FILTERS AND INTERNAL EROSION IN SWEDISH DAMS

SUSCEPTIBILITY OF INTERNAL EROSION IN THE SUORVA DAM

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Workshop on Internal Erosion and Piping of Dams and Foundations
25-27 April 2005 Aussois France

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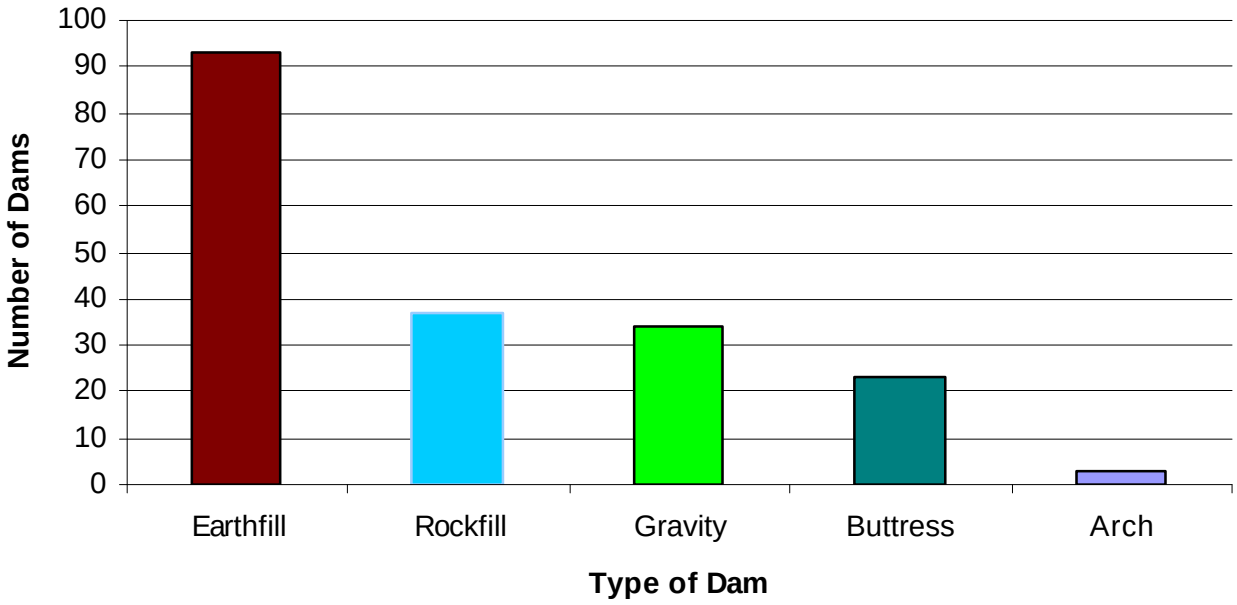
Introduction

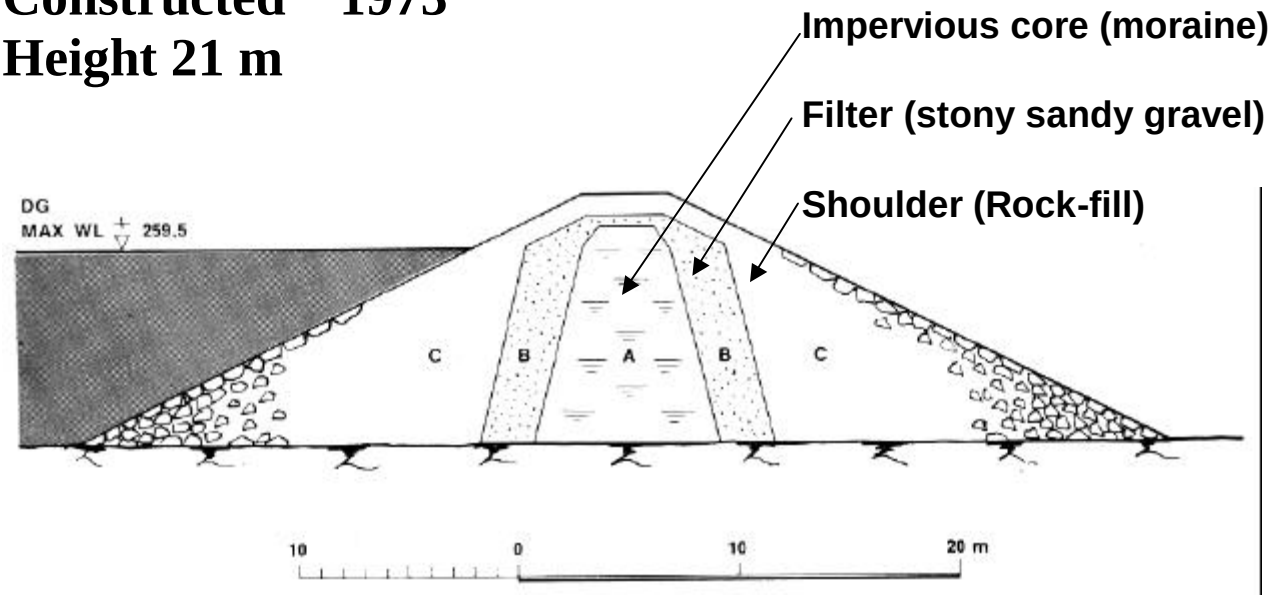
1. Experience of sinkholes
2. Filters in Swedish dams
3. Internal erosion
4. Summary and for discussion

