Jonathan Fannin

J.Fannin : top-left with UBC research team

Dr. Jonathan Fannin, P.Eng., F.E.I.C., is a Prof. of Civil Engineering at the University of British Columbia. He has more than 25 years experience in teaching, research, and specialist consulting on matters of seepage and internal erosion in zoned earthfill structures. His research advancements are recognised with an IGS Award for laboratory and field contributions to design practice, a CGS Award for the best paper in the Canadian Geotechnical Journal, and a Distinguished Visiting Fellow Award from the U.K. Royal Academy of Engineering. Jonathan has provided specialist technical consulting advice on dams and dikes in Canada, the USA, and South America.

Developments in research and practice: a Canadian perspective

There is longstanding appreciation for the three most significant modes of dam failure being slope instability, overtopping, and internal erosion. The state-of-practice for assessing the susceptibility of a zoned earthfill dam to internal erosion is described with reference to current CDA, ICOLD, and USBR-USACE guidance. An application of the state-of-practice is described, with reference to materials testing and assessment for a dam in Canada. Consideration is then given to the state-of-art in Canada, and the role and contribution of university-industry research to advancing the state-of-practice, most notably with reference to BC Hydro sponsored research at the University of British Columbia.

Developments in research and practice: a Canadian perspective

Jonathan Fannin, PhD, PEng, FEIC
University of British Columbia

ICOLD, Ottawa

14 June 2019

What is internal erosion?

PENMAN'S RANKINE LECTURE

"the most serious… problem relating to embankment dams"

ENGEMOEN'S USBR DATABASE

"… one in every four Reclamation embankment dams"

COURSIER DAM, B.C., CANADA

"… springs,… leaks,… piping, … sinkholes, … crest erosion"

WAC BENNETT DAM, B.C., CANADA

State-of-Practice (BCH)

State-of-Art (UBC/BCH/NSERC)

Dam safety management

PENMAN, A. D. M. (1986). *Géotechnique* **36**, No. 3, 303–348

On the embankment dam

The causes of failure of embankment dams are almost equally divided between

(*a*) erosion by overtopping
(*b*) rotational slips
(*c*) internal erosion.

Improved hydrological studies and methods of predicting flood flows are reducing overtopping risks but there is a geotechnical requirement to improve resistance to accidental overtopping.

Dam safety management

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(*a*) erosion by overtopping
(*b*) rotational slips
(*c*) internal erosion.

Failure by rotational slip usually occurs during construction, before there is water in the reservoir: various aspects will be discussed in the next section.

Dam safety management

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On the embankment dam

The causes of failure of embankment dams are almost equally divided between

(*a*) erosion by overtopping
(*b*) rotational slips
(*c*) internal erosion.

Failure by internal erosion is much more dangerous because it can occur suddenly, with a full reservoir. It is the most serious current geotechnical problem relating to embankment dams.

What is internal erosion?

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USBR database (Engemoen, 2016)

INTERNAL EROSION INCIDENTS AT RECLAMATION DAMS

- Reviews of Reclamation internal erosion incidents indicate there have been a total of 98 known incidents including one failure. Internal erosion incidents have occurred throughout the history of Reclamation embankments, and sometimes multiple times at the same dam. The total number of dams that have experienced incidents is 62, or about 1 in every 4 Reclamation embankment dams.
- These incidents are not limited to first filling but can occur at any time in a dam's life. About 30 percent of Reclamation incidents have occurred during the first five years of reservoir operation, and 70 percent of all incidents have occurred after more than five years of successful operation. At least two incidents occurred after more than 90 years of successful operation.

What is internal erosion?

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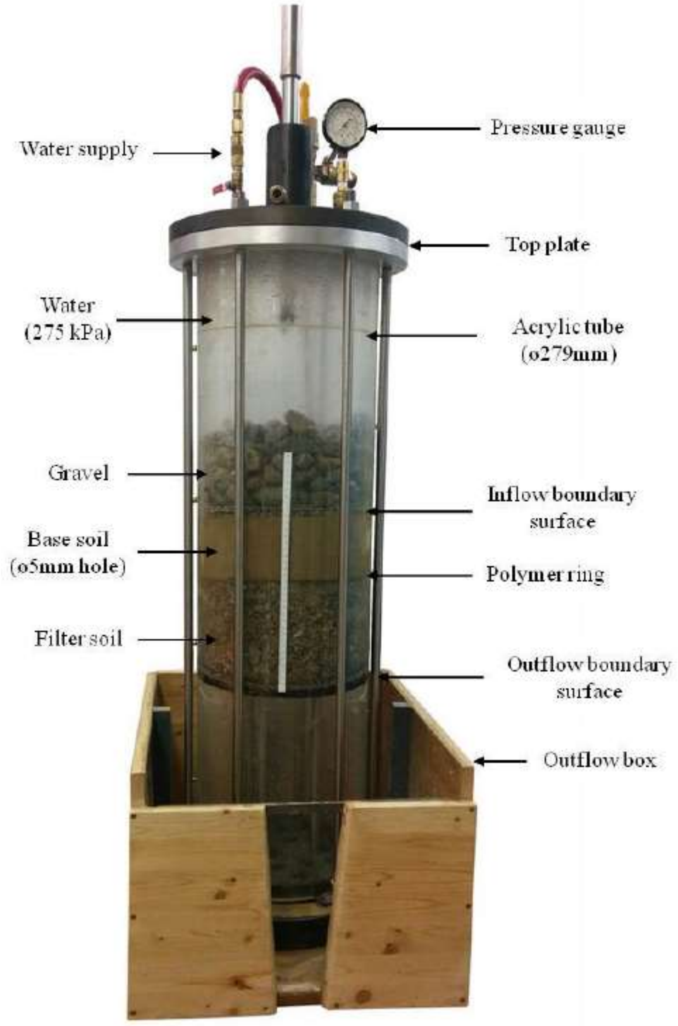
Coursier Dam: springs, leaks, piping, sinkholes, and crest erosion

