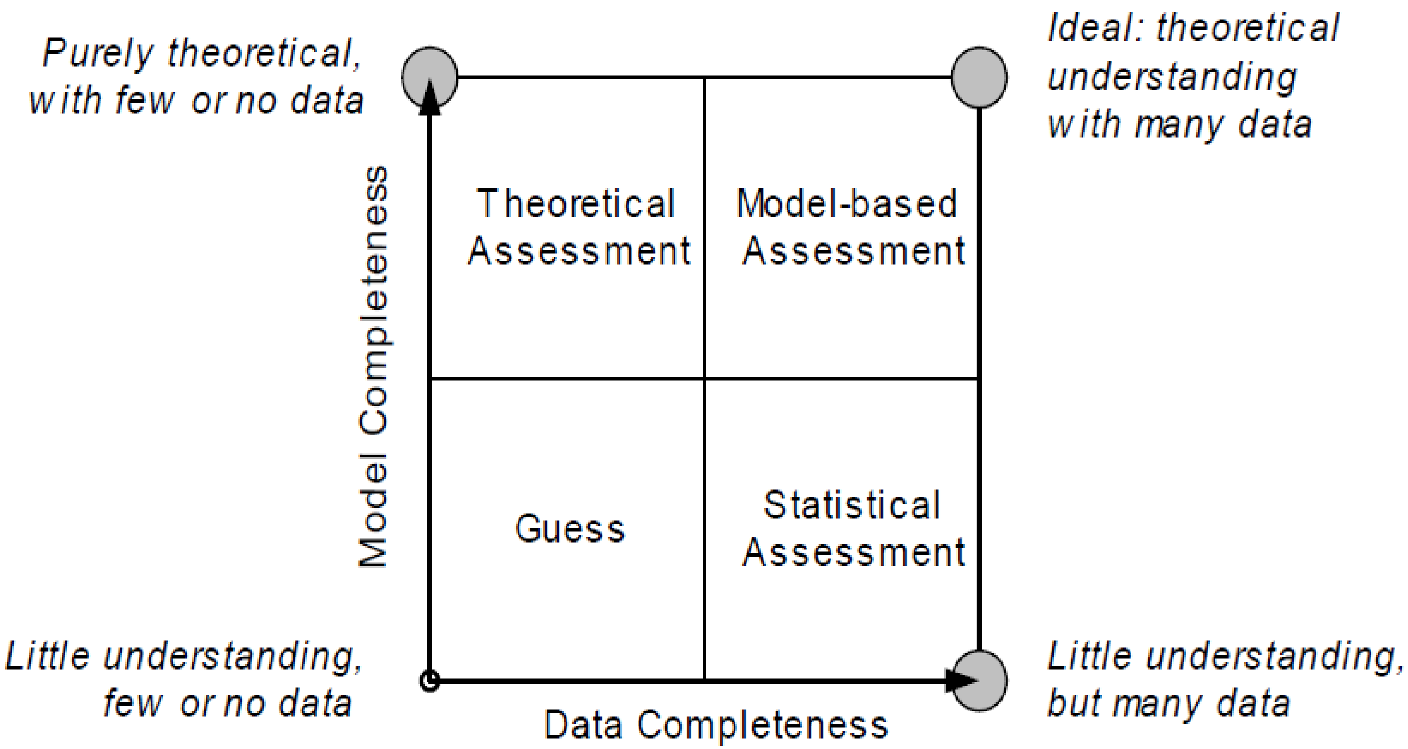
Permeameter testing – the UBC perspective on progress and needs

Jonathan Fannin, Ph.D., P.Eng.
University of British Columbia

Imperial College London, 1 September 2017

Overview

- **<u>Progress</u> to-date**
- **Knowledge gaps and research <u>needs</u>**



The Canadian context…

Canada is the world's biggest producer of hydroelectric power.

British Columbia generates almost 90 % of its energy from renewable hydropower sources.

The Bennett Dam in British Columbia was,
in 1967, the largest embankment dam in the
Mica, and Revelstoke dams) generate over

They represent an enormous investment by
of our public infrastructure, these embankm
potential for water seeping from the reservo
and its foundation.

Internal erosion is a dam safety risk that was not understood at the time of construction - it is now recognised to pose one of the greatest risks to dam safety.

CGS annual conference (2000)

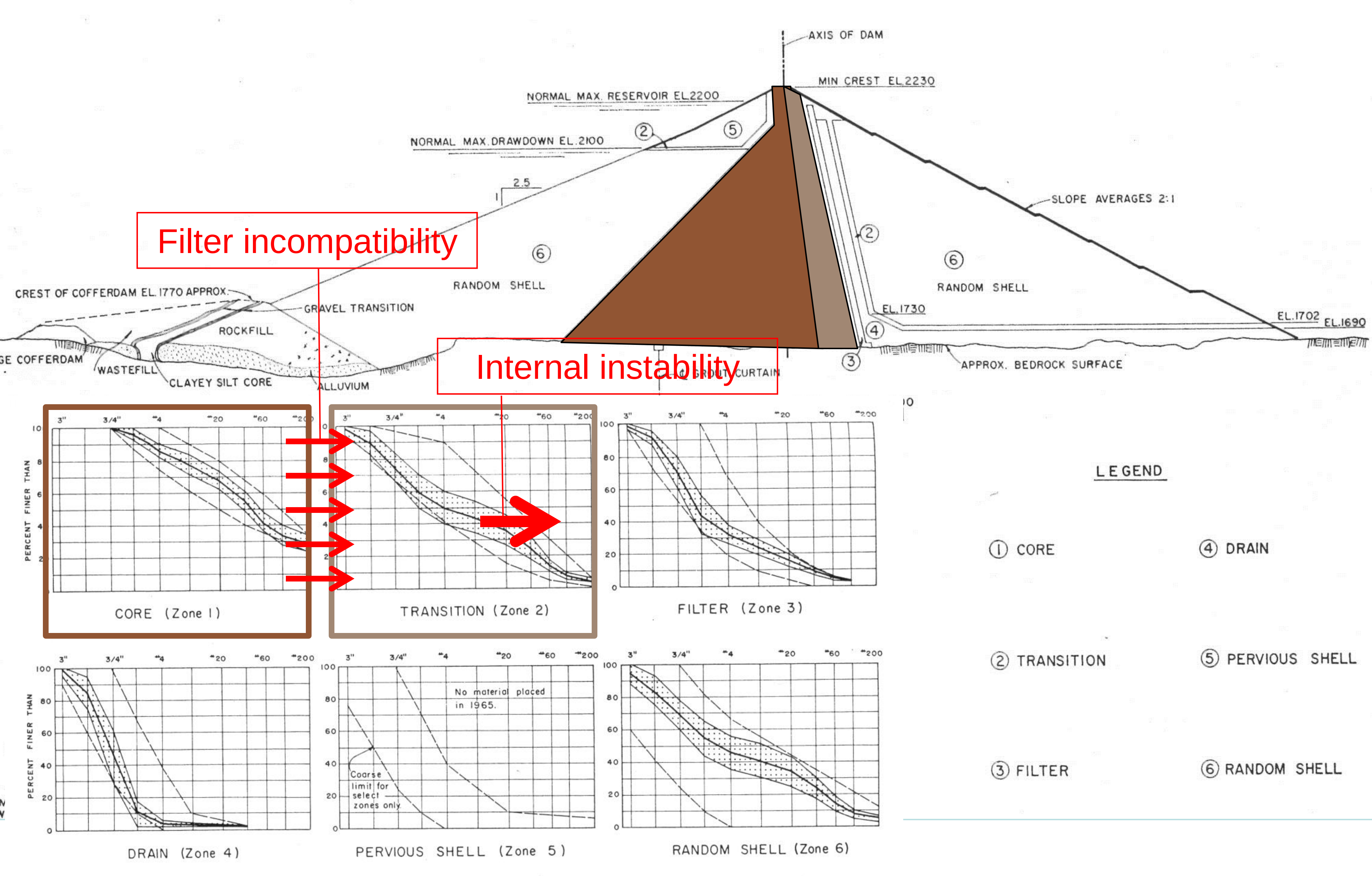
THE WAC BENNETT DAM SINKHOLE INCIDENT

R.A. Stewart, Director of Dam Safety,
BC Hydro, Vancouver, Canada
B.D. Watts, Vice President,
Klohn Crippen Consultants Ltd., Vancouver, Canada

At the time of the sinkhole the freshet was underway and the reservoir was rising towards full pool. In order to halt the reservoir filling and provide additional freeboard as a precautionary measure, the spillway gates were opened on 24 June. For the next 7 weeks about 3,000 m^3/s were released over the spillway (Figure 7) in addition to the 2000 m^3/s through the turbines. This was only the second spill in the 30-year history of the dam. The spill became a tourist attraction as the 3000 m^3/s spill was slightly larger than the typical flow over the Canadian Niagara Falls. Over the 7 weeks, the reservoir dropped only 2 m, reflecting the enormous area of the reservoir.

he crest of the 183 m high
. Following this incident the
ions of the dam. This paper
he crisis, to control the risks
; provide additional details of