High dams in Sweden

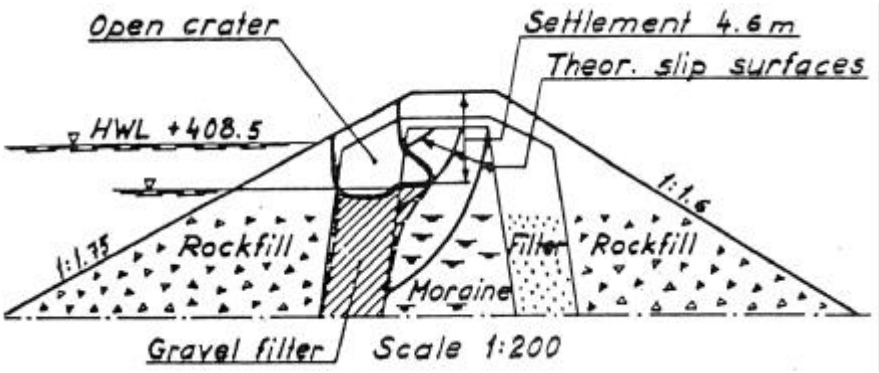


Akkats Dam

Constructed 1973
Height 21 m



Bastusel Dam

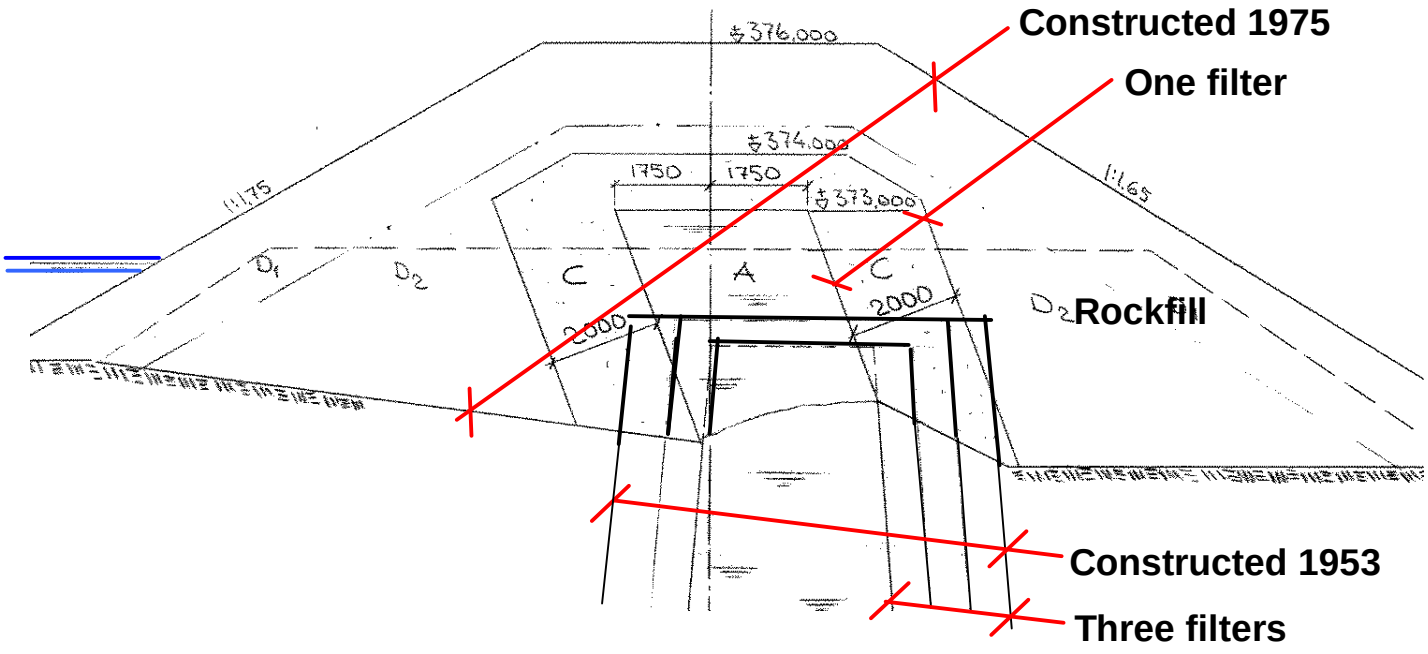


Sinkholes occurred
1972
1973
1974
1983
1993

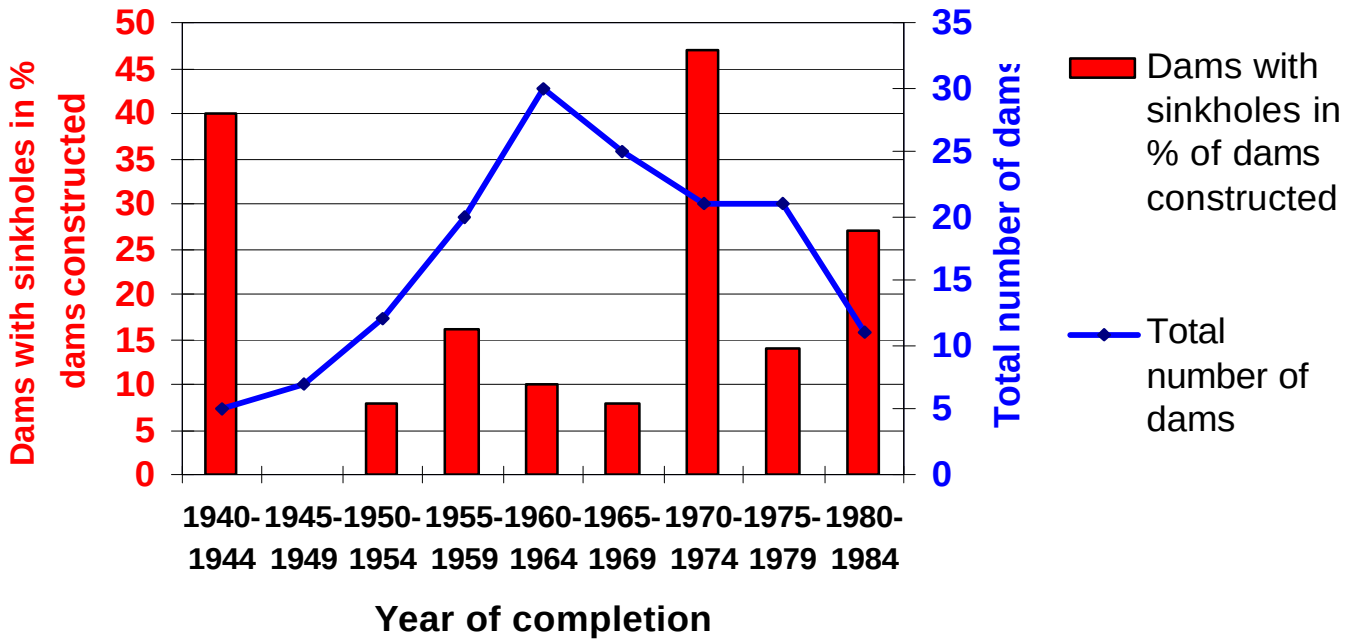
Downstream filter
D_{max} = 16 mm ?
D_{15} = 1,6 mm
D_{50} = 5,3 mm

Impervious core
Content of fines = 60%

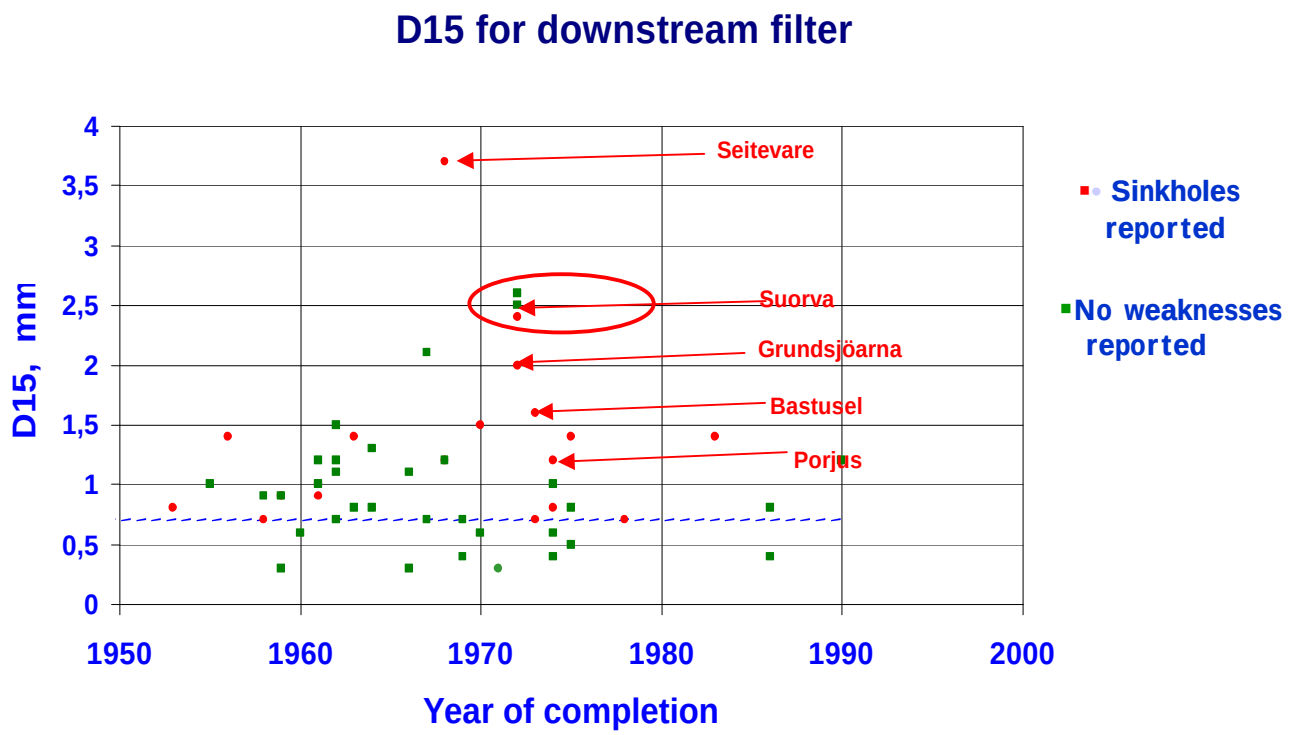
Porjus Dam


Constructed 1975
One filter
Rockfill
Constructed 1953
Three filters
1:1.75
1:1.65
1750
1750
2000
2000
C
A
C
D1
D2
D2

Inventory of sinkholes



D15 for the filter vs year of completion of the dam



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MEASURES TAKEN DUE TO REPORTED SINKHOLES

Hällby Dam constructed in 1970 has experienced several sinkholes during the years and the core was grouted in 1983.

Hällby Dam was in 2004/05 strengthened by a rockfill berm

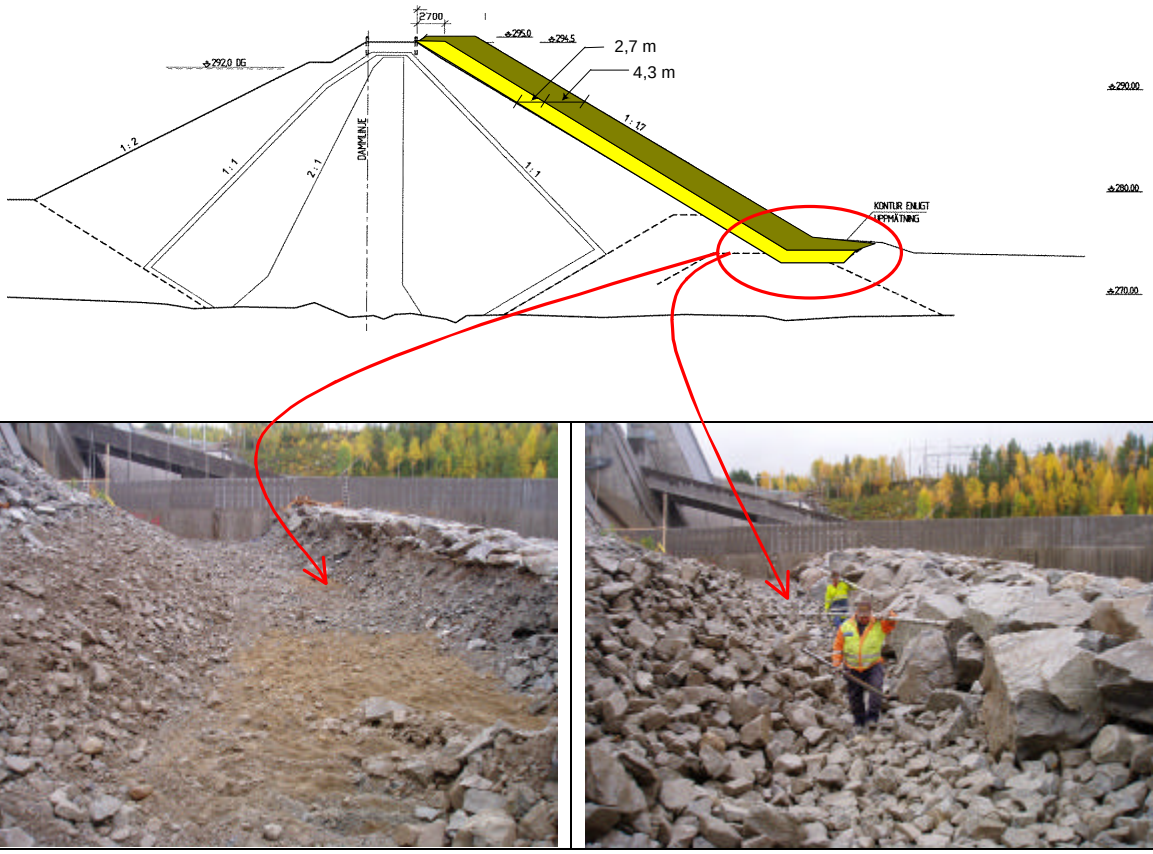

Figure 11 Hällby Dam was in 2004/05 strengthened by a rockfill berm in order to allow for possible large leakages in the future.