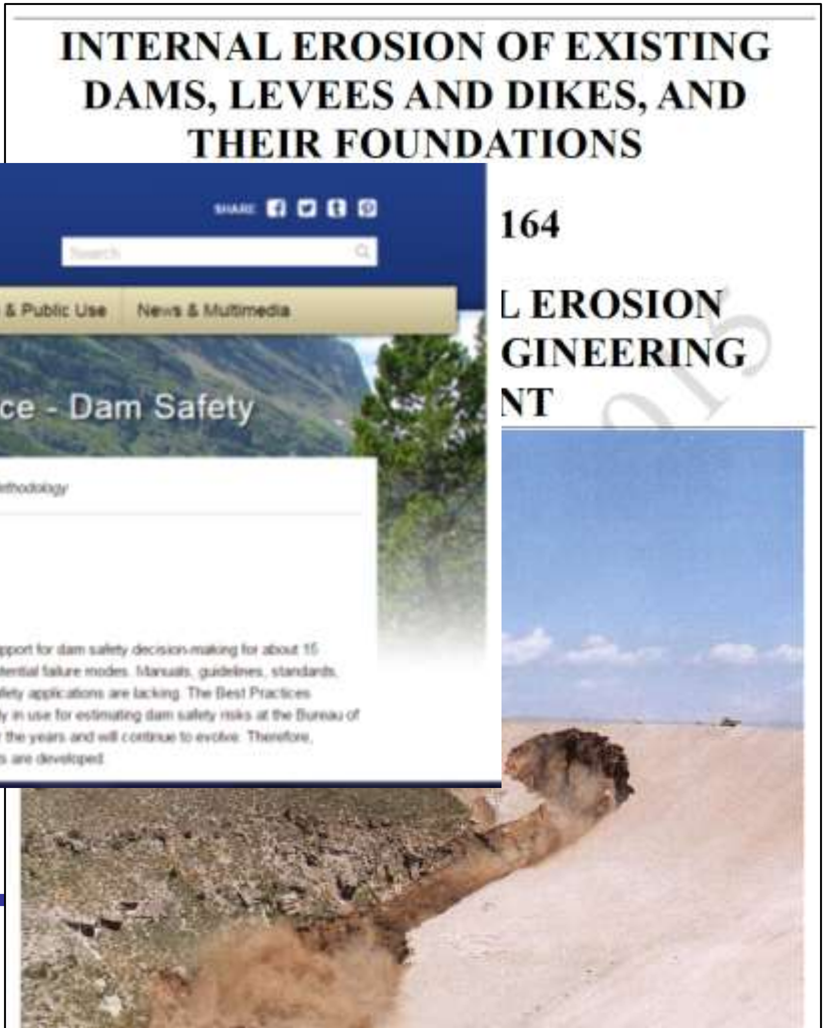
Date	Incident	Response
1963-69	Seepage and springs at downstream toe	Drainage pipes installed when dam was raised in 1969
1969	Downstream face leakage upon first filling of reservoir after the dam was raised	Upstream blanket, additional drains and weirs (1970-71) ($150,000)
1971	Seepage, springs on downstream side	Downstream berm, drains ($150,000)
1972	Leak in the low level outlet causing piping	Joint and erosion caused by piping repaired ($25,000)
1973	Seepage and piping	Drains and weirs installed. Downstream slope flattened to improve stability. Piezometers installed. ($670,000)
1974	Sinkhole discovered	Inspections/observations
1984	Crest erosion	Crest Protection ($150,000)
1984	Depressions, piping and seepage	Inspections/observations
1987	Artesian pressures identified	11 piezometers installed ($43,000)
1988	Piping	Inspections/observations
1989	Piping	Pea gravel filter placed in drain pipes in attempt to reduce piping ($30,000)
1990	Piping	Inspections/observations
1991	Seepage, stability concerns at low level	New valve house, downstream slope flattened ($1,500,000)
1991	Piping	Pea gravel filter replaced in drain pipes ($20,000)
1992-93	Sinkholes and piping Elevated pressures in downstream shell Depressions and artesian pressures	Reservoir drawn down Installation of geomembrane and upstream cut-off (1995-96) Enhanced instrumentation and surveillance ($3,500,000)
1998	Piping and seepage	Reservoir drawn down: Reservoir lowered to maintain Maximum Normal Operating Level of 1274 metres. Alternatives studied. ($150,000)
1999	Sinkhole (probably formed in 1998) on upstream side at about El. 1276.0 m	Dam decommissioned in 2003 ($4,600,000)

Coursier Dam: UBC field & lab study



What is internal erosion?

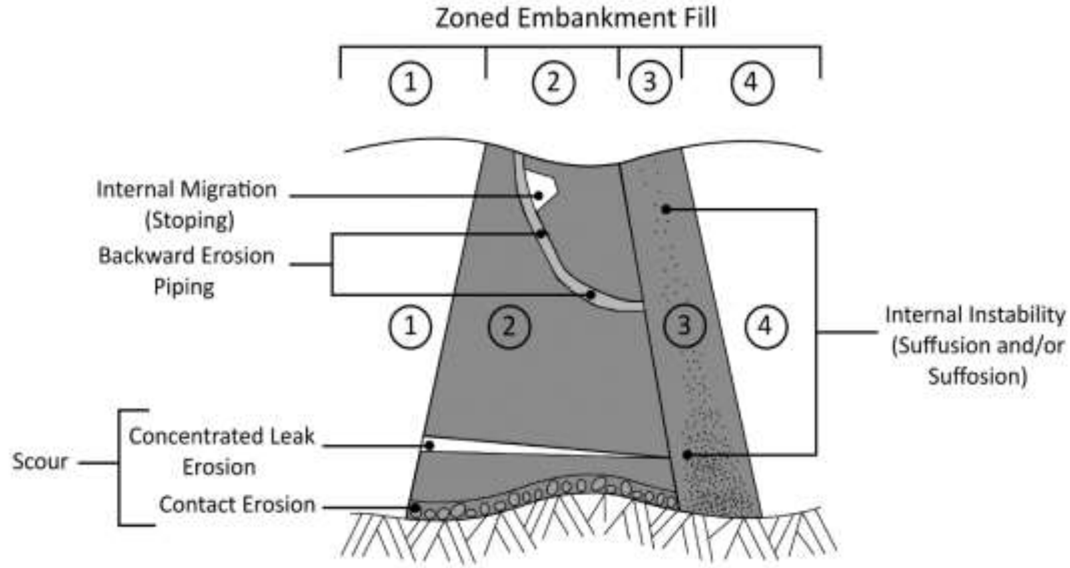
… it is likely the greatest dam safety risk at many sites