Internal erosion



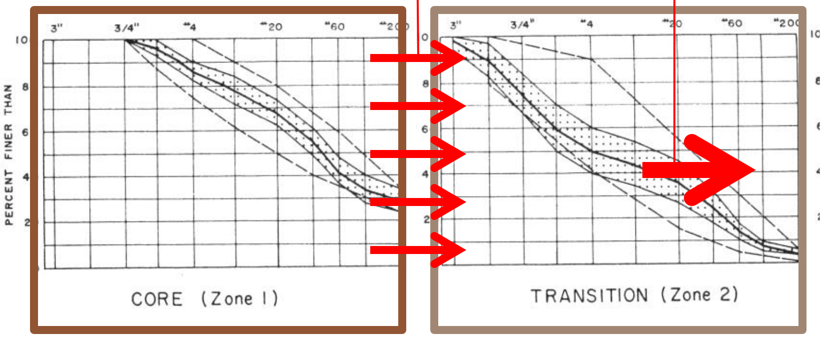
Empirical screening tools

Foster-Fell threshold index

Filter incompatibility: D15max/D15EE

Internal instability: (H/F)min:

Kenney-Lau threshold index

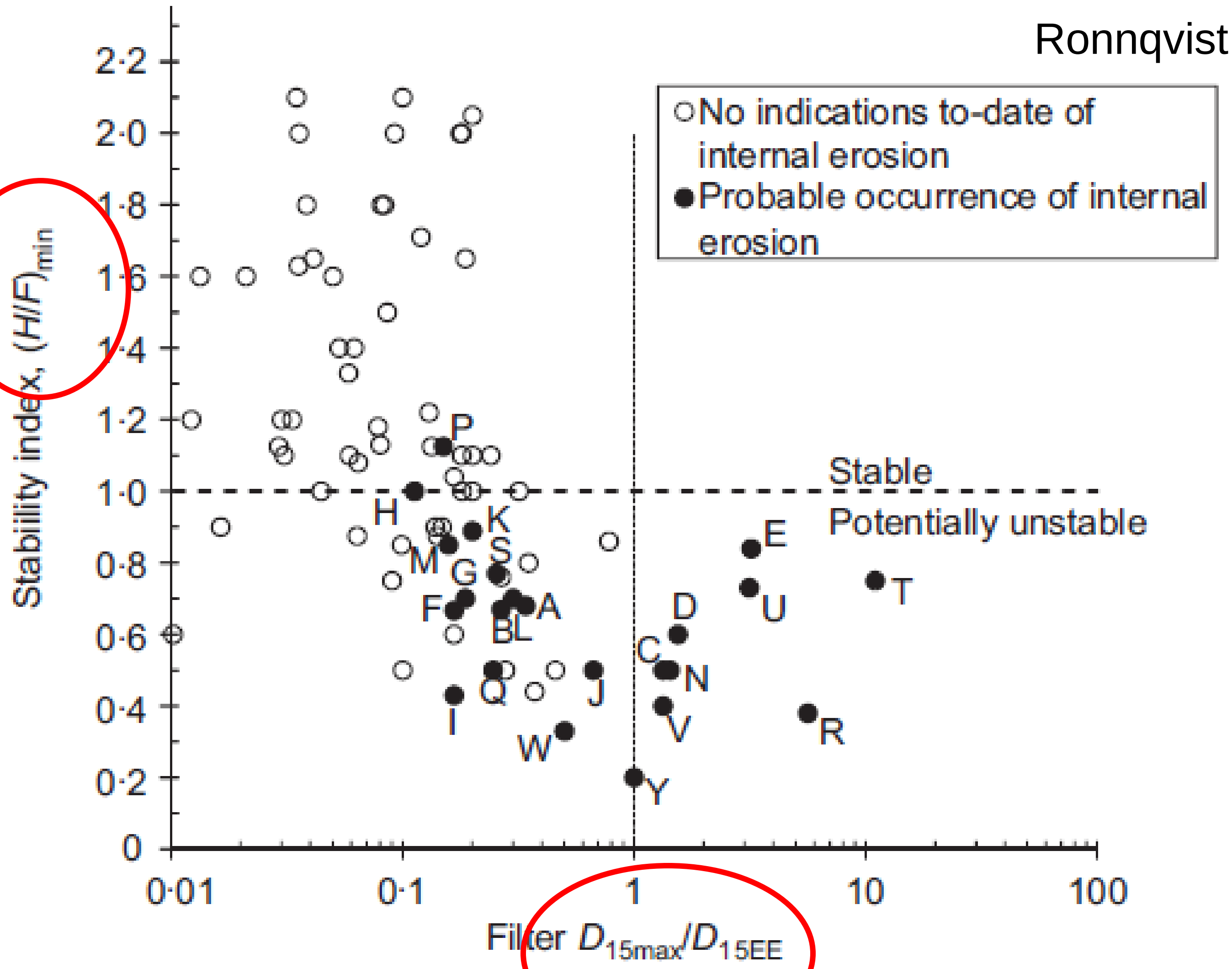


Rönnqvist, H. *et al.* (2014) ***Géotechnique Letters* 4**, 272–282, http://dx.doi.org/10.1680/geolett.14.00055

On the use of empirical methods for assessment of filters in embankment dams

H. RÖNNQVIST*, J. FANNIN† and P. VIKLANDER*

Ronnqvist database



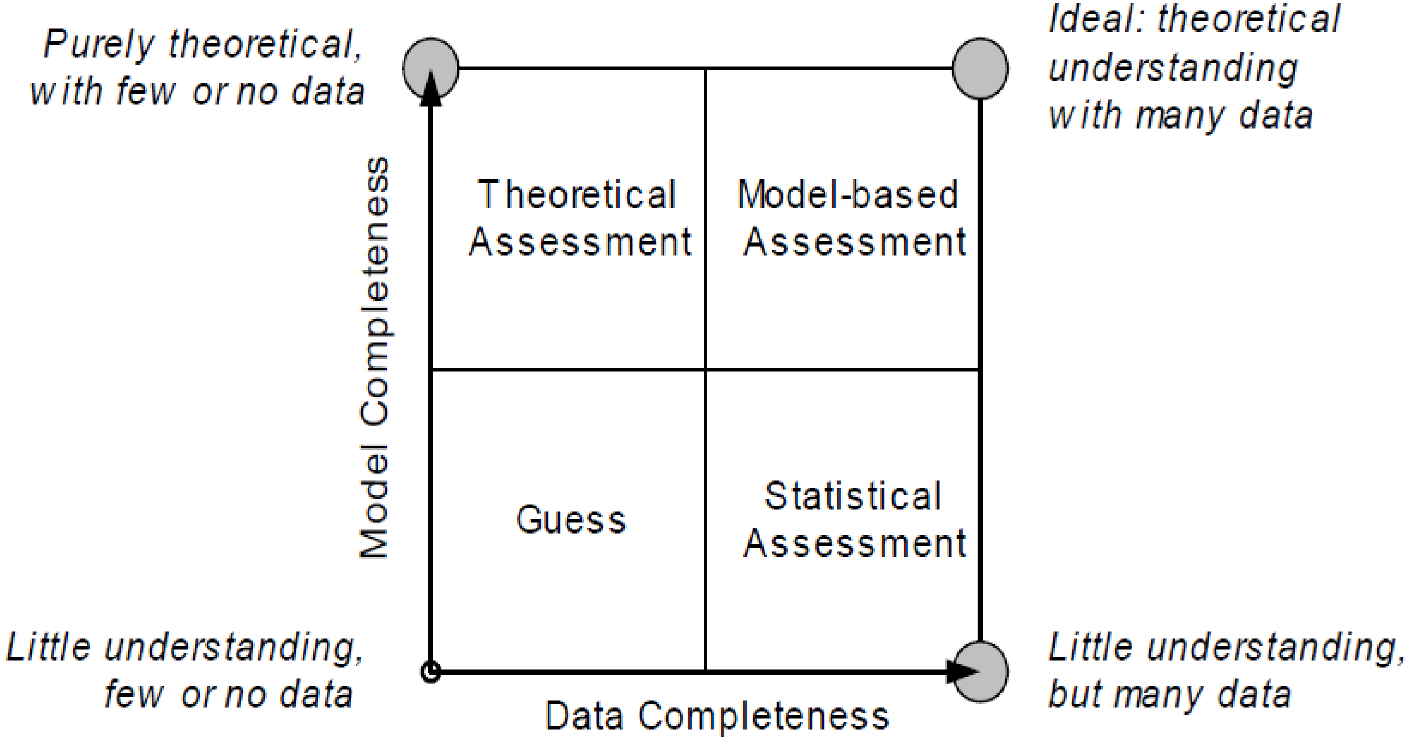
(57 dams)

(23 dams)

On progress and needs…

- **<u>Progress</u> to-date**

- **Knowledge gaps and research <u>needs</u>**



Knowledge gaps: research needs

- Empirical criteria provide a screening tool for evaluating the susceptibility of a gradation to internal instability