Hällby Dam was in 2004/05 strengthened by a rockfill berm in order to allow for possible large leakages in the future.

SUMMARY

In Sweden it is at present considered ***not possible*** with the present knowledge ***to rule out the risk for internal erosion*** for a specific dam by e.g. study the gradation curves for the core and filter material.

In the guidelines all high consequence dams have to be assumed to be susceptible for internal erosion and a '***design leakage'*** has to be determined.

Almost all high consequence dams have to be ***upgraded*** to allow for this design leakage.

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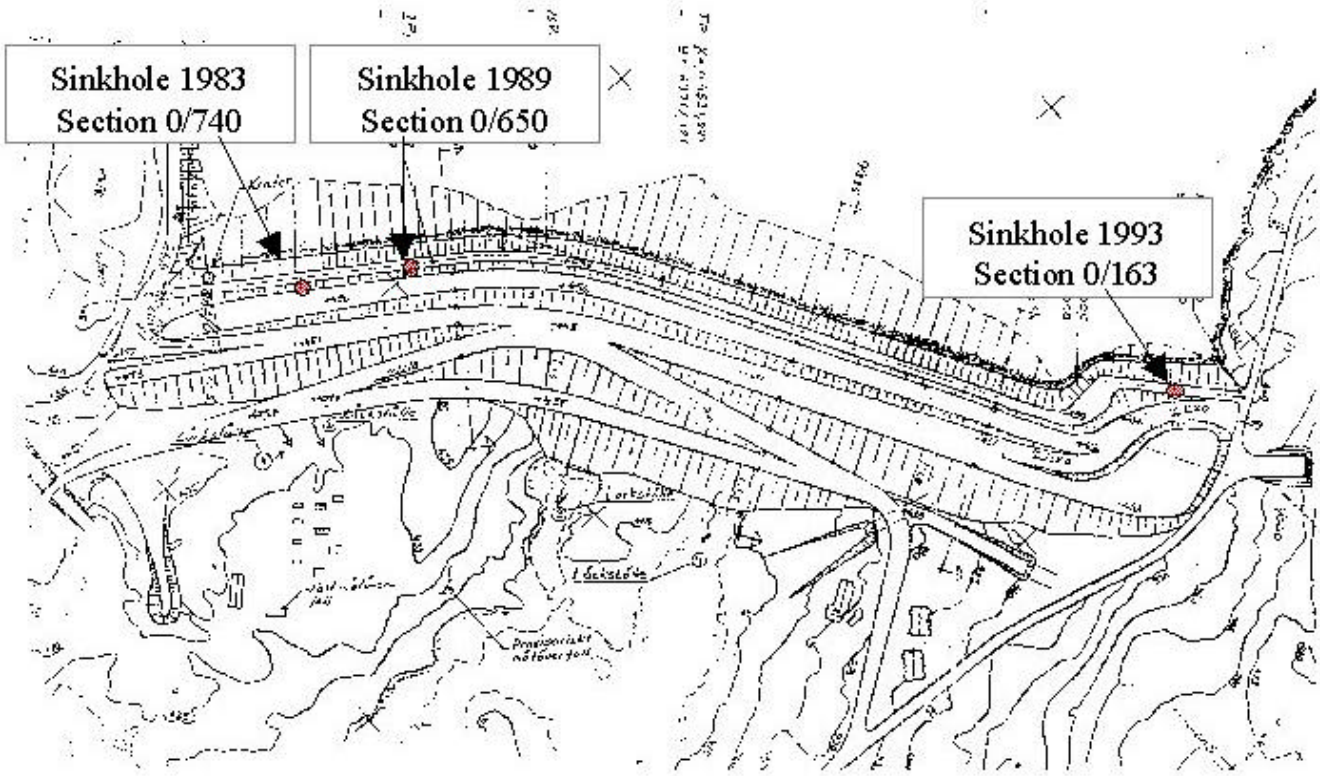
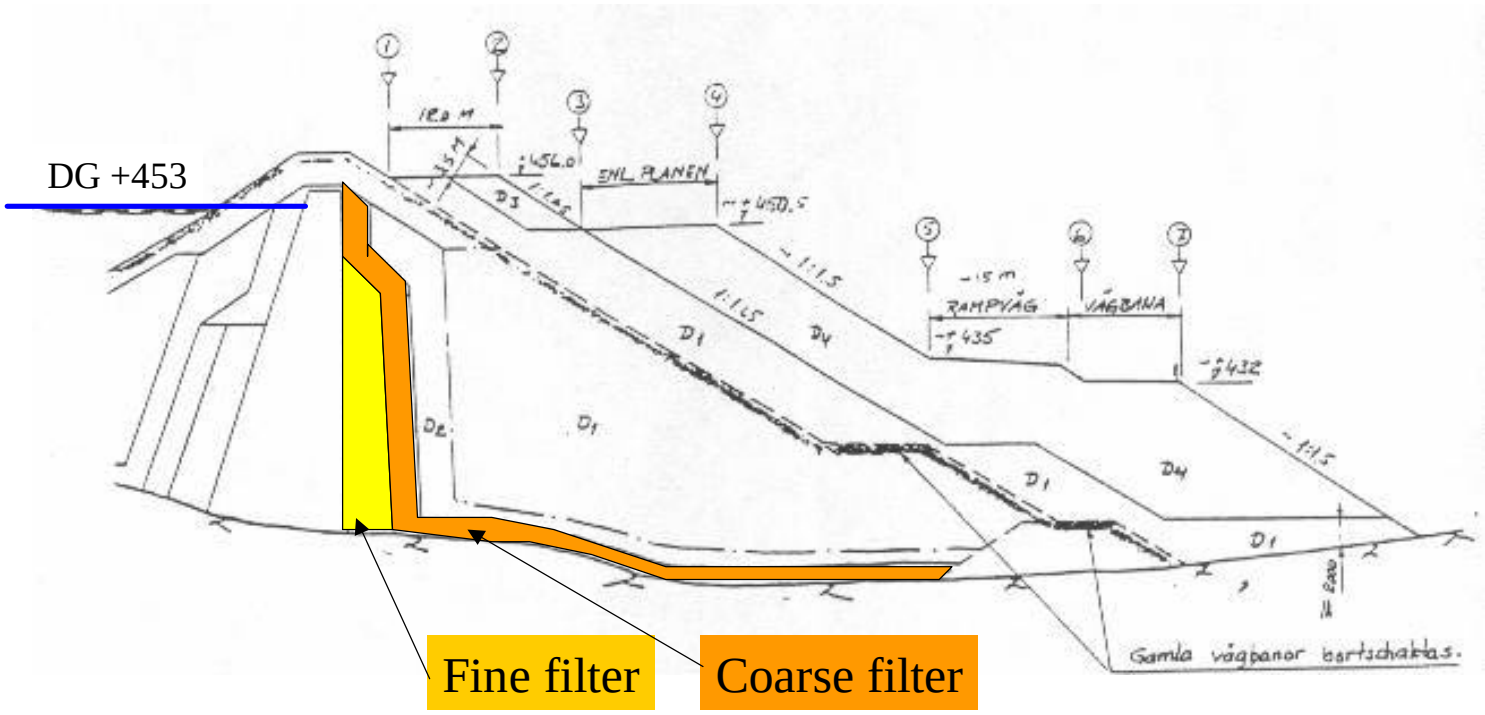
Introduction

1. Sinkholes
   - in 1983
   - in 1989
   - in 1993
2. Evaluation of the internal erosion process
   - Susceptibility for the continuation of the internal erosion process
3. Measures taken to allow for active dampening of floods by a 2 m higher storage level
4. Summary and for discussion