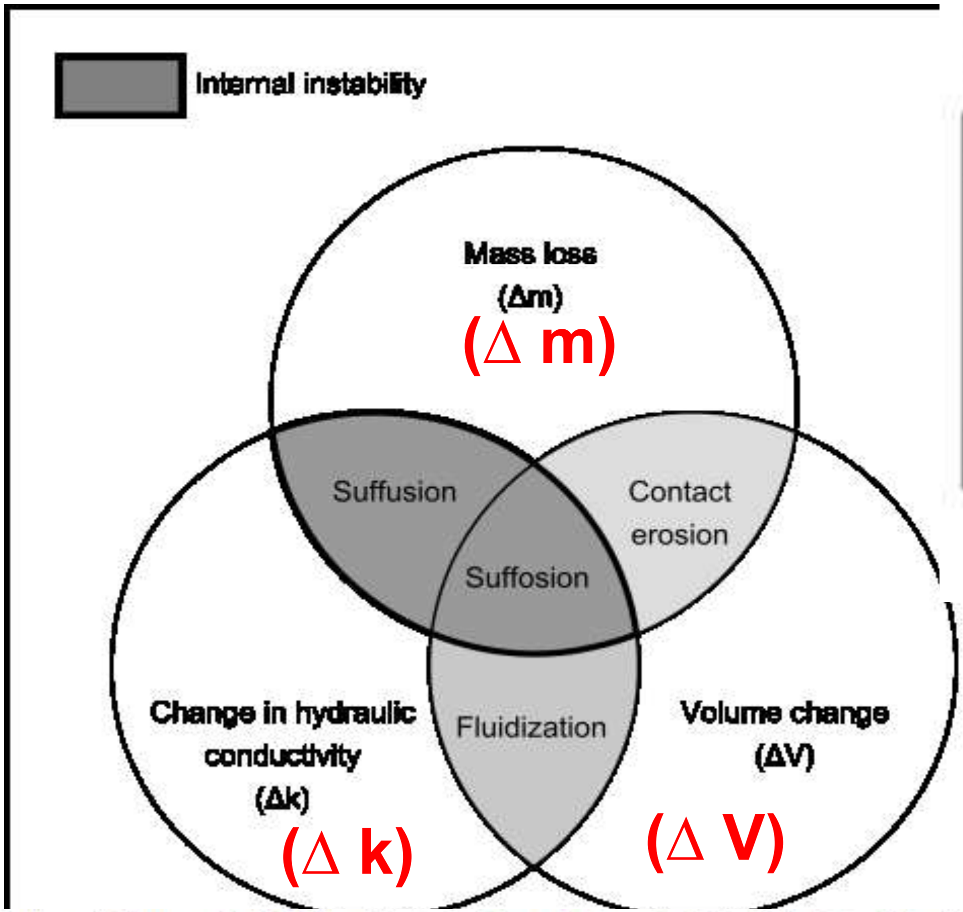
Terminology: USBR-USACE (2015)

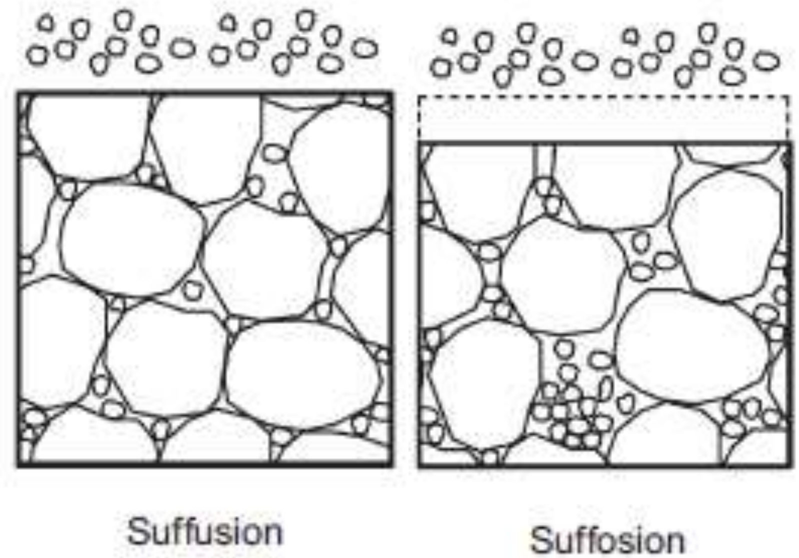
Table IV-4-1. Mechanisms of Internal Erosion

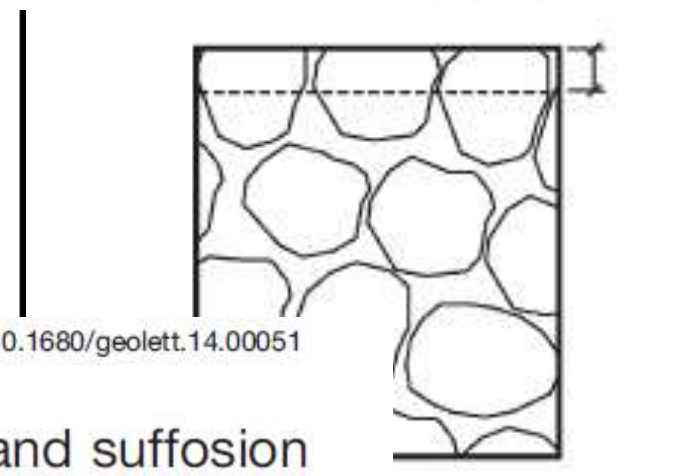
USACE (adapted from ICOLD)	Reclamation
(Note: Reclamation's description of the BEP mechanism is applicable to	**Backward erosion piping (BEP)**: Occurs when soil erosion (particle detachment)
(Note: Reclamation's description of the	**Internal migration (stoping)**: Occurs
Concentrated leak erosion: involves erosion of the walls of an opening (crack)	**Scour**: Occurs when tractive seepage forces along a surface (i.e., a crack within
Internal instability (Note: Reclamation's description of the mechanisms for internally unstable soil are applicable to USACE.)	**Internal Instability - Suffusion, and Suffosion**: Both are internal erosion mechanisms that can occur with internally