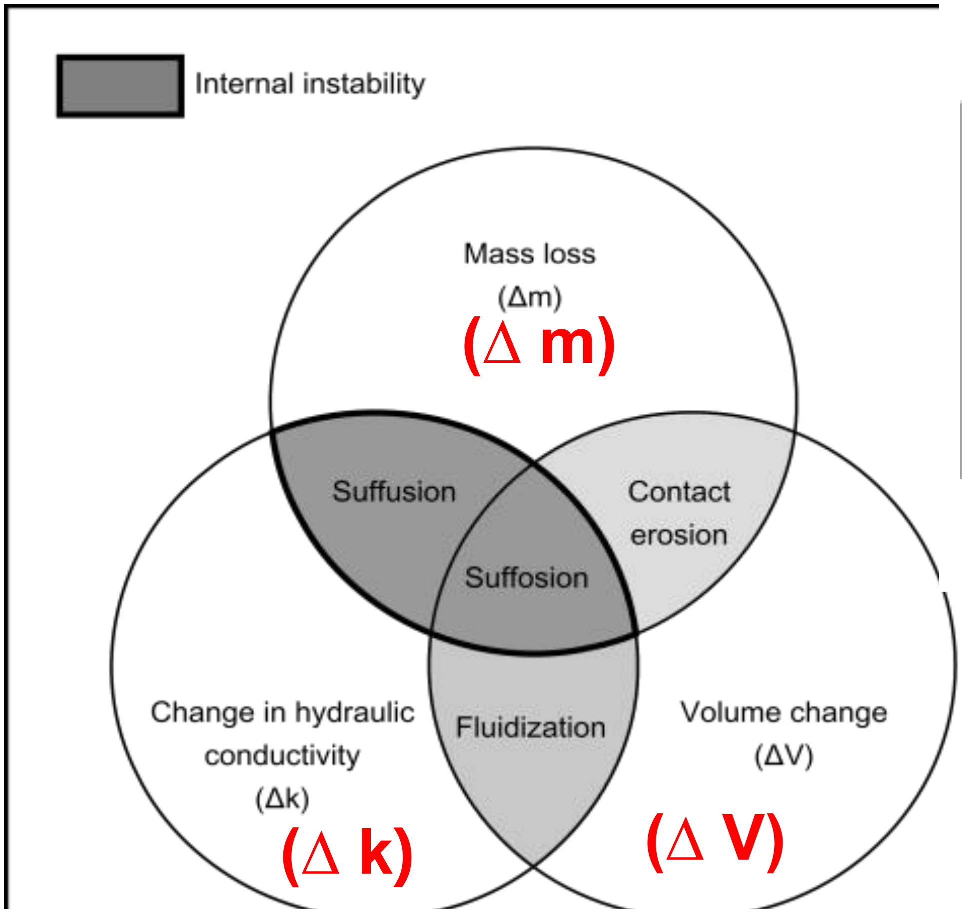
SPATIAL

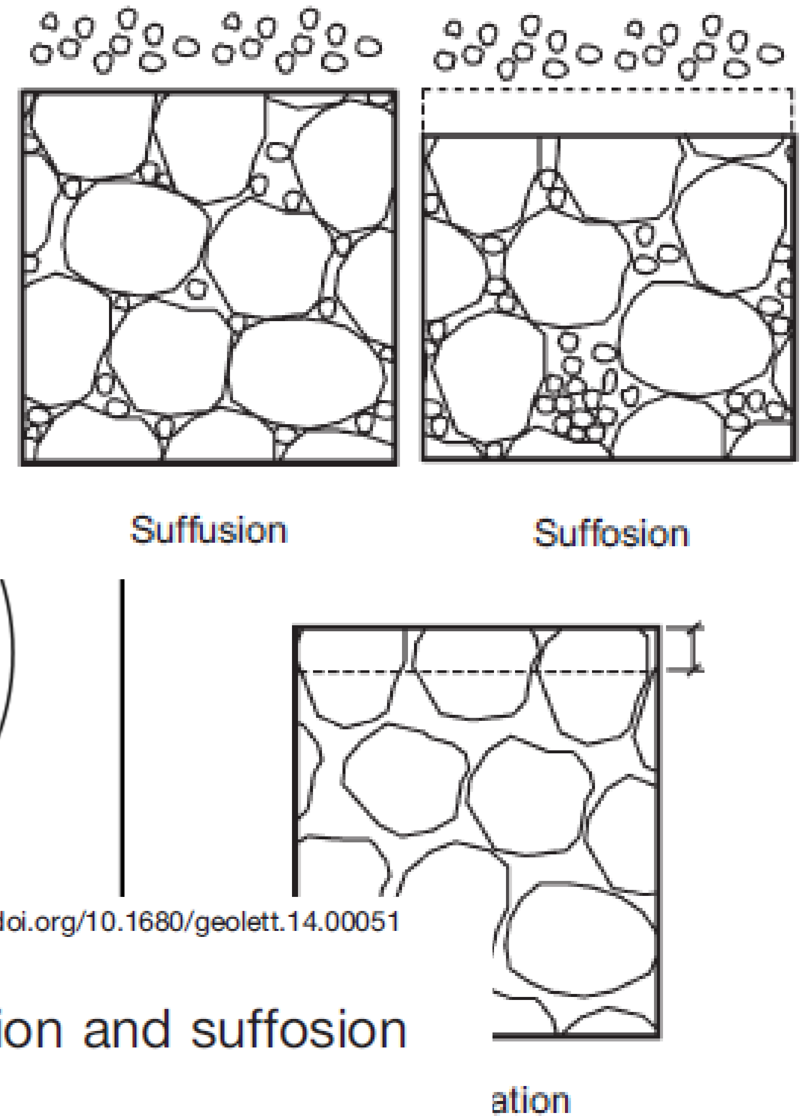
- However they do not, indeed cannot, address the question of where the onset of internal erosion occurs, nor the rate at which it can be expected to progress.

TEMPORAL

- Laboratory testing, and companion theoretical development, are needed to advance a mechanics-based understanding of the response that offers potential to address these key concerns for dam safety engineering.

Internal instability





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

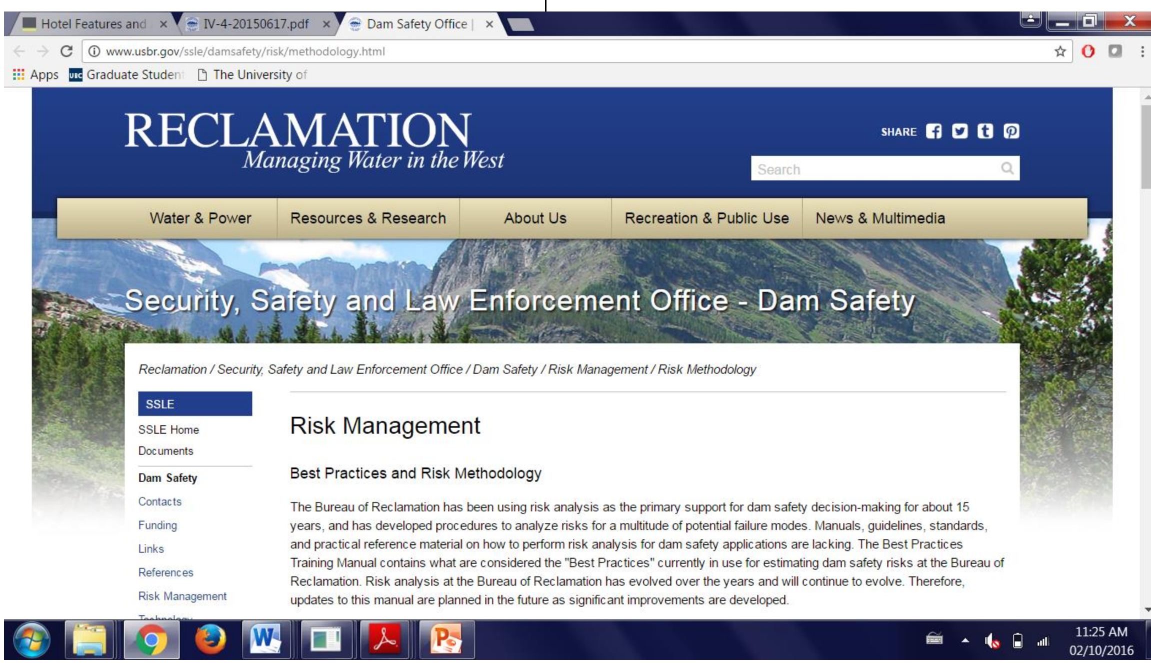
On the distinct phenomena of suffusion and suffosion