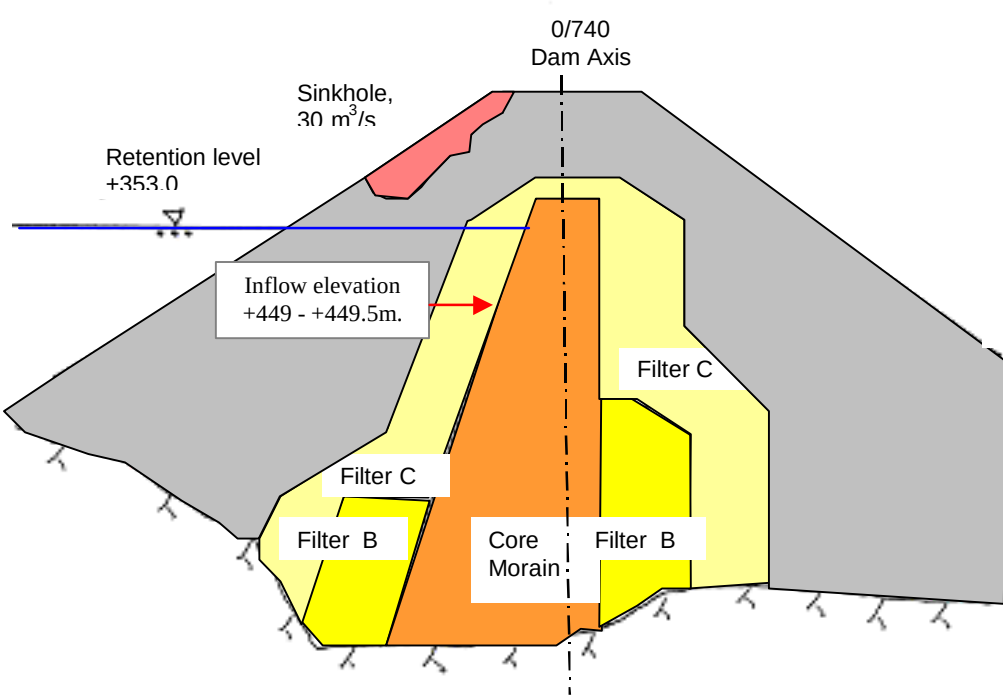
East Suorva Dam



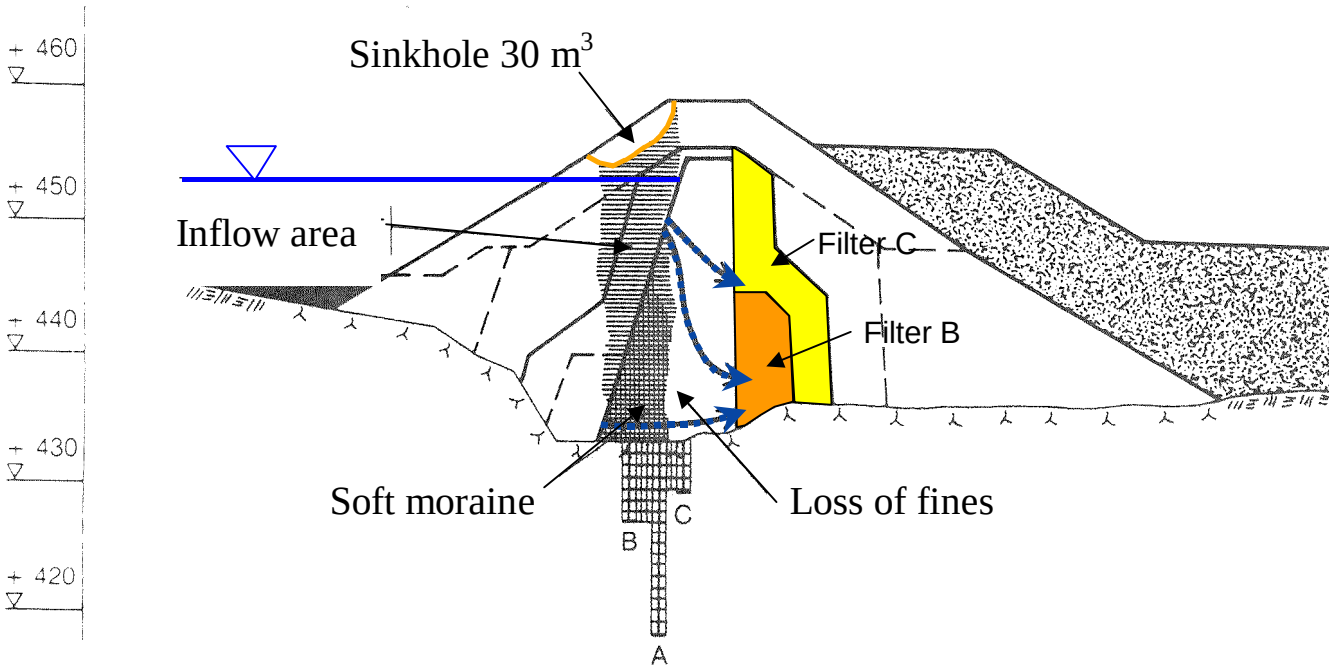
East Suorva Dam



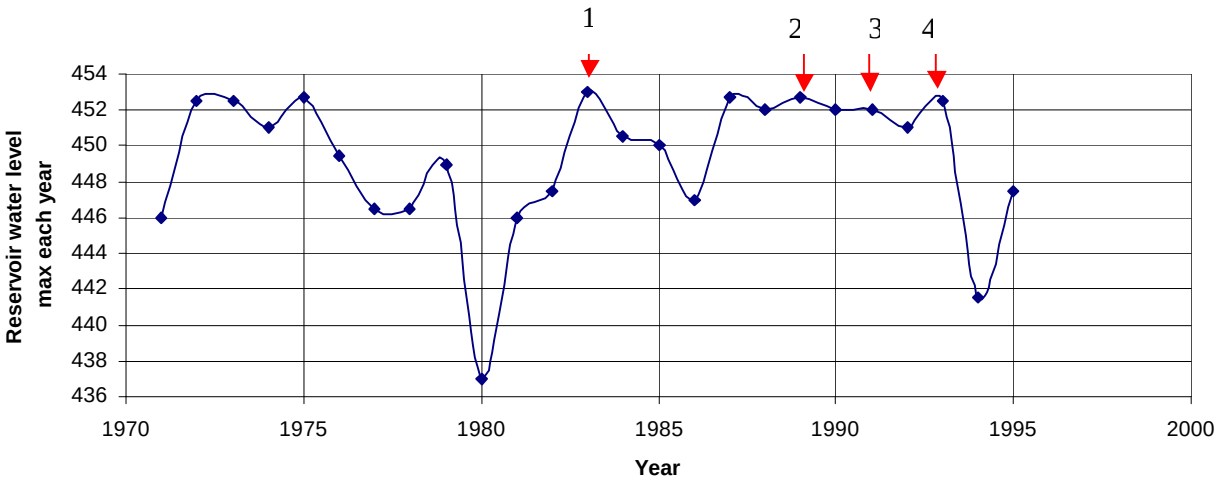
Section at the sinkhole which occurred in 1983



Possible leakage path during the incident in 1983

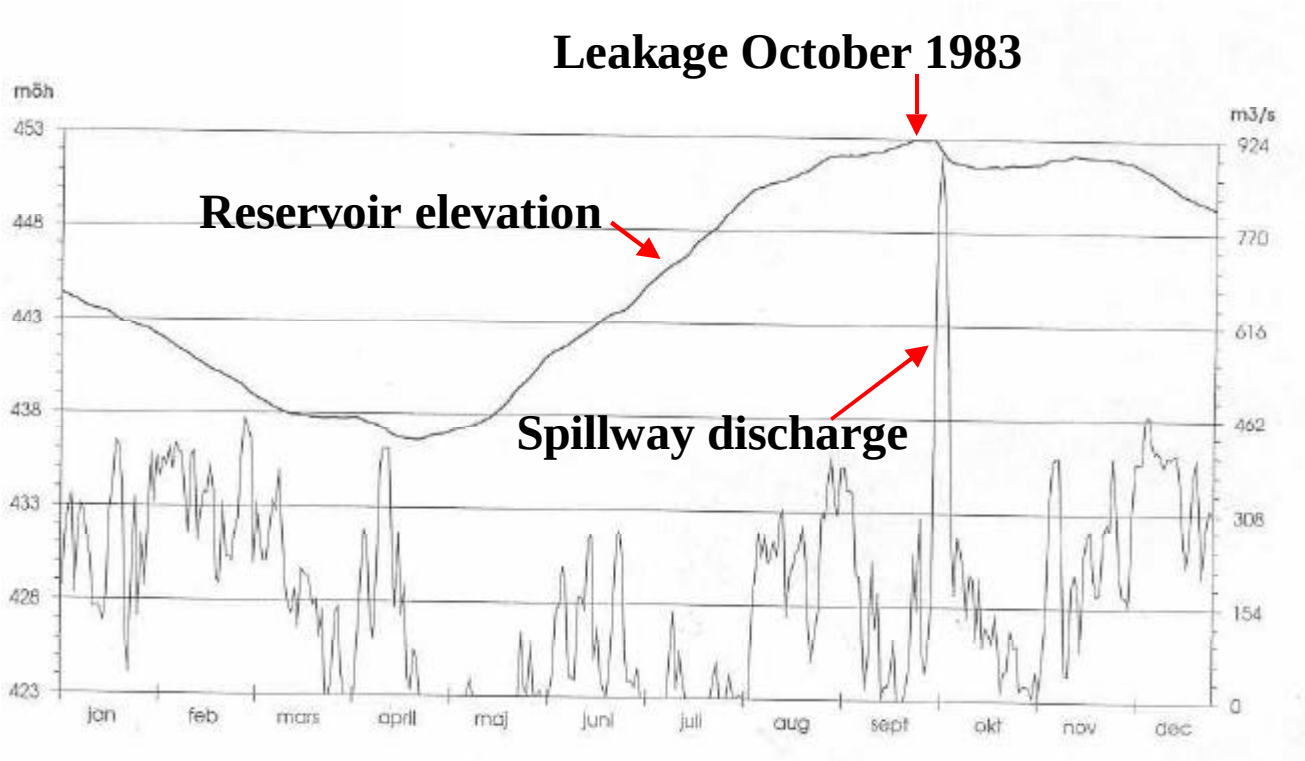


Reservoir level



1. **1983-10-04 sinkhole app. 30 m3 in the East Dam (0/740)**
2. **1989-08-14 sinkhole 4 to 7 m3 in the East Dam in chainage 0/650**
3. **October 1991 turbid water and increased leakage in measuring weir M1 in the East Dam**
4. **August 1993 ”small depression in the East Dam**

