Failure of rockfill dams

in overtopping scenario

Serpa (UPM) research

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SERPA - Dam Safety Research

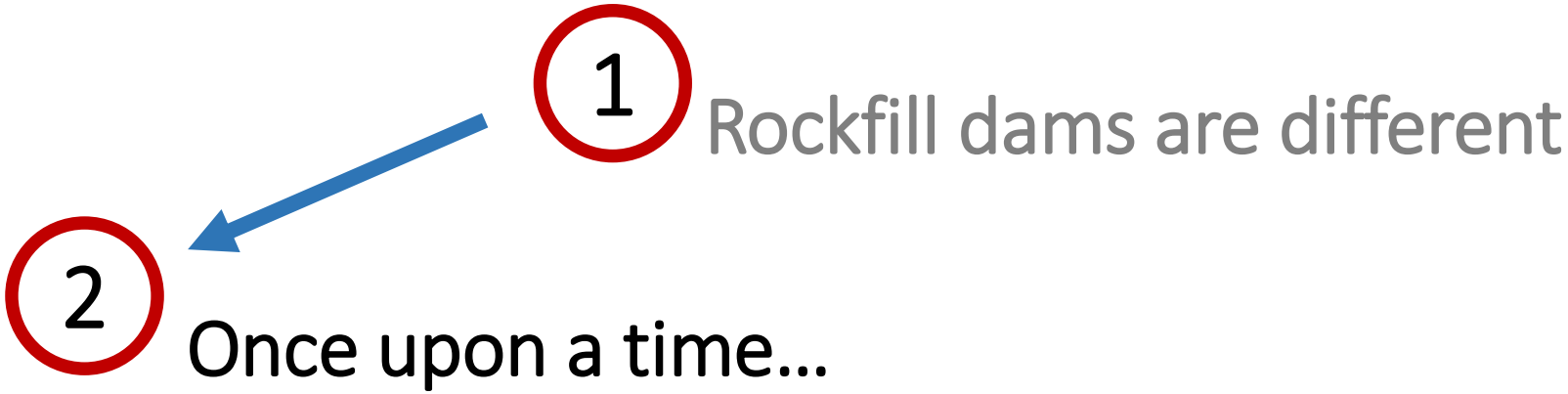
POLITÉCNICA

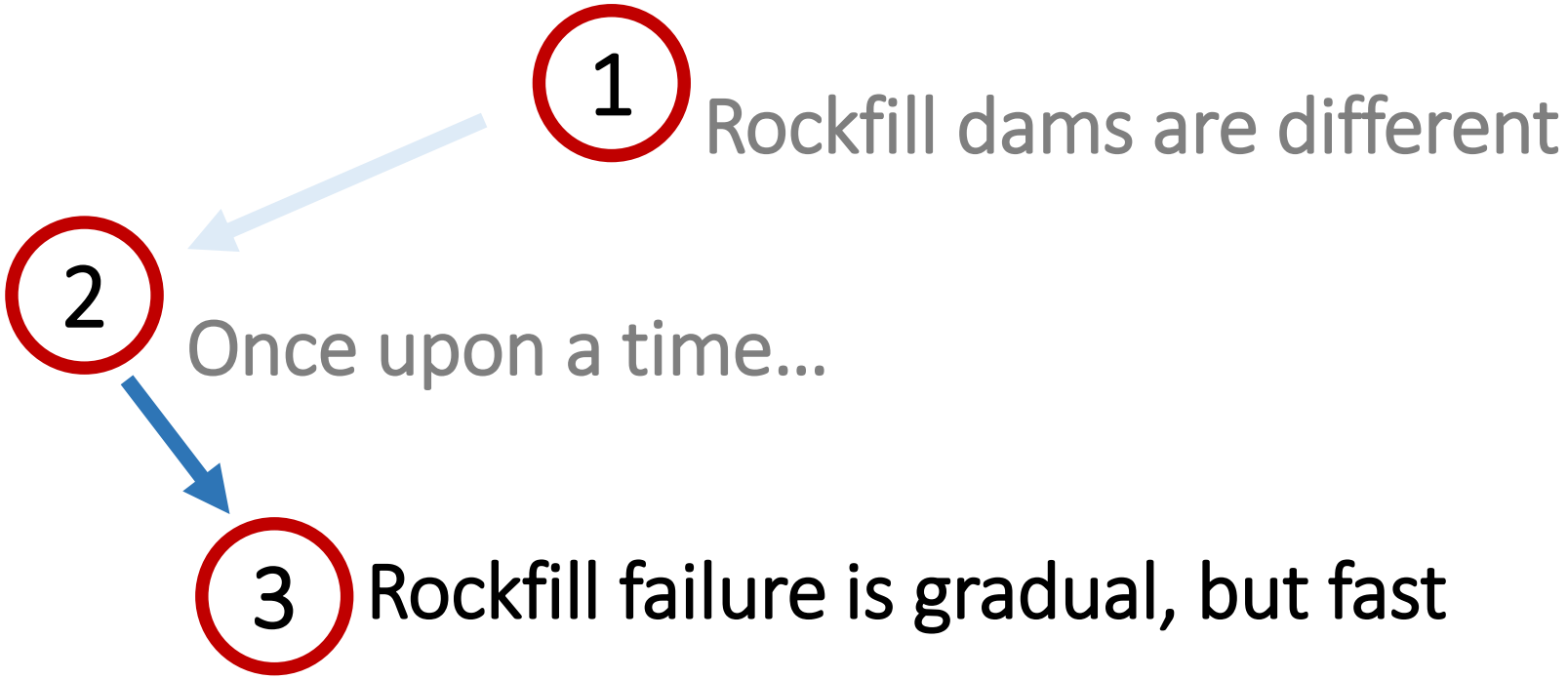
serpa
Dam Safety Research

RESEARCH GROUP
ON HYDROINFORMATICS
AND WATER MANAGEMENT

Aussois, 11-14 December 2017

1 Rockfill dams are different


1
Rockfill dams are different
2
Once upon a time…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Rockfill dams are different
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Once upon a time…
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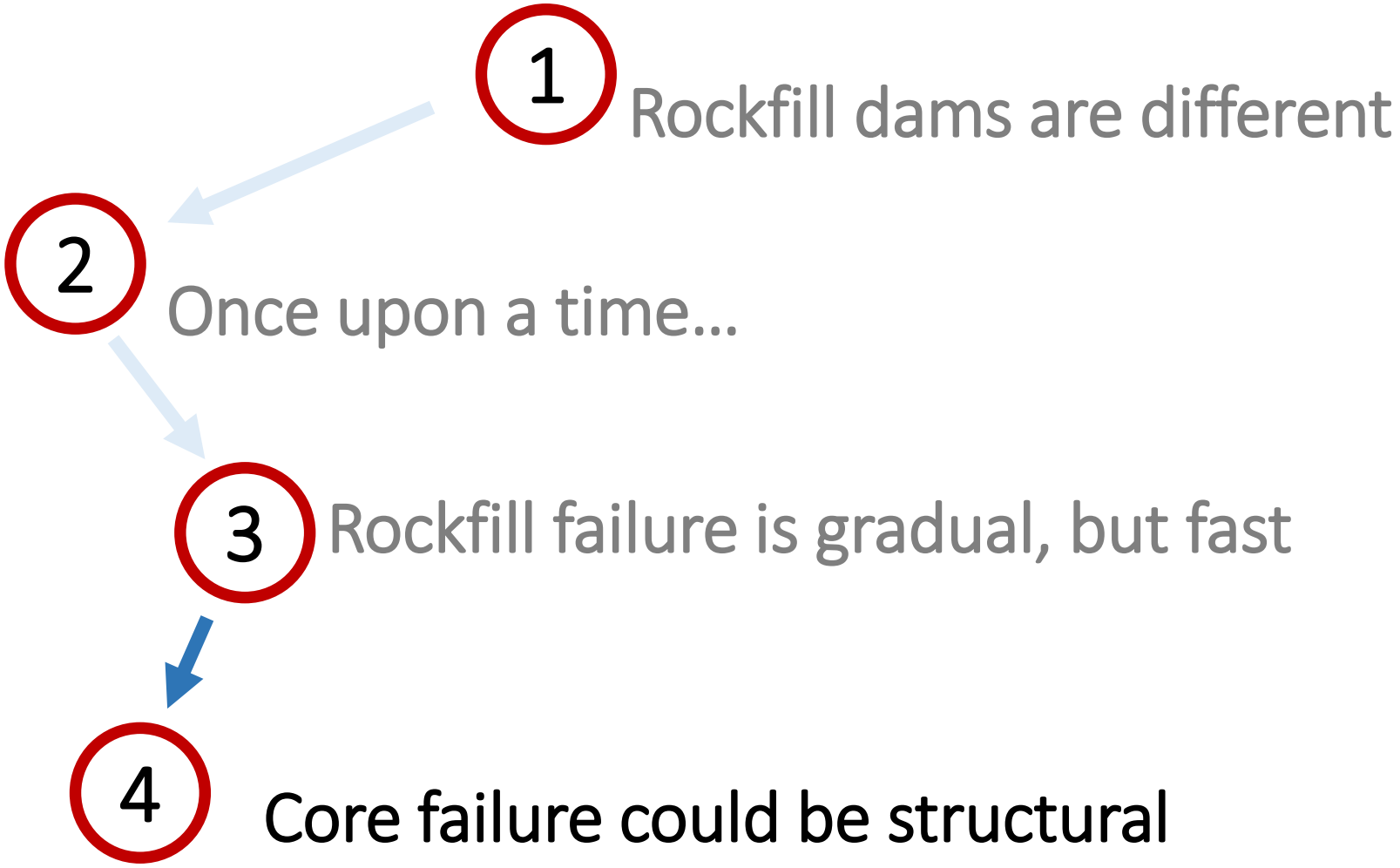
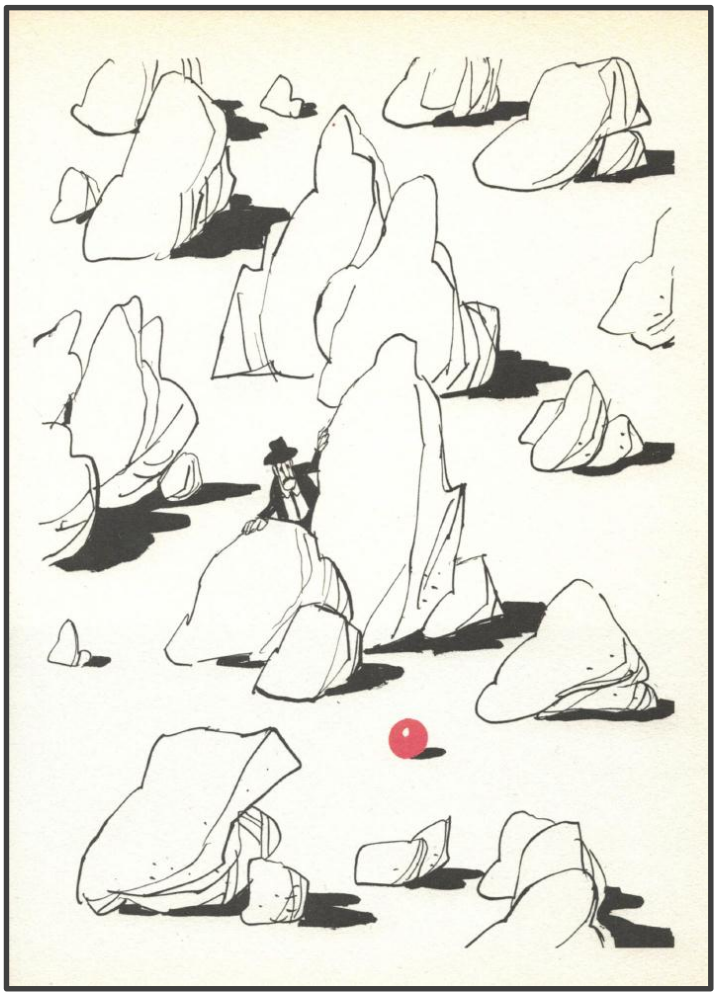
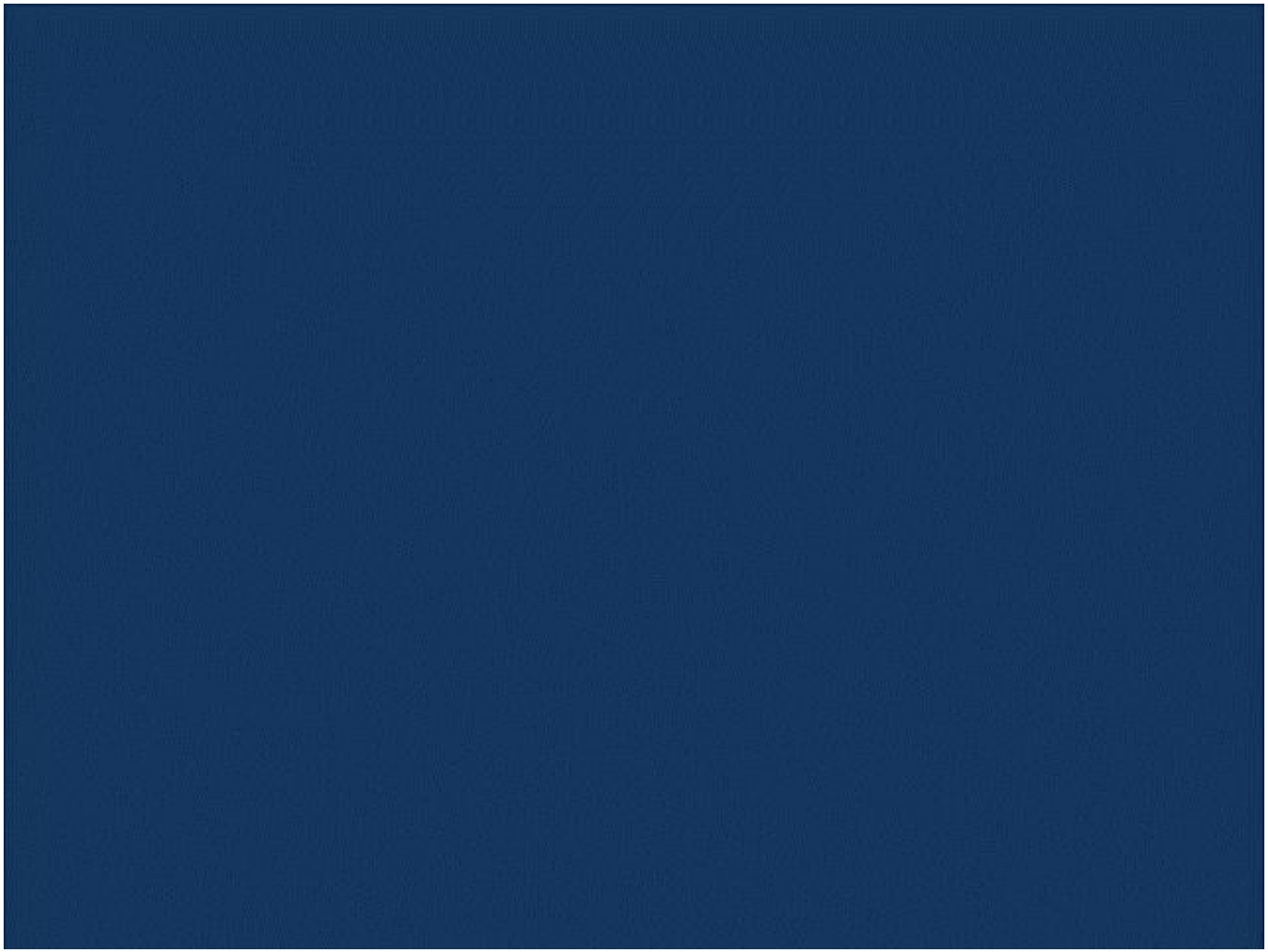
Rockfill failure is gradual, but fast


1
Rockfill dams are different
2
Once upon a time…
3
Rockfill failure is gradual, but fast
4
Core failure could be structural and sudden

1 Rockfill dams are different



Hombre solo; Author: Antonio Mingote, 2008; Ed. Planeta



1 Time needed for losing the rockfill support

Time needed for losing the rockfill support

2 Core remains unsupported some more time

Time needed for losing the rockfill support

Core remains unsupported some more time

3 The core overturned

Time needed for losing the rockfill support

Core remains unsupported some more time

The core overturned

4

Lower part of the core remains

Time needed for losing the rockfill support

Core remains unsupported some more time

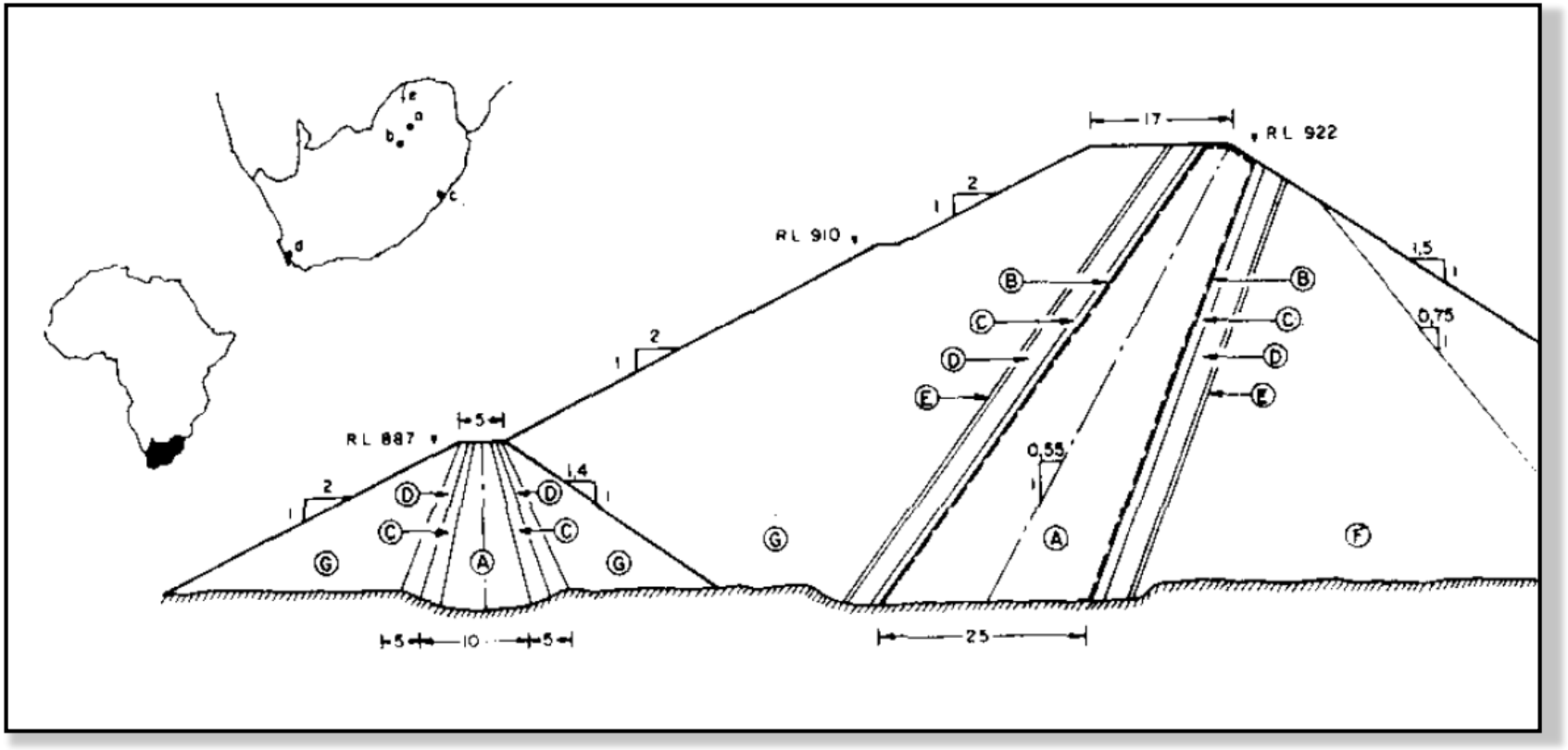
The core overturned

Lower part of the core remains

5

Large chunks

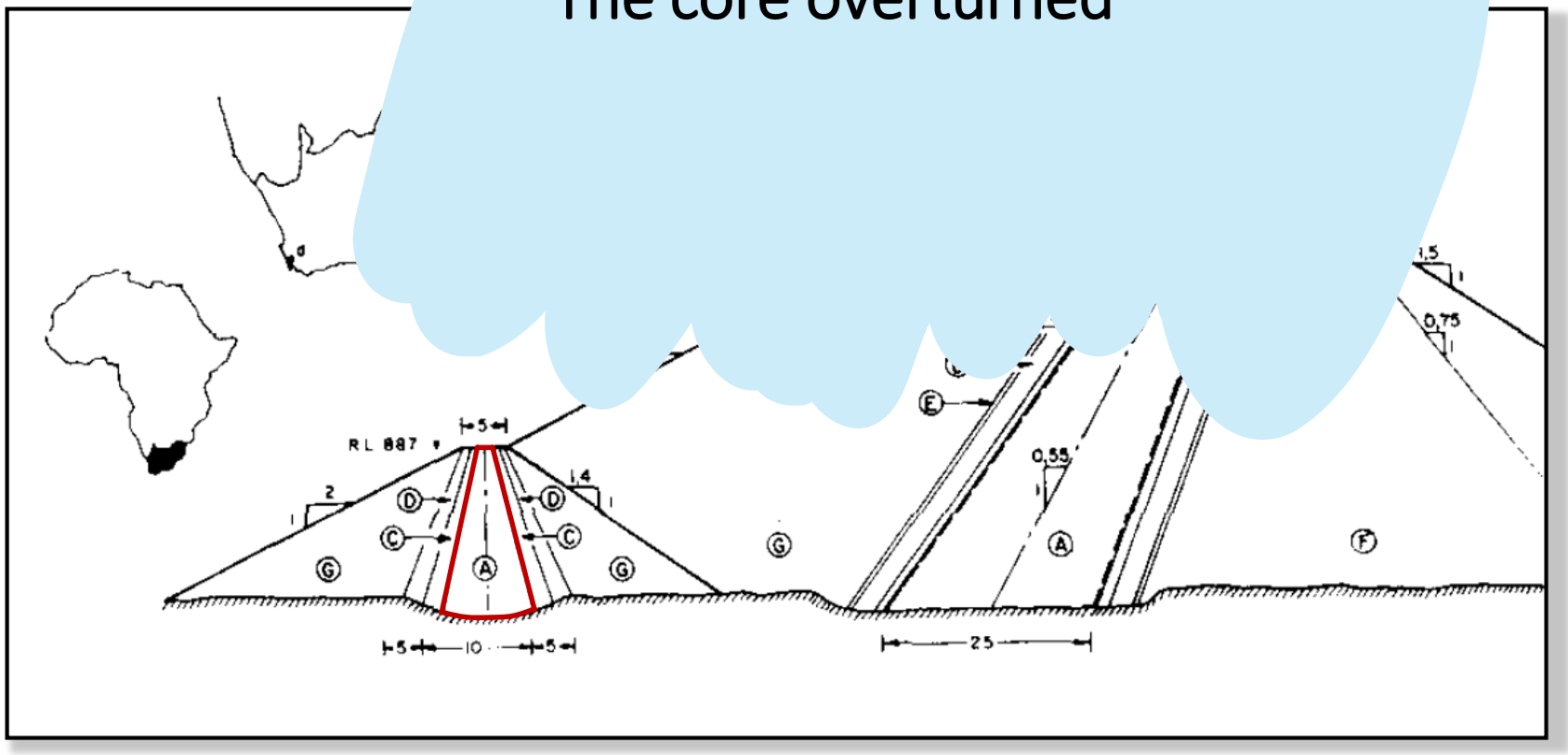
Hans Strydom cofferdam (failed 1977)