R. J. FANNIN* and P. SLANGEN*

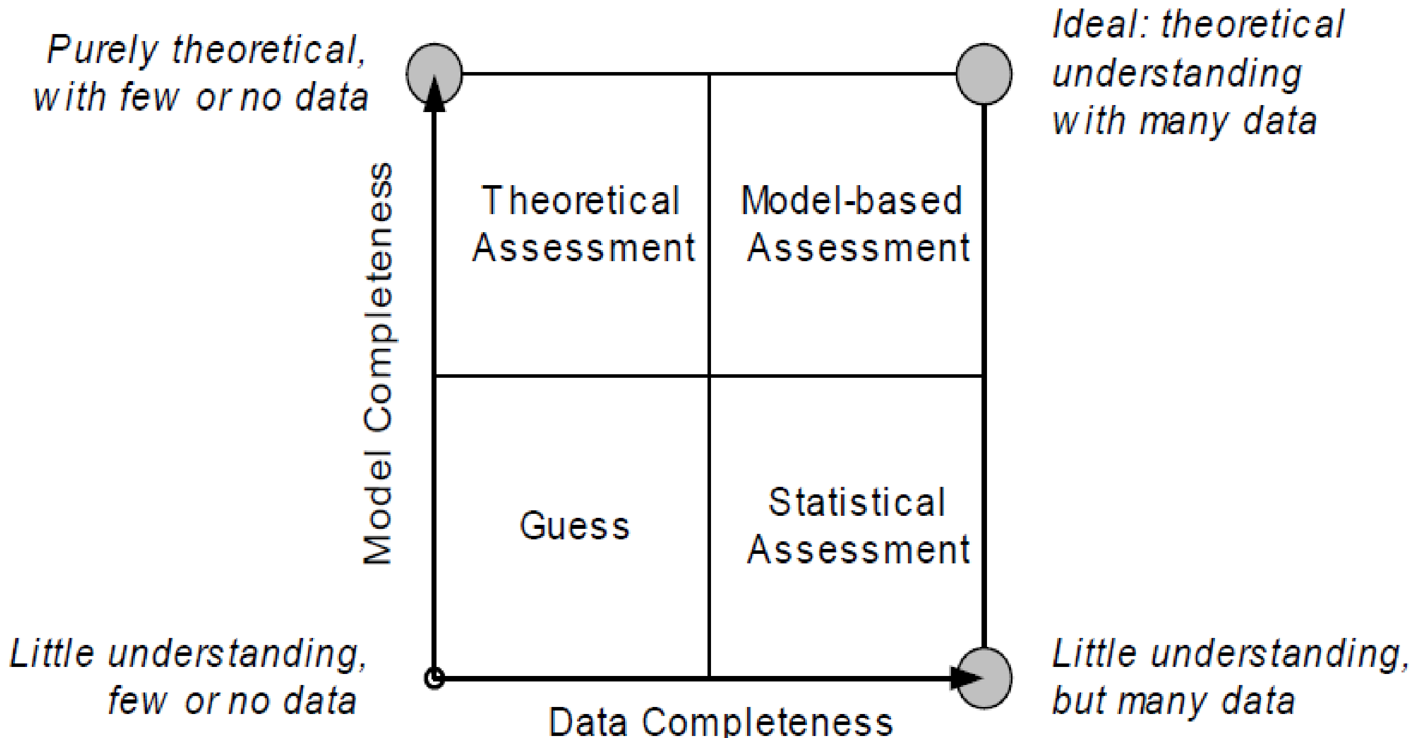
IV-4. Internal Erosion Risks for Embankments and Foundations

USBR-USACE (2015)

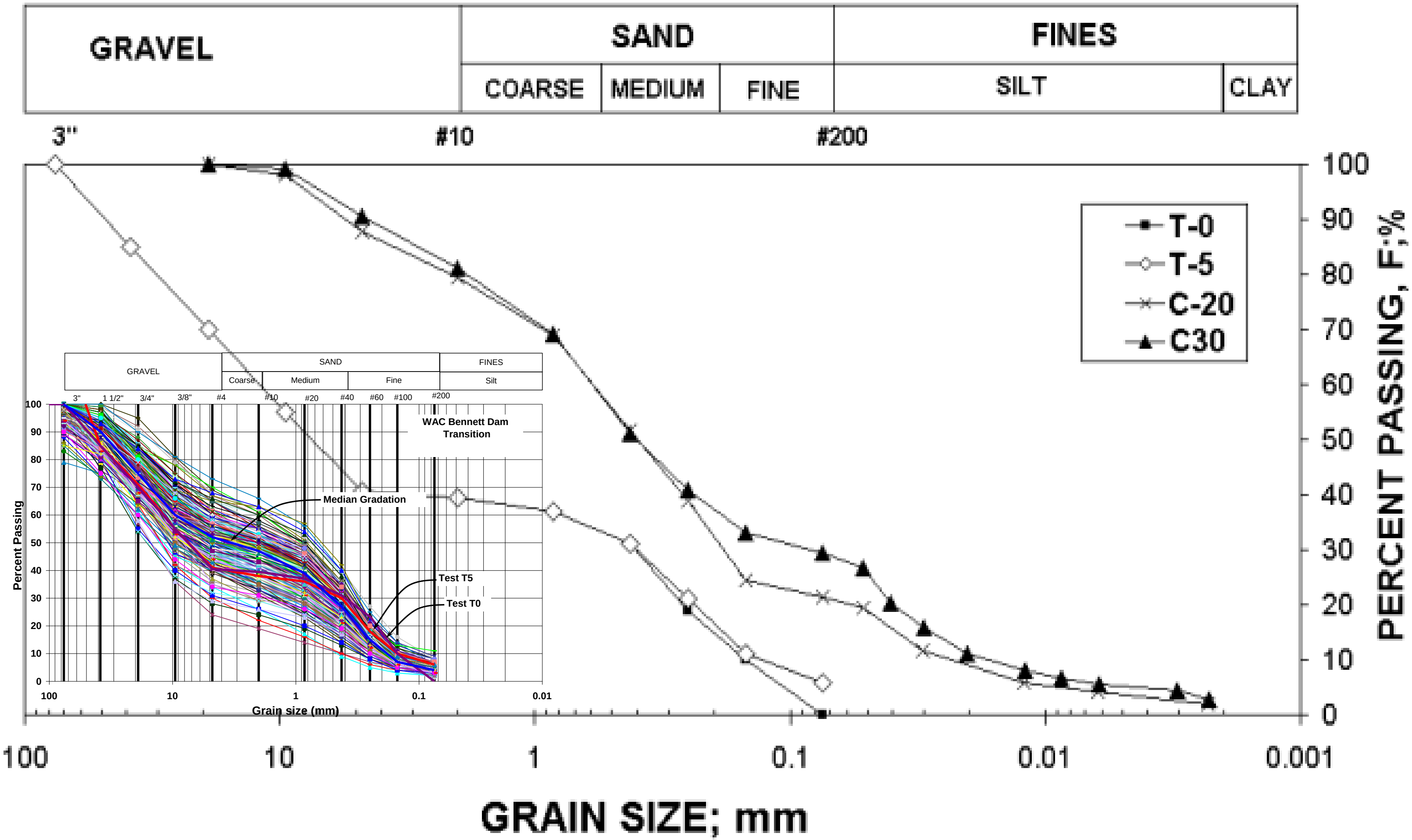
Internal instability (Note: Reclamation's description of the mechanisms for internally unstable soils are applicable to USACE.)	**Internal Instability - Suffusion, and Suffosion**: Both are internal erosion mechanisms that can occur with internally unstable soils. It is possible that these mechanisms as well as internal migration (stoping) can occur in complex glacial environments where tills, glacio-lacustrine and outwash deposit co-exist. **Suffusion** involves selective erosion of finer particles from the matrix of coarser particles (that are in point-to-point contact) in such a manner that the finer particles are removed through the voids between the larger particles by seepage flow, leaving behind a soil skeleton formed by the coarser particles. With suffusion there is typically little or no volume change. **Suffosion** is a similar process, but results in volume change (voids leading to sinkholes) because the coarser particles are not in point-to-point contact. Suffosion is less likely under the stress conditions and gradients typically found in embankment dams. Note: This