Reservoir level



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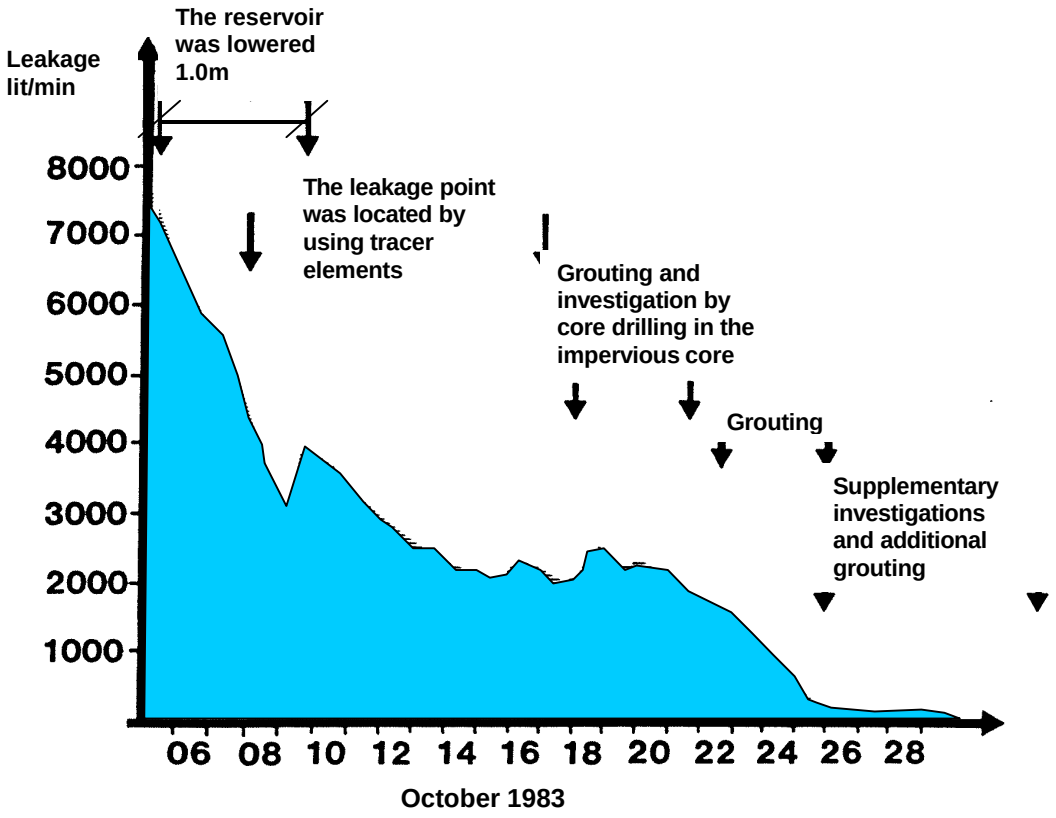
Leakage during the Suorva incident in 1983



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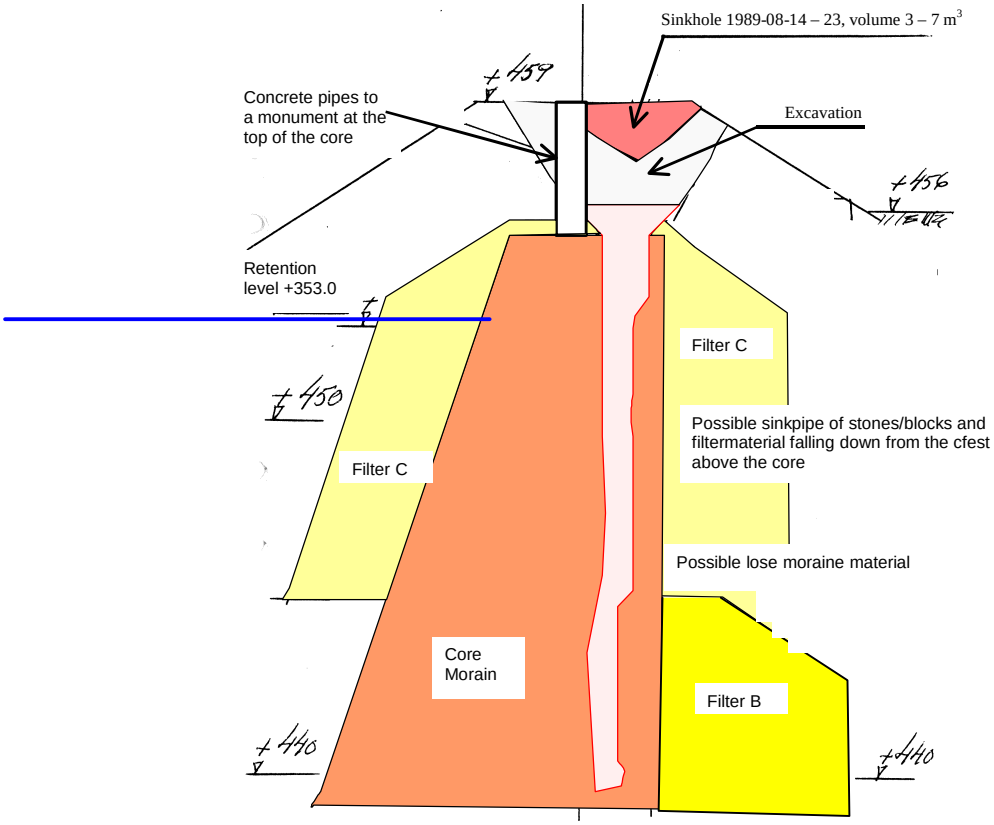
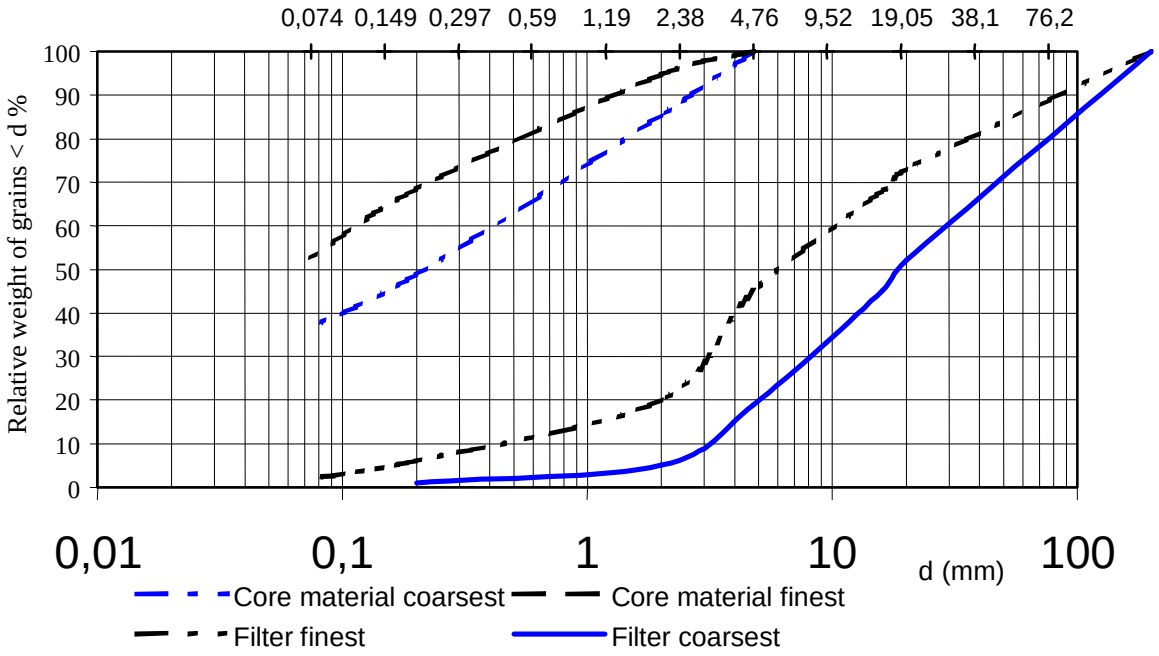
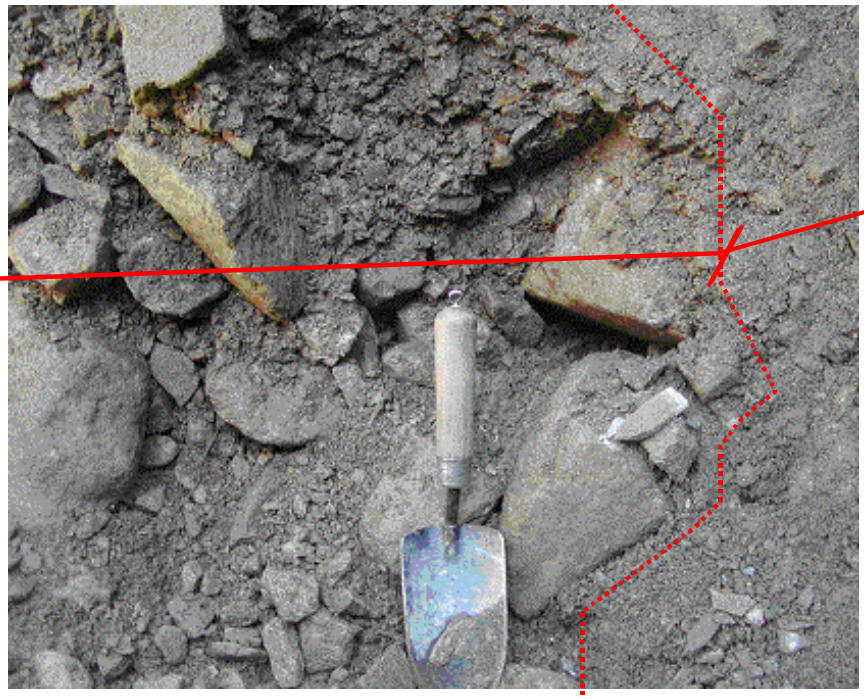
Sinkhole that occurred in 1989