Odendaal and Van Zyl 1979

Hans Strydom co

The core overturned

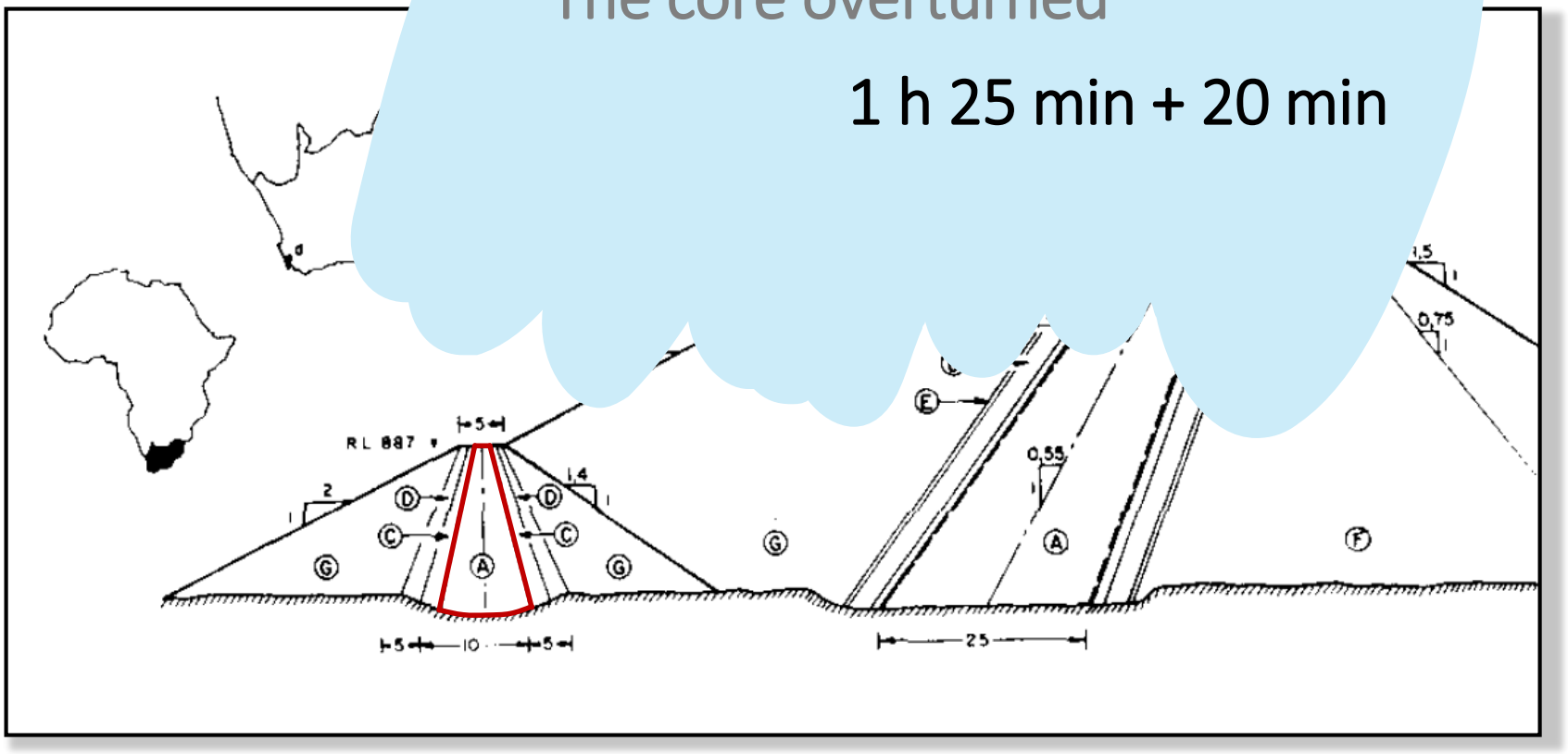


Odendaal and Van Zyl 1979

Hans Strydom co

The core overturned

1 h 25 min + 20 min



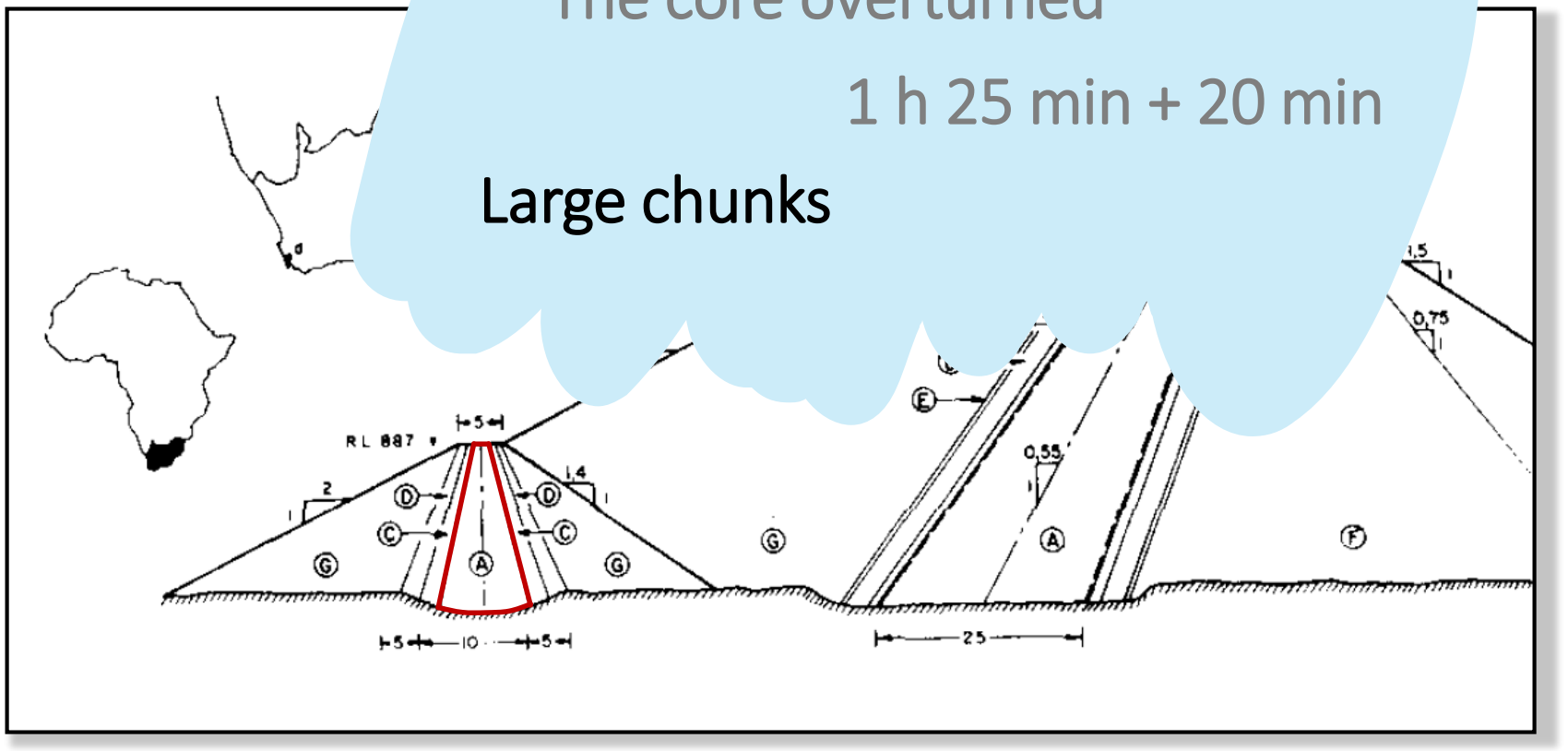
Odendaal and Van Zyl 1979

Hans Strydom co

The core overturned

1 h 25 min + 20 min

Large chunks



Odendaal and Van Zyl 1979

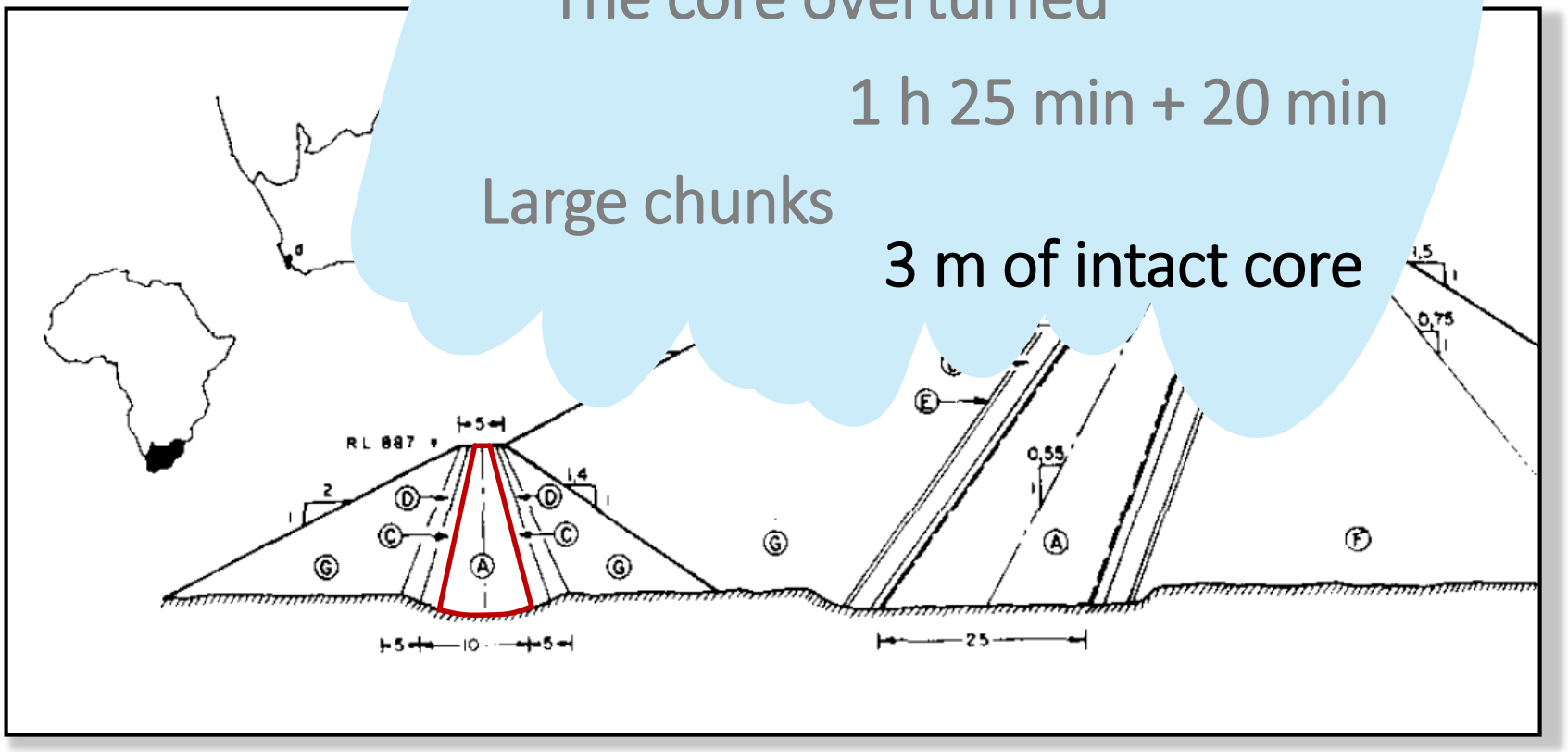
Hans Strydom co

The core overturned

1 h 25 min + 20 min

Large chunks

3 m of intact core

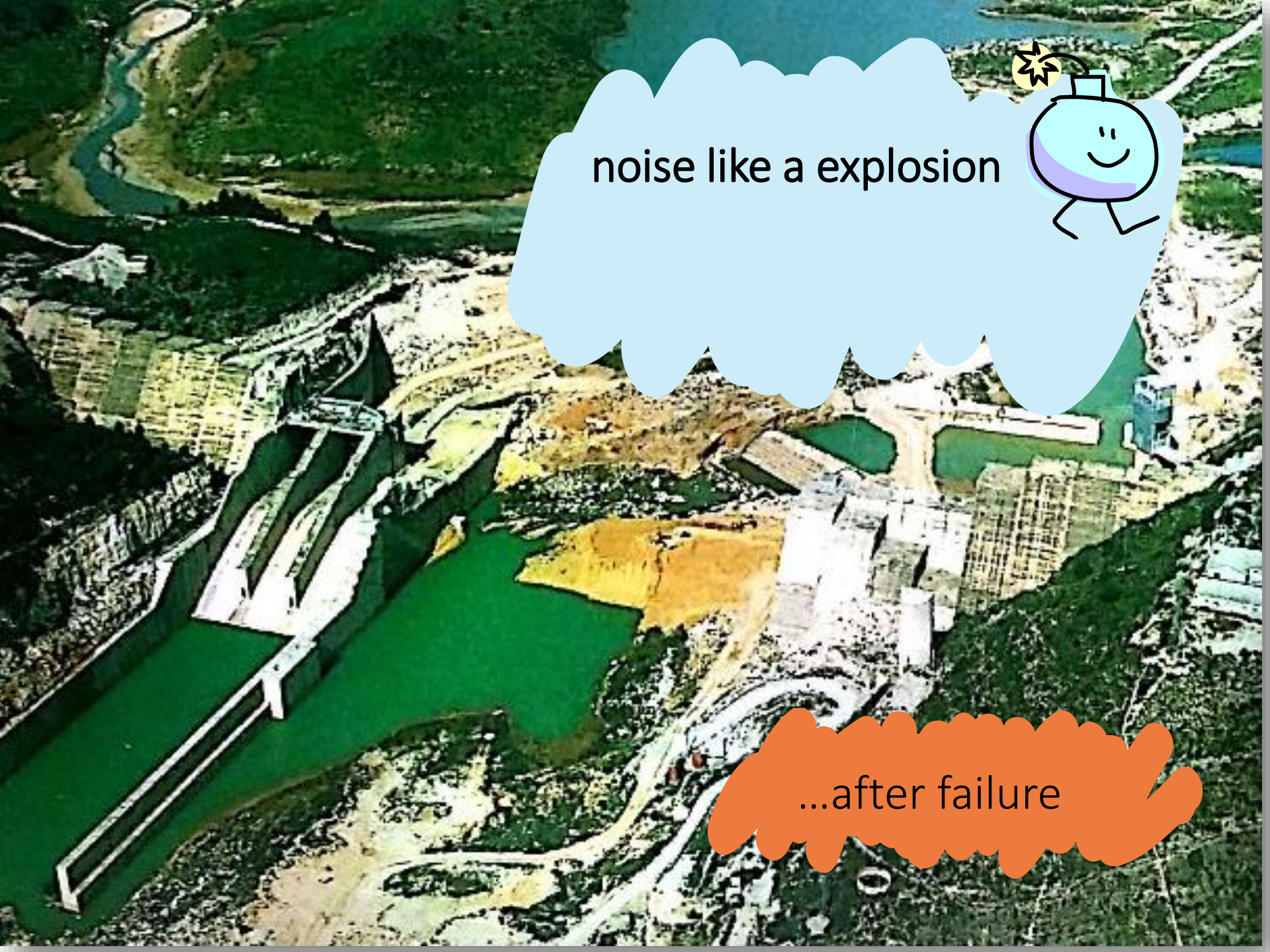


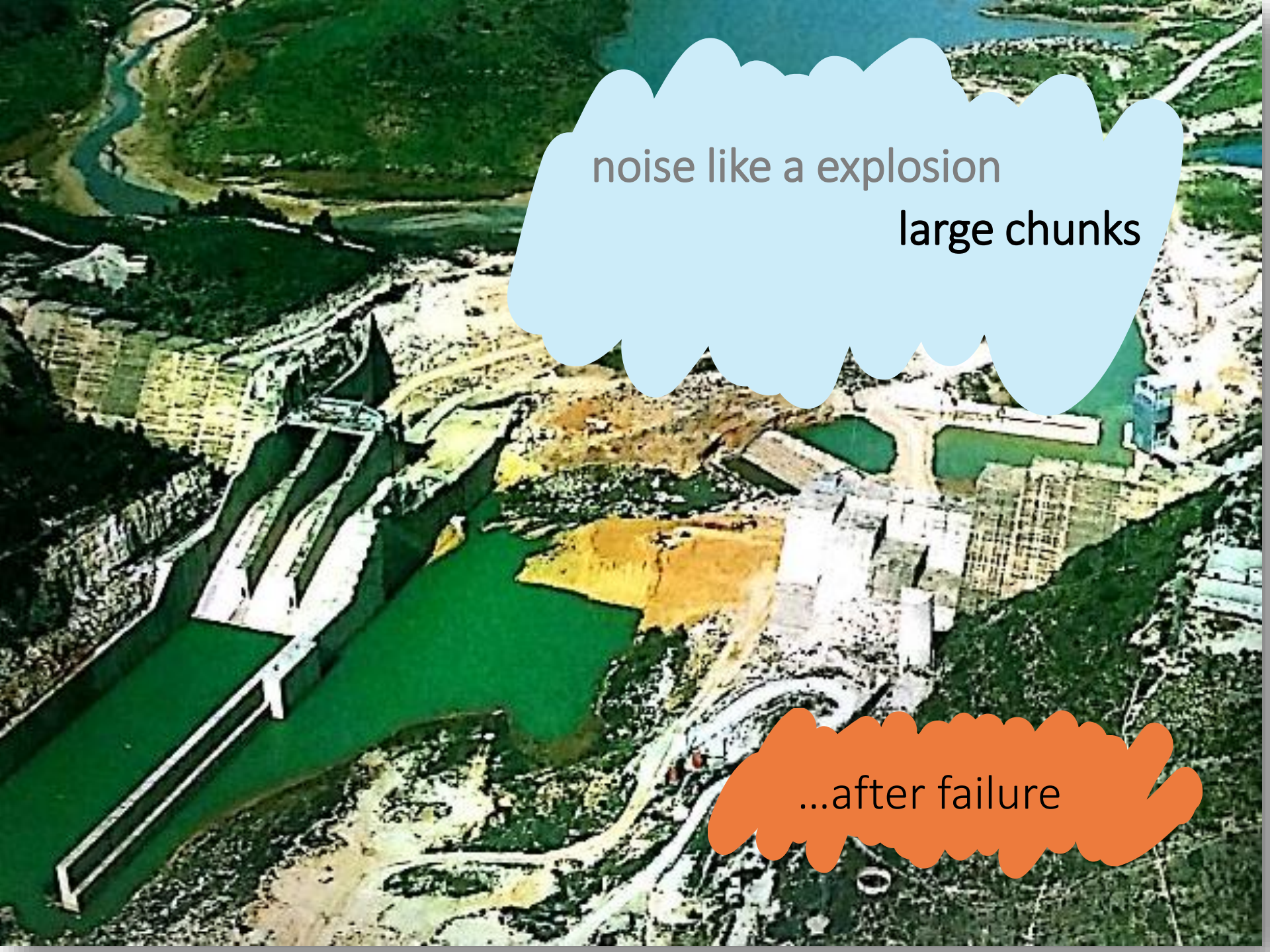
Odendaal and Van Zyl 1979

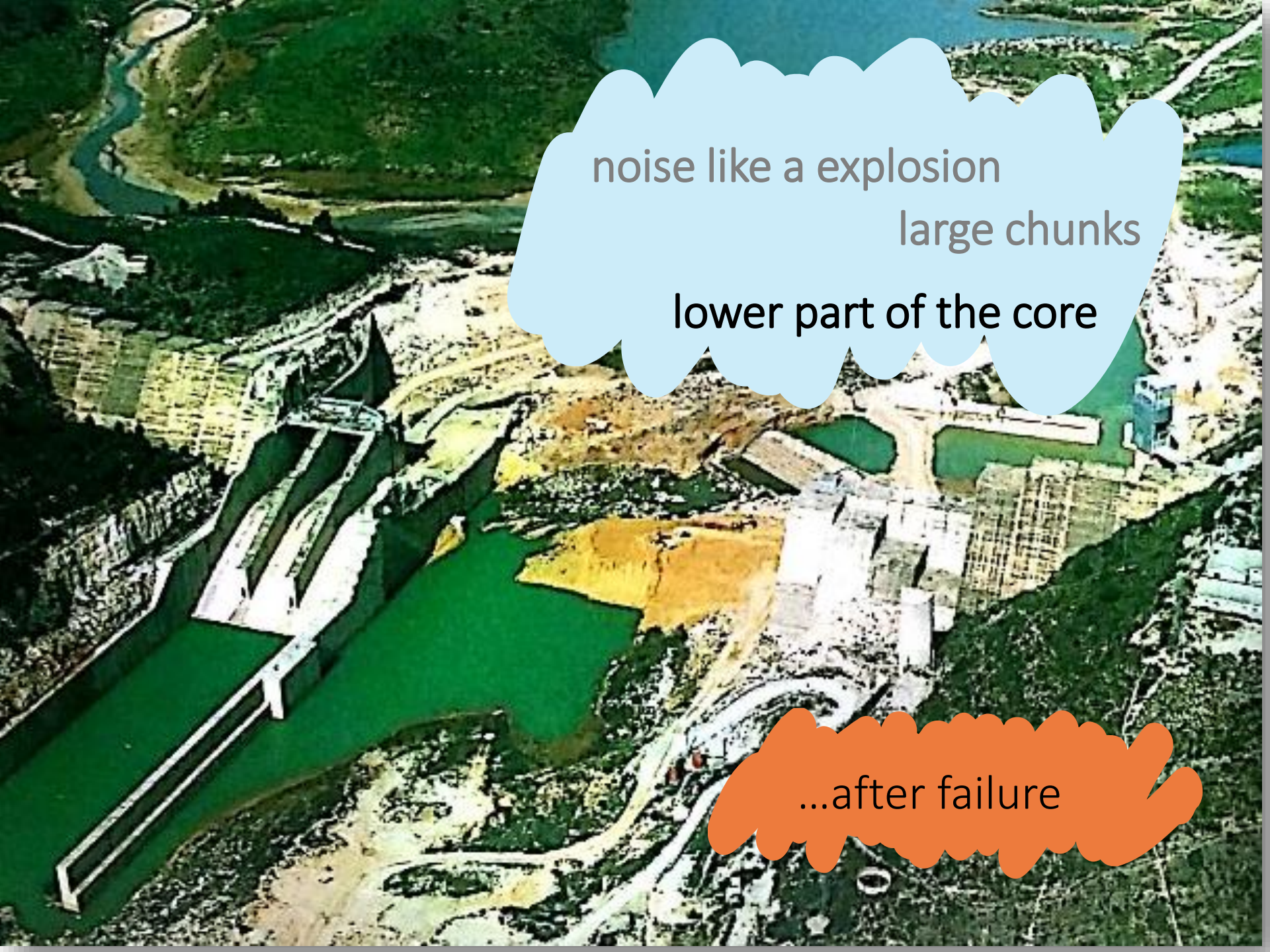

Tous dam
(failed 1982)
before failure…

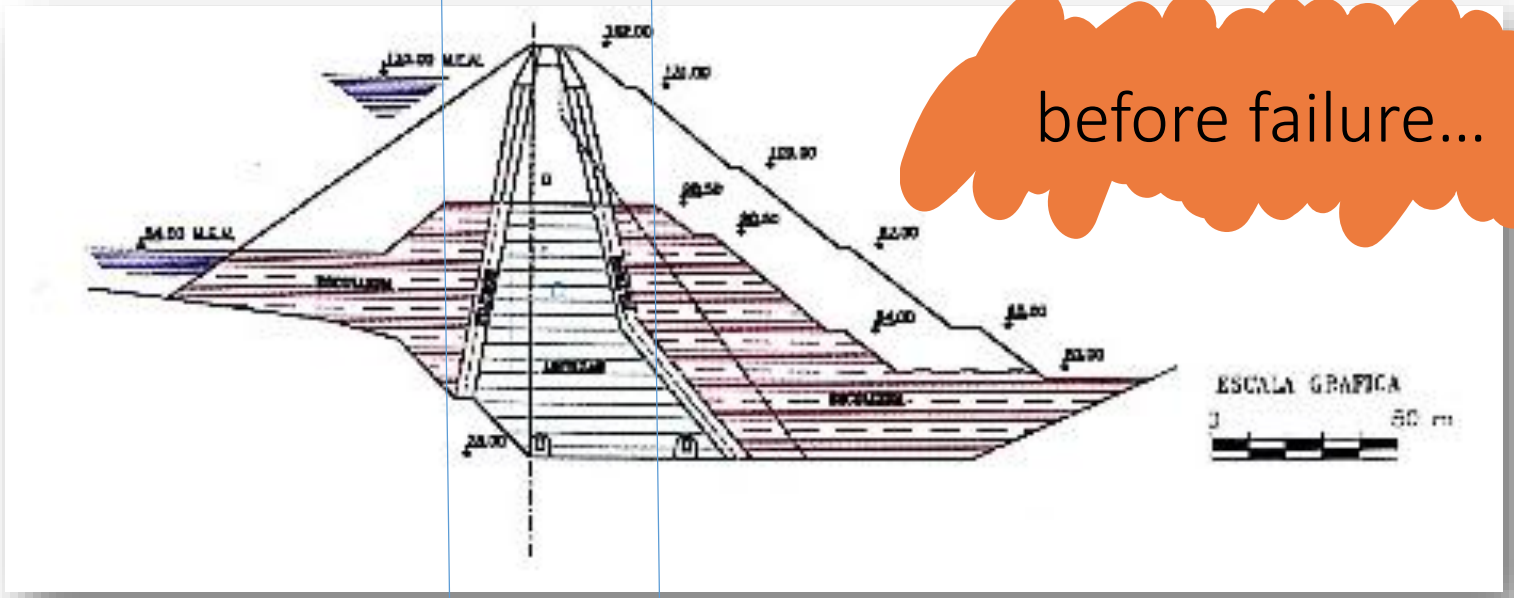

…after failure


…after failure