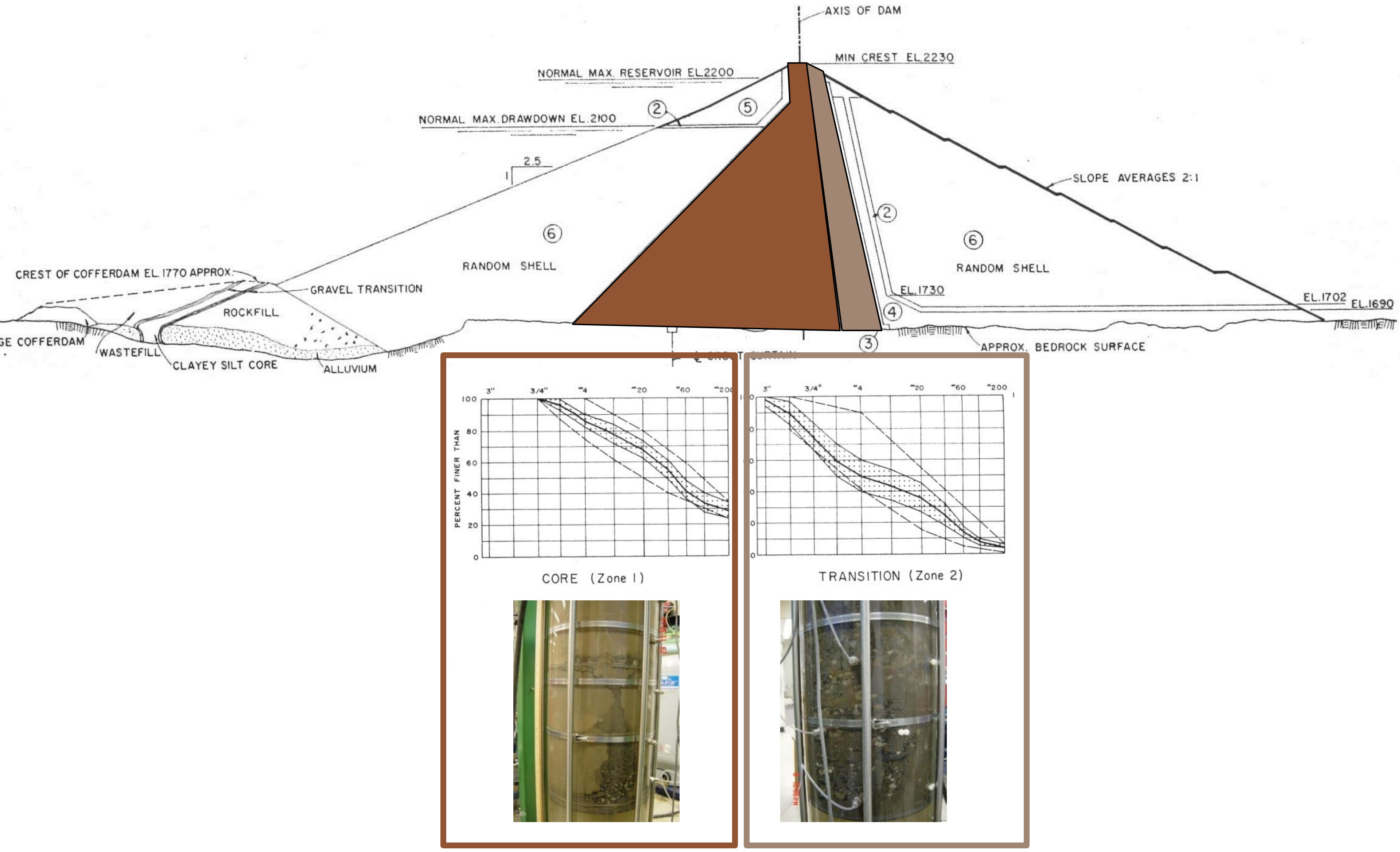
Experimental Research



WAC Bennett Dam: core and transition materials



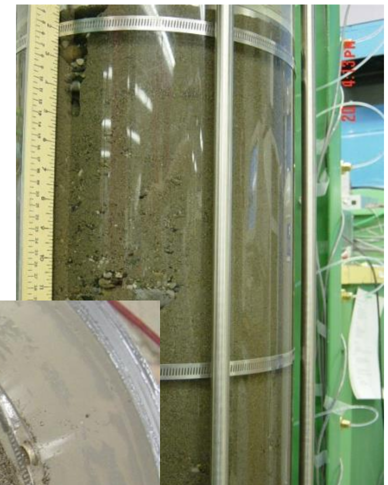
Rigid-wall permeameter I



Rigid-wall permeameter I

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

t = 1180 s



60 s

Rigid-wall permeameter I

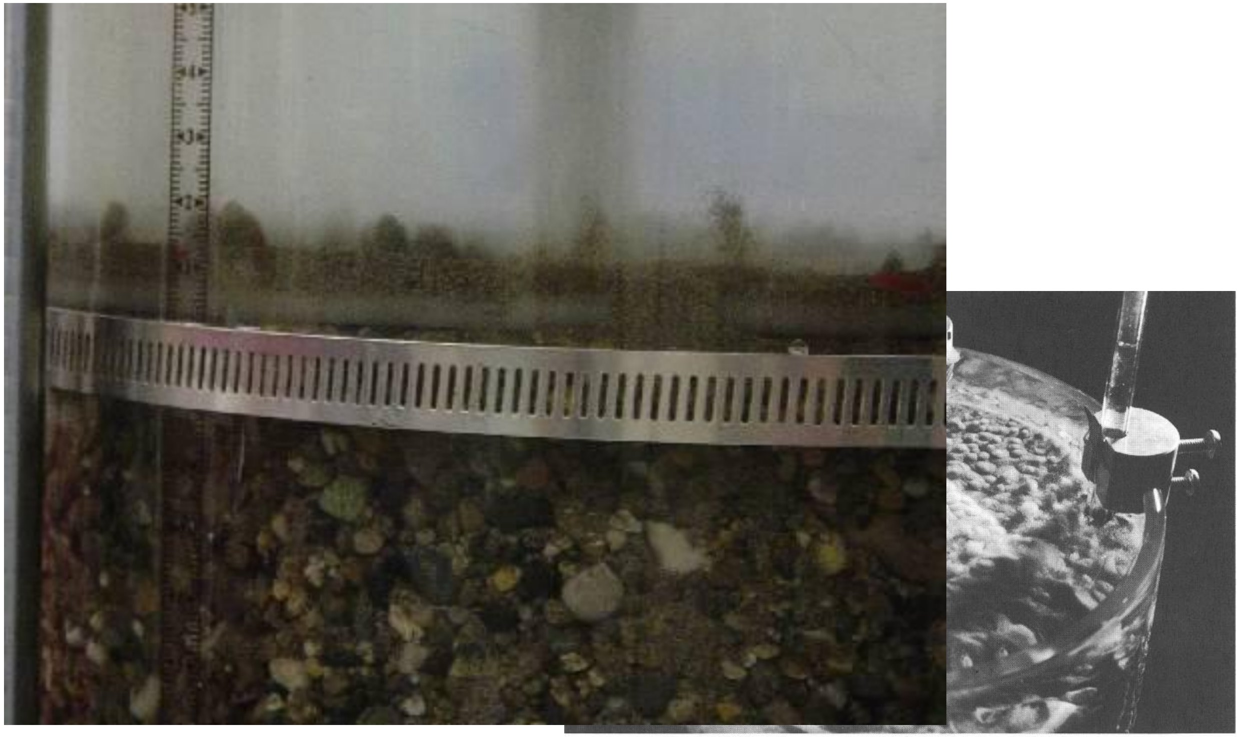
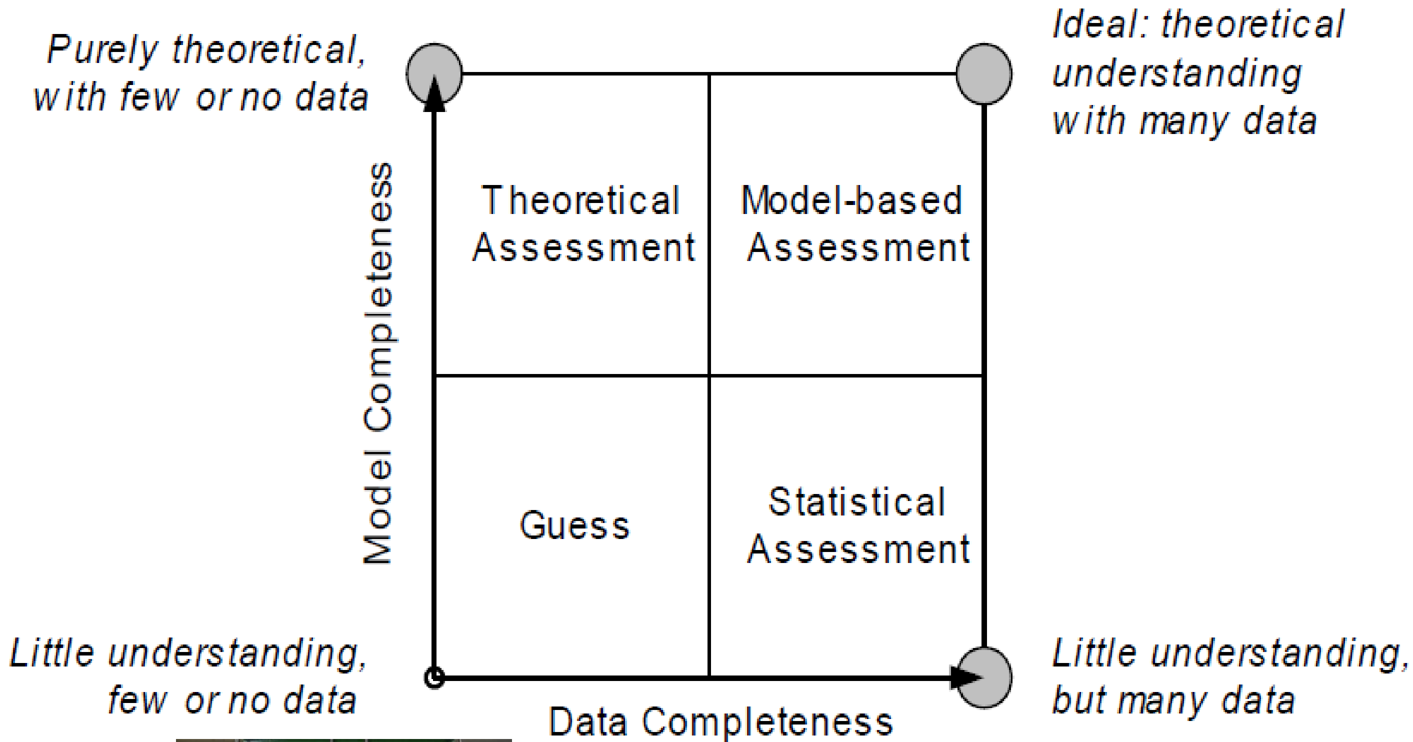