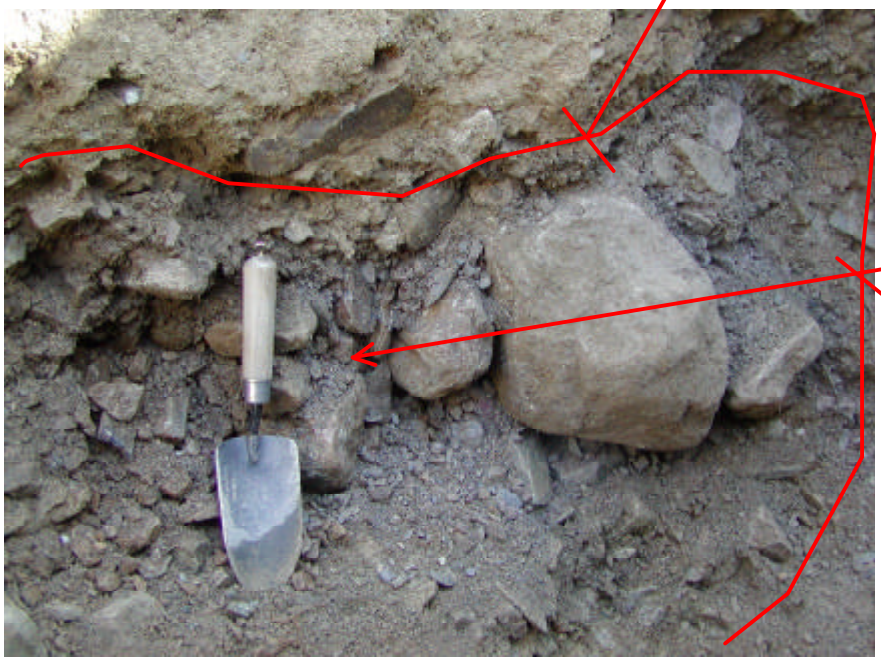


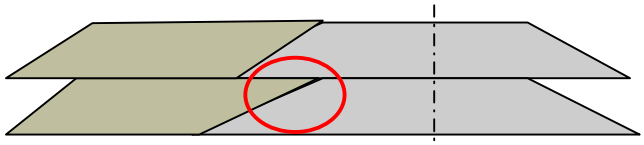
Grain size distributions for downstream filter in the upper part of the dam and moraine in the core



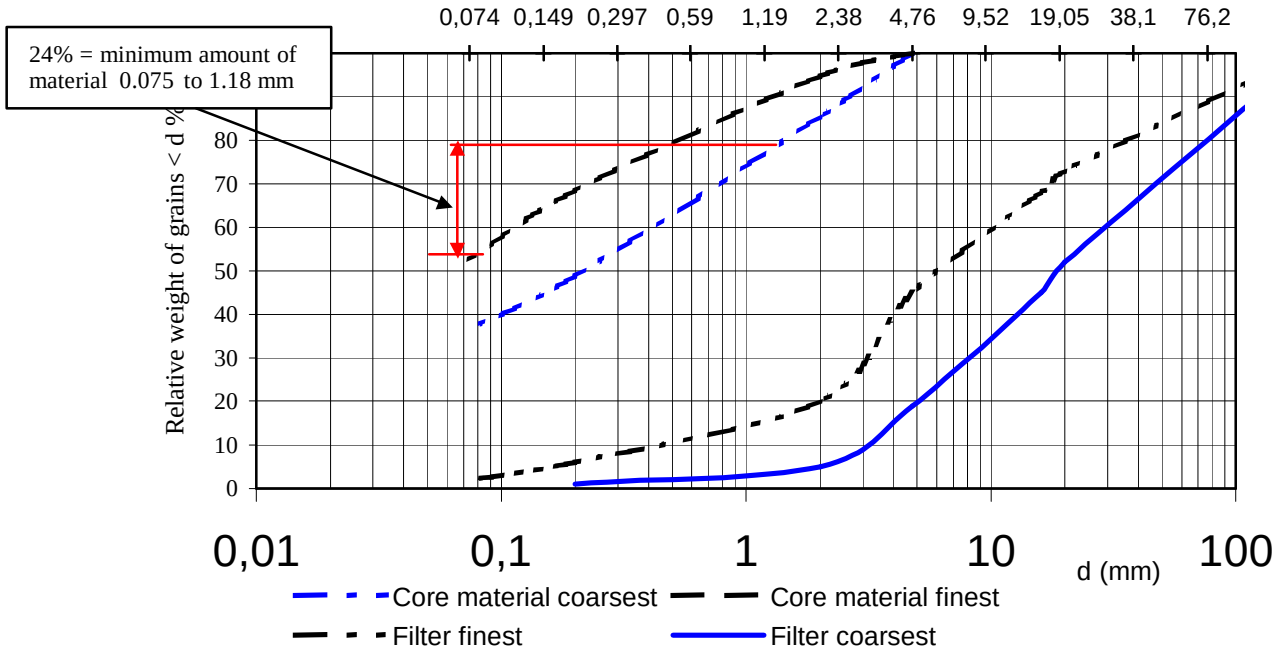
Downstream filter in the upper part of the dam (to the left in the photo) and moraine in the core (to the right in the photo).



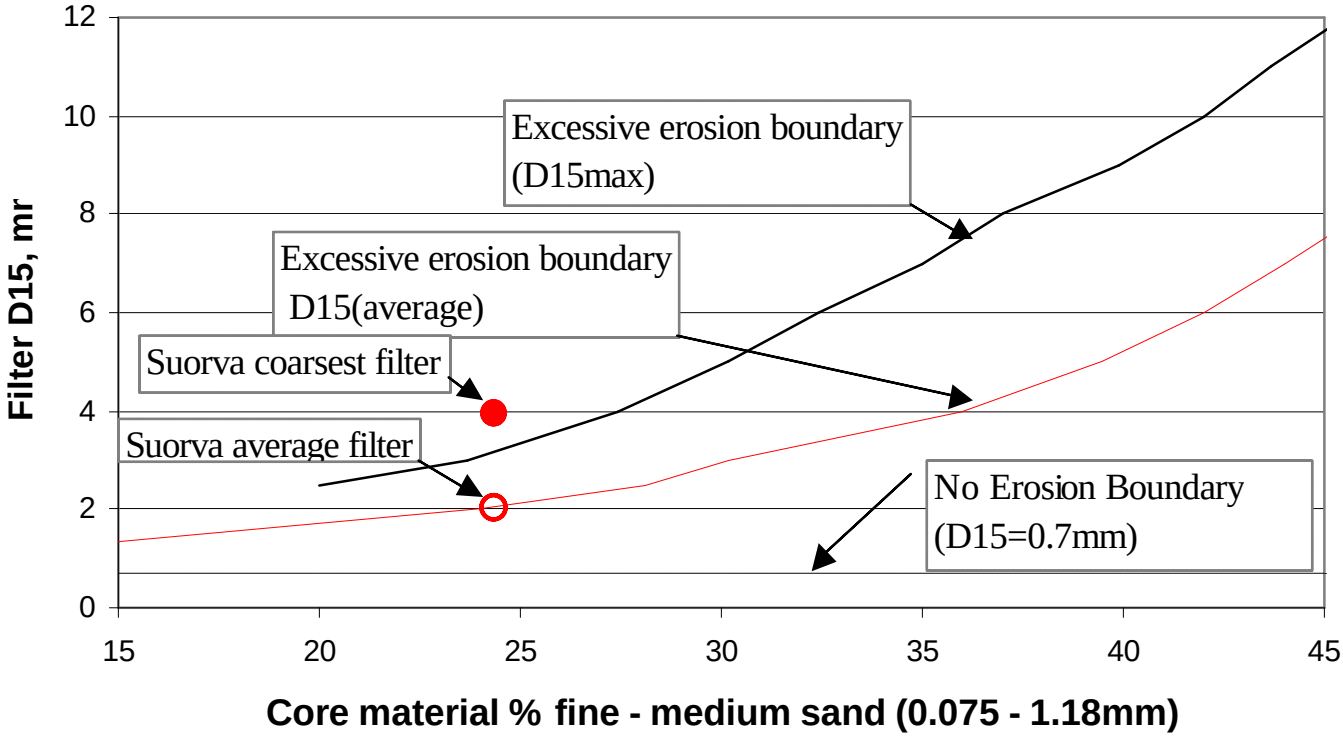

Moraine
”Filter”