Internal instability: suffusion & suffosion







Fannin R. J. and Slangen P. (2014) ***Géotechnique Letters*** **4**, 289–294, http://dx.doi.org/10.1680/geolett.14.00051

On the distinct phenomena of suffusion and suffosion

R. J. FANNIN* and P. SLANGEN*

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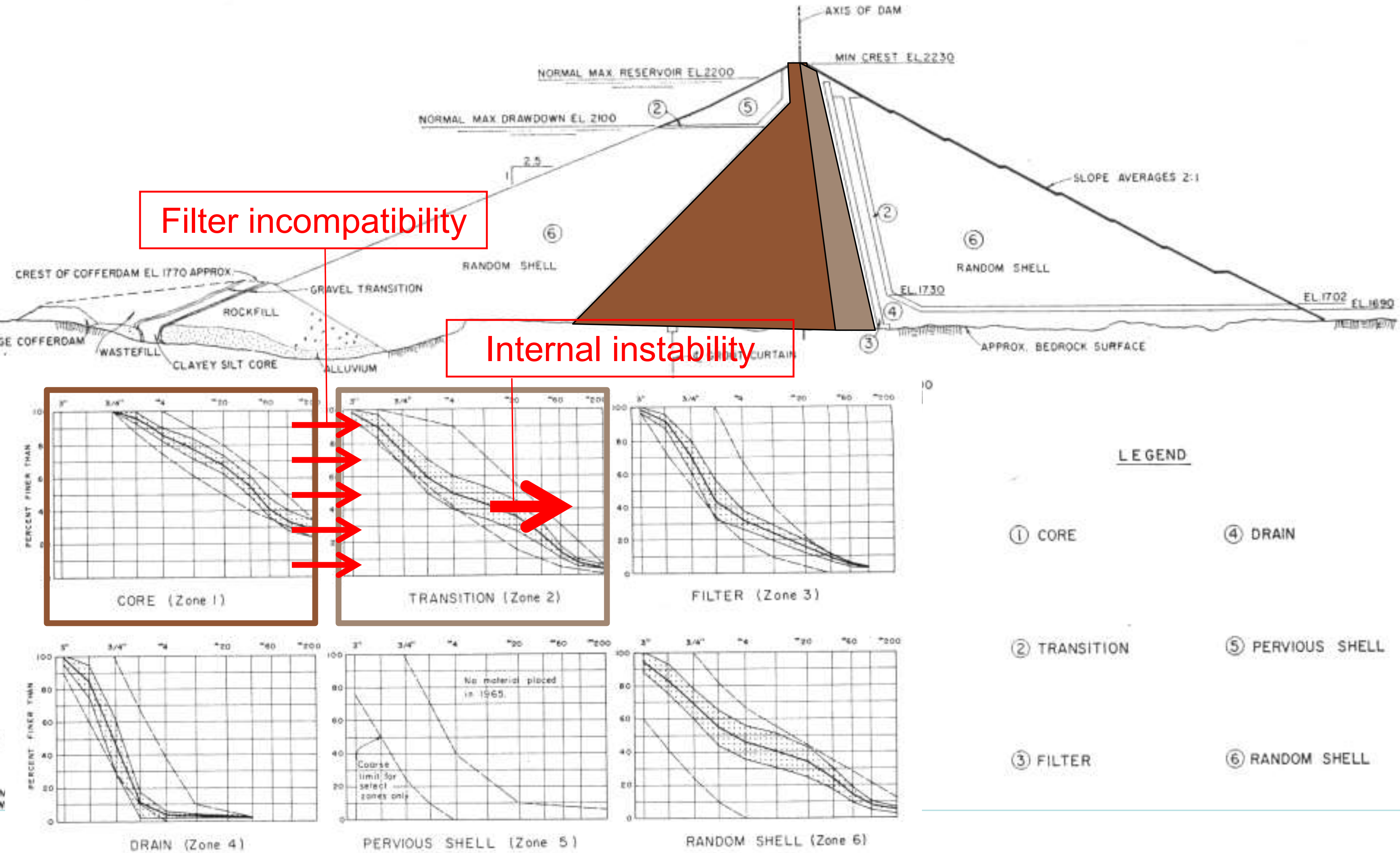
State-of-Art (UBC/BCH/NSERC)

State-of-practice: internal erosion

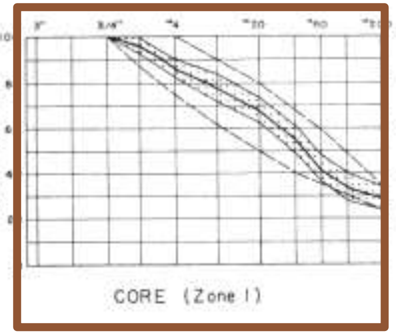


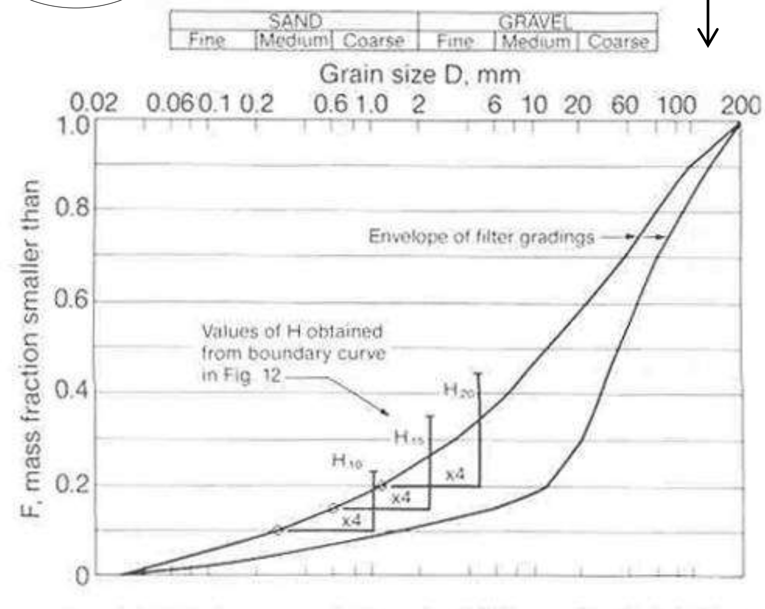
Internal instability: empirical criteria