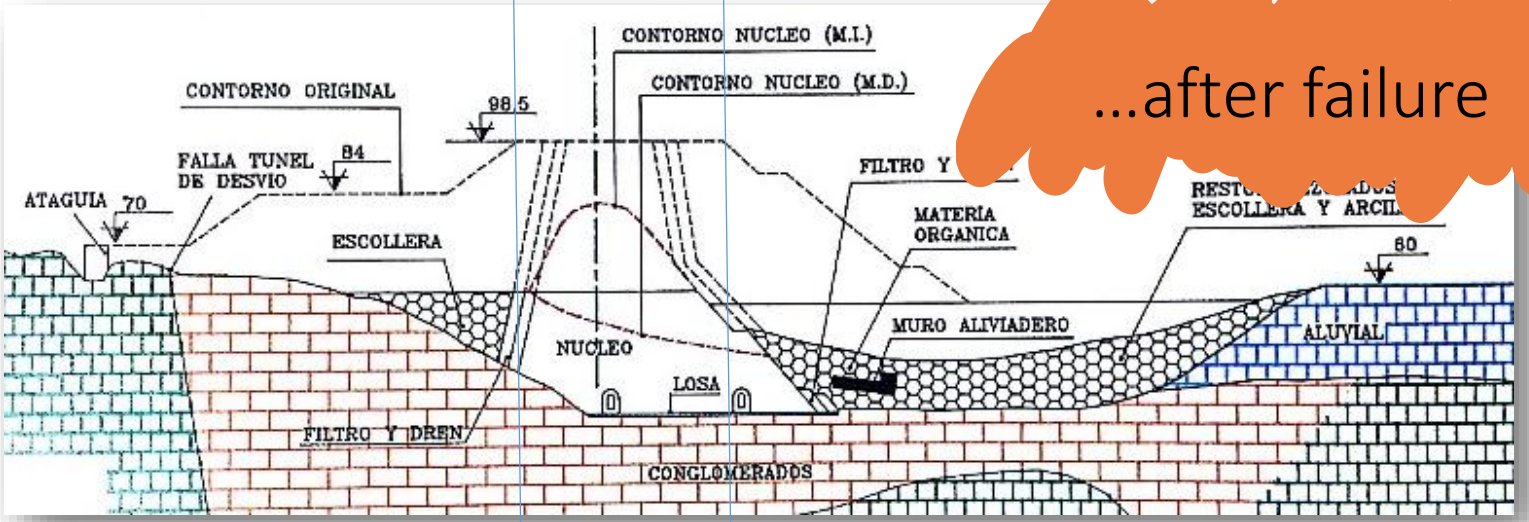

noise like a explosion
…after failure


noise like a explosion
large chunks
…after failure

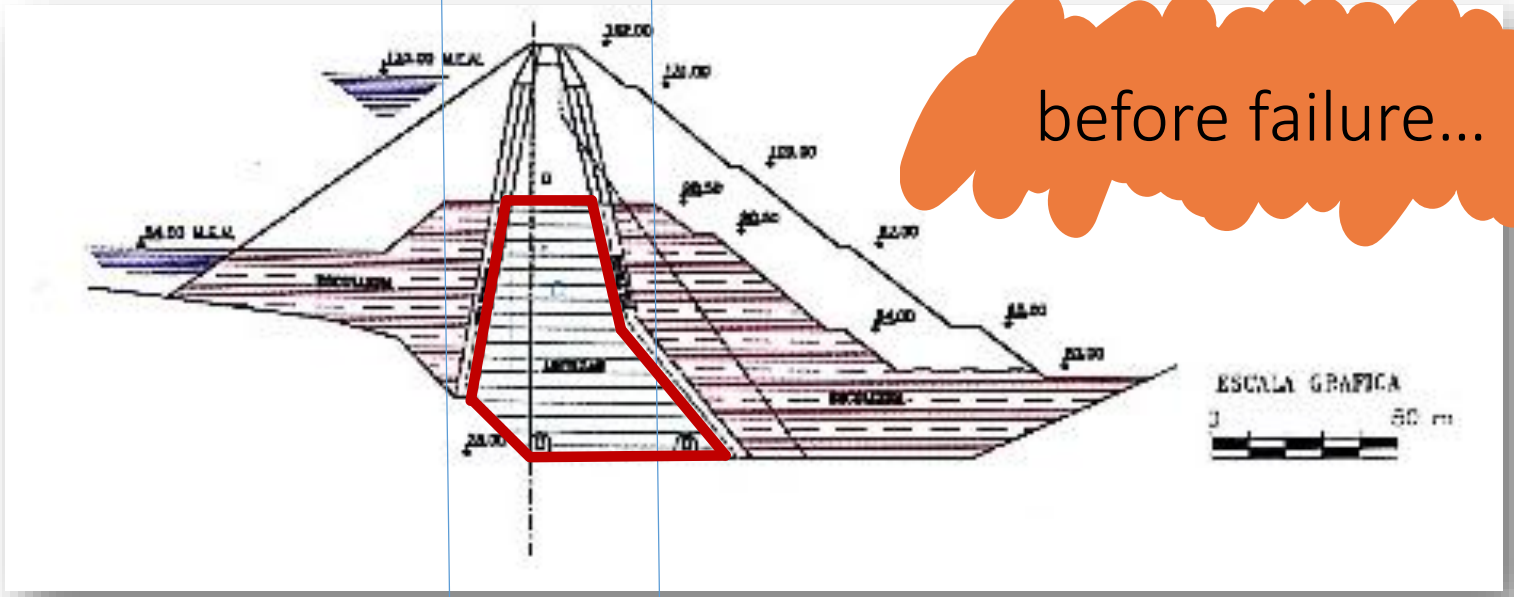

noise like a explosion
large chunks
lower part of the core
…after failure



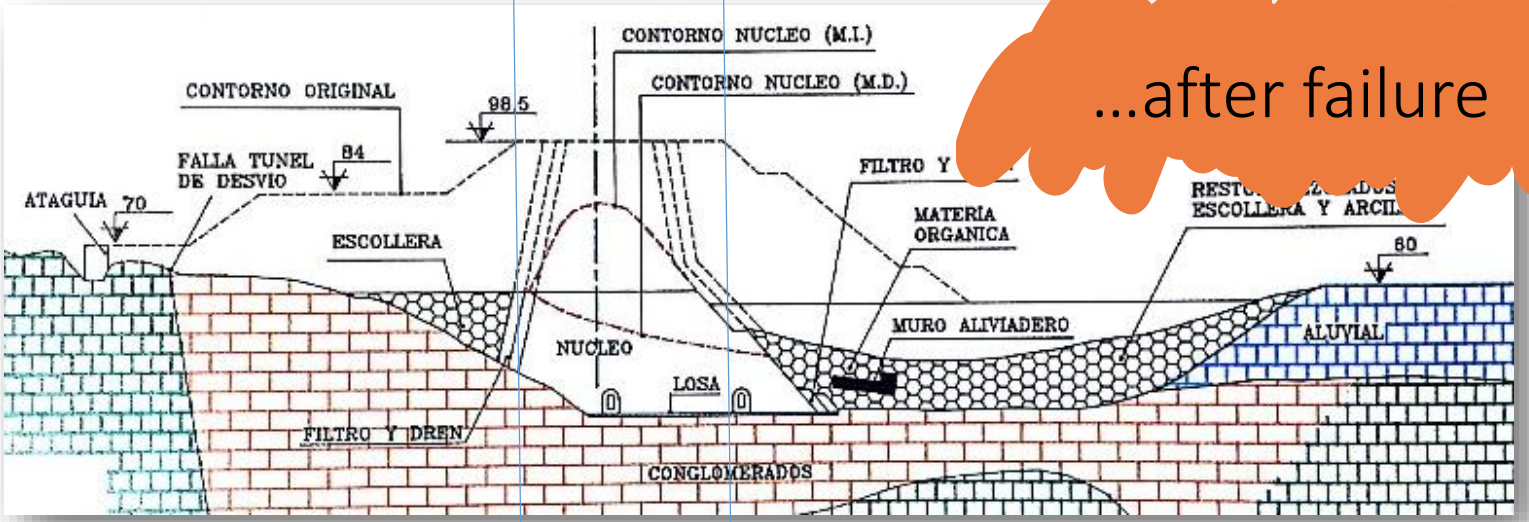
before failure…



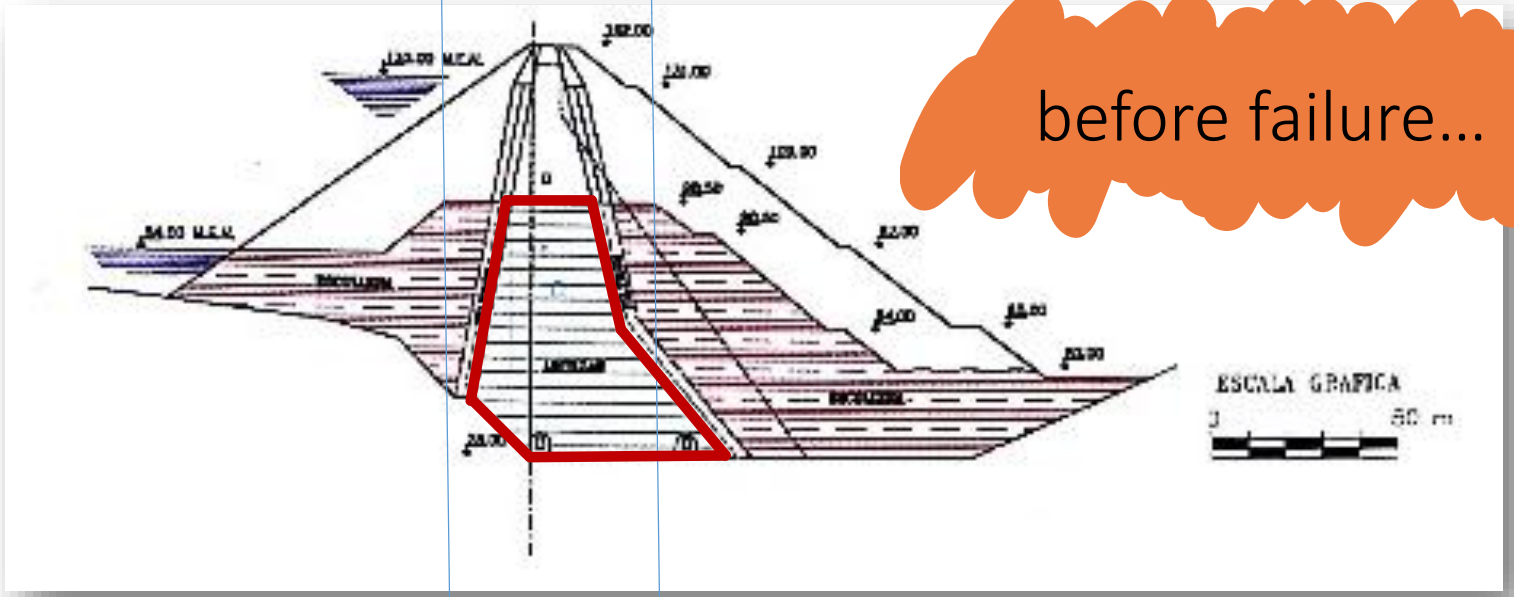
…after failure



before failure…

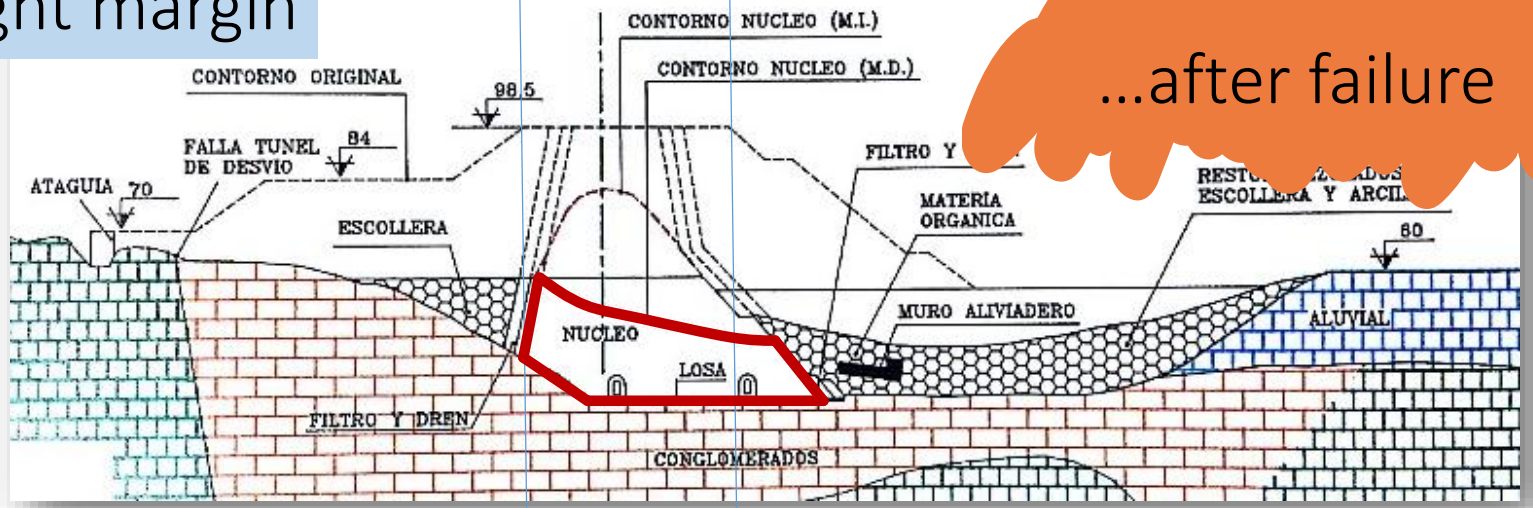


…after failure

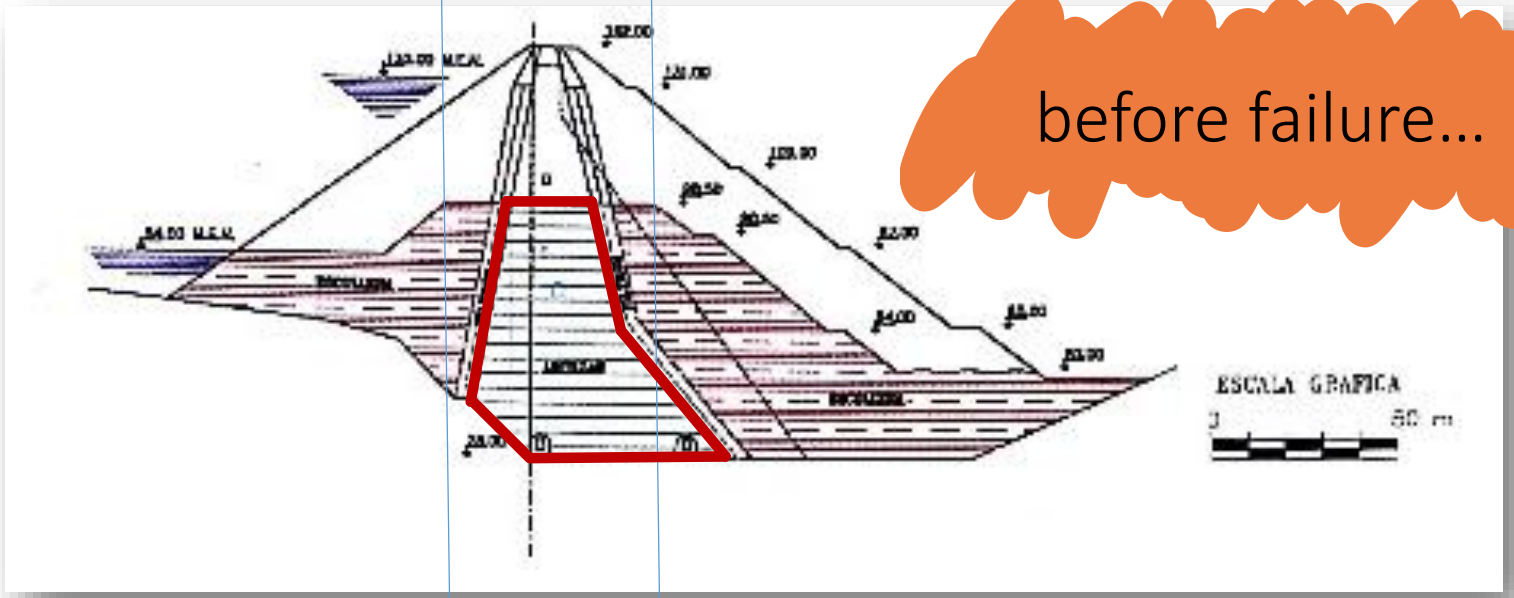


before failure…

right margin

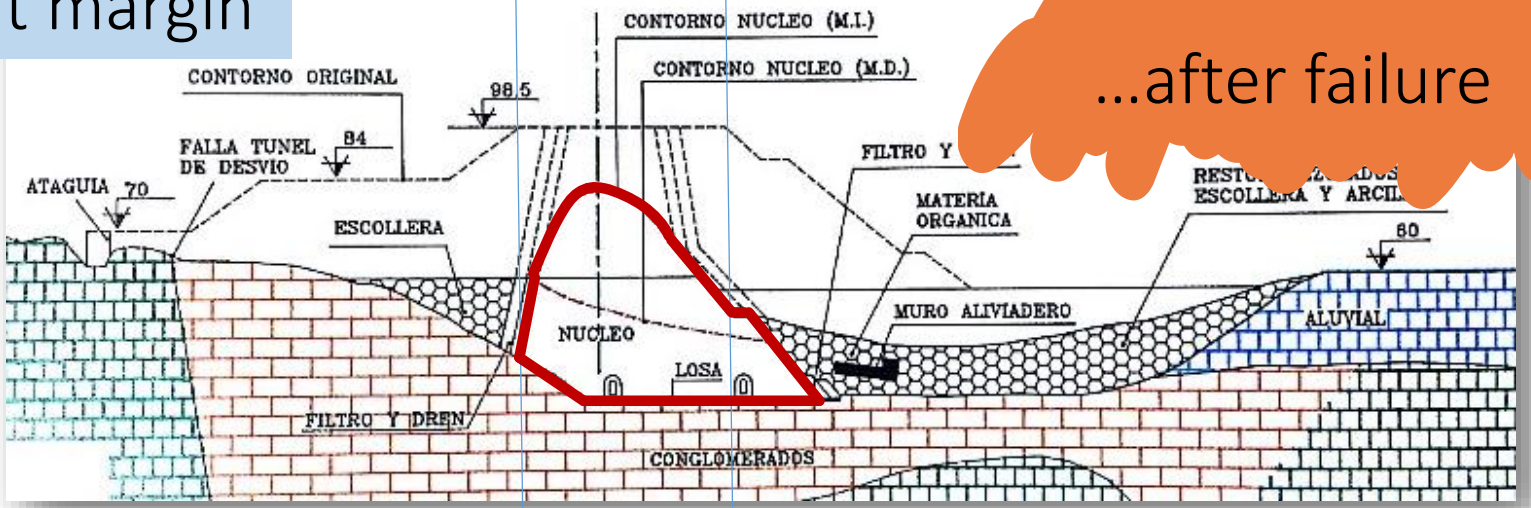


…after failure



before failure…

left margin



…after failure

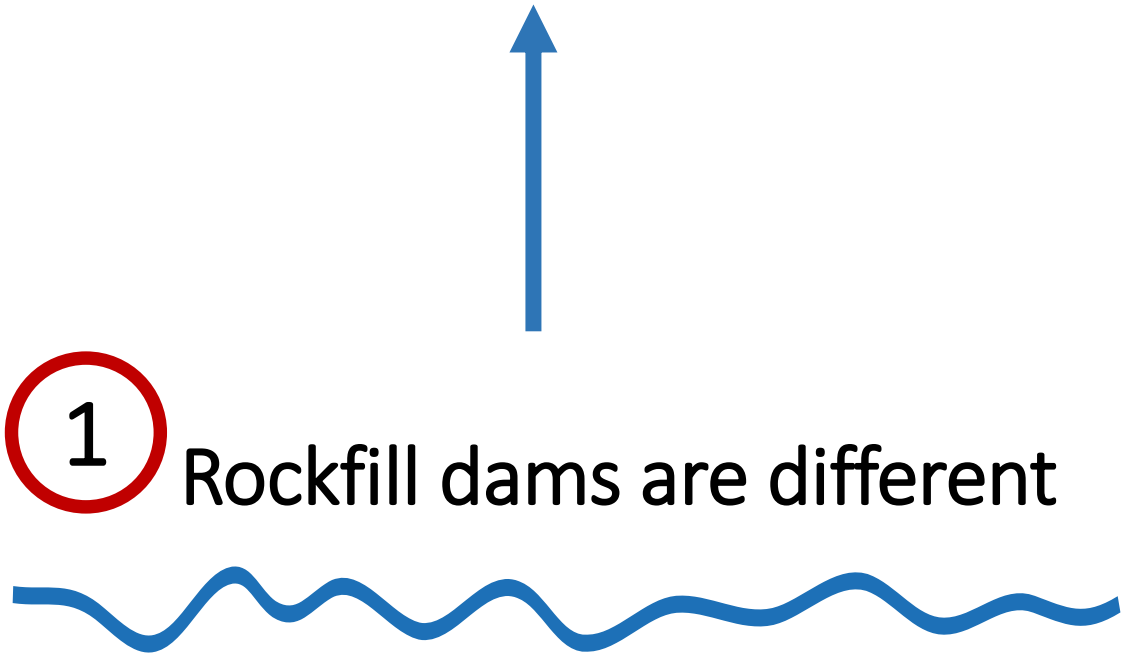
Hombre solo; Author: Antonio Mingote, 2008; Ed. Planeta

It is good to have a guidance to follow..

