

# Permeameter testing – the UBC perspective on progress and needs

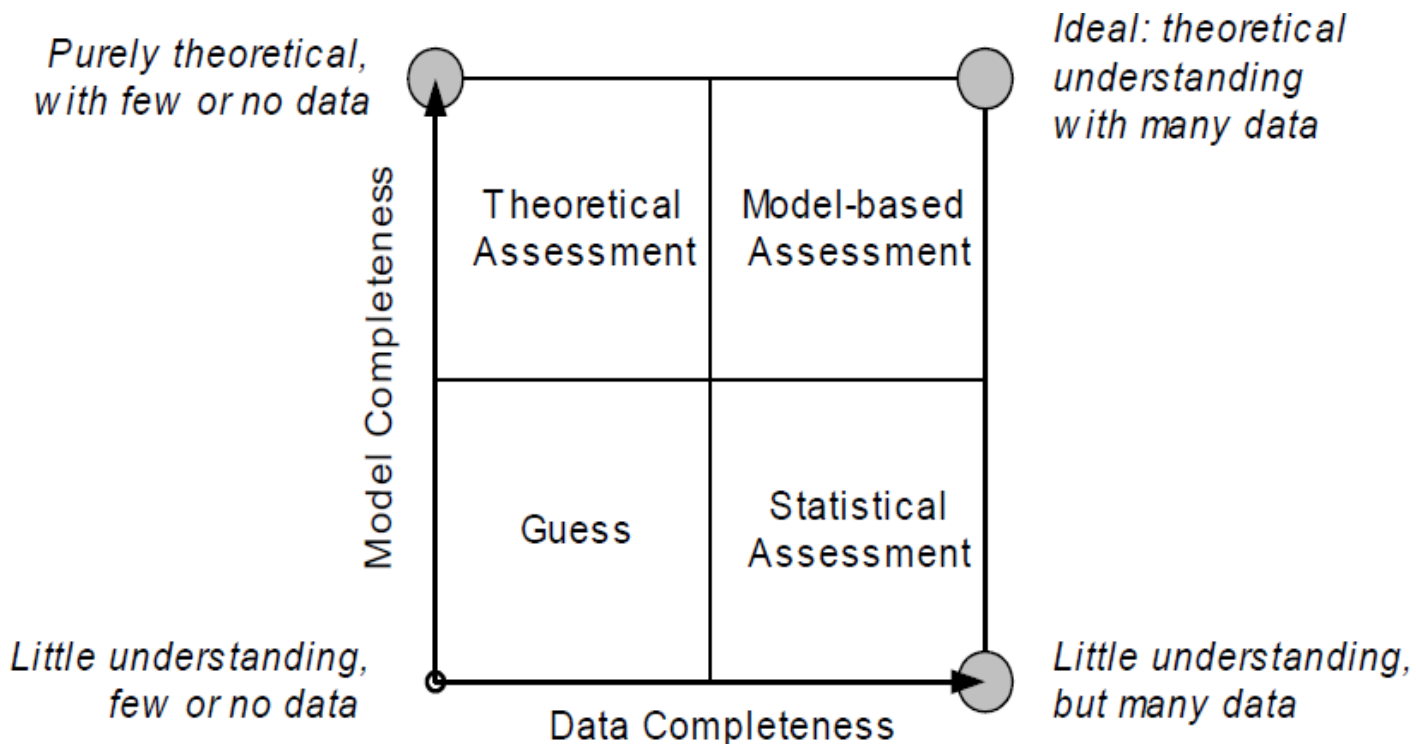


**Jonathan Fannin, Ph.D., P.Eng.  
University of British Columbia**

**Imperial College London, 1 September 2017**

# Overview

- Progress to-date
- Knowledge gaps and research needs



# 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 world (along with the Mica, and Revelstoke dams) generate over

They represent an enormous investment by the government. As a result of our public infrastructure, these embankment dams have a high potential for water seeping from the reservoir 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