Empirical screening tools:

Kezdi
Sherard
eg. Kenney-Lau (K&L)
Li-Fannin (L&F) adaptation
Burenkova
Wan-Fell (W&F) adaptation

Internal instability: **(H/F)min**:





Empiricism: laboratory (non-standardized) tests

Test: T-0-25-D (i_{av} = 11)




t = 1180 s

60 s

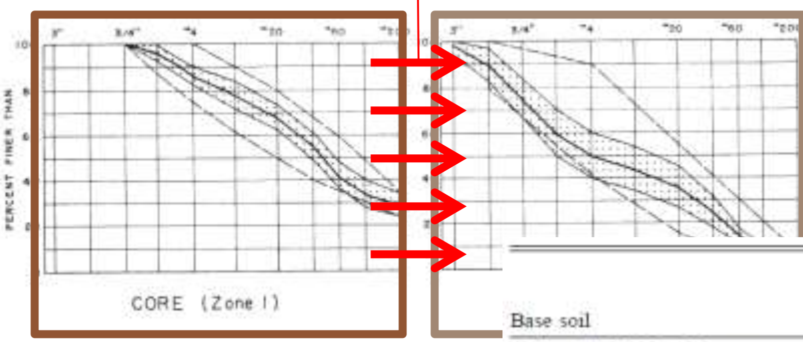
Spatial and temporal progression of internal erosion in cohesionless soil

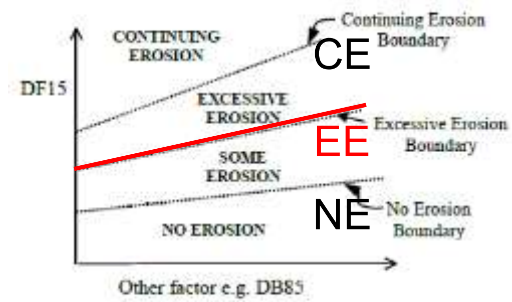
Ricardo Moffat, R. Jonathan Fannin, and Stephen J. Garner