Hombre solo; Author: Antonio Mingote, 2008; Ed. Planeta

…unless there is somethig wrong with the guidance…

1 Rockfill dams are different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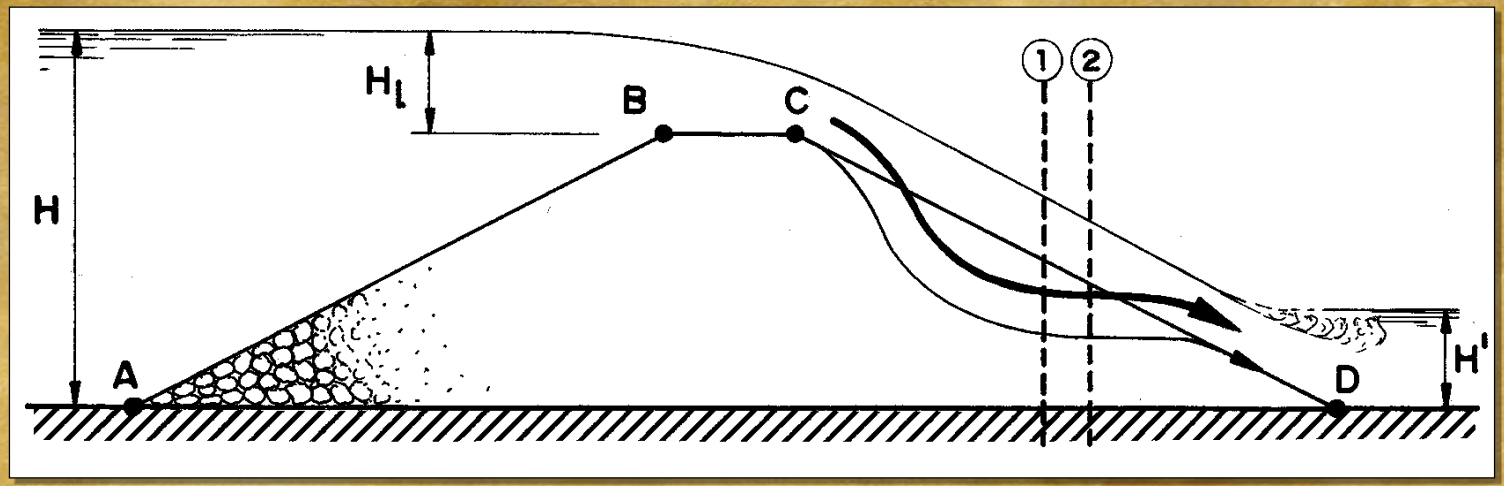
Rockfill dams are different

2 Once upon a time…



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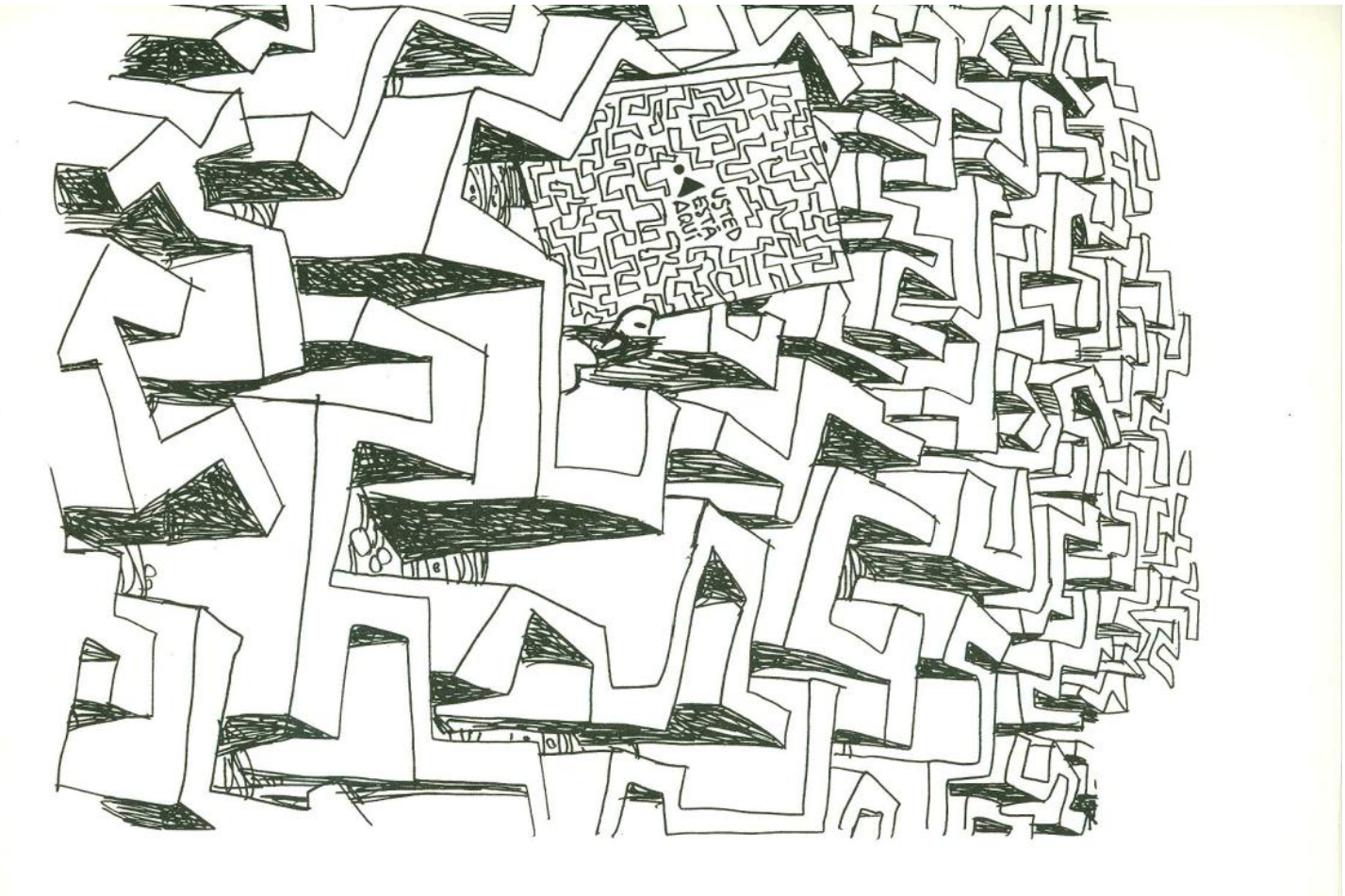
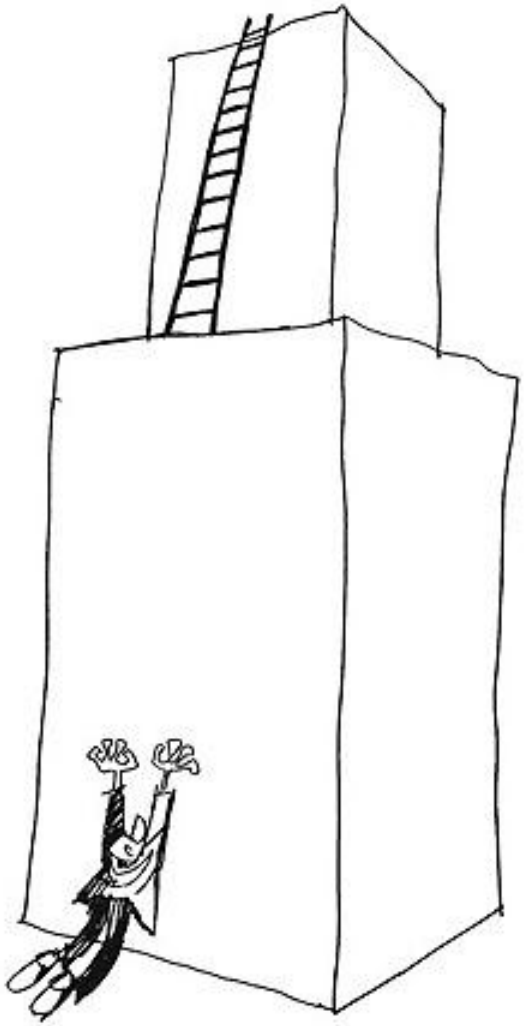
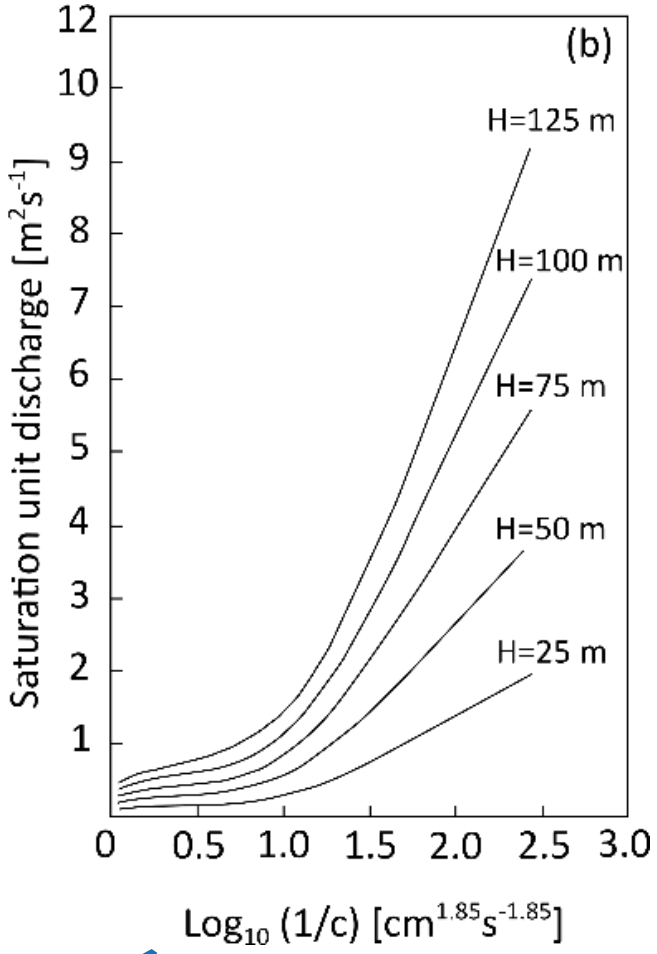




Hombre solo; Author: Antonio Mingote, 2008; Ed. Planeta

Overflow for saturation is not negligible

Overflow discharge for complete saturation



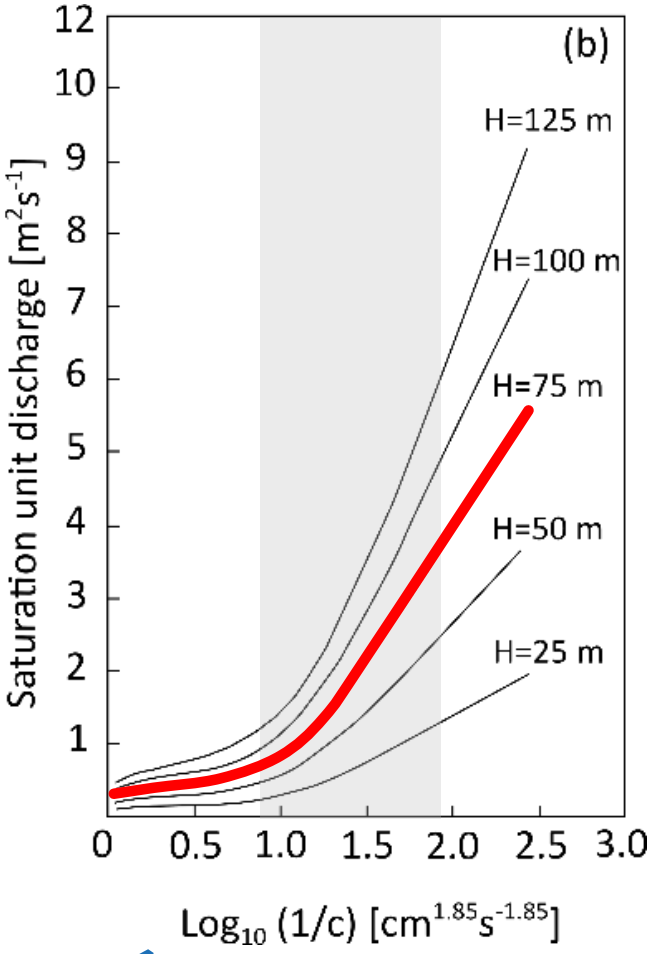
Dam heigth

$$i = c\,V^{n}$$

Permeability

A certain not small overflow is necesary

Overflow discharge for complete saturation

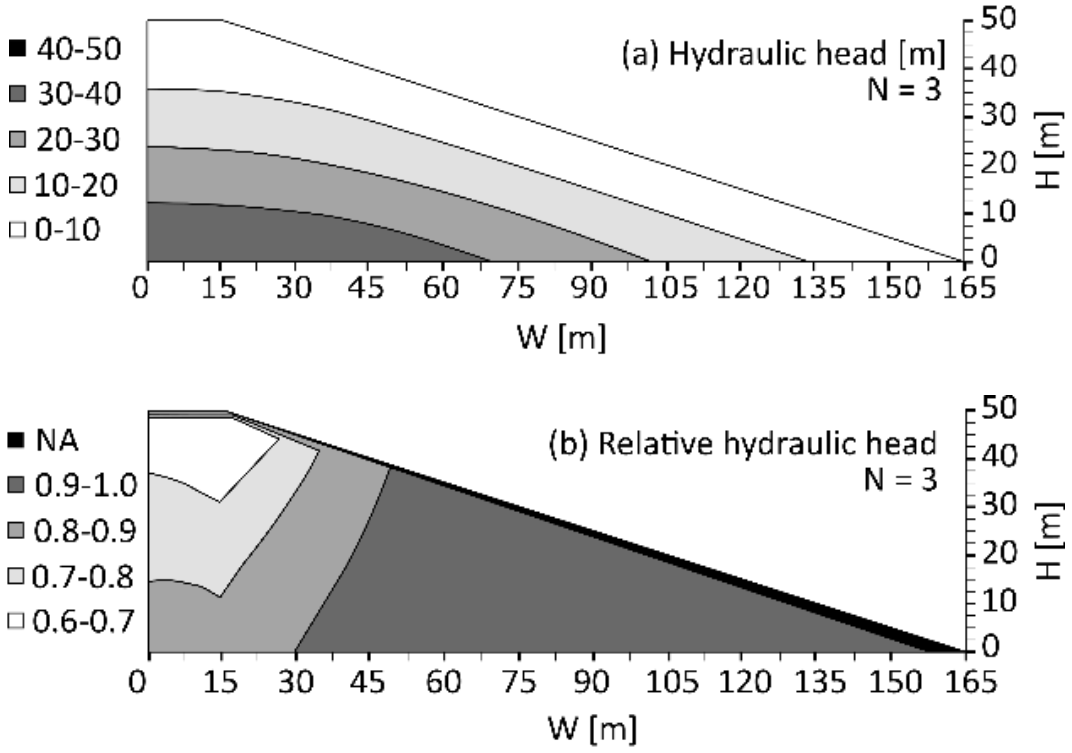


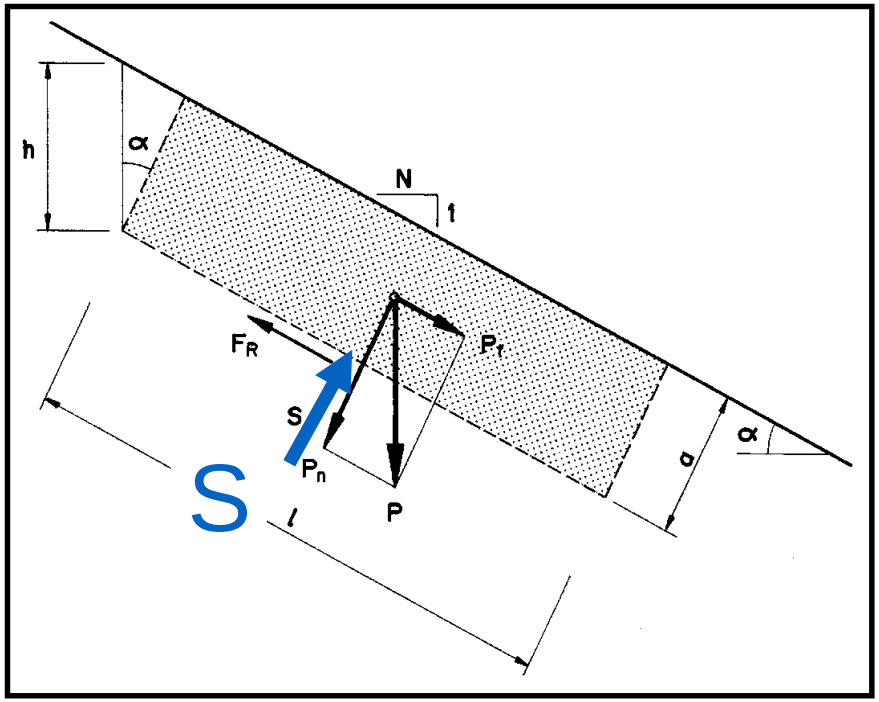
Dam heigth

$i = c\ V^{n}$

Permeability

Cuasi-hydrostatic pore pressure and mass sliding should be expected





$$F = \frac{1}{\gamma_{e,sat}} \cdot \left(\gamma_{e,sat} - \frac{\beta \cdot \gamma_w}{\cos^2 \alpha} \right) \frac{\tan \varphi}{\tan \alpha}$$

1 Rockfill dams are different

2 Once upon a time…

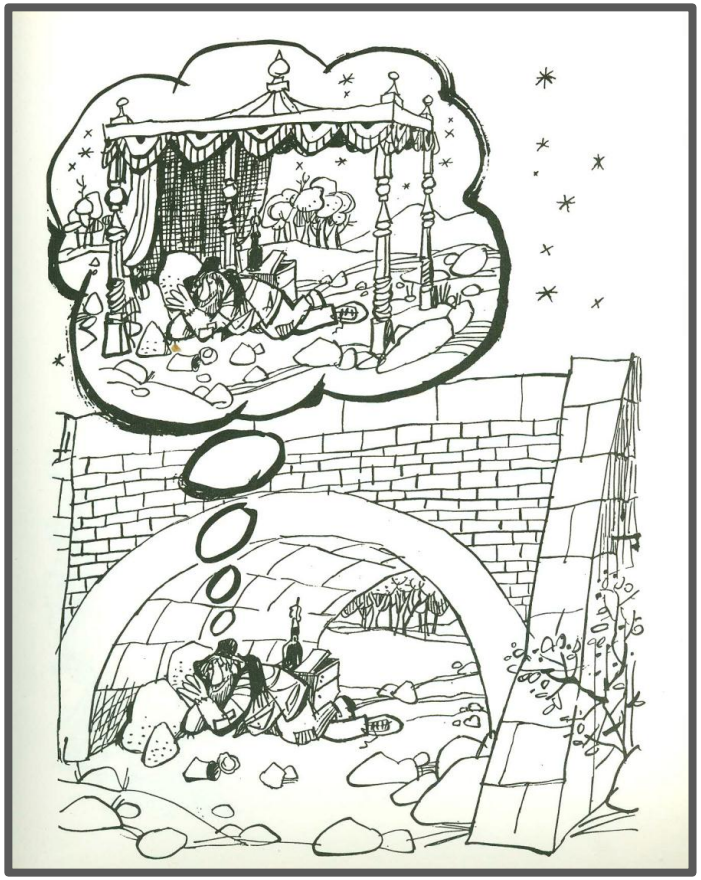
1 Overflow for saturation is not negligible

2 Cuasi-hydrostatic pore pressure and mass sliding should be expected

3 Safety factor against mass sliding can be estimated

3

Rockfill failure is gradual, but fast



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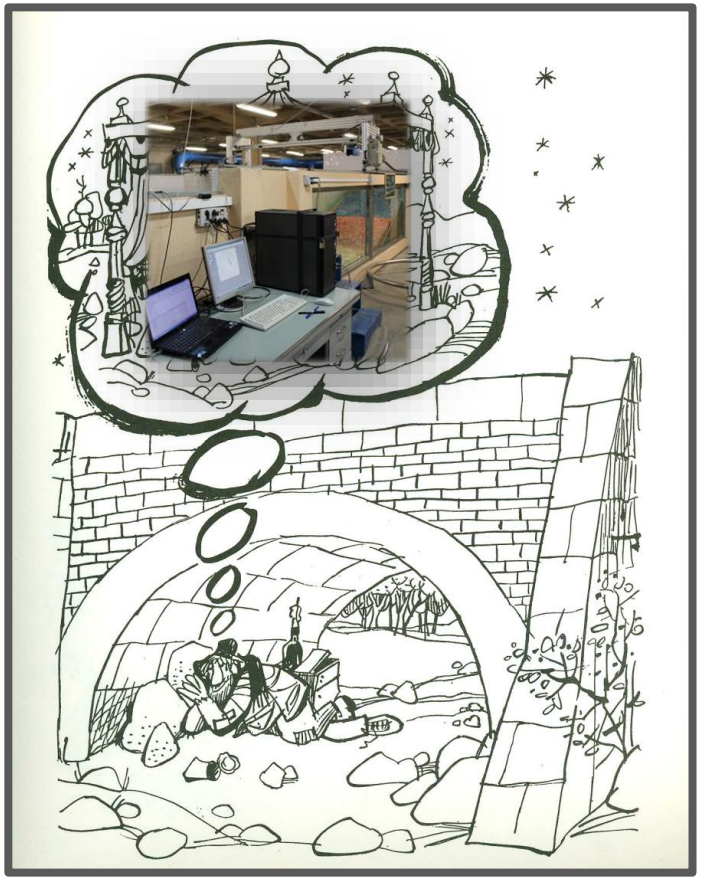
3

Rockfill failure is gradual, but fast



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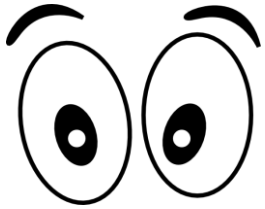
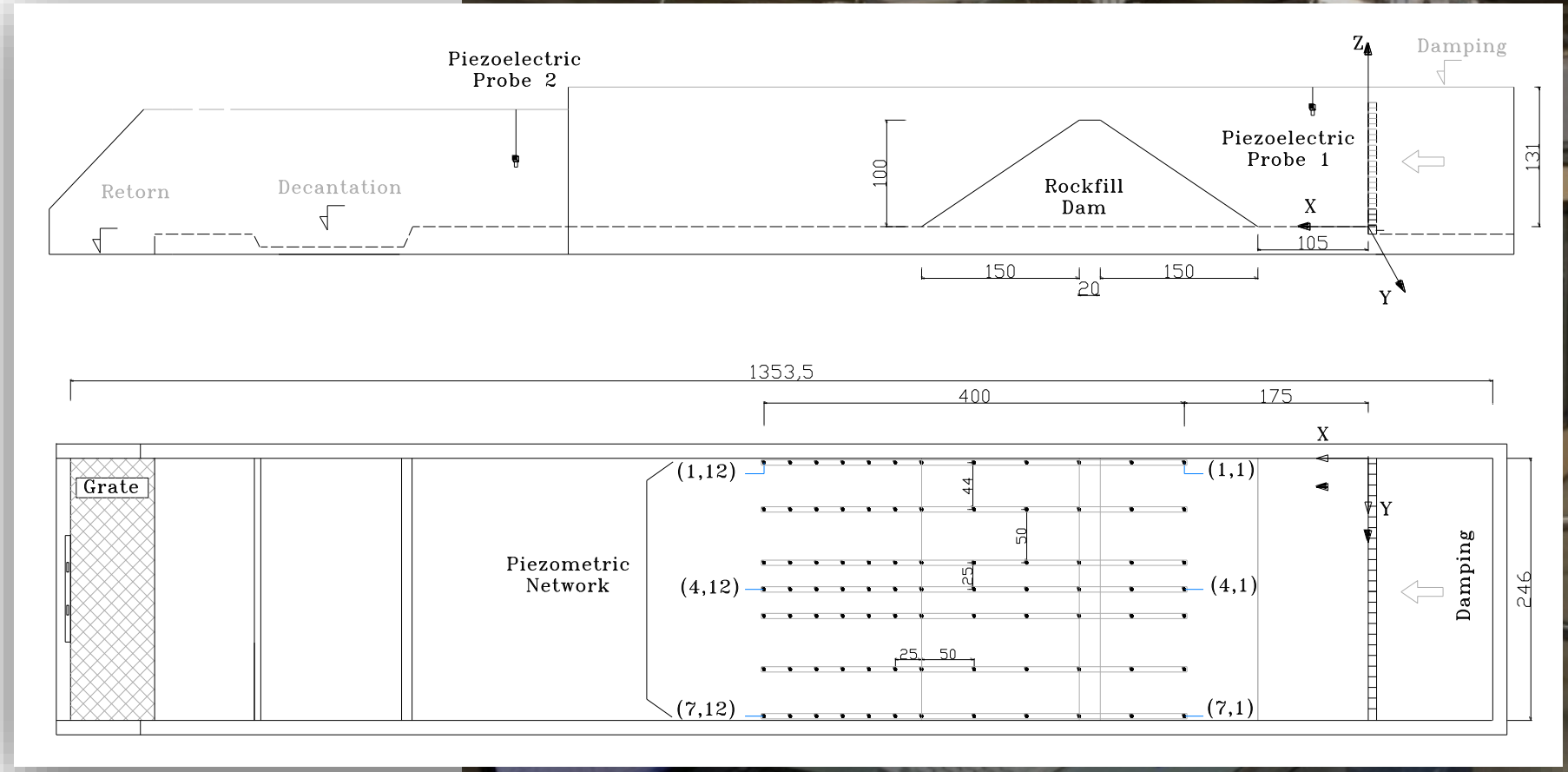
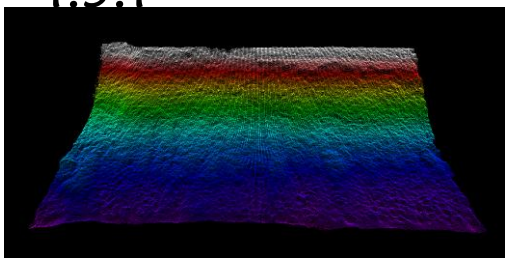


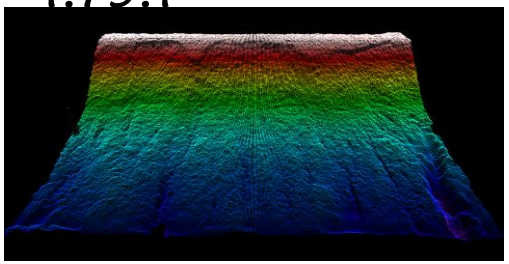

Piezoelectric
Probe 2
Retorn
Decantation
100
Rockfill
Dam
Piezoelectric
Probe 1
Z
Damping
131
X
105
150
20
150
Y
1353,5
400
175
X
Grate
(1,12)
(1,1)
44
50
Y
Piezometric
Network
(4,12)
(4,1)
25
Damping
246
25
50
(7,12)
(7,1)