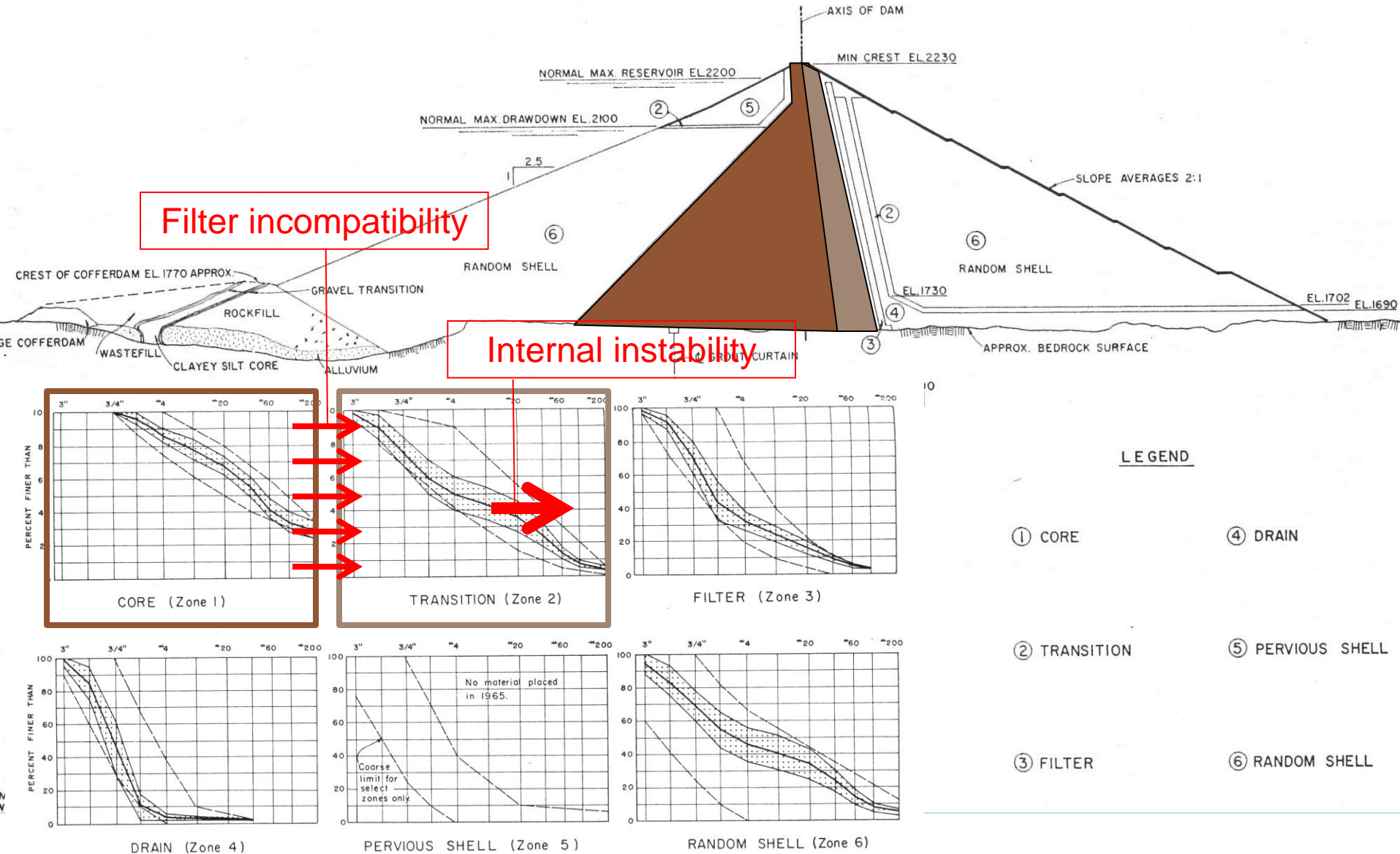


At the time of the sinkhole the freshet was underway and the reservoir was rising towards full pool. In order to halt the reservoir filling and provide additional freeboard as a precautionary measure, the spillway gates were opened on 24 June. For the next 7 weeks about  $3,000 \text{ m}^3/\text{s}$  were released over the spillway (Figure 7) in addition to the  $2000 \text{ m}^3/\text{s}$  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  $3000 \text{ m}^3/\text{s}$  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