Filter compatibility: empirical criteria

Filter incompatibility: **D15max/D15EE**

Foster-Fell threshold index

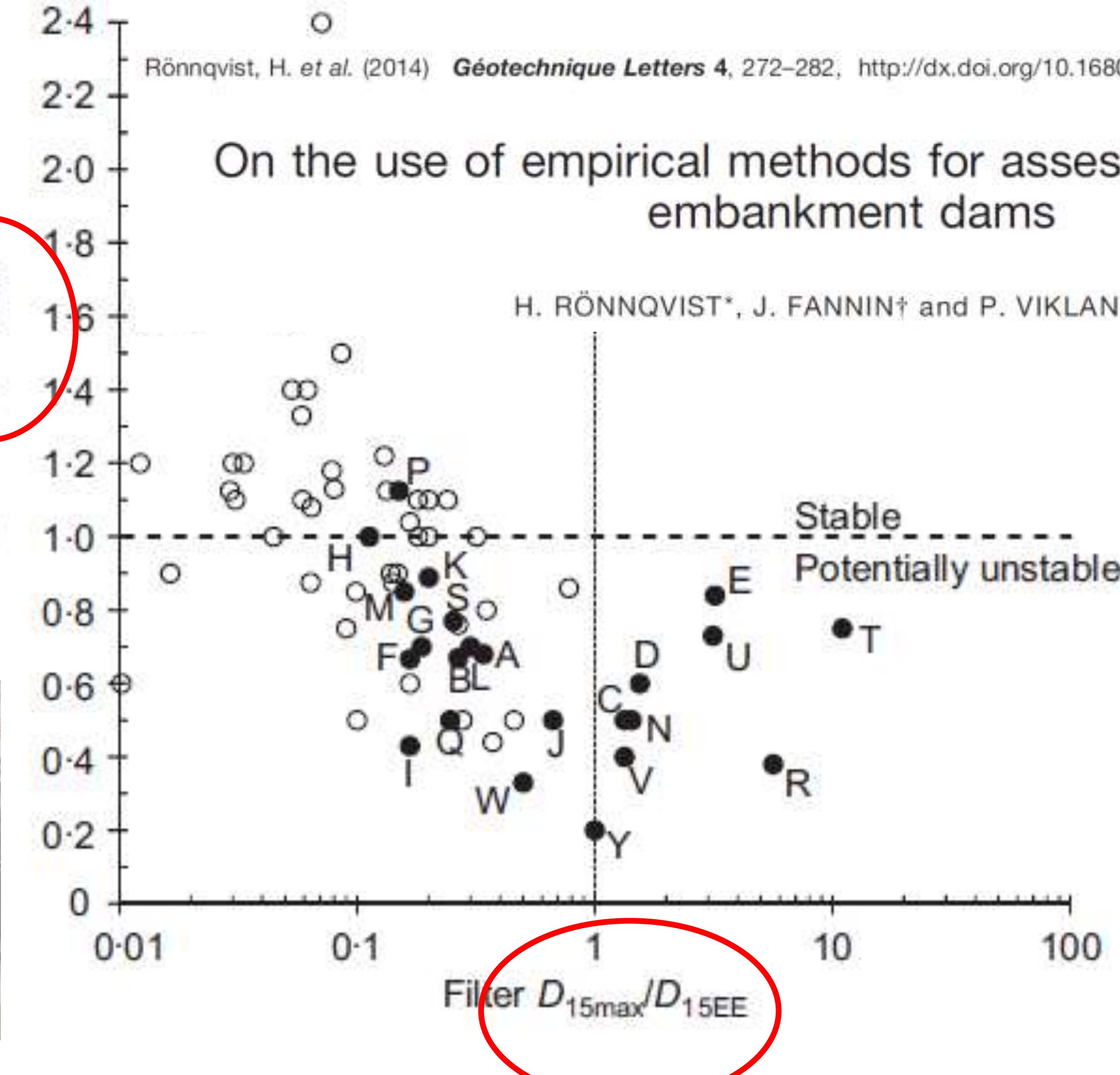




Base soil	Proposed criteria for excessive-erosion boundary	Proposed criteria for continuing-erosion boundary
Soils with DB95 < 0.3 mm	DF15 > 9DB95	DF15 > 9DB95
Soils with 0.3 < DB95 < 2 mm	DF15 > 9DB90	DF15 > 9DB95
Soils with DB95 > 2 mm and fines content >35%	Average DF15 > DF15, which gives an erosion loss of 0.25 g/cm² in CEF test (0.25 g/cm² contour line in Fig. 9); or coarse limit DF15 > DF15, which gives erosion loss of 1.0 g/cm² in CEF test (1.0 g/cm² contour line in Fig. 9)	DF15 > 9DB95
Soils with DB95 > 2 mm and fines content <15%	DF15 > 9DB85	DF15 > 9DB95
Soils with DB95 > 2 mm and fines content 15–35%	DF15 > 2.5DF15design, where DF15design is given by: DF15design = (35 − pp%75µm)(4DB85 − 0.7)/20 + 0.7	DF15 > 9DB95

Note: Criteria are directly applicable to soils with DB95 up to 4.75 mm. For soils with coarser particles, determine DB85 and DB95 using grading curves adjusted to give maximum size of 4.75 mm.

State-of-practice: empirical rules



Advancing the State-of-Art

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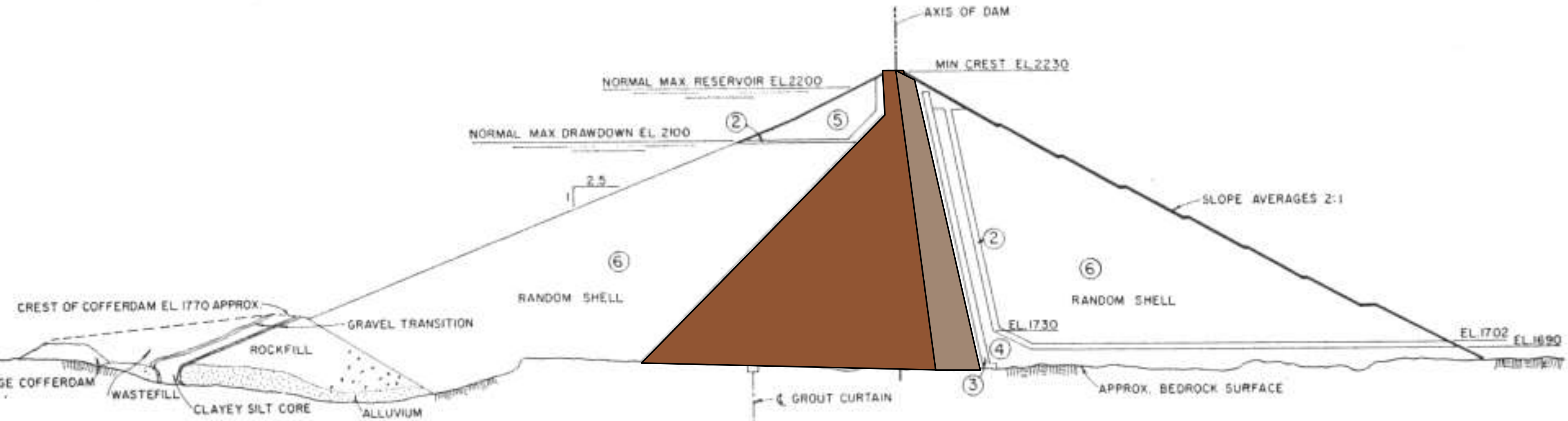
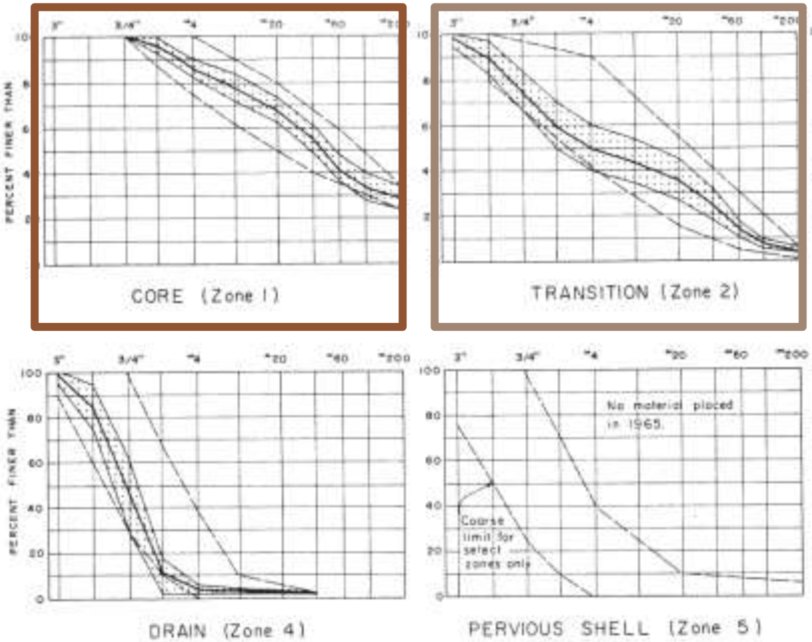
State-of-Art (UBC/BCH/NSERC)