Mass sliding prevails for usual steep slopes

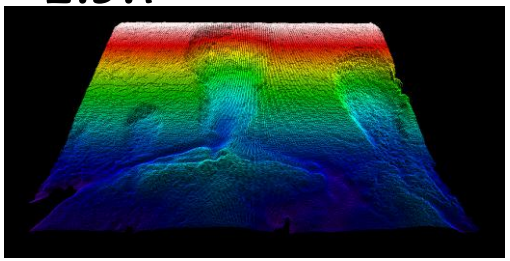
1.5:1



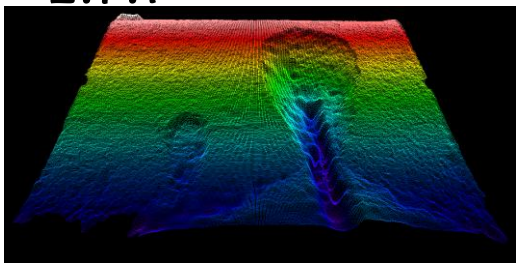
1.75:1



2.5:1

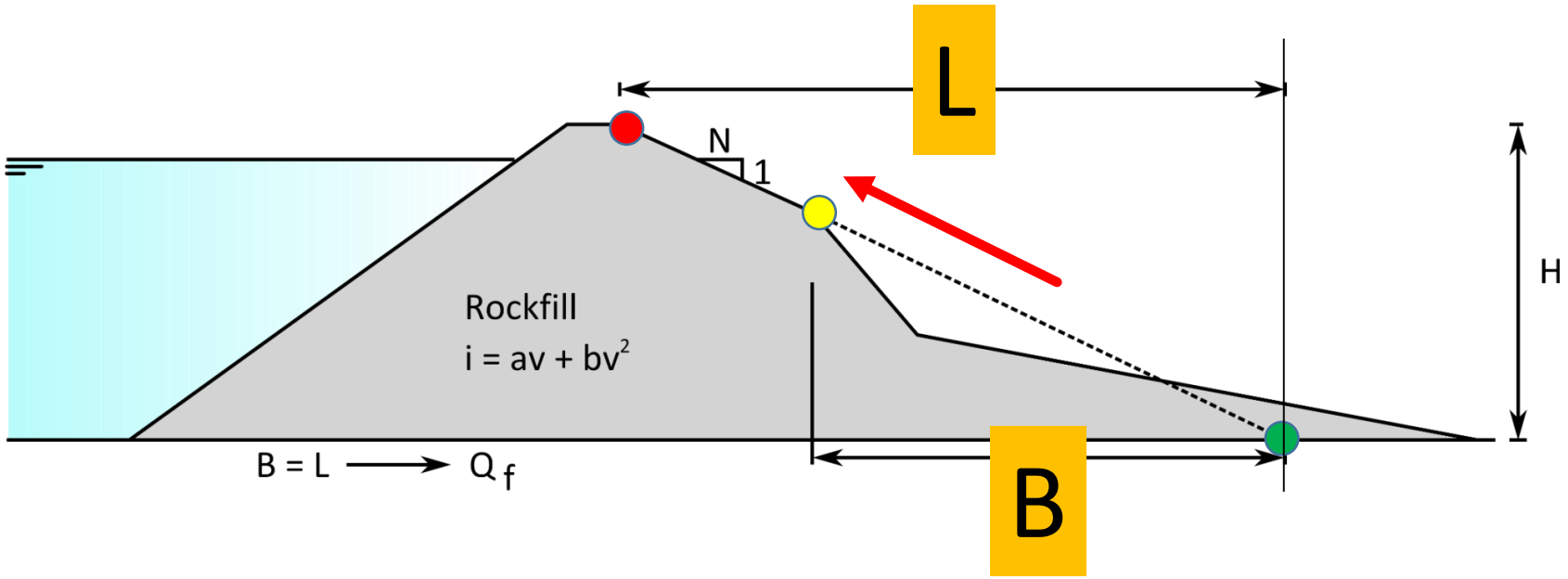


2.7:1



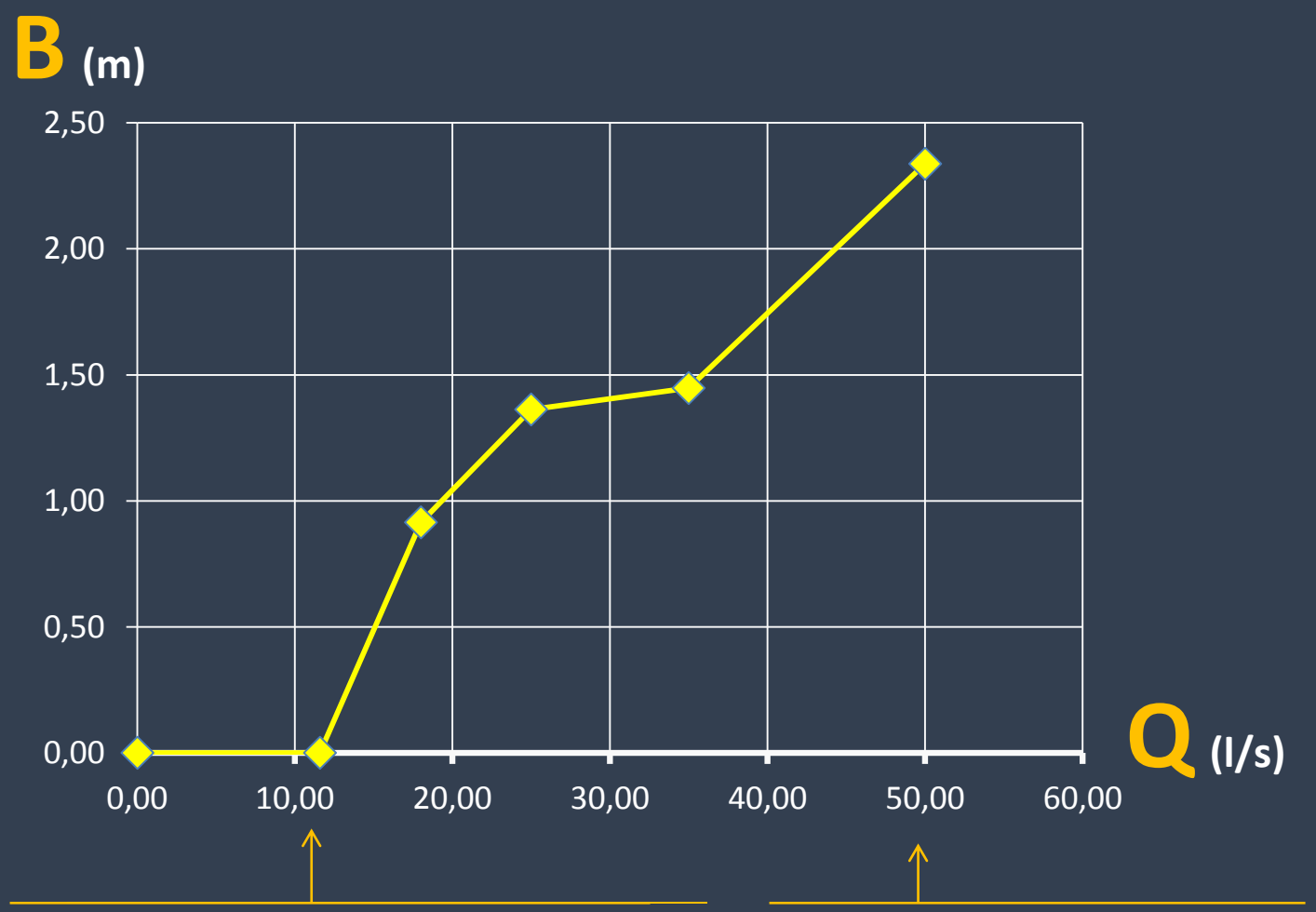
Particle dragging prevails for gentle slopes

Failure develops from the dam toe to the crest



Degree of advance of failure: B/L

The "failure path" describes the process of failure



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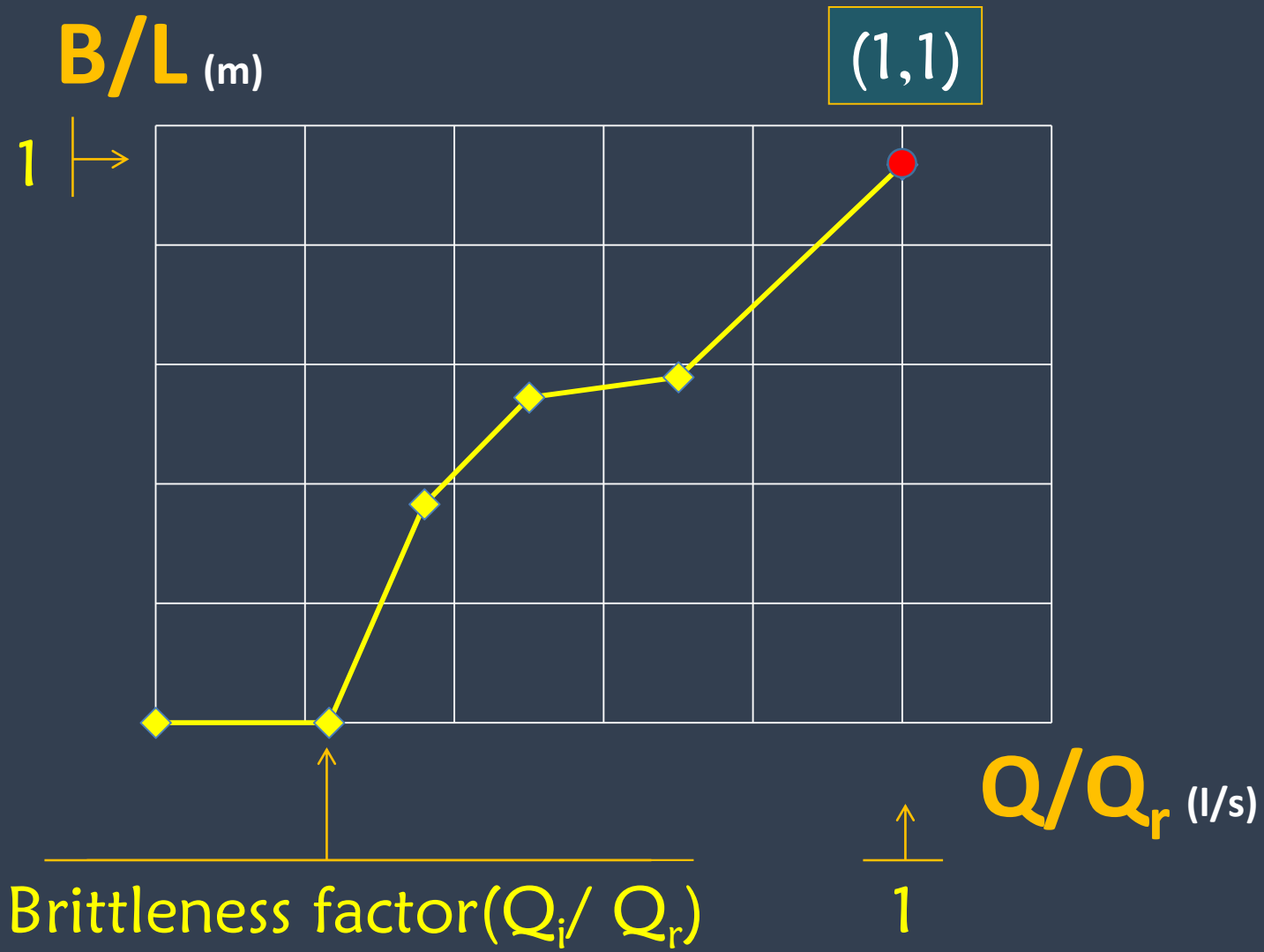
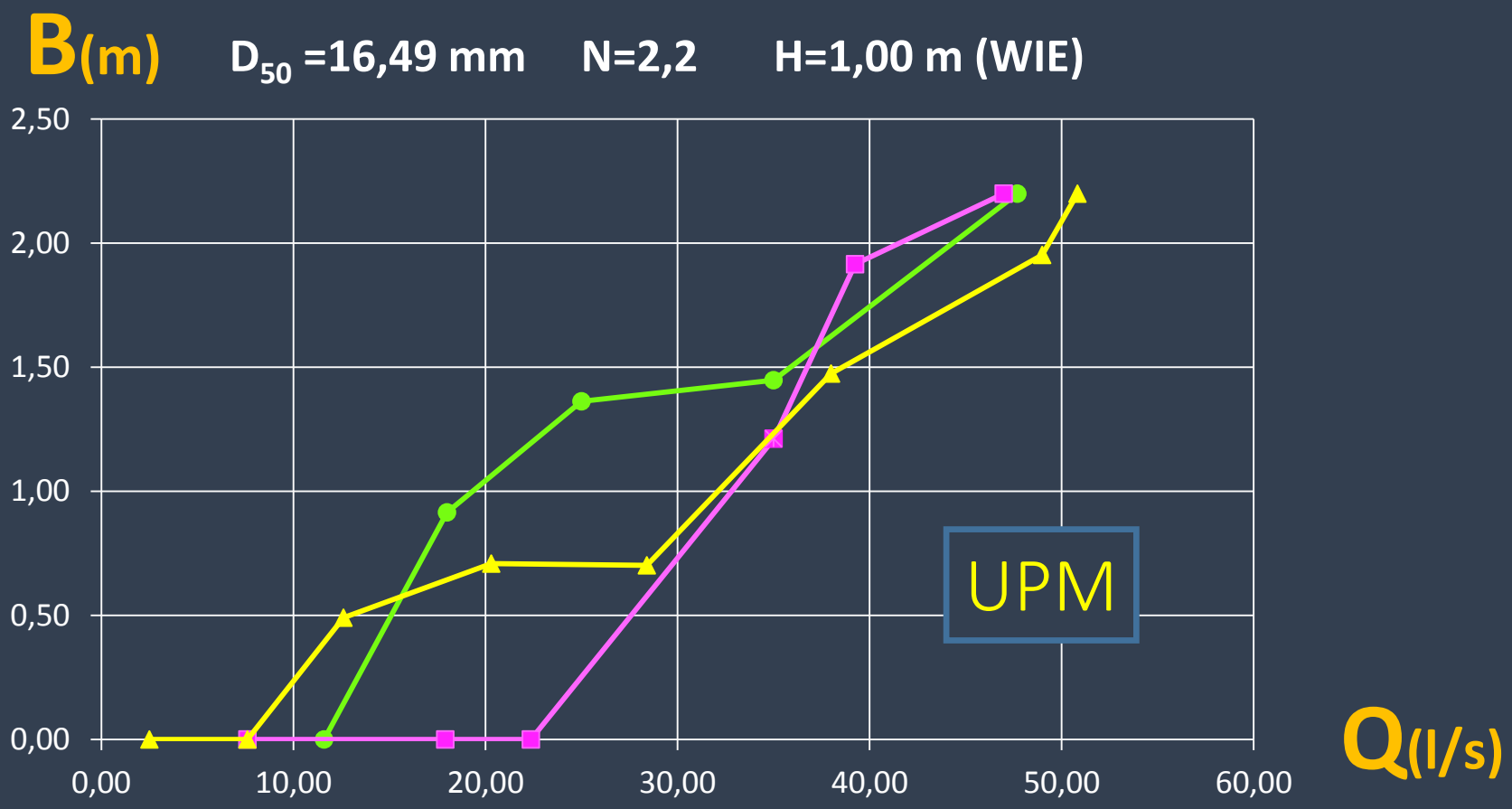
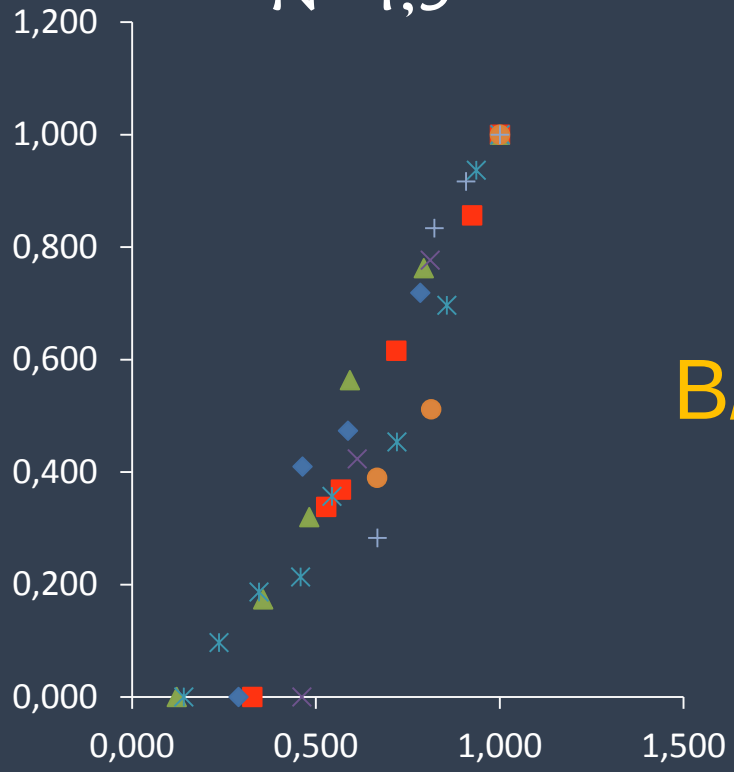


Randomness plays a role in the process but it is minor regarding the “failure discharge”



Slope plays a predominant role in the failure process

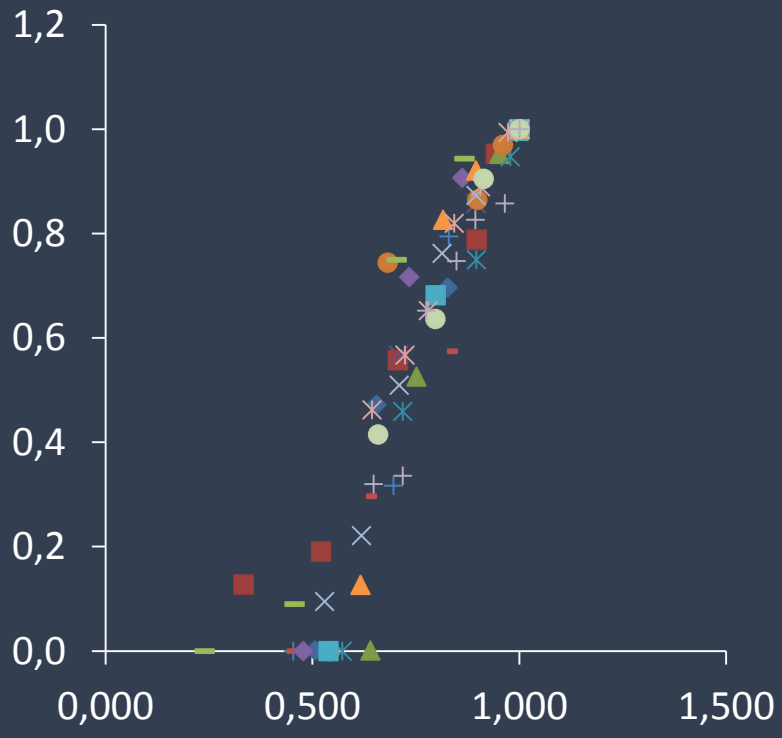
Steep slope;
N=1,5



B/L

Q/Qr

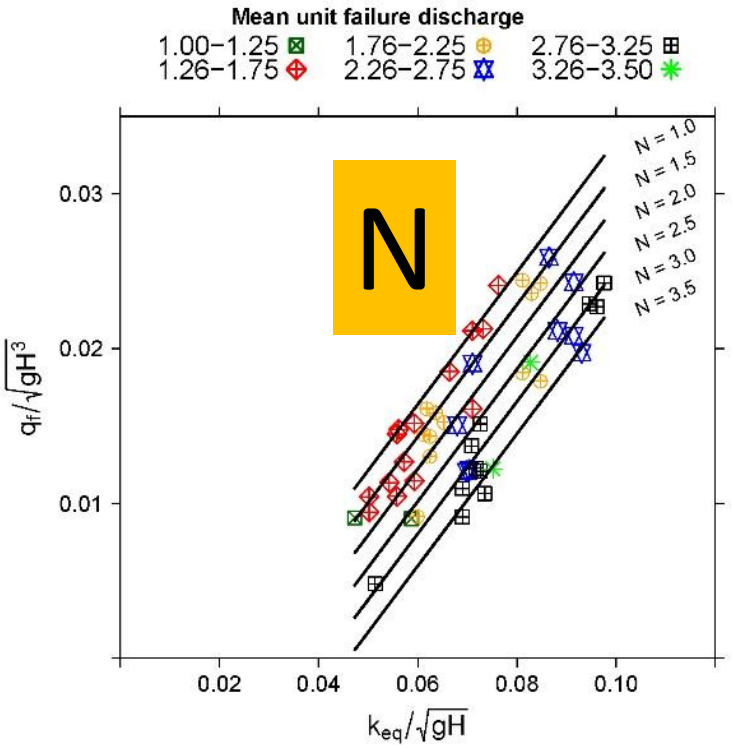
Gentle slope;
N=3



Q/Qr

Failure discharge can be estimated at testing size

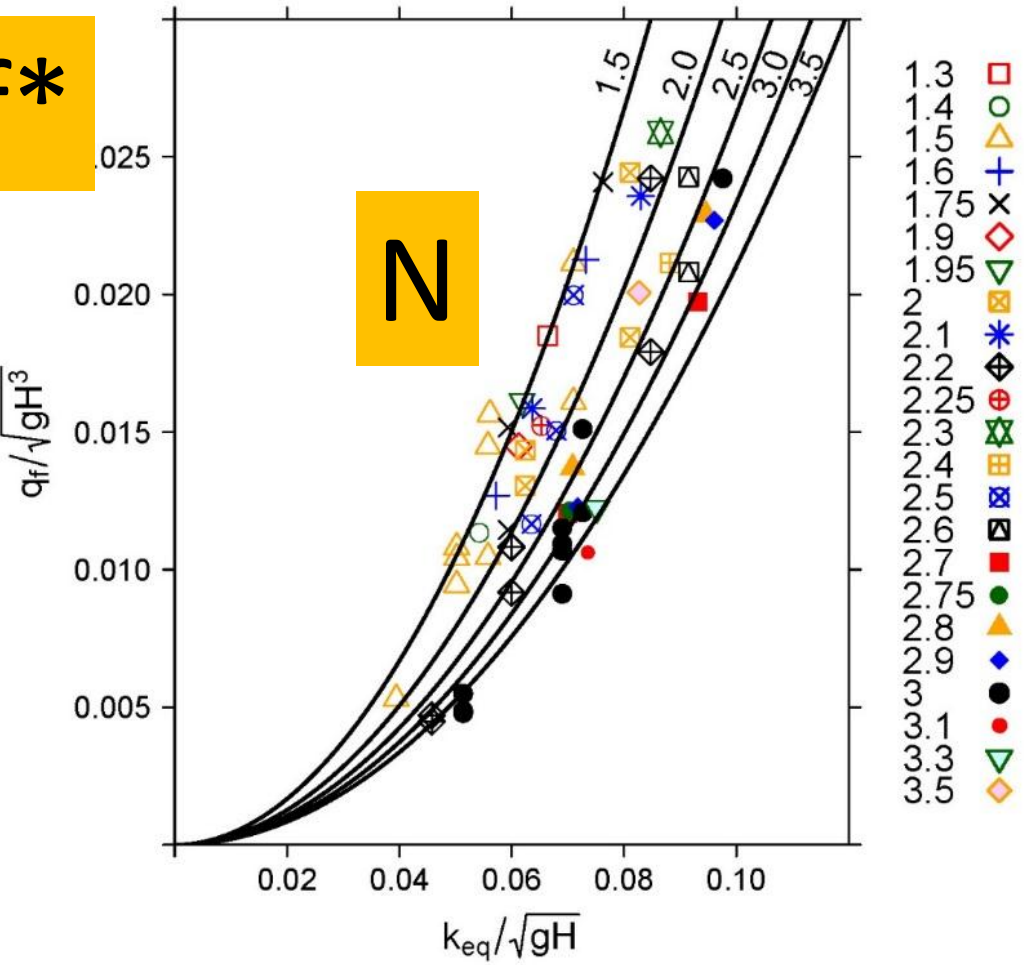
qf*



Keq*

$$q_f^* = -0.0049 + 0.4242 \cdot k_{eq}^* - 0.0041 \cdot N$$

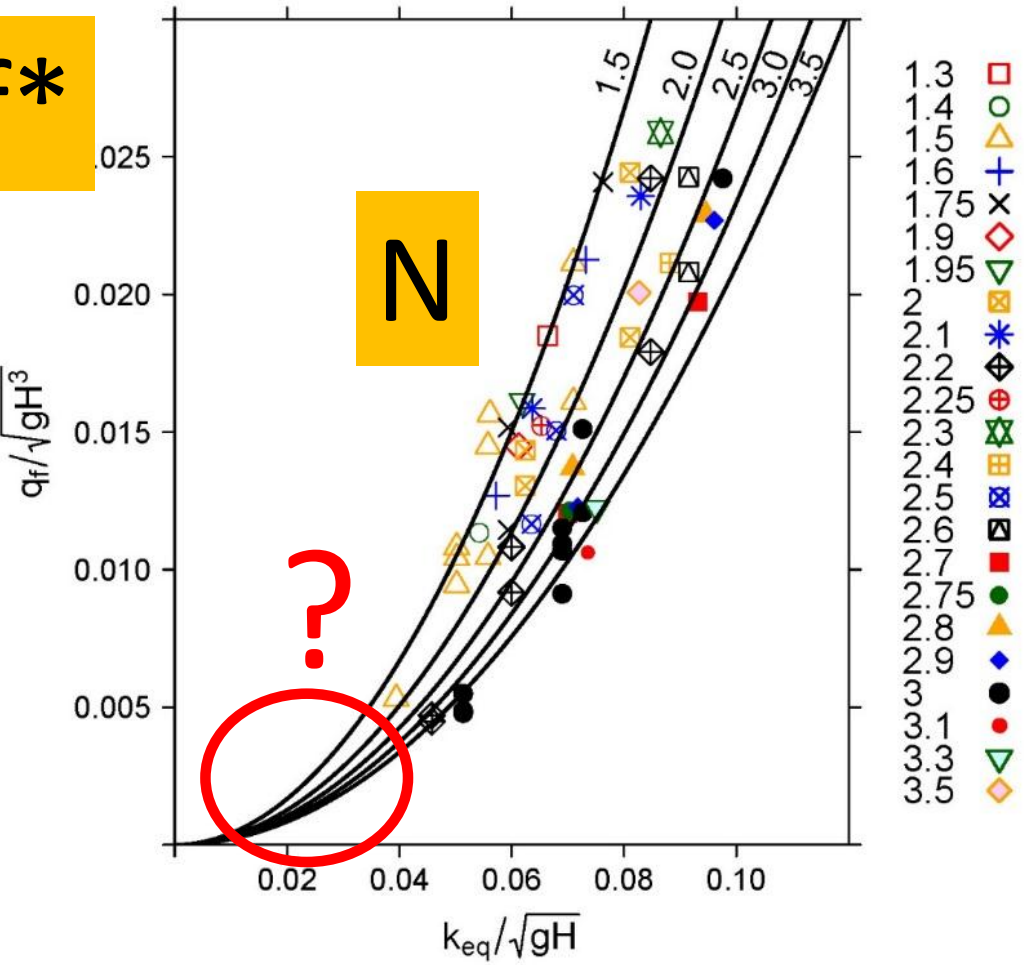
qf*


N
1.5
2.0
2.5
3.0
3.5
0.025
0.020
0.015
0.010
0.005
0.02
0.04
0.06
0.08
0.10
$q_f/\sqrt{gH^3}$
$k_{eq}/\sqrt{gH}$
1.3
1.4
1.5
1.6
1.75
1.9
1.95
2
2.1
2.2
2.25
2.3
2.4
2.5
2.6
2.7
2.75
2.8
2.9
3
3.1
3.3
3.5

Keq*

What happens for real size dams?