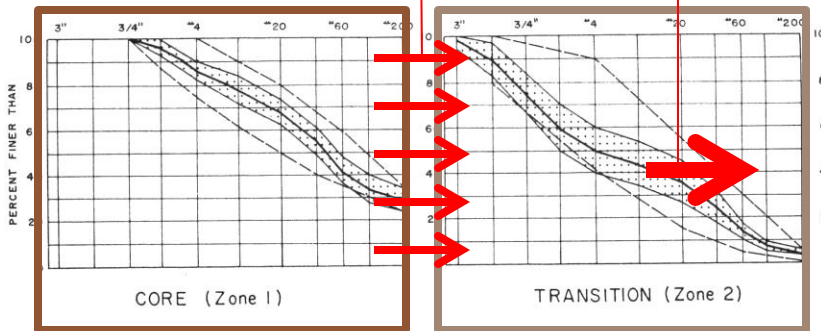
# Empirical screening tools

Foster-Fell threshold index

Filter incompatibility:  $D_{15max}/D_{15EE}$

Internal instability:  $(H/F)_{min}$

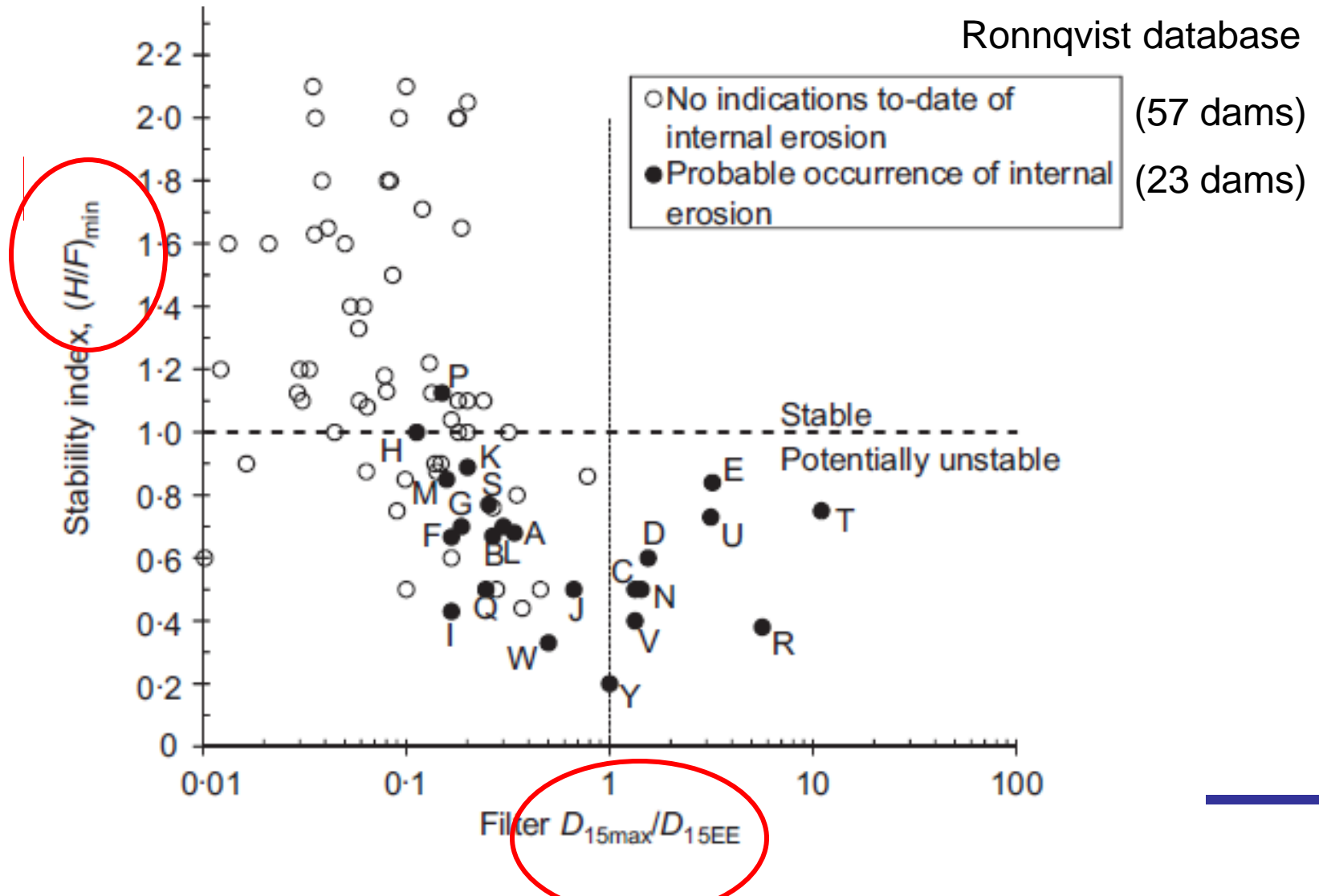
Kenney-Lau threshold index



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

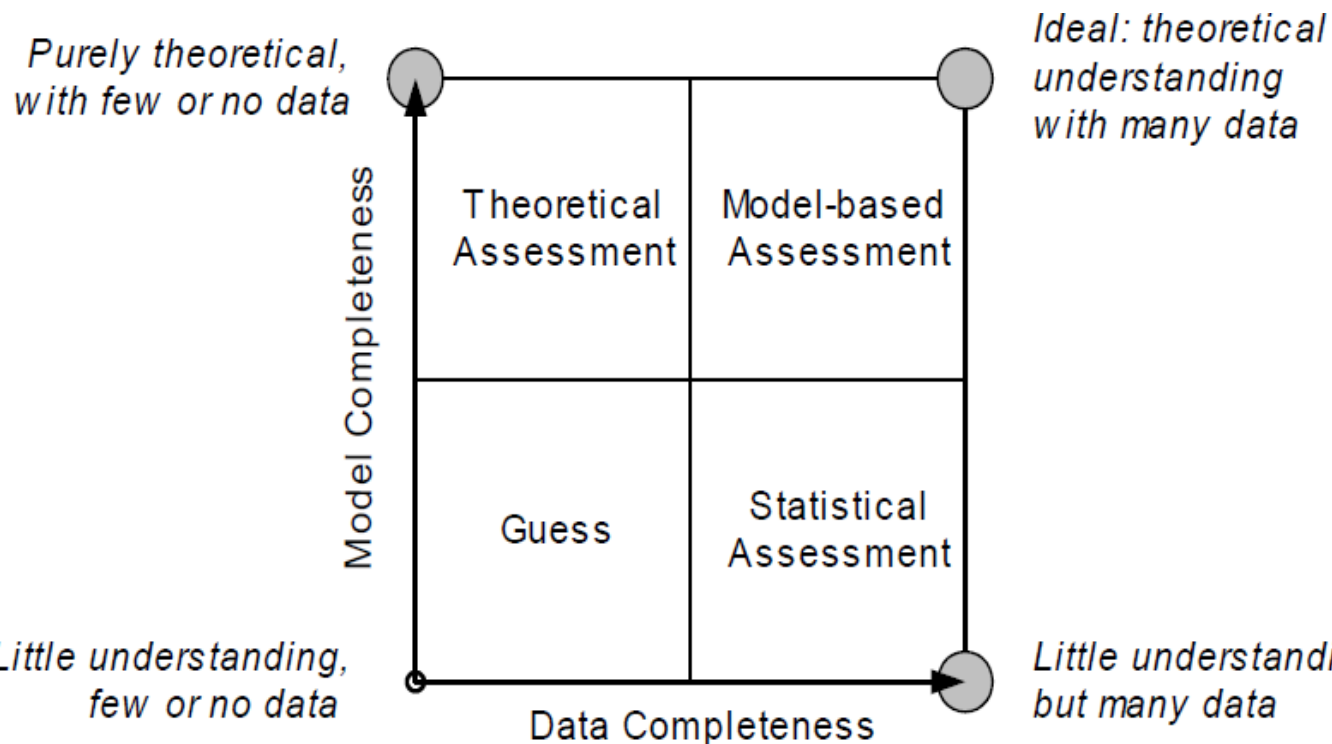
H. RÖNNQVIST\*, J. FANNIN† and P. VIKLANDER\*