WAC Bennett Dam, Canada

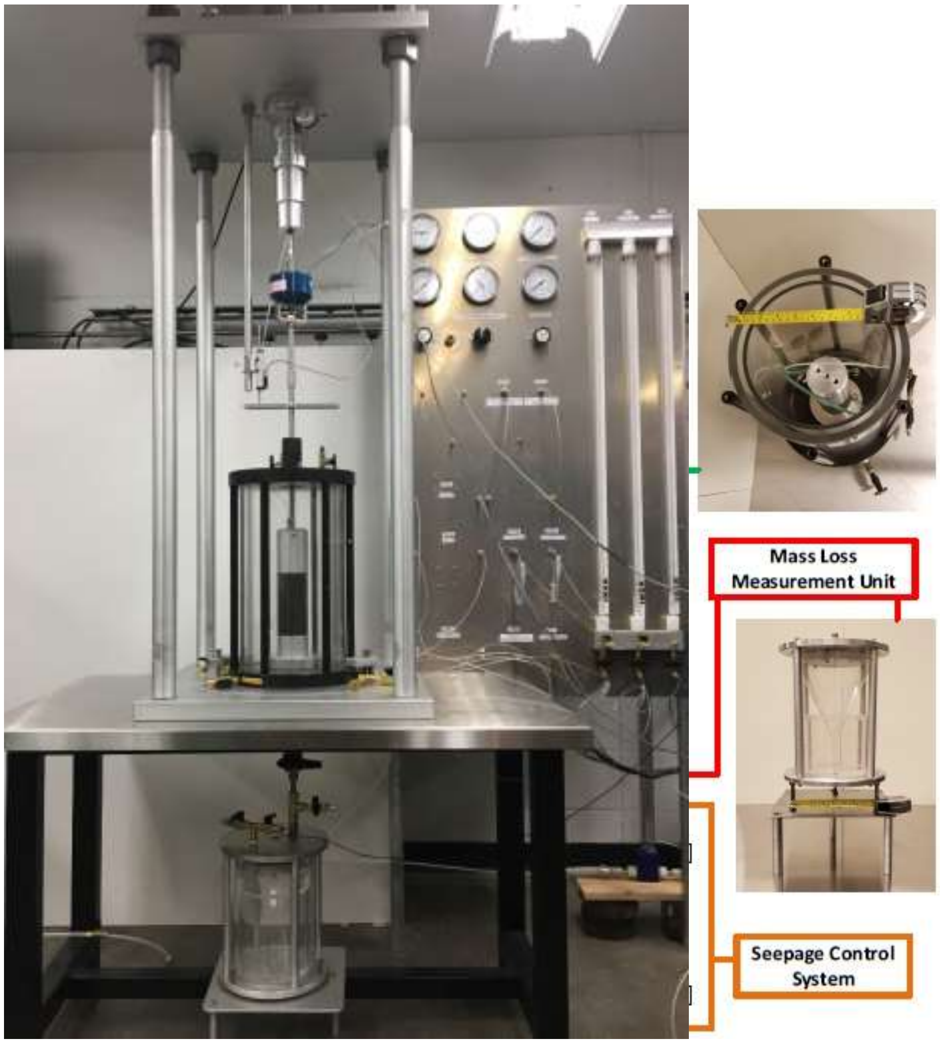




Bennett Dam: UBC soil sampling (Oct. 2018)

State-of-art: advanced triaxial-permeameter (TX-P)

Specimen reconstitution – consolidation – multi-stage seepage - shear



Δ **V**

Δ **m**

Δ **k**

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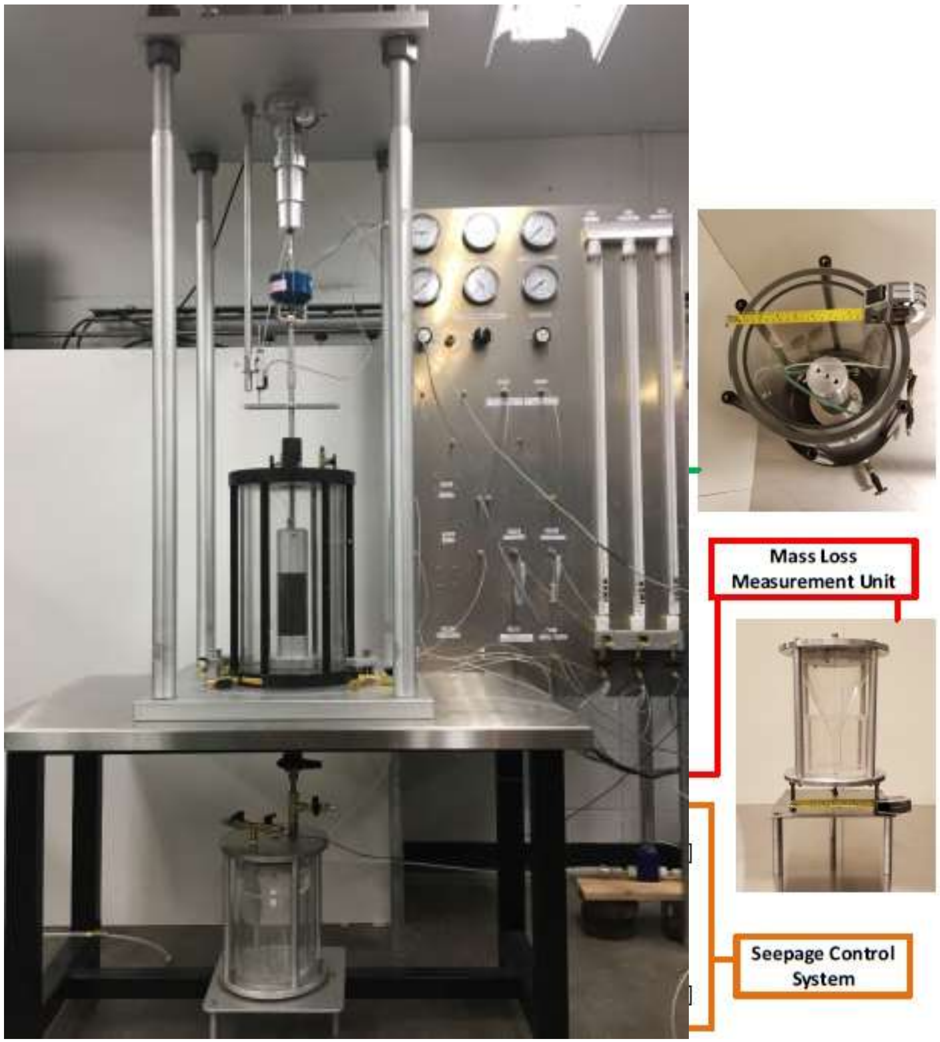
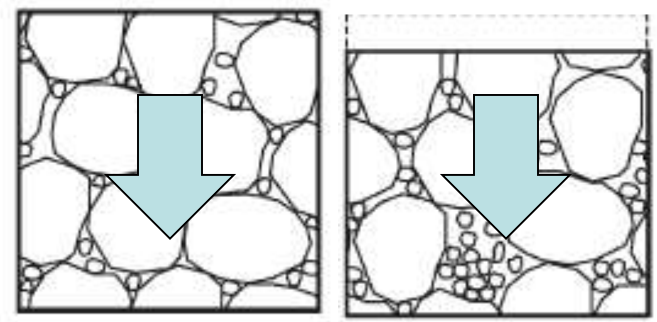