Grain size distributions for downstream filter in the upper part of the dam and moraine in the core (Foster and Fell 2001)



Erosion losses of base soils measured in filter tests (Foster and Fell 2001)



Likelihood of filter performance in event of concentrated leak (Foster and Fell 2001)

Type	Comparison of D15 in Dam to Filter Test Erosion Boundaries		Likelihood of the Filter Performance in Event of Concentrated Leak		
	Average D15 in dam	Coarsest D15 in dam	**Seals with no erosion (I)**	**Seals with some erosion (II)**	**Partial or no seal with large erosion (III)**
1	< NE	< NE	Highly likely	Unlikely	Highly unlikely
2	< NE	>NE < EE	Equally likely	Equally likely	Unlikely
3	> NE < EE	< EE	Unlikely	Equally likely	Equally likely
4	> NE < EE	> EE	Unlikely	Unlikely	Likely
5	> EE	> EE	Highly unlikely	Unlikely	Highly likely

NE = No-erosion boundary,

EE = Excessive-erosion boundary,

CE = Continuous Erosion

Coarse rock is placed on top of a transition zone of coarse filter material (West Suorva Dam 2004)

Construction of the berm along the toe almost completed (West Suorva Dam 2004

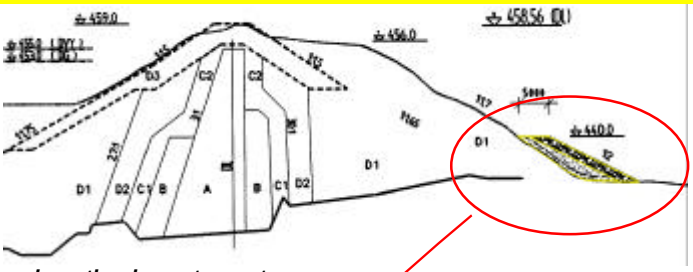
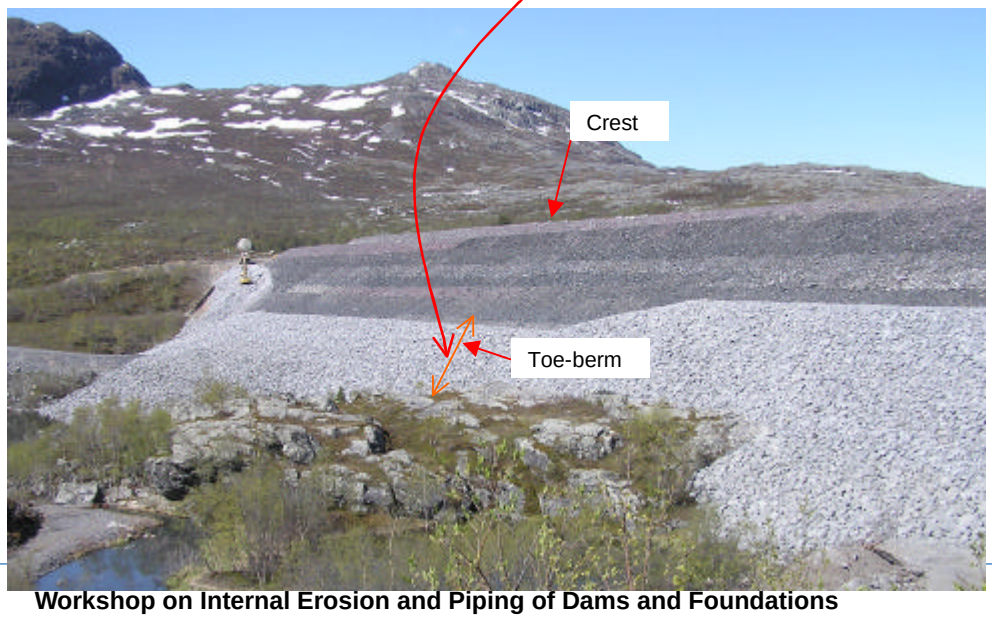


Figure 13 Berm along the downstream toe



Summary and for discussion

1. Process of internal erosion:

All the incidents occurred at high water levels in the reservoir.

The content of fines in the moraine in the impervious core is high (usually >40%).

Downstream filter is coarse with a D15 of approximately 4 mm as a maximum and 2 mm as an average.

In at least one of the incidents the leakage started at the foundation level. The main reason for the internal erosion to continue and create sinkholes is judged to be the coarse filter.

Backward erosion is likely to have occurred in the core.

2. Self-healing

All the leakages self-healed. In one of the incidents grouting and lowering of the reservoir was also used.

Self-healing process was likely caused by collapse of the erosion pipe.

The washing-in of material from the upstream filter into the sinkhole is expected to have assisted in the self-healing process.

3 ACTIVE DAMPENING

During floods with a frequency of 1 in 120 years the gates will be kept closed and the reservoir allowed to be raised to maximum 2 m higher water level than the reservoir ever has been before.

It is judged that sinkholes are likely to be expected in the future, and the active dampening will result in an increased risk of piping.

