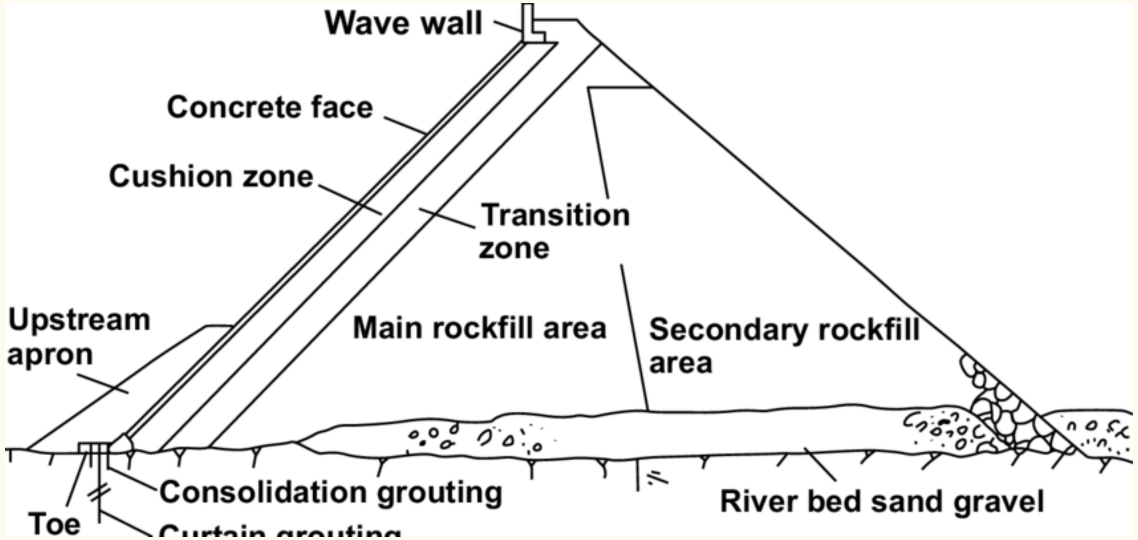
PERIOD 4 – > 2000

Main areas of interest : South America, Africa & Asia

Main technology:

CFRD (Concrete Face Rockfill Dam)

Heigths : > 200m



Genesis of **SUSTAINABLE DEVELOPMENT :** main consequence = **RE-USE of LOCAL MATERIAL**

Brief history of dikes and dams

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PERIOD 4 – > 2000

PATHOLOGIES

CASE STUDY 1 / CAMPOS NOVOS DAM (BRAZIL – 2005)

Hydro-power, H 202m

FAILURE of the concrete face during 1st filling

Brief history of dikes and dams

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PERIOD 4 – > 2000

PATHOLOGIES

CASE STUDY 2 / MOHALE DAM (LESOTHO – 2006)

H 145m,

FAILURE of the concrete face during 1st filling

+ HEAVY RAINS

Leakage of 600 l/s

Brief history of dikes and dams

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PERIOD 4 – > 2000

PATHOLOGIES

CFRD	ISSUE	CAUSE
Aguamilpa h=187m	Concrete facing cracking	Rockfill deformability
Barra Grande h=185m	Concrete facing cracking	Joint failures
Campos Novos h=202m	Concrete facing cracking	Rockfill defformability
Itá h=125m	Slabs cracking	Rockfill deformability
Itapebi h=120m	Cracks parallel to the plinth	Foundation geometry
Mohale h=145m	Compression joint rupture	Rockfill deformability
Tianshengqiao 1 h=178m	Horizontal cracking	Construction sequence
Xingó h=150m	Slabs cracking	Sharp geometry of the left abutment and material deformability

(Ma and Cao 2007)

Brief history of dikes and dams

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PERIOD 4 – > 2000

ACCIDENTOLOGY

SIMILARITIES

- PERIOD : 2000 <   < 2010
- CFRD involving ROCKFILL
- FAILURE during 1st FILLING
- FAILURE of the CONCRETE face
- Use of LOCAL resources

COMMON FEATURES

- No technical capacity to evaluate rockfill quality
- High mechanical stresses
- Lack of geotechnical knowledge
- Influence of water