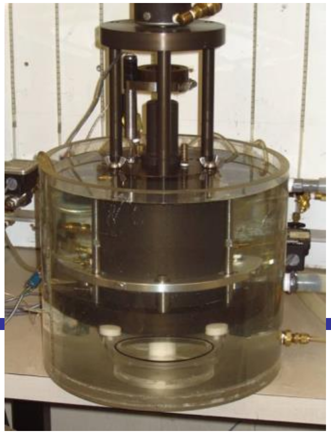
Fig. 9. Material A: strong general piping of fines ($i = 0{\cdot}22$, $v = 0{\cdot}27$ cm/s)

$$i_{cr} = \alpha i_c$$

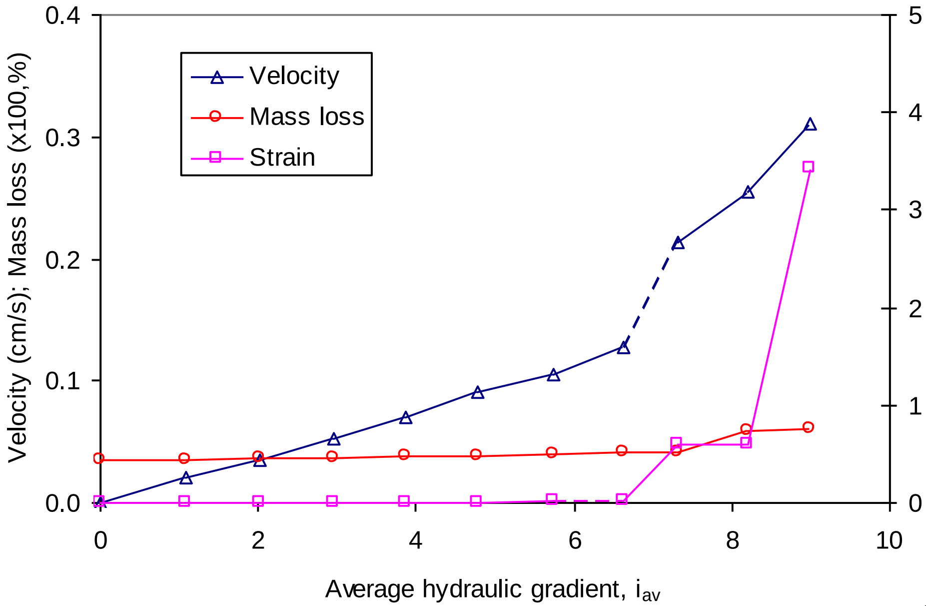
"… for unstable materials, the critical hydraulic gradient could be roughly 1/3 to 1/5 of the normal threshold of 1.0."

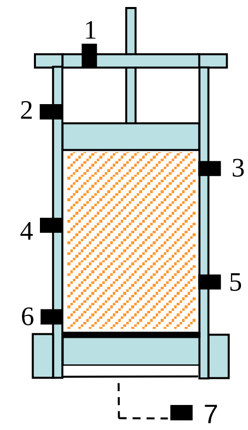
Experimental Research

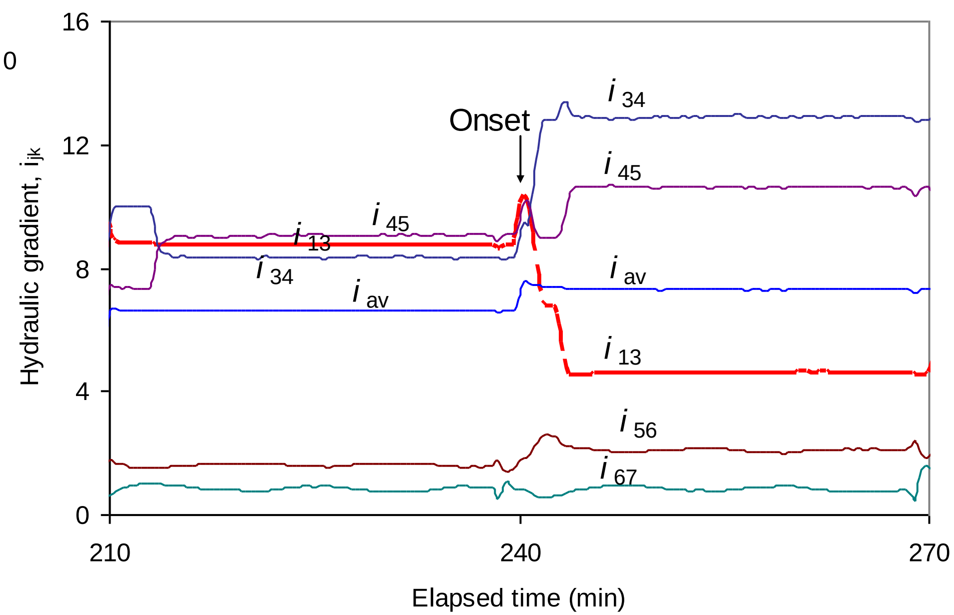




Rigid-wall permeameter II

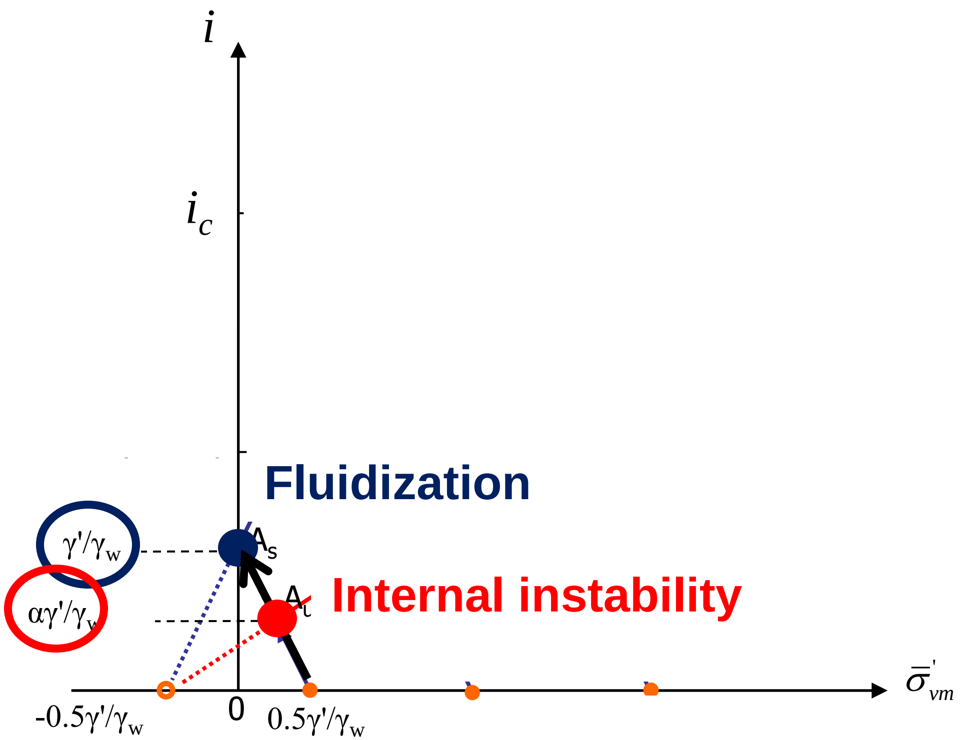






i_{av} = 6.6 and 7.3

Stress reduction α-concept:



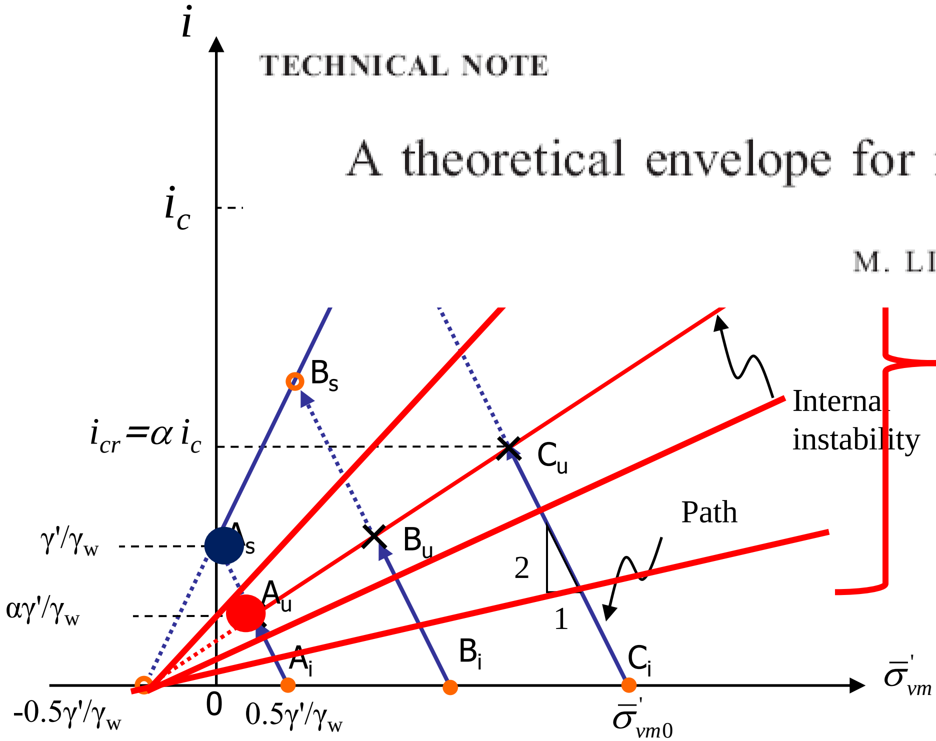
Expanding the α-concept in stress-gradient space:

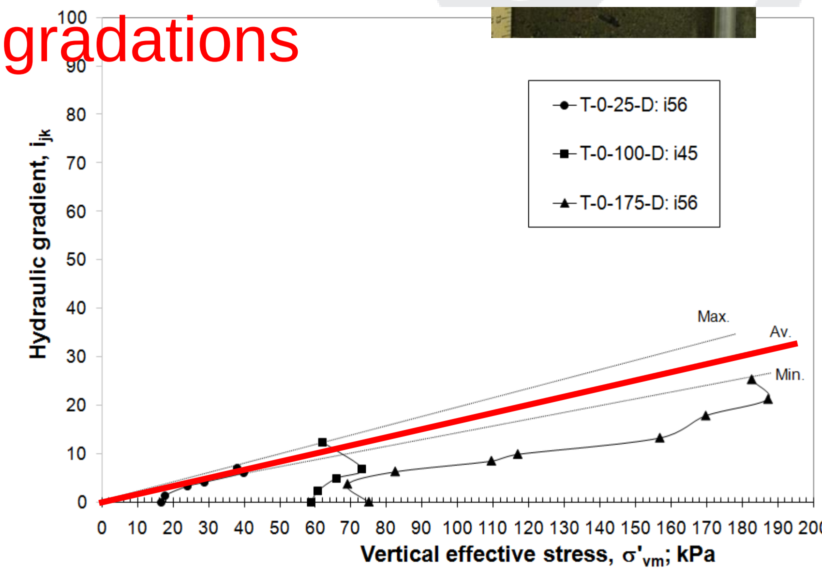
Li, M. & Fannin, R. J. (2011). *Géotechnique* **61**, No. 00, 1–4 [**doi:** 10.1680/geot.2011.61.00.1]

TECHNICAL NOTE

A theoretical envelope for internal instability of cohesionless soil

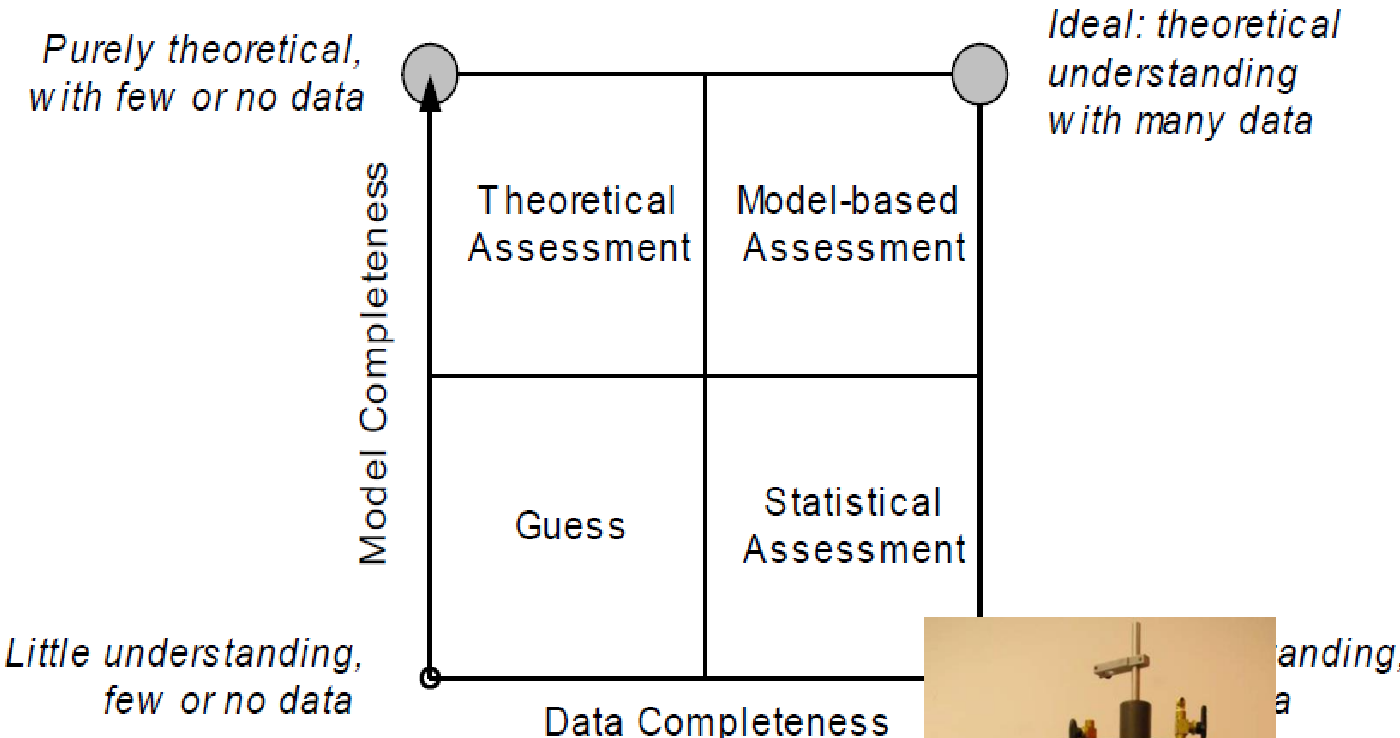
M. LI* and R. J. FANNIN†

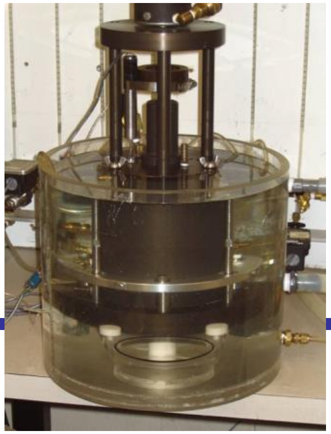




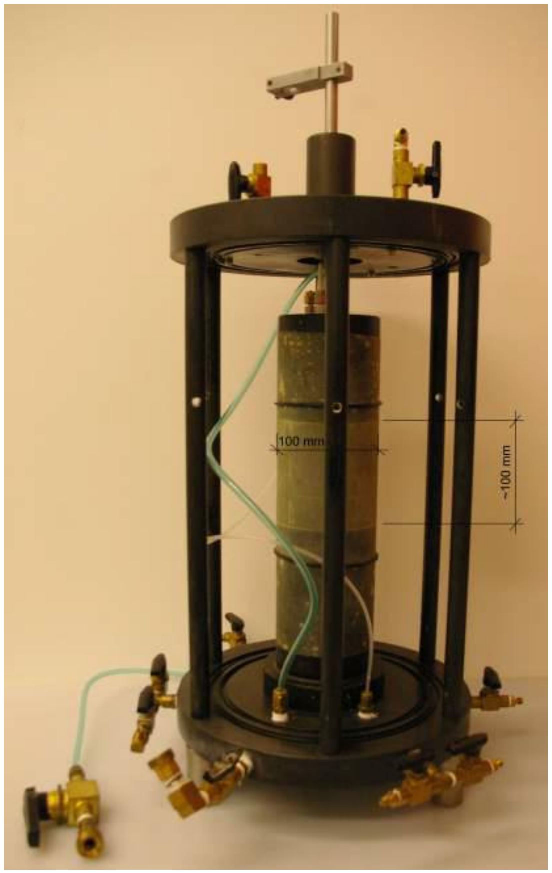
Constantinople (1922) – London (1994) – Vancouver (2011)

Experimental Research





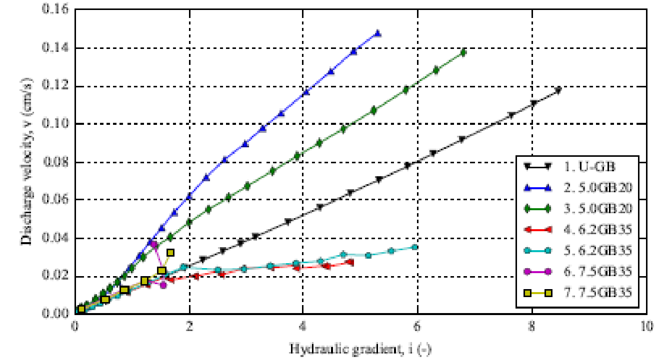
Flexible wall permeameter



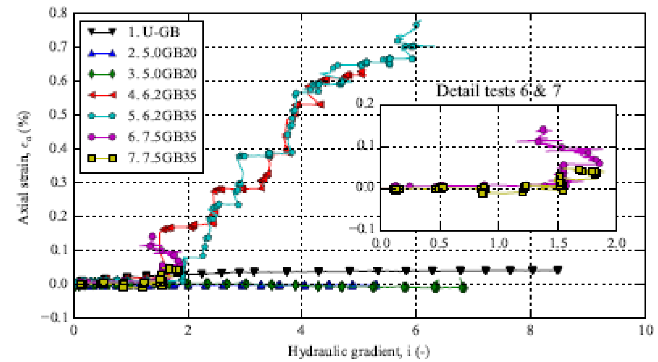
Discharge velocity
Axial strain
Volumetric strain

vs.