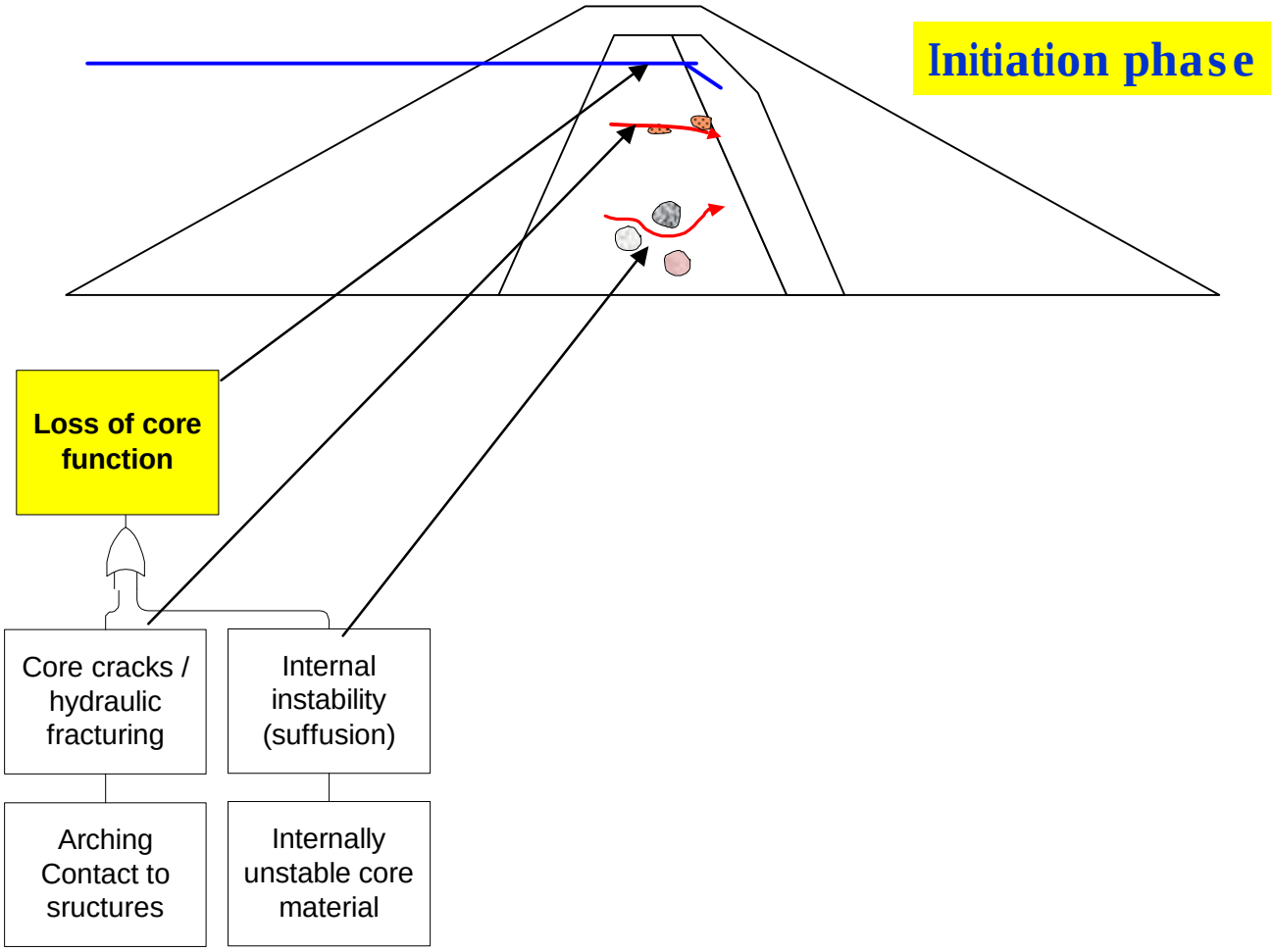
4. Strengthening methods

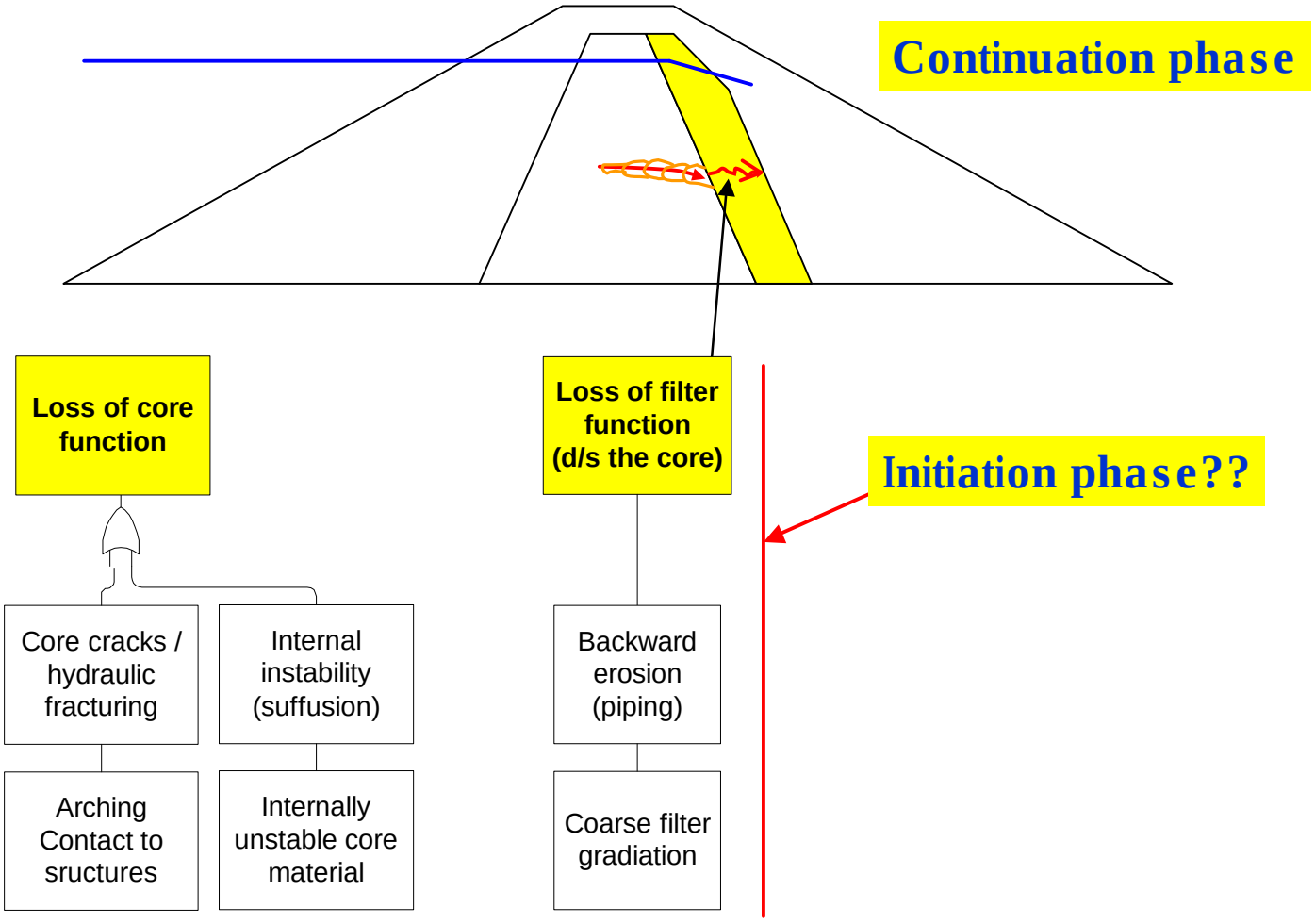
An acceptable measure was found to be to influence the possible process of internal erosion in the breach face.

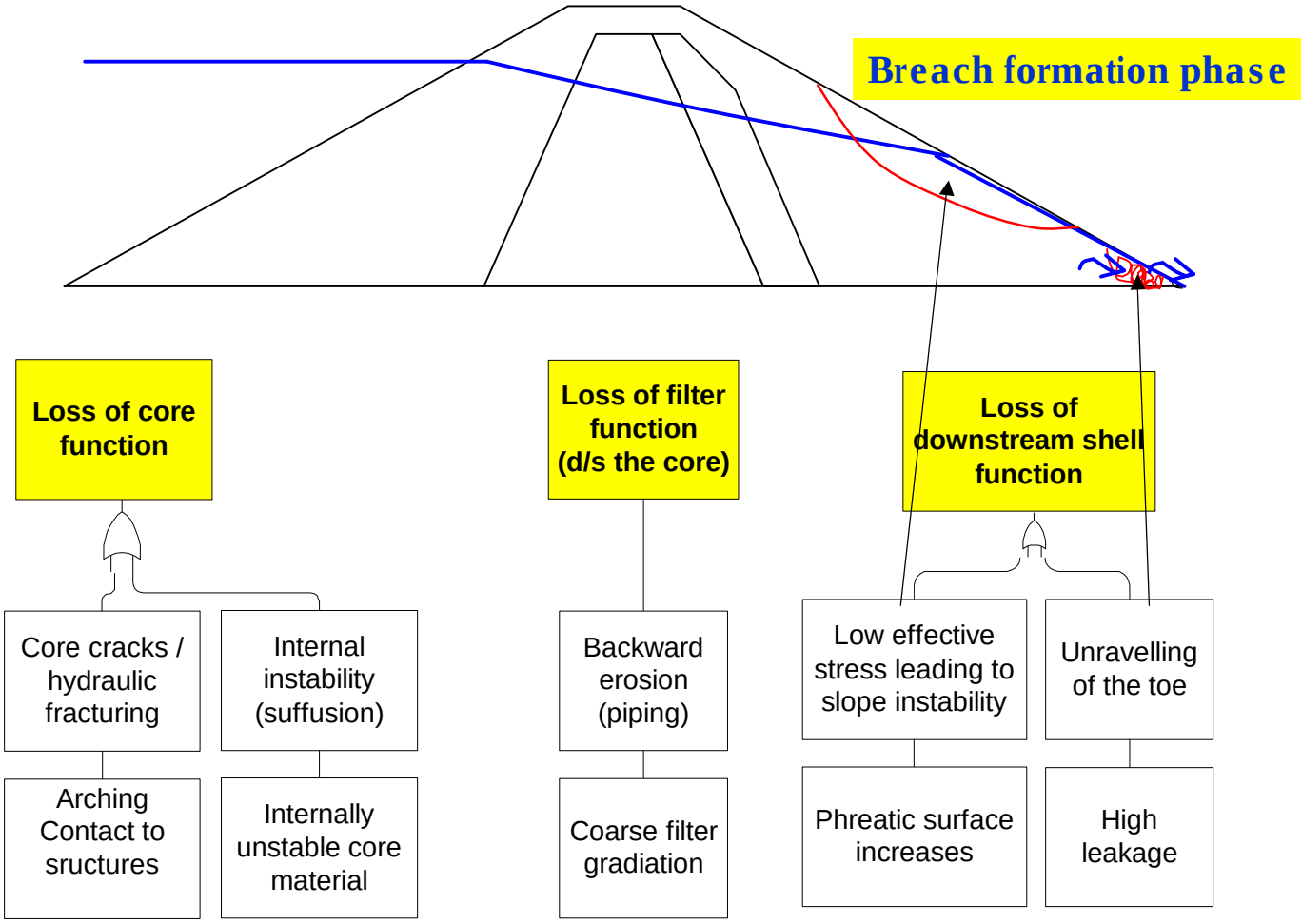
A stabilizing reverse filter of rockfill (a transition layer and a layer of boulders) was placed along the downstream toe and the lower part of the downstream slope.

Is the process always expected to self-heal?

Active dampening: this can be achieved by ***either*** lower the retention level by 2 m, and carry out the dampening up to the present retention level, ***or*** allow the dampening to raise the reservoir 2 m higher than it has never been before.


Initiation phase
Loss of core function
Core cracks / hydraulic fracturing
Internal instability (suffusion)
Arching Contact to sructures
Internally unstable core material


Continuation phase
Loss of core function
Loss of filter function (d/s the core)
Initiation phase??
Core cracks / hydraulic fracturing
Internal instability (suffusion)
Backward erosion (piping)
Arching Contact to sructures
Internally unstable core material
Coarse filter gradiation


Breach formation phase
Loss of core function
Loss of filter function (d/s the core)
Loss of downstream shell function
Core cracks / hydraulic fracturing
Internal instability (suffusion)
Backward erosion (piping)
Low effective stress leading to slope instability
Unravelling of the toe
Arching Contact to sructures
Internally unstable core material
Coarse filter gradiation
Phreatic surface increases
High leakage