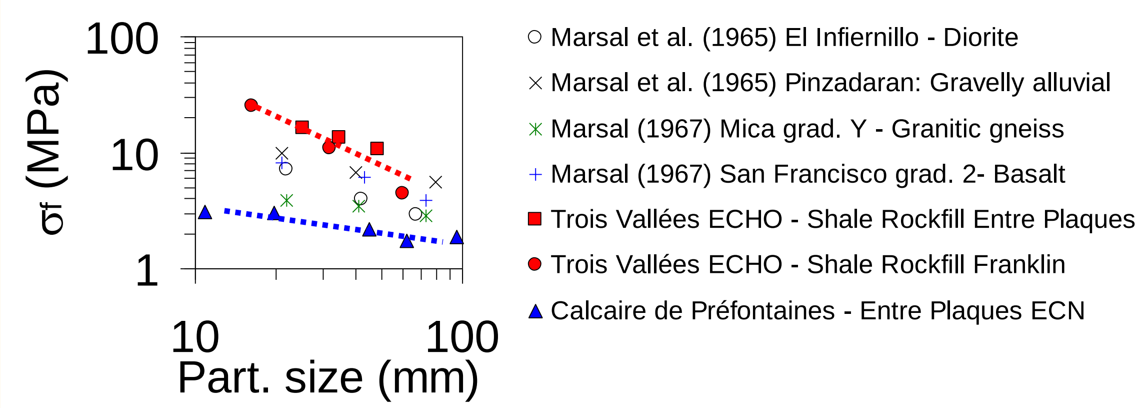
MECHANICAL / HYDRO ISSUE

Geotechnical investigation / MECH

ISSUE 1 : ANY SIZE EFFECT AT THE « GRAIN » SCALE ?

Protodyakonov tests
Franklin tests
…

$$\sigma_f \propto \frac{F_f}{d^2}$$



CONCLUSION: 1

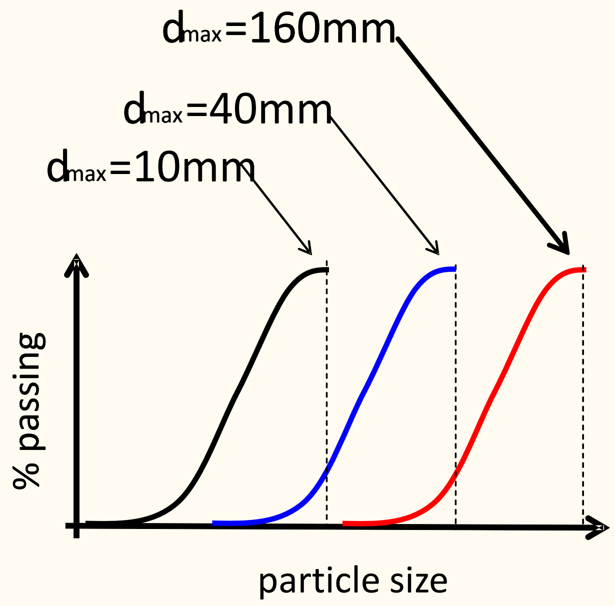
YES THERE IS **A SCALE EFFECT** AT THE GRAIN SCALE

(Weibull 's distribution)

Geotechnical investigation / MECH

ISSUE 2 : IT THE SAME AT THE SAMPLE SCALE ?

SAMPLE SIZE : at least 6 to 10 times the maximum grain size



Extrapolation to rockfill in the field

Geotechnical investigation / MECH

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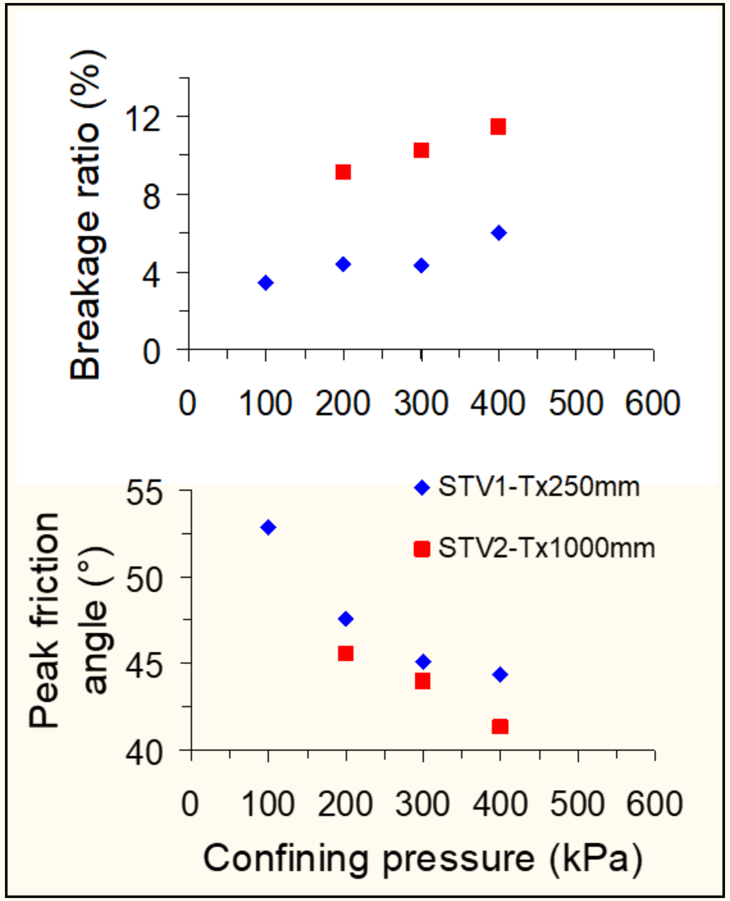
ISSUE 3 : IT THE SAME AT THE SAMPLE SCALE ?