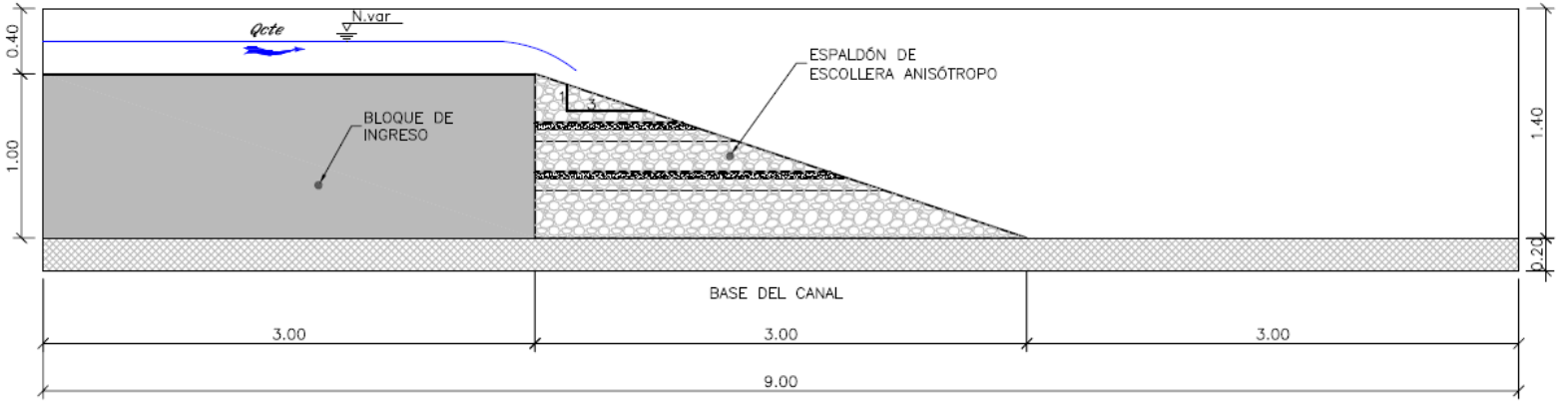
qf*

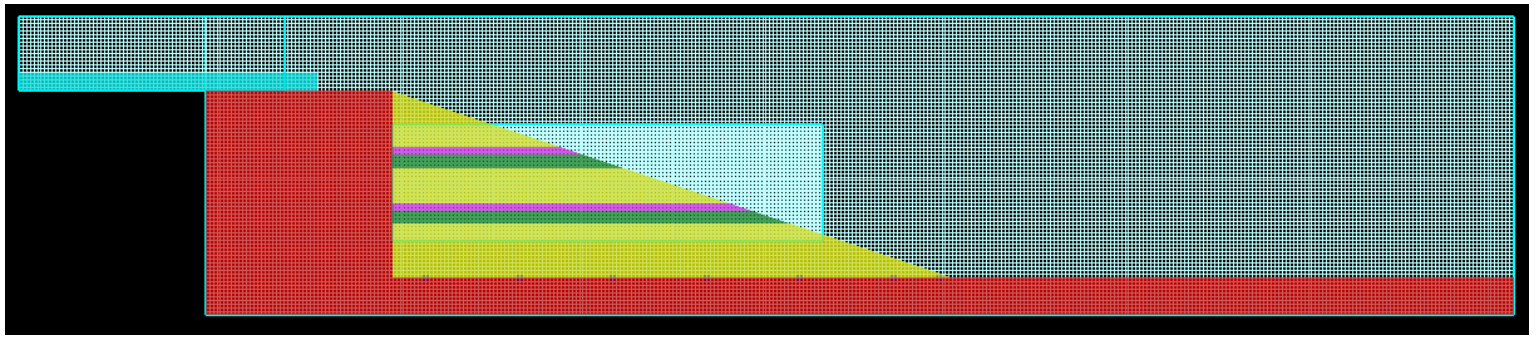


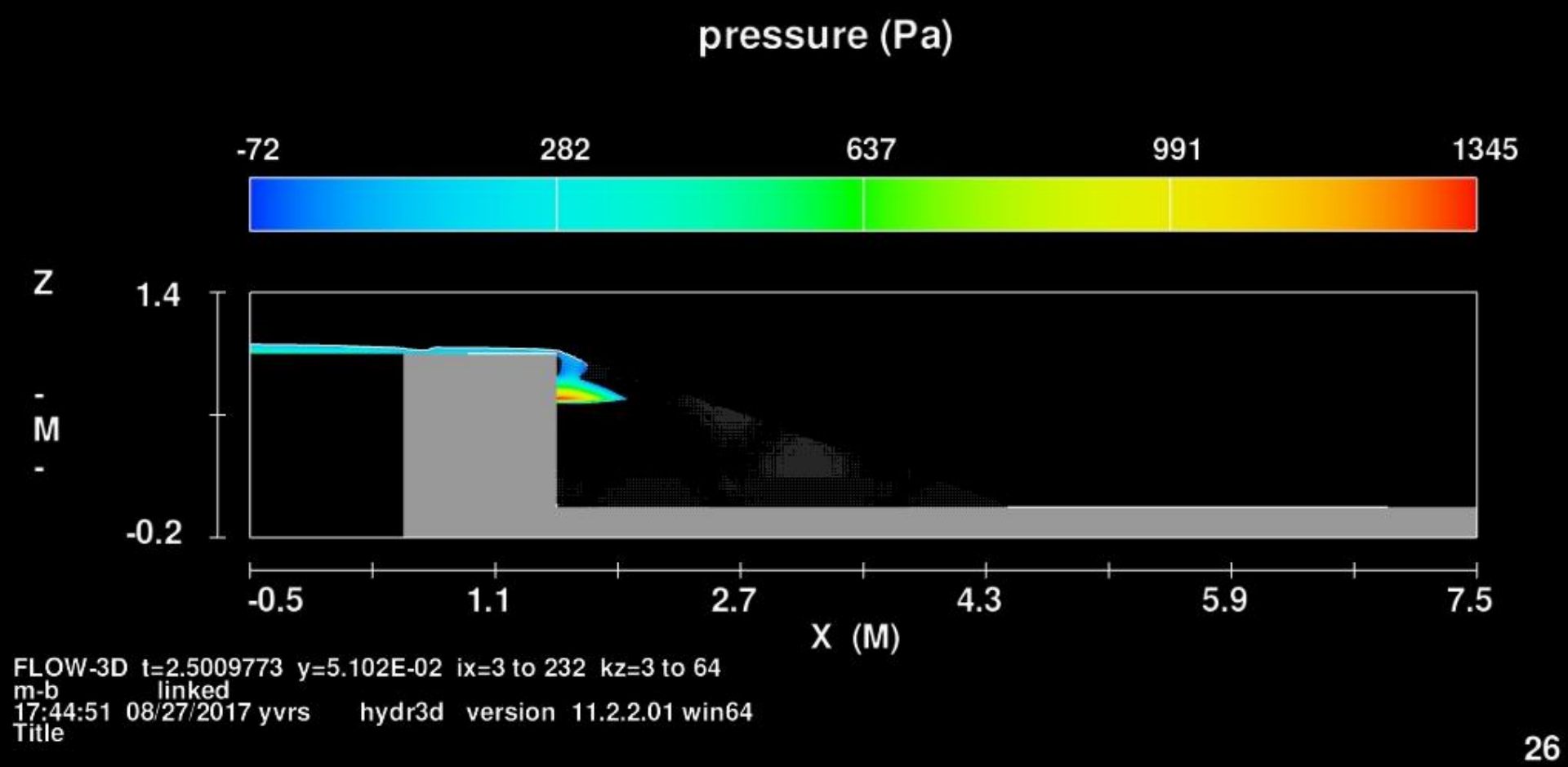
N

Keq*

What about anisotropy?