Δ **V**



Suffusion

Suffosion

Δ **m**

Δ **k**

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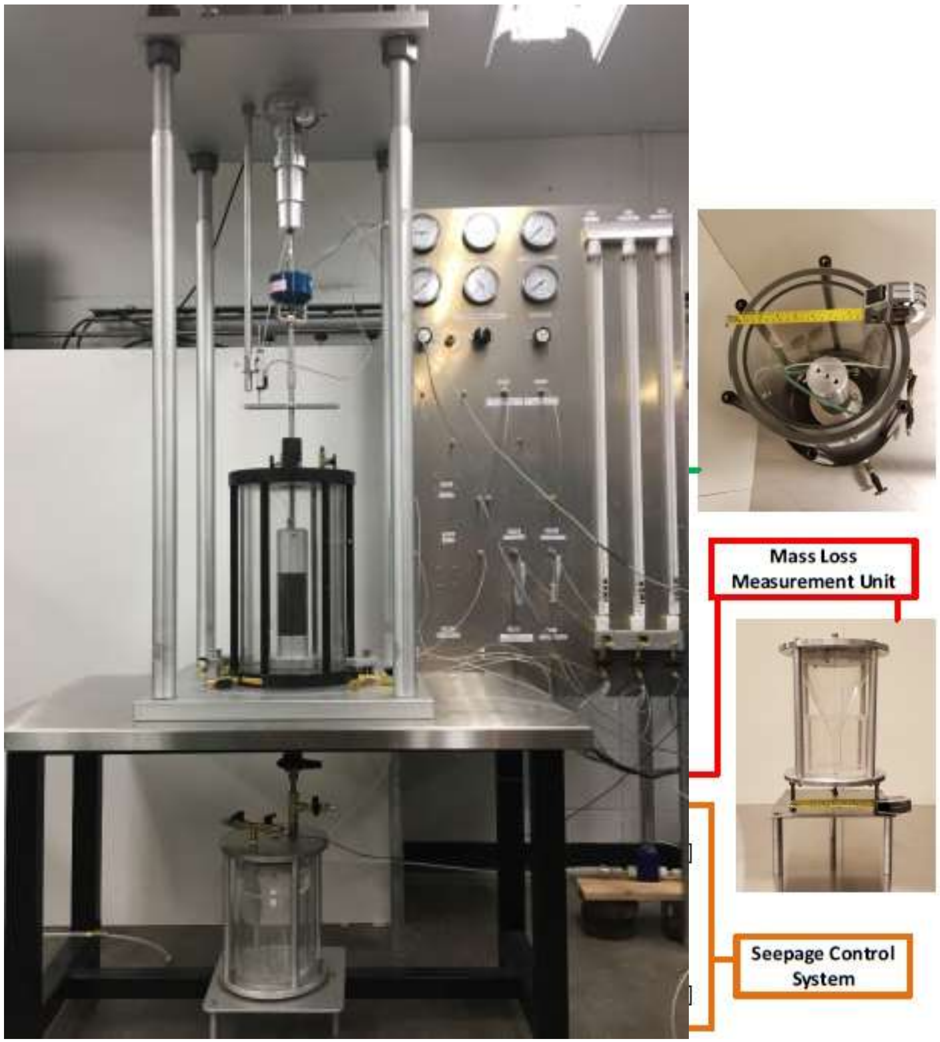
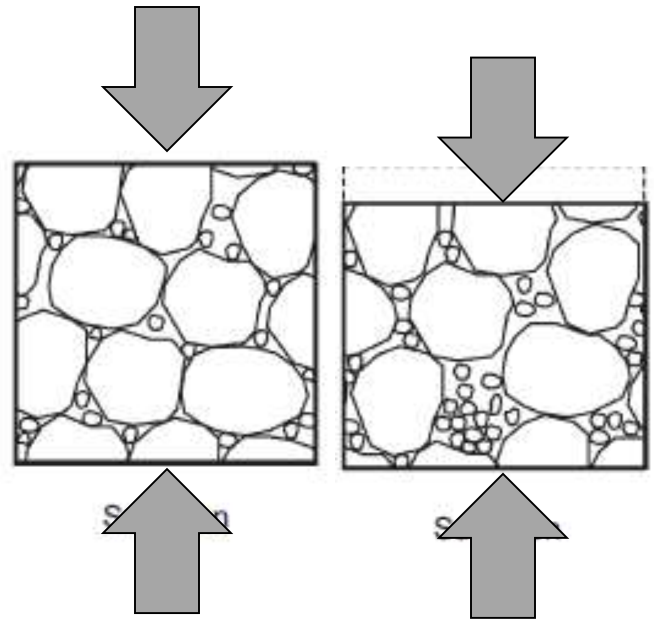


Δ **V**

Δ **m**

Δ **k**



CSSM model

Acknowledgements

The UBC laboratory testing and modelling of internal erosion is funded by BC Hydro, in partnership with the Natural Sciences and Engineering Research Council of Canada (NSERC).

COURSIER DAM, B.C., CANADA
WAC BENNETT DAM, B.C., CANADA

DAM 'M', CANADA
DAM 'C', CANADA
DAM 'S', CANADA
DAMS 'S/R', CANADA
DAM 'I', COLOMBIA
DAM 'S', SWEDEN
DAM 'W', USA

UBC

BC Hydro
Power smart

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