CONCLUSION: 3

YES

- Decrease of the shear strength with increasing particle size
- Increase of grain breakage
- More compressible volumetric behaviour (more prone to settlement)

Geotechnical investigation / HYDR

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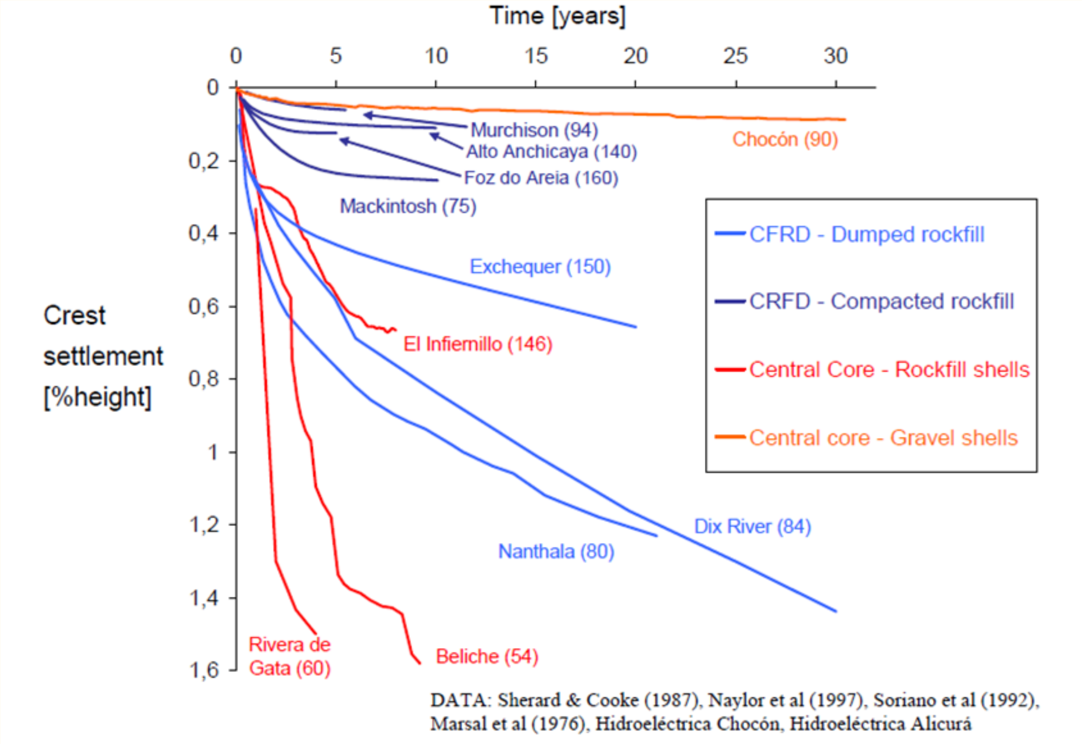
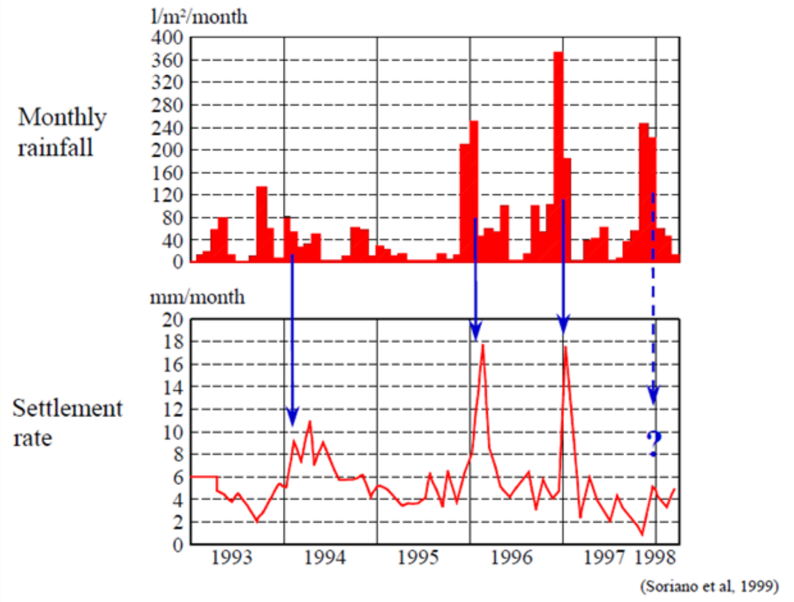