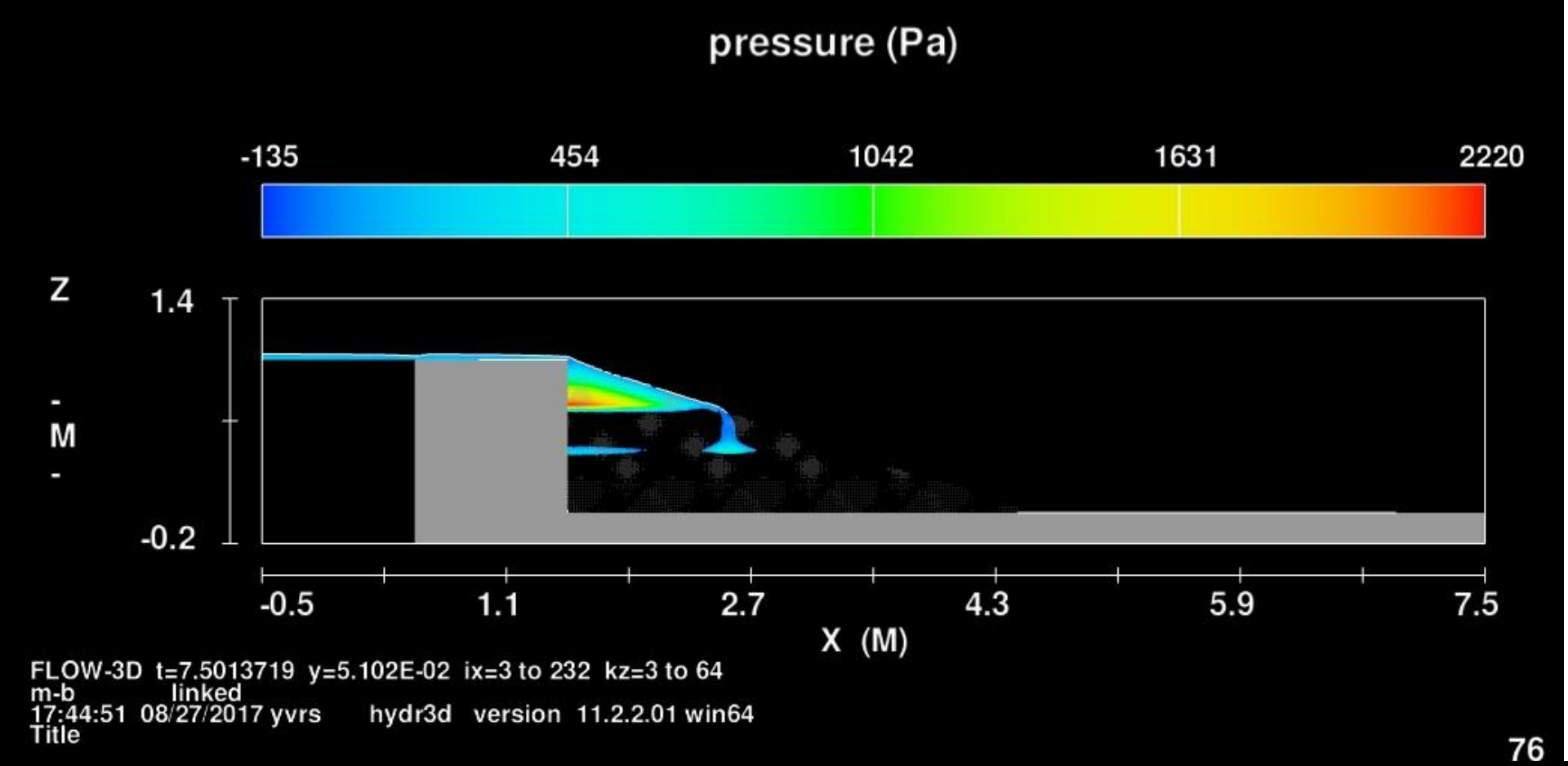






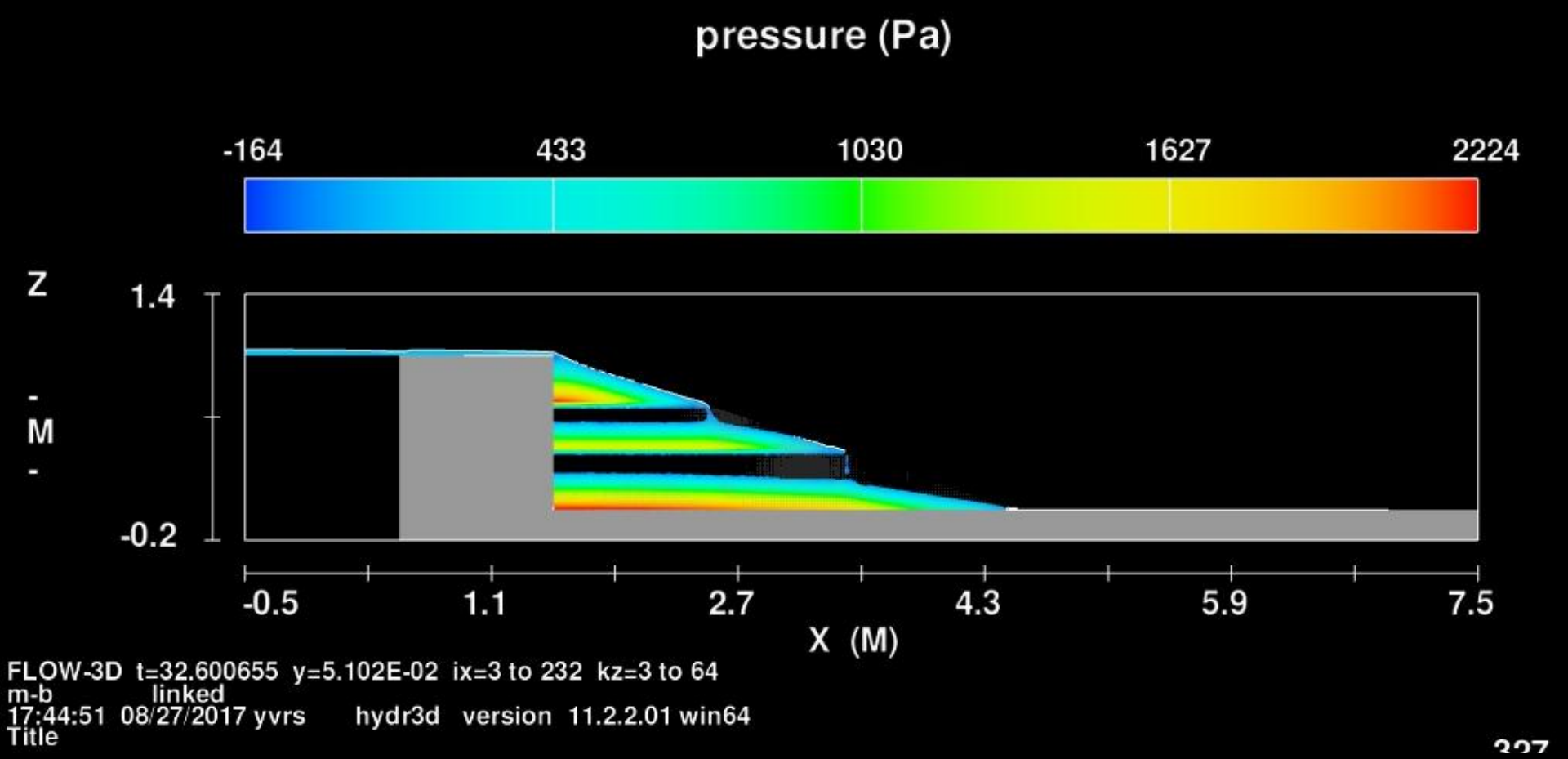
Overflow discharge: 15 l/s/m

$K = 10^{-3}$ m/s



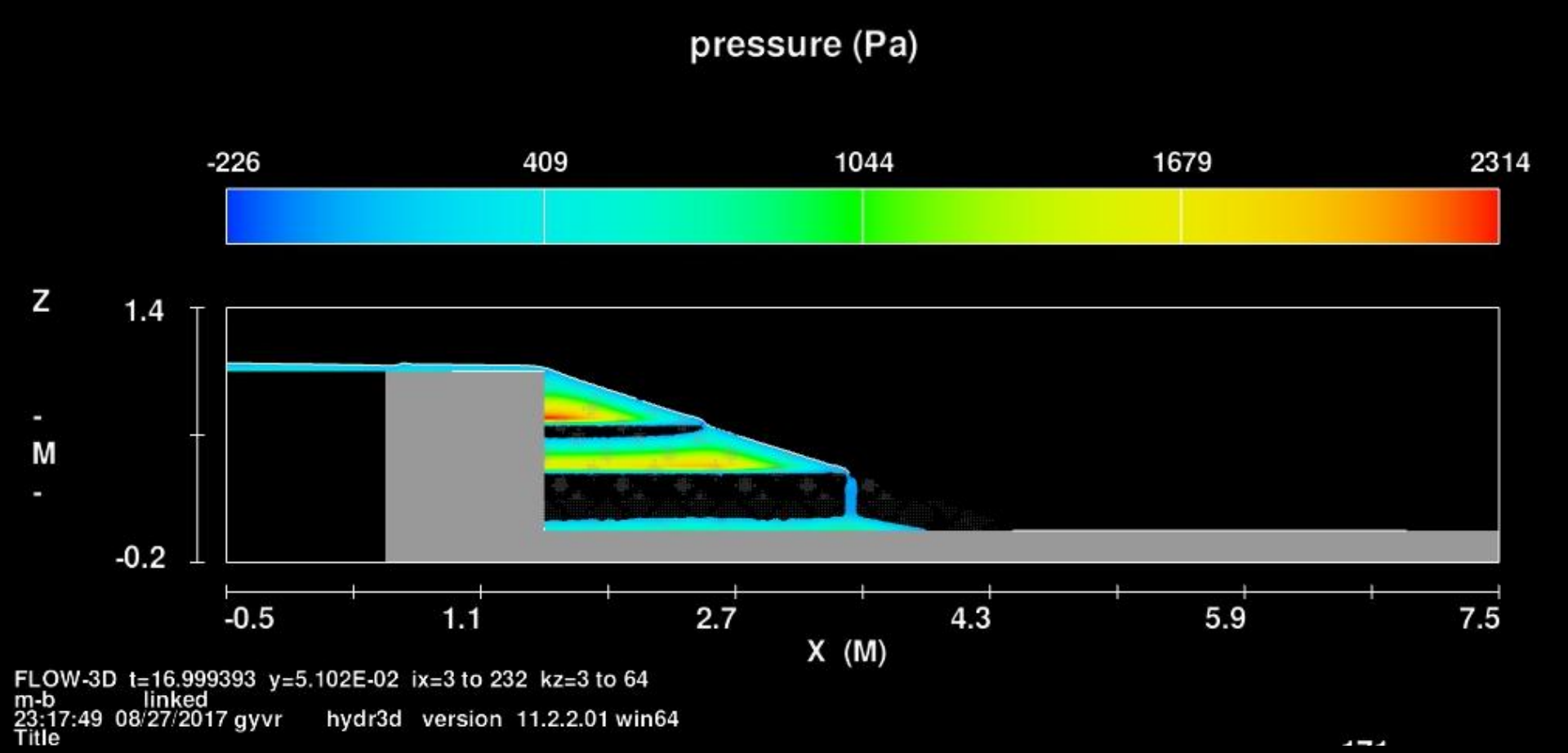
Overflow discharge: 15 l/s/m

$K = 10^{-3}$ m/s



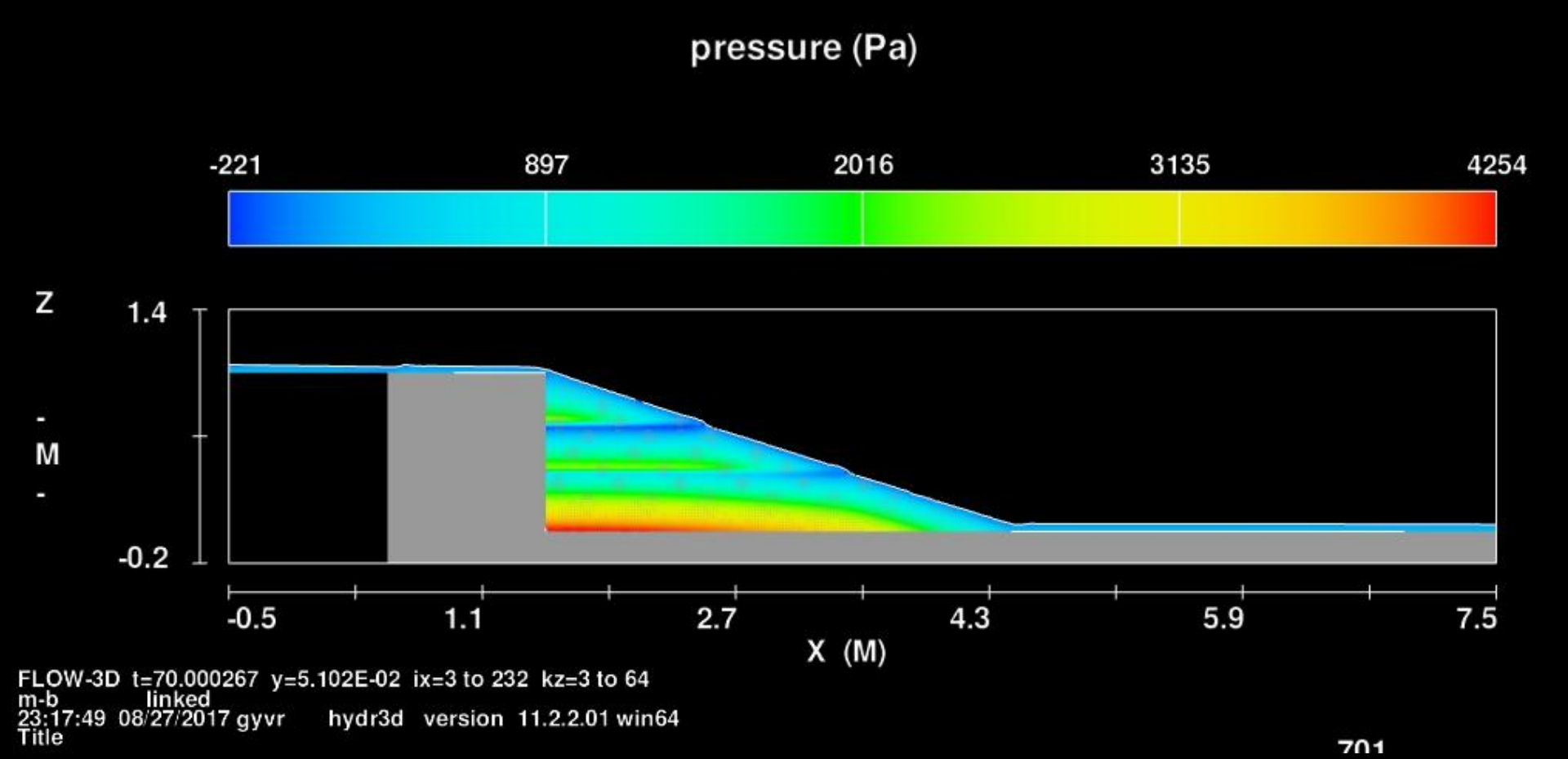
Overflow discharge: 15 l/s/m

$K = 10^{-3}$ m/s



Overflow discharge: 24 l/s/m

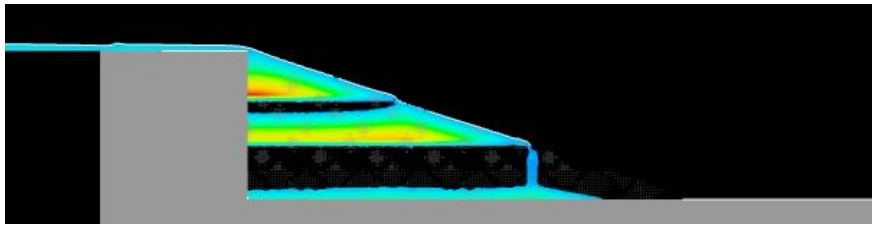
$K = 10^{-3}$ m/s



Overflow discharge: 24 l/s/m

$K = 10^{-3}$ m/s

Anisotropy might lead to an early failure



Hombre solo; Author: Antonio Mingote, 2008; Ed. Planeta

1 Rockfill dams are different

2 Once upon a time…

3 Rockfill failure is gradual, but fast

1 Dam slope determines the prevailing failure mechanism

2 Failure discharge can be estimated (at testing size)

3 Anisotropy might shorten the failure time, and discharge

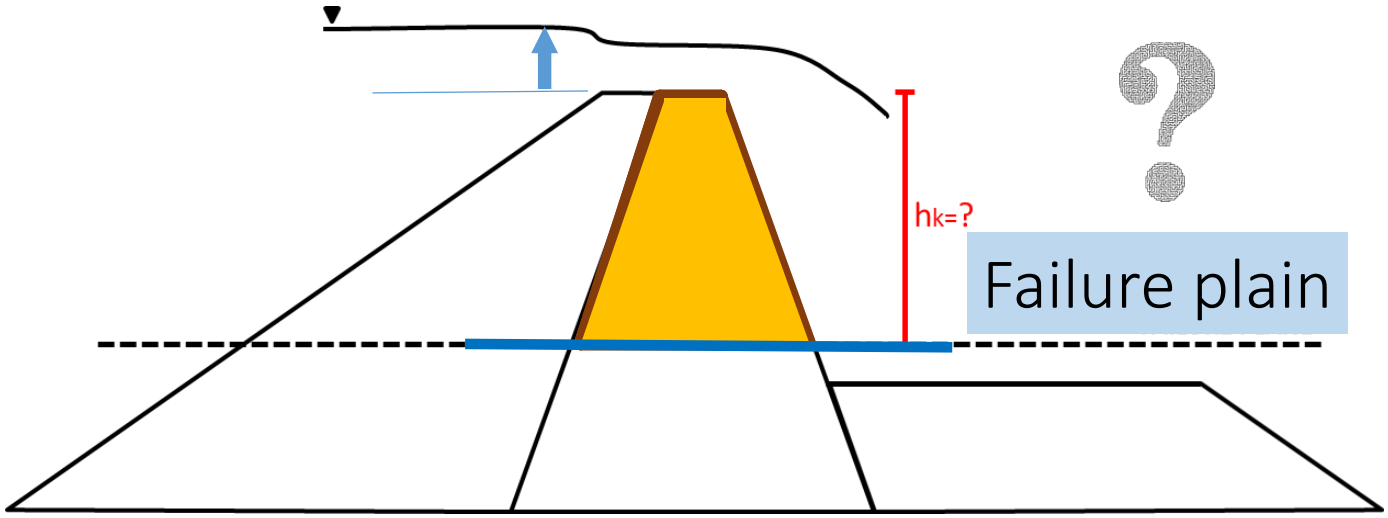
4

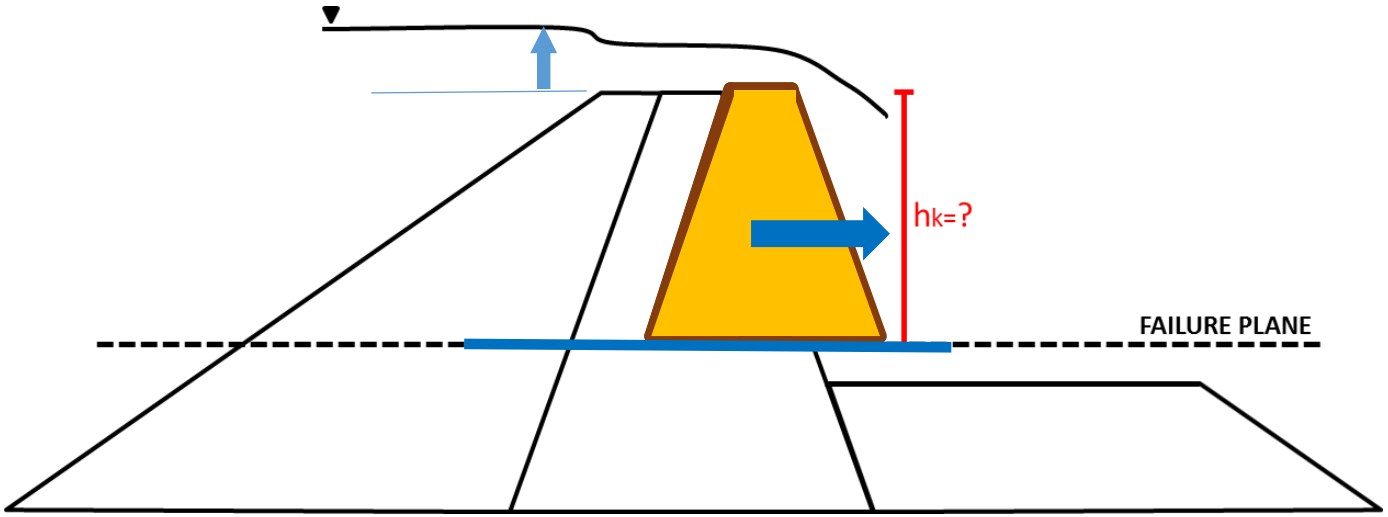
Core failure could be structural, and sudden

Hombre solo; Author: Antonio Mingote, 2008; Ed. Planeta

Core fails with an overflow
quite similar to rockfill failure discharge

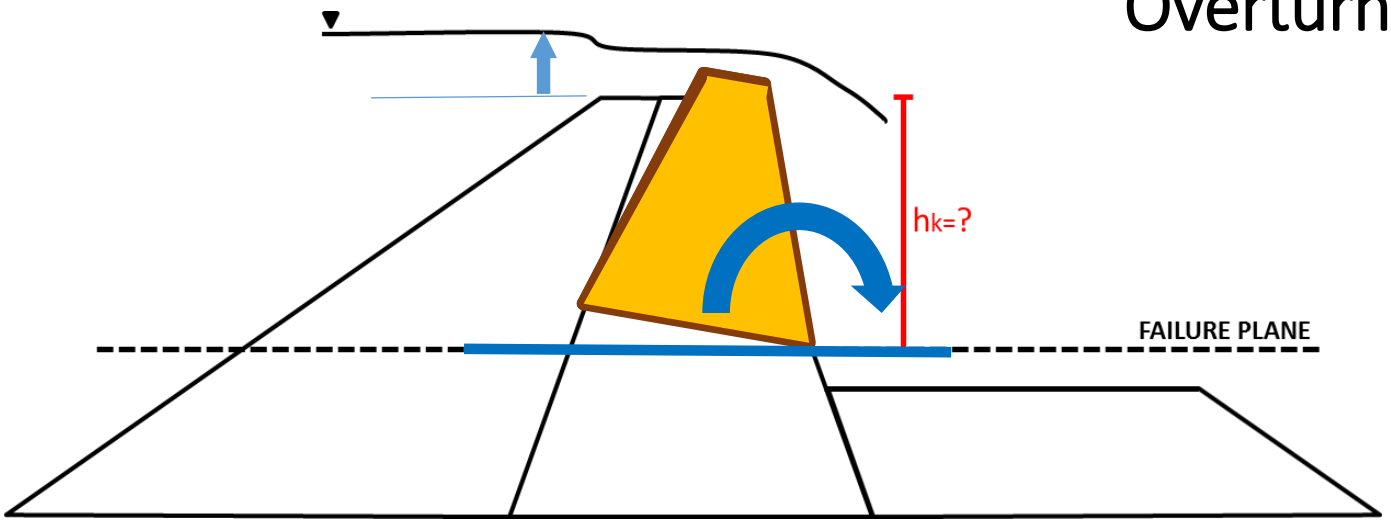
Is it posible to model the structural failure of the core in a “simple” way?

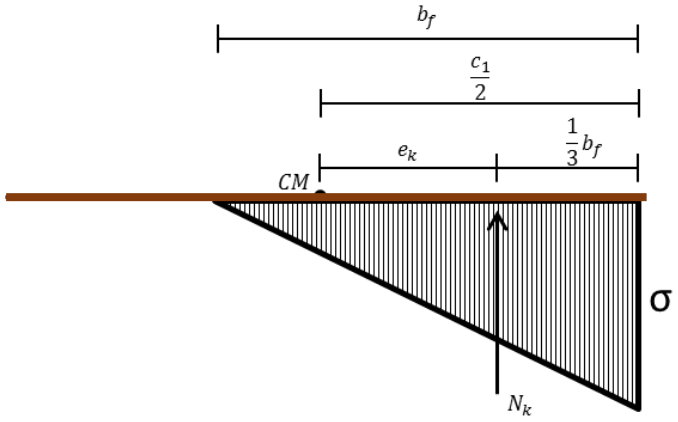




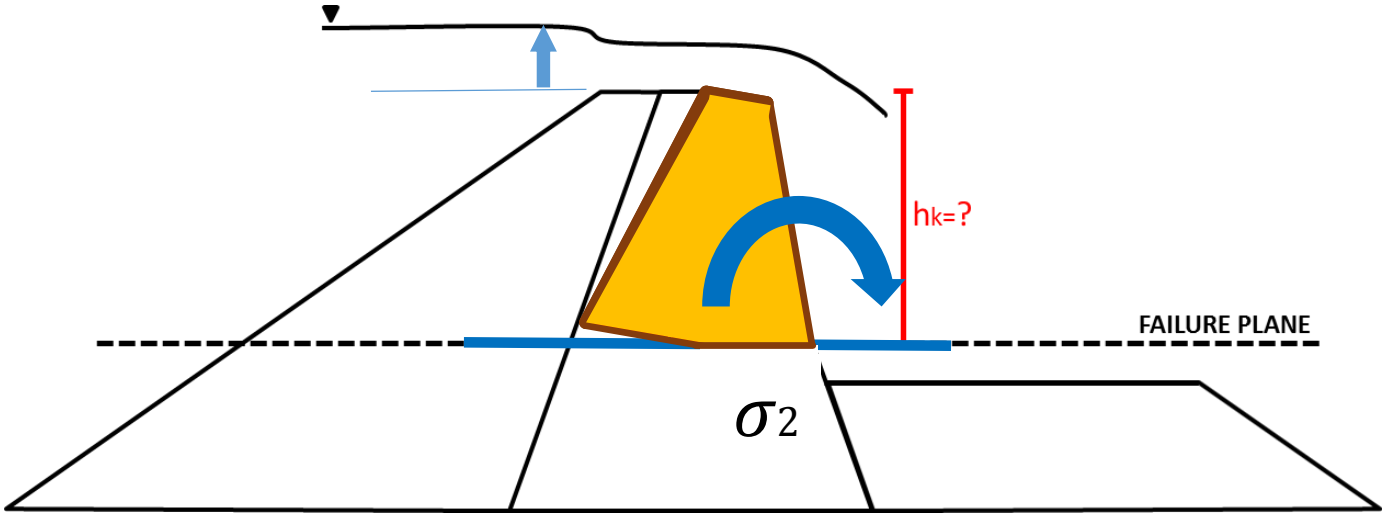
Mass sliding

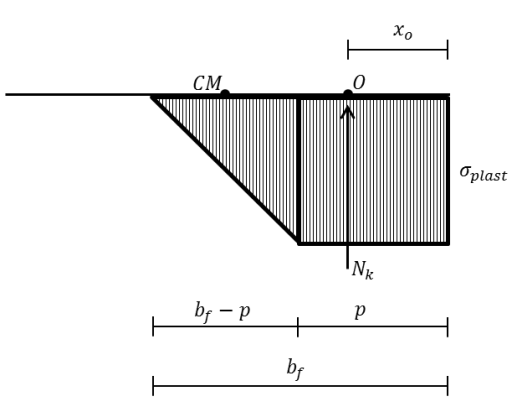
Overturning



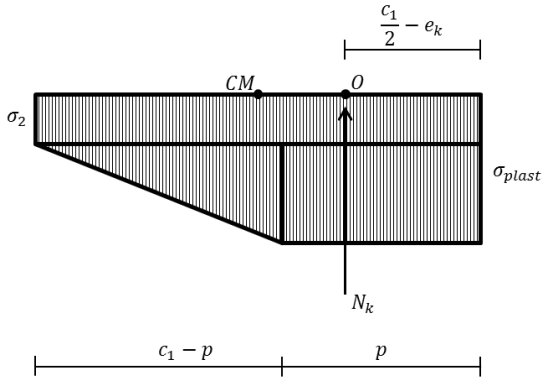


Plastic overturning



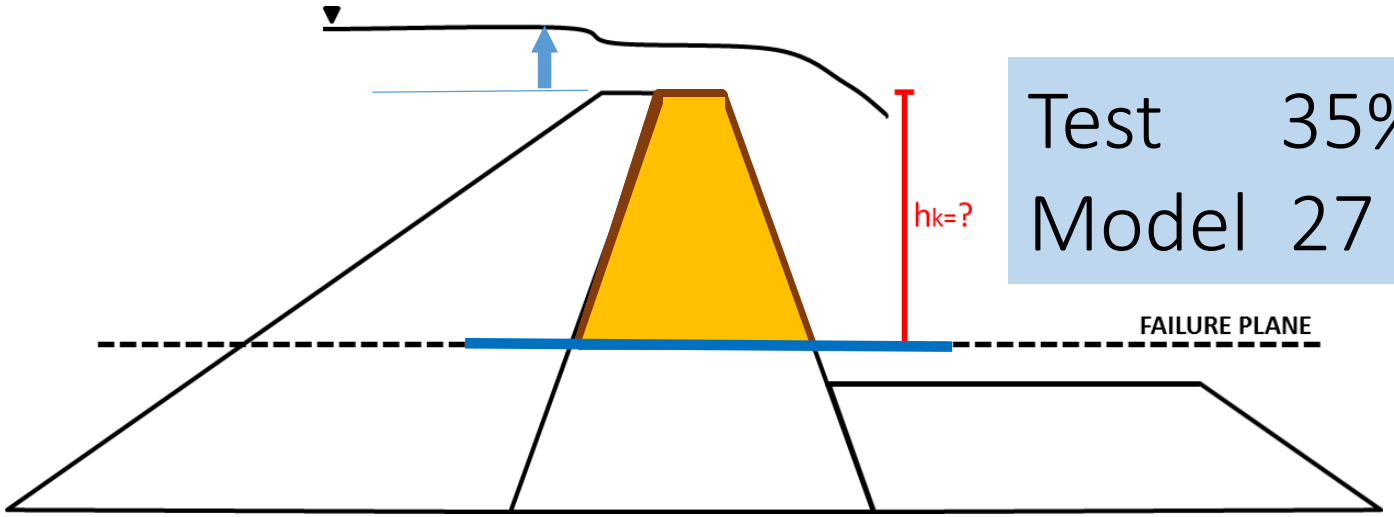


with crack



without crack

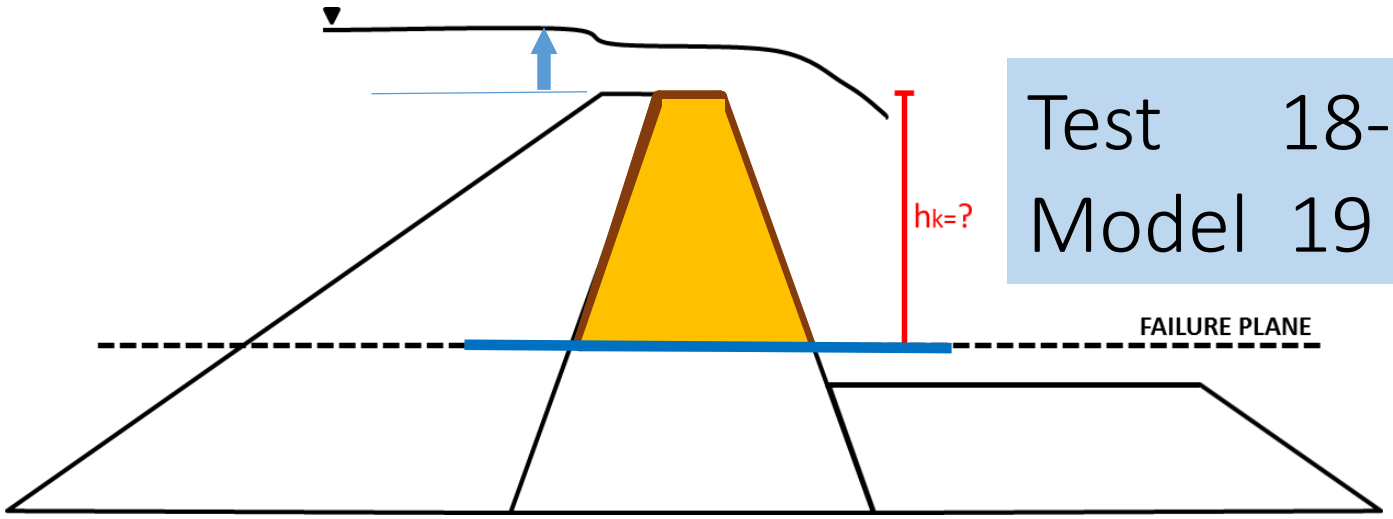
Thick core



Test	35%
Model	27 %

Failure mechanism: overturning

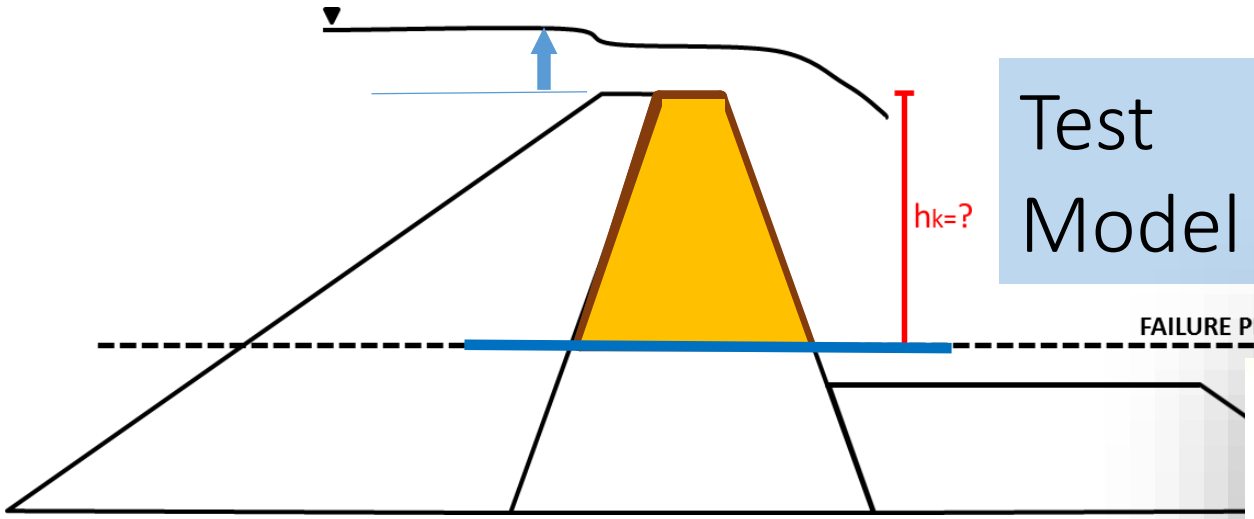
Thin core



Test 18-23%
Model 19 %

Failure mechanism: overturning

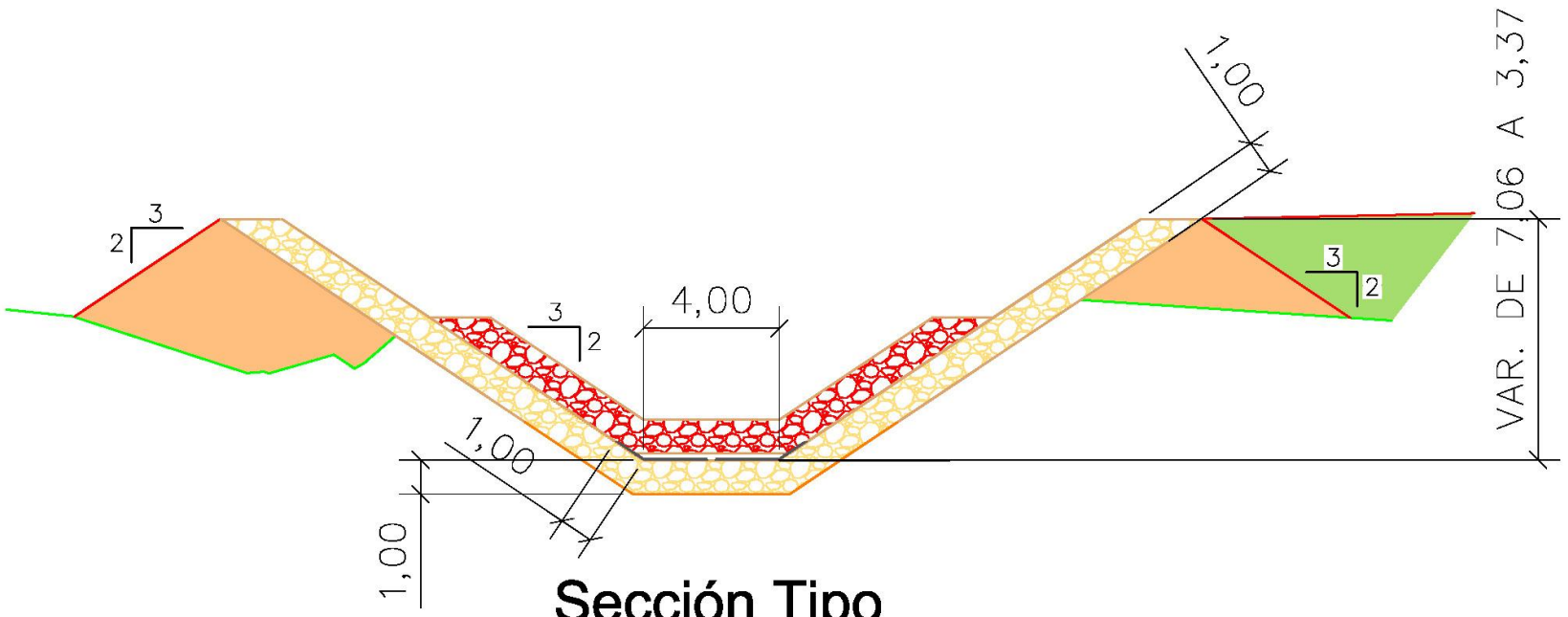
Thin core



Test 18-23%
Model 19 %

Failure mechanism: overturning


Toma en
Acequia de Sora
500 m
Zona
Ensayos



Sección Tipo

Escollera a mantener

Escollera a demoler

Escollera nueva

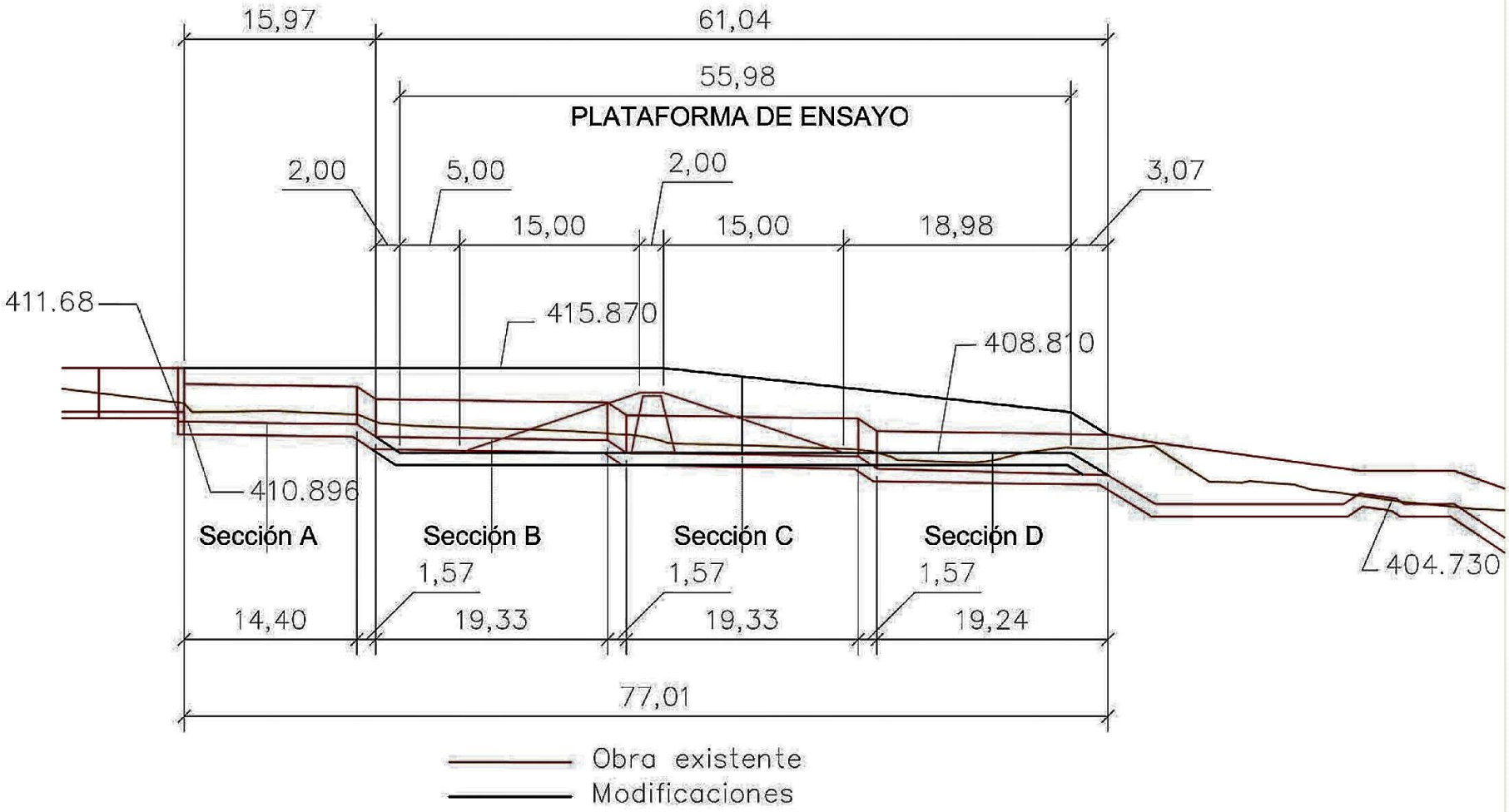
Terraplén

0.05 m de HM-20

Límite de terraplén

Terreno

Relleno de explanada


15,97
61,04
55,98
PLATAFORMA DE ENSAYO
2,00
5,00
2,00
3,07
15,00
15,00
18,98
411.68
415.870
408.810
410.896
404.730
Sección A
Sección B
Sección C
Sección D
1,57
1,57
1,57
14,40
19,33
19,33
19,24
77,01
Obra existente
Modificaciones