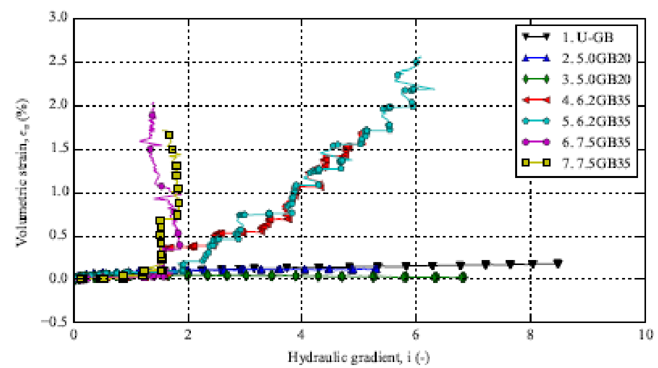
Hydraulic gradient



(a)

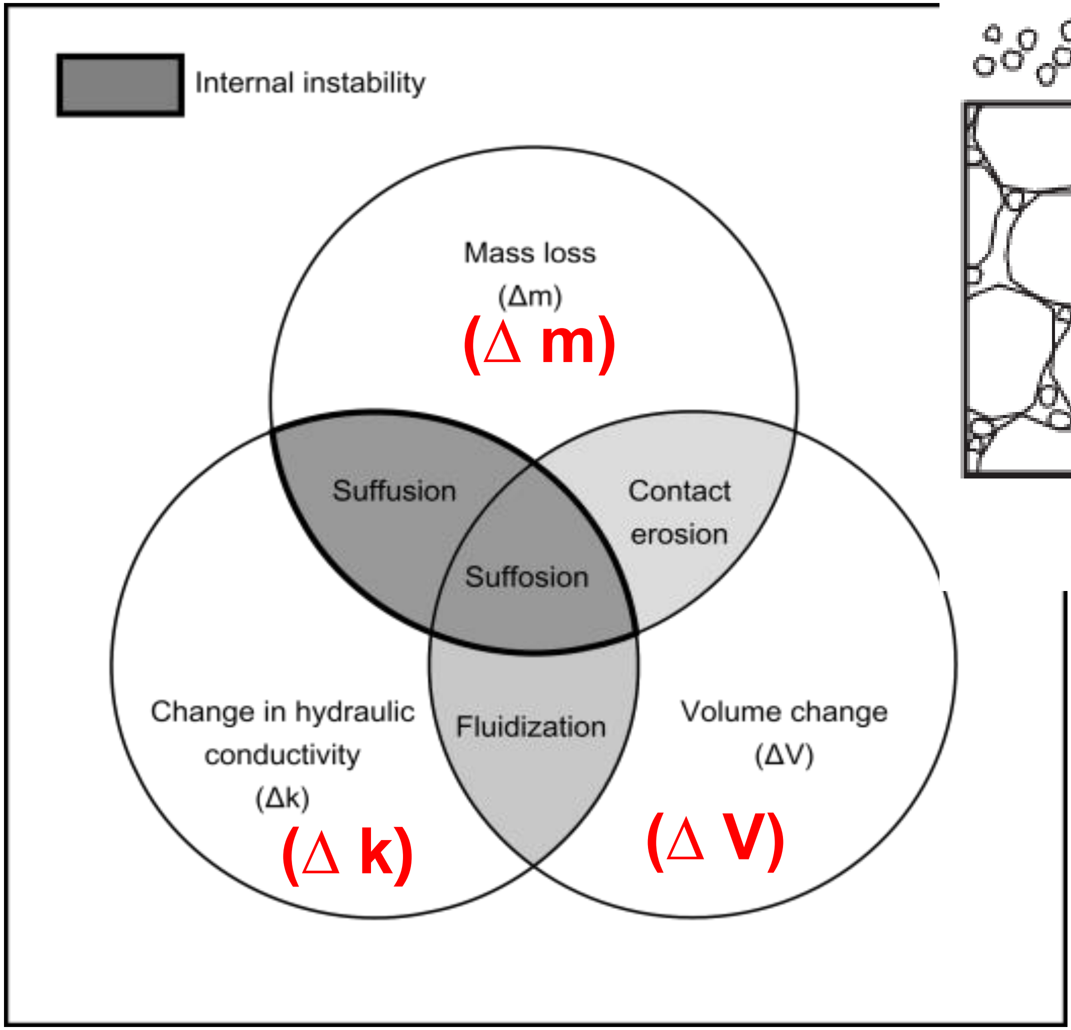


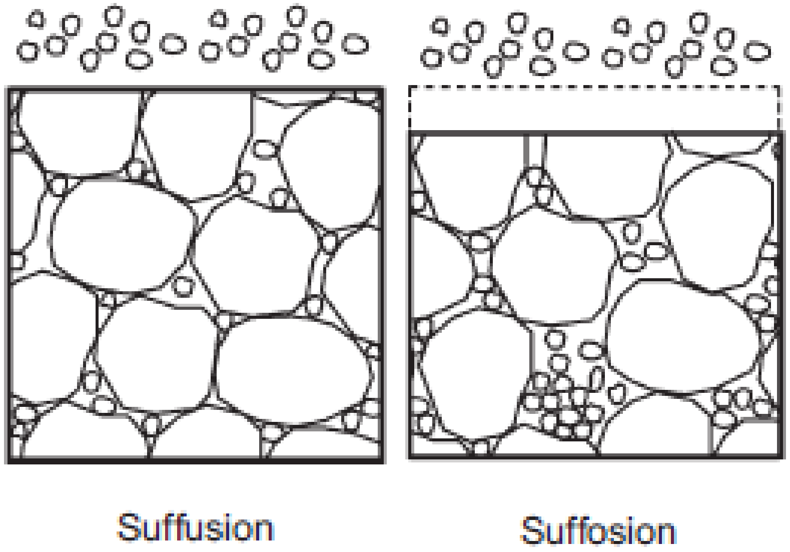
(b)



(c)

Suffusion vs. Suffosion

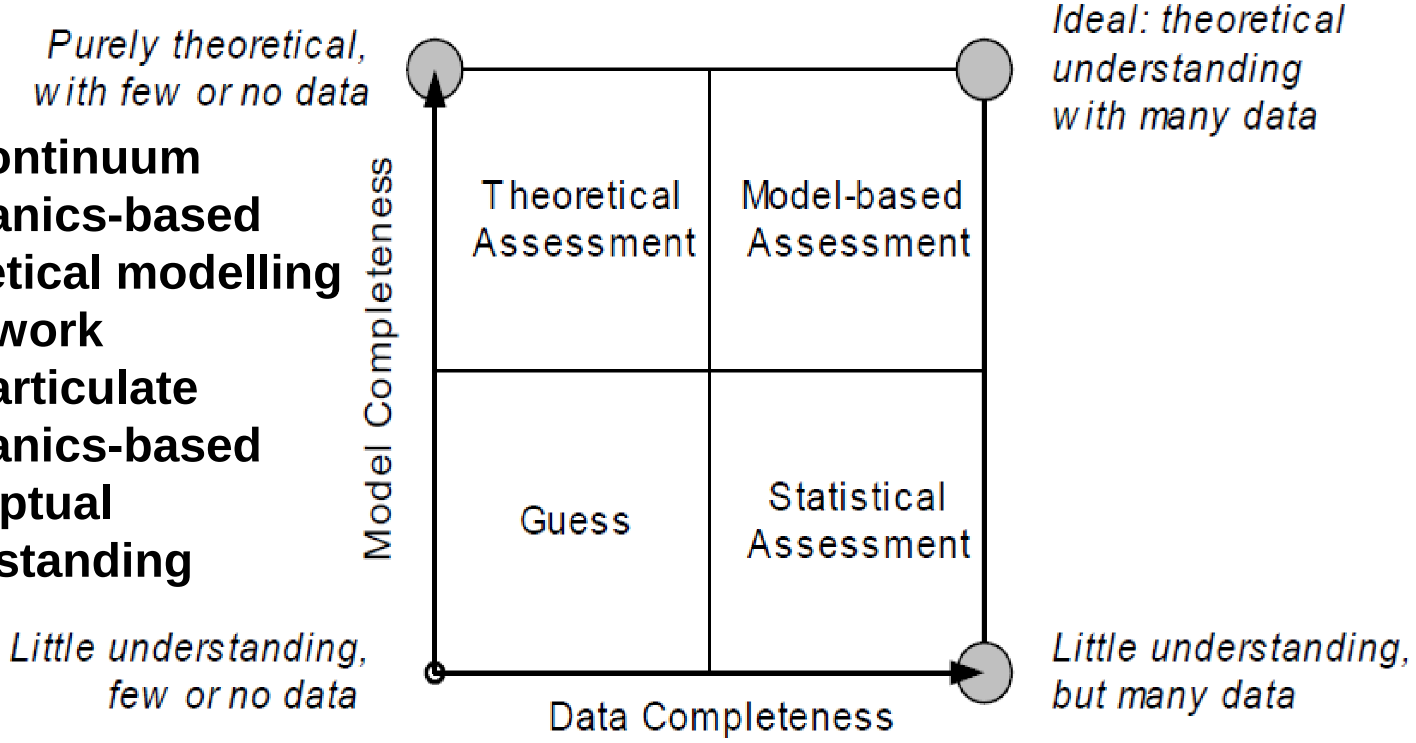




Summary remarks: experimental research

- model-informed experimental investigations

- a continuum mechanics-based theoretical modelling framework
- a particulate mechanics-based conceptual understanding



- "normative" procedures for specimen reconstitution and laboratory testing
- inter-laboratory comparison of test results