Oldecop (2005)



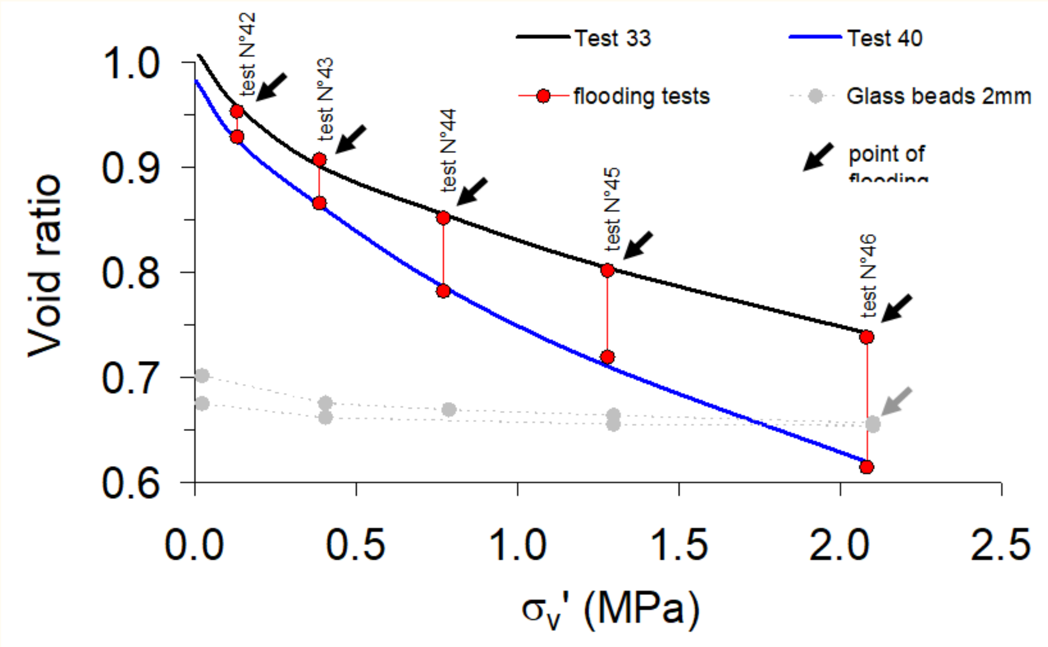
SETTLEMENT EMPHASIZED BY RAINFALLS

Geotechnical investigation / HYDR

SETTLEMENT EMPHASIZED BY RAINFALLS

1D compression tests

Clear instanteneous effect of imbibition



Geotechnical investigation / HYDR

SETTLEMENT EMPHASIZED BY RAINFALLS

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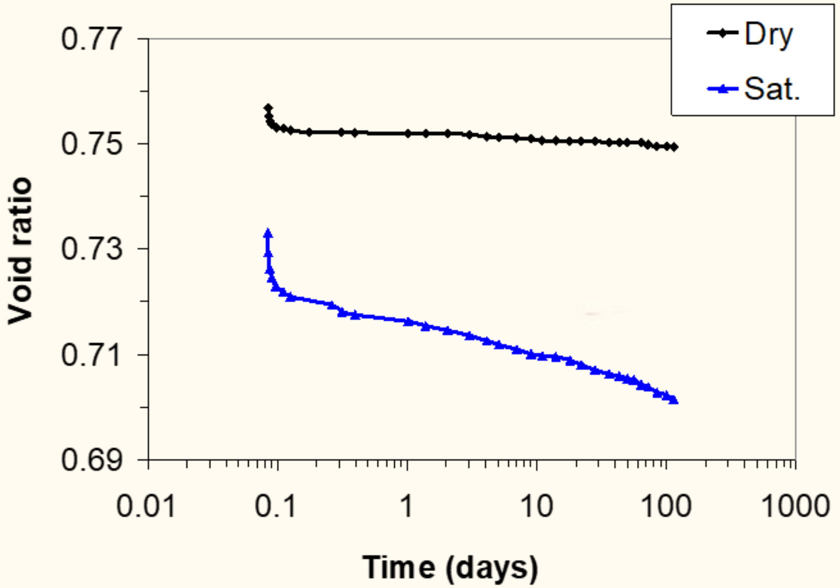
1D compression tests