1 Rockfill dams are different

2 Once upon a time…

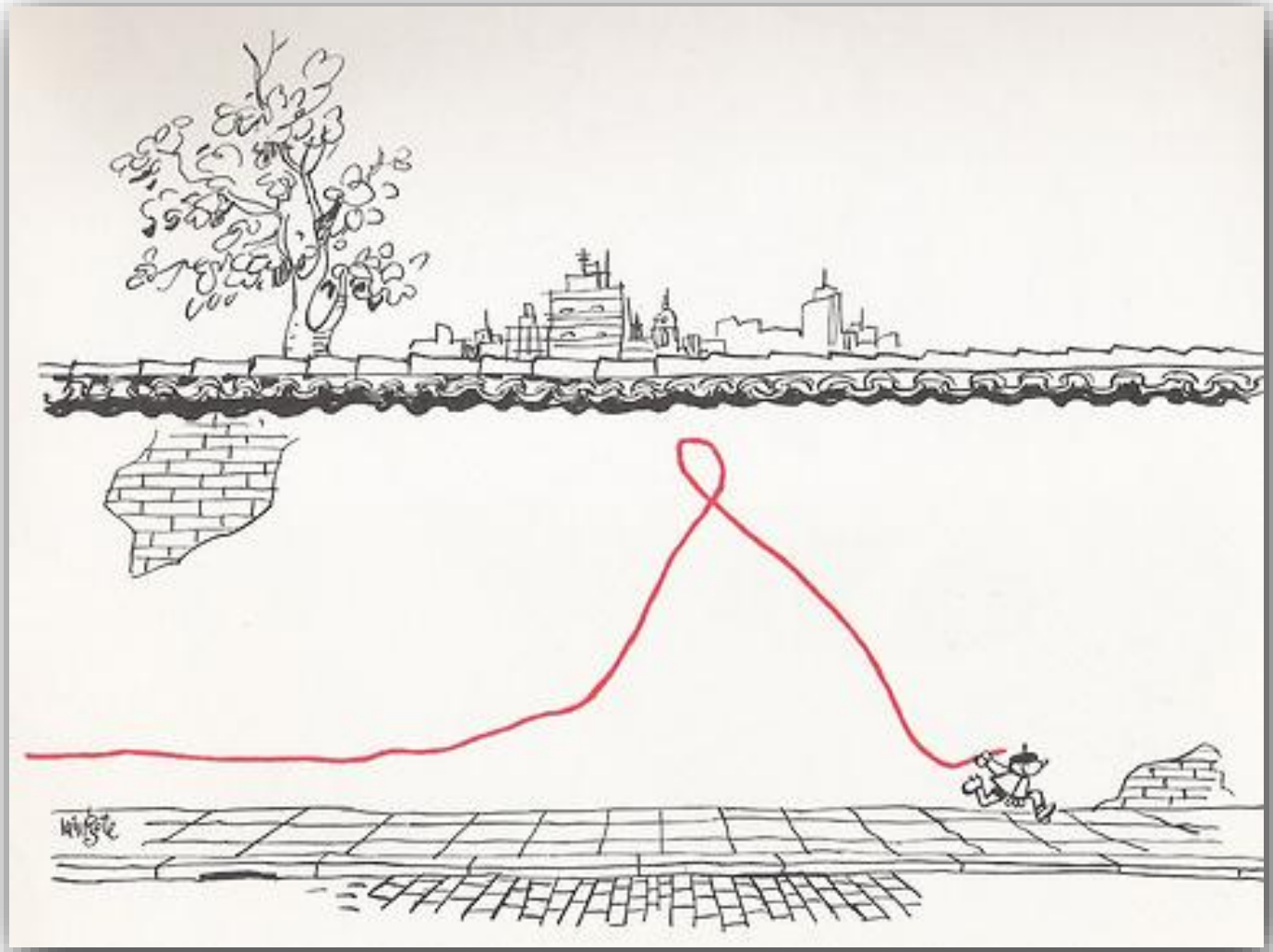
3 Rockfill failure is gradual, but fast

4 Core failure could be structural and sudden

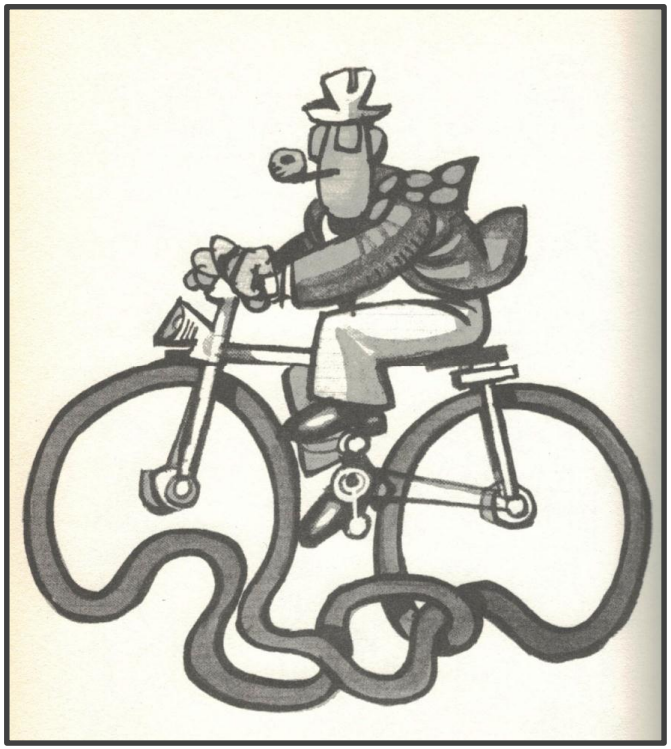
1 Overflow discharge for rockfill failure and core failure are quite similar

2 Structural failure implies a specially destructive failure hydrograph

3 Modeling the structural failure is compulsory for estimating the flood plain



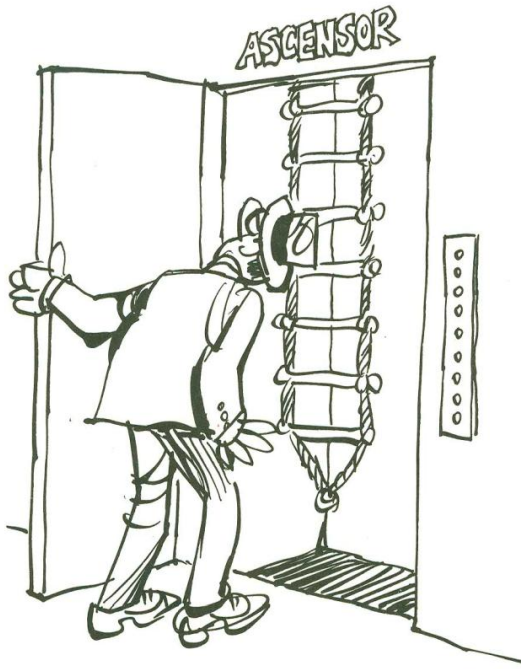
Hombre solo; Author: Antonio Mingote, 2008; Ed. Planeta



Hombre solo; Author: Antonio Mingote, 2008; Ed. Planeta

Dam owner trying to make a decisión about a rockfill dam…

Rockfill dams are different…
…and require a specific new tool



Hombre solo; Author: Antonio Mingote, 2008; Ed. Planeta

POLITÉCNICA

serpa
Dam Safety Research

RESEARCH GROUP
ON HYDROINFORMATICS
AND WATER MANAGEMENT

blogs.upm.es/serpa
miguelangel.toledo@upm.es

La Verné

Ebro river basin; Spain


314 km (1h:20min AVE)
312 km (1h:30min AVE)
Zaragoza
Barcelona
Madrid
España
Portugal
Andorra

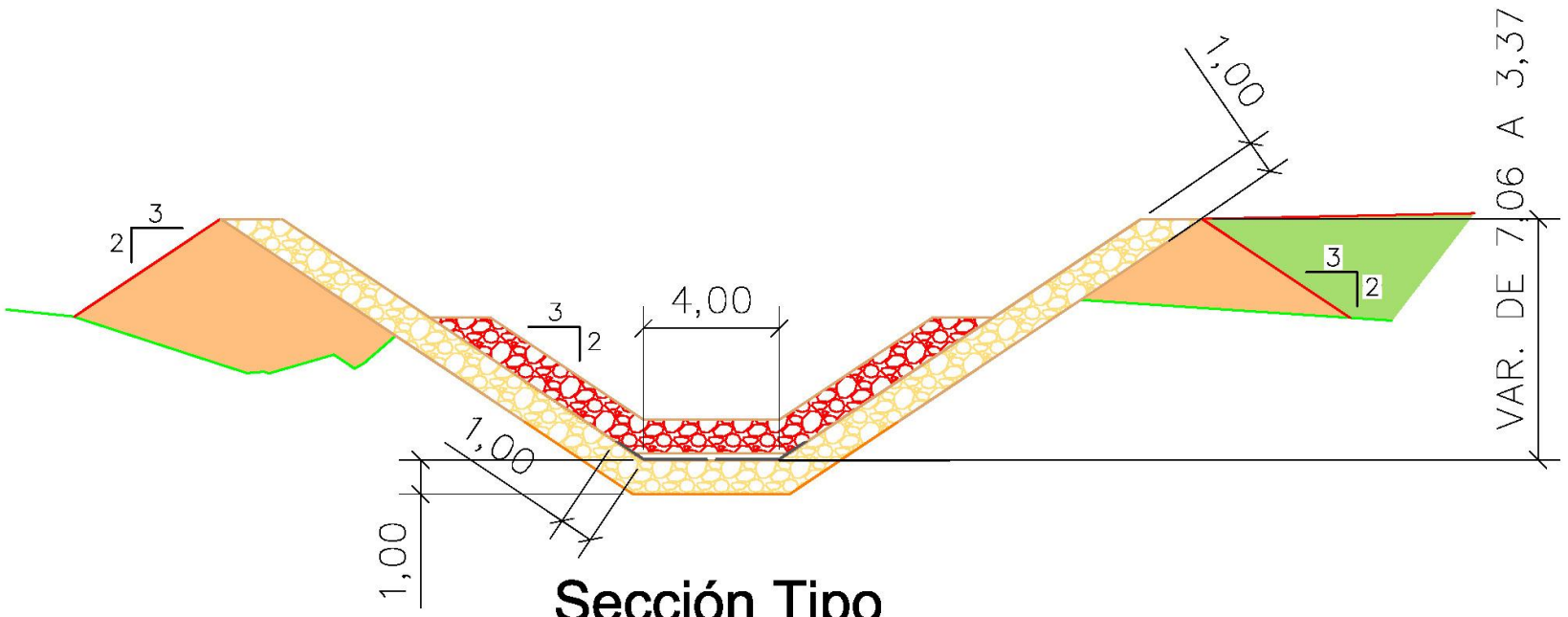

Ejea de los Caballeros
75 km (1h:00min)
Zaragoza
Gurrea de Gállego
Zuera
Villanueva de Gállego
Alagón
Utebo
La Puebla de Alfindén


Ejea de los Caballeros
(16.500 hab)
6 km (21min)
Presa de Laverné


3km (10 min)
Zona Ensayos
Embalse de Laverné
Presa de Laverné


Toma en Acequia de Sora
500 m
Zona Ensayos


Toma en
Acequia de Sora
500 m
Zona
Ensayos



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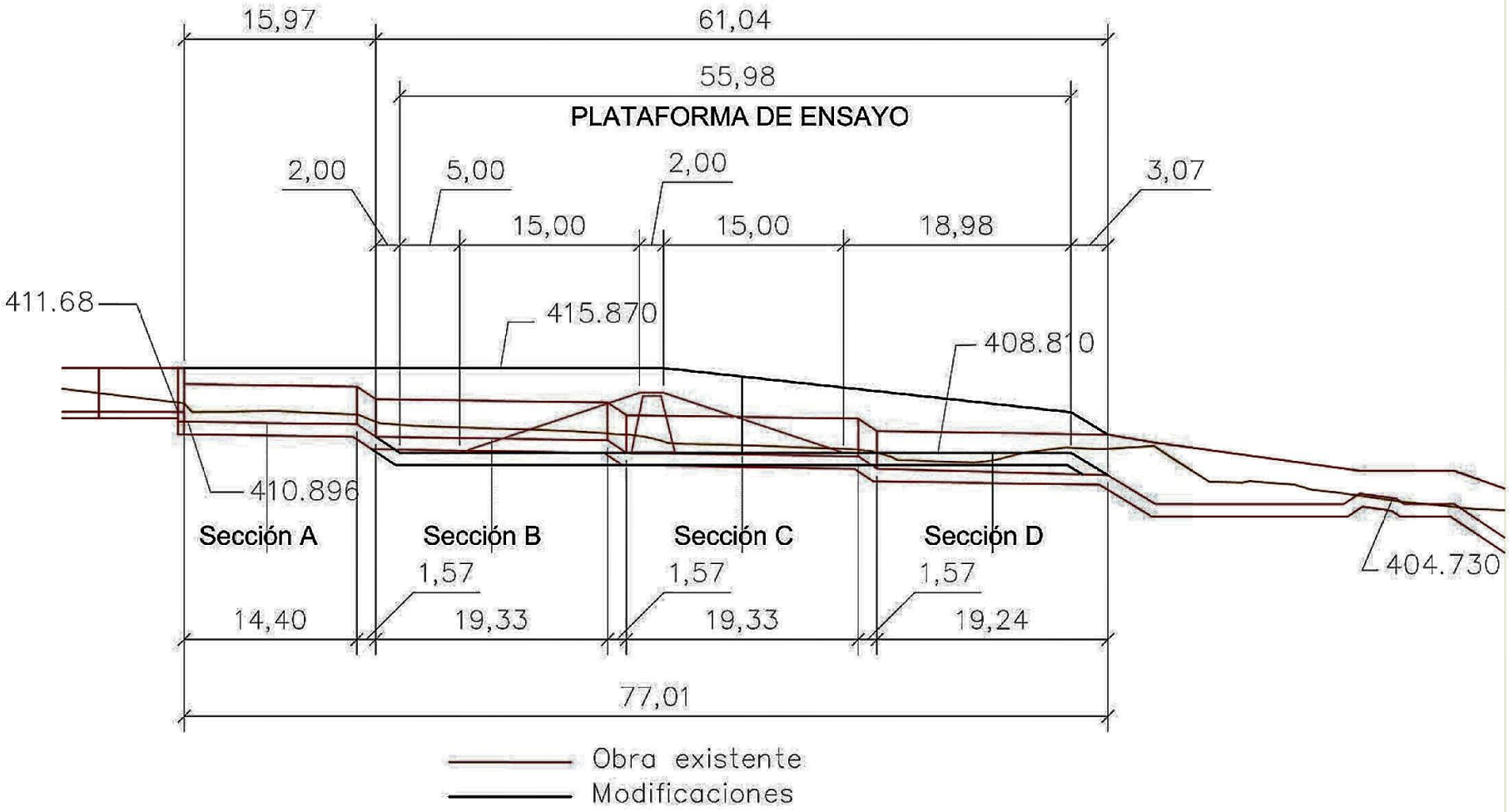
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PLATAFORMA DE ENSAYO
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Sección A
Sección B
Sección C
Sección D
1,57
1,57
1,57
14,40
19,33
19,33
19,24
77,01
Obra existente
Modificaciones

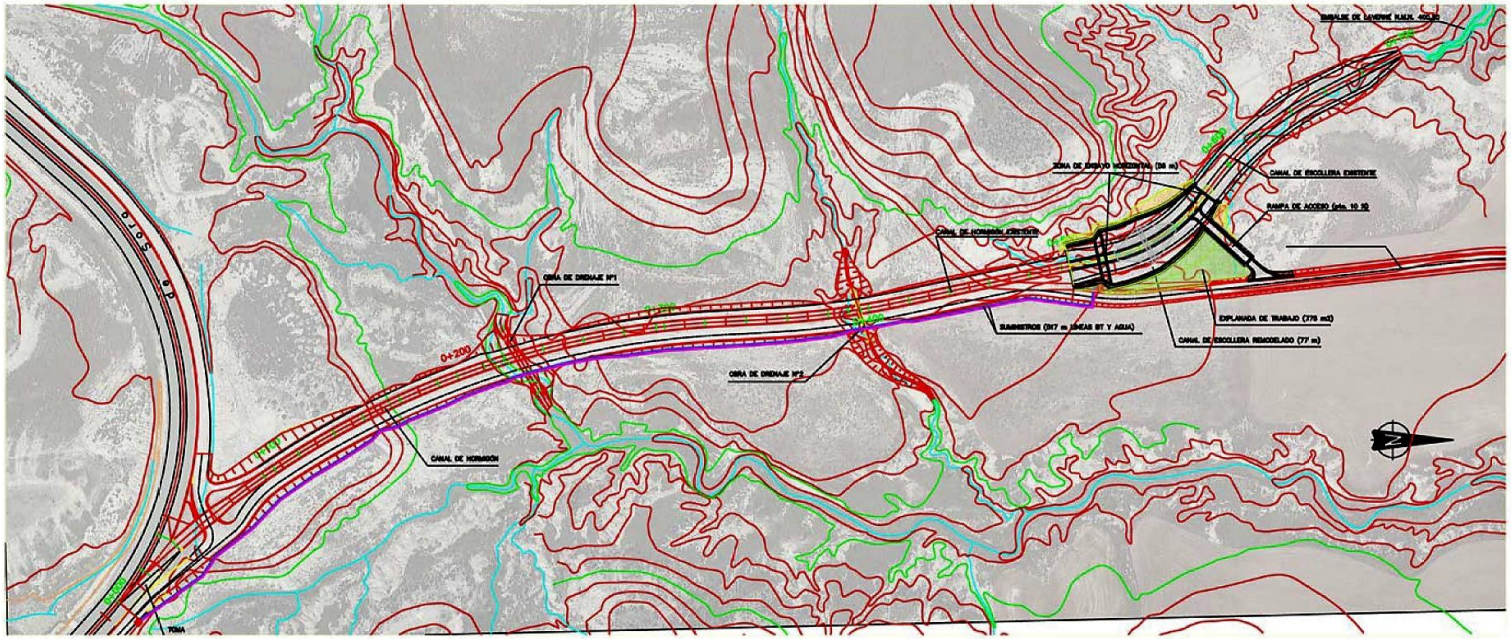

Planta General del canal de alimentación desde la Acequia de Sora)

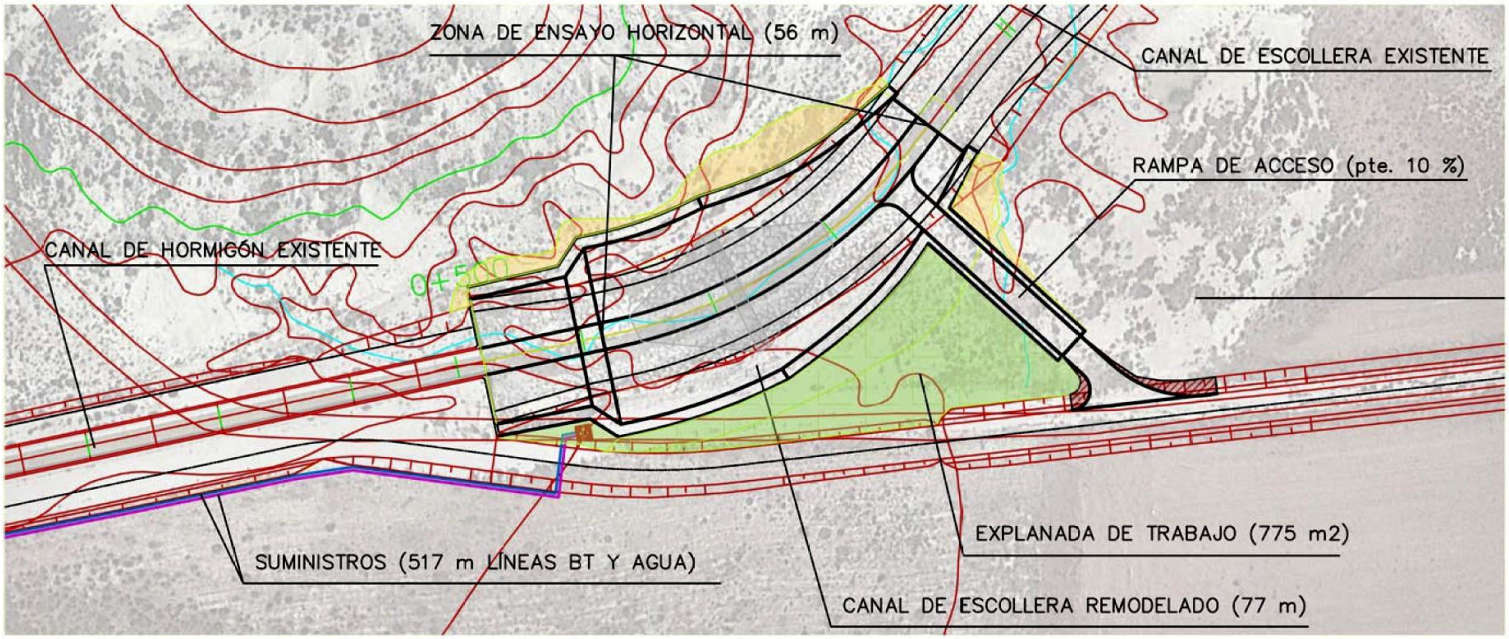

Obra de Toma existente en la Acequia de Sora e inicio del canal de hormigón)


Canal de hormigón y rápida (16% de pendiente)


Final del canal de hormigón e inicio del canal de escollera)


Zona prevista para los ensayos


CANAL DE HORMIGON
OBRA DE DRENAJE Nº1
OBRA DE DRENAJE Nº2
0+200
0+105
TOMA
ZONA DE ENSANCHE HORIZONTAL (36 m)
CANAL DE ESCOLLERA EXISTENTE
RAMPA DE ACCESO 6m. 10 %
CANAL DE HORMIGON EXISTENTE
SUMINISTROS (247 m LINEAS BT Y AGUA)
CANAL DE ESCOLLERA REMODELADO (77 m)
EXPLANADA DE TRABAJO (775 m2)
N


ZONA DE ENSAYO HORIZONTAL (56 m)
CANAL DE ESCOLLERA EXISTENTE
RAMPA DE ACCESO (pte. 10 %)
CANAL DE HORMIGÓN EXISTENTE
0+500
EXPLANADA DE TRABAJO (775 m2)
SUMINISTROS (517 m LINEAS BT Y AGUA)
CANAL DE ESCOLLERA REMODELADO (77 m)