Long-term effect in both dry or saturated rockfills



Geotechnical investigation / HYDR

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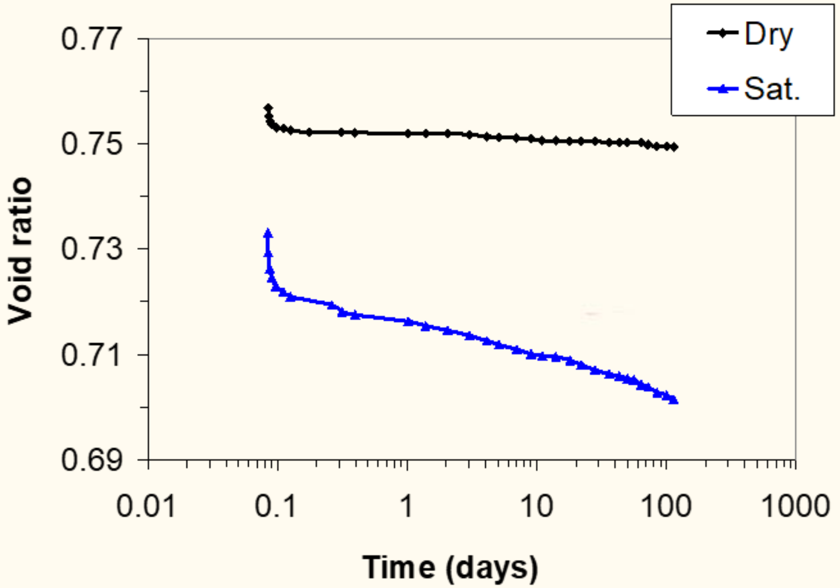
SETTLEMENT EMPHASIZED BY RAINFALLS

1D compression tests

Long-term effect in both dry or saturated rockfills



Geotechnical investigation

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CAMPOS NOVOS CFRD

- 1st filling of the reservoir

⇓

Contact between water and rock blocks

⇓

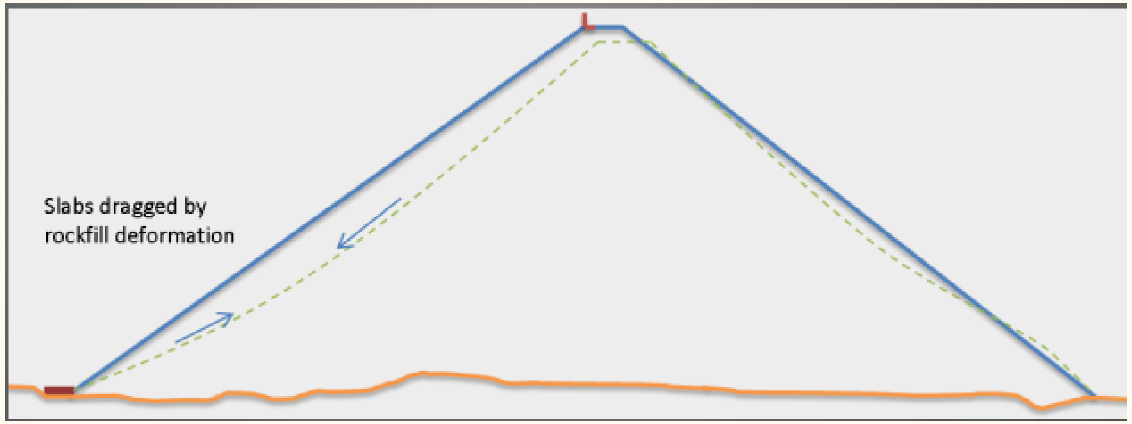
Breakage of blocks at the base

⇓

Settlement of the rockfill +
bending of the concrete face (traction)

⇓

Failure of the concrete face + leakage



Erosion

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External erosion (backward)

Detachment of particles downstream

⇓

Loss of stability

Internal erosion

Flow of small particles inside the structure

⇓

Change of mechanical and hydraulic properties that could lead to failure

Conclusions

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- Rockfill behaviour not completely known

- Use of local rock ressources : not mechanically optimized

- Material senstive to stresses and water (imbibition or flow)

- Time-dependency of the behaviour : requirement of an adequate monitoring of the structures

THANK YOU FOR YOUR ATTENTION

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