Rönnqvist database



# On progress and needs...

- Progress to-date
- Knowledge gaps and research needs





# Knowledge gaps: research needs

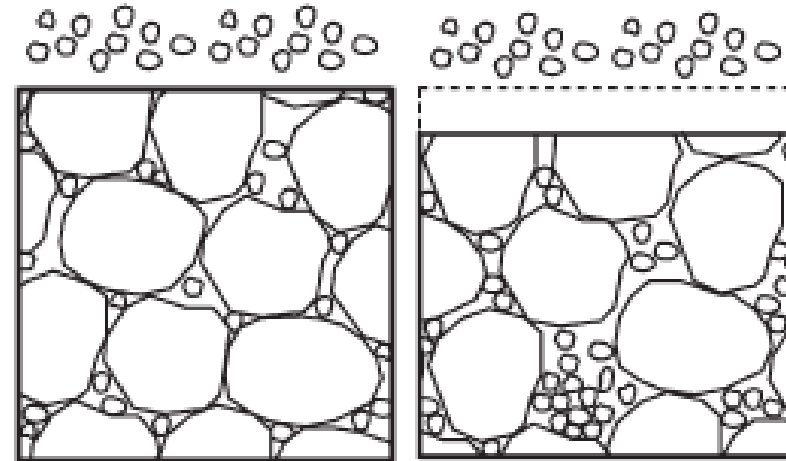
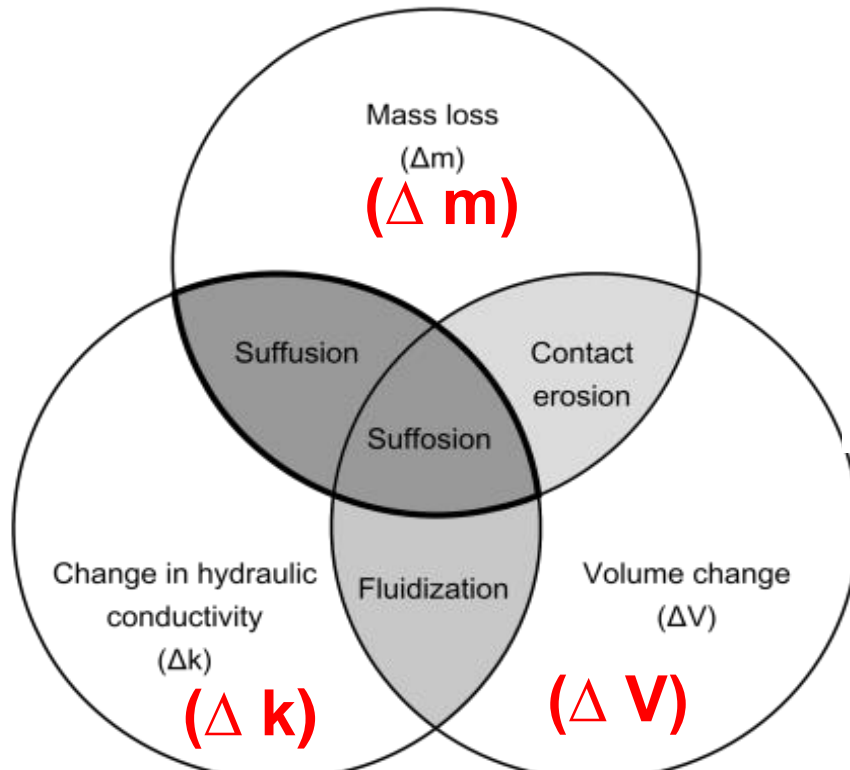
- Empirical criteria provide a screening tool for evaluating the susceptibility of a gradation to internal instability
- However they do not, indeed cannot, address the question of where the onset of internal erosion occurs, nor the rate at which it can be expected to progress.
- Laboratory testing, 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.

**SPATIAL**

**TEMPORAL**

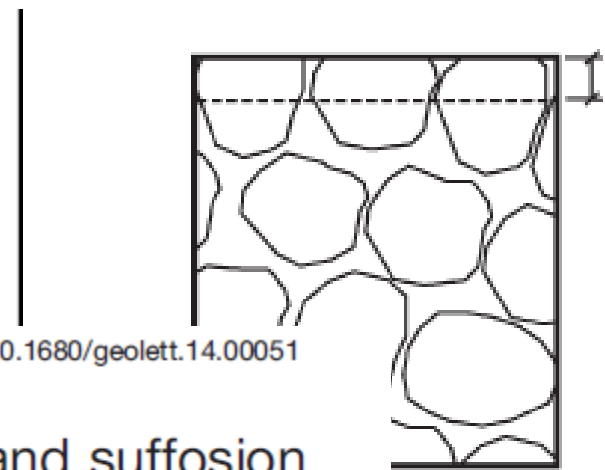
# Internal instability

Internal instability



Suffusion

Suffusion



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

ation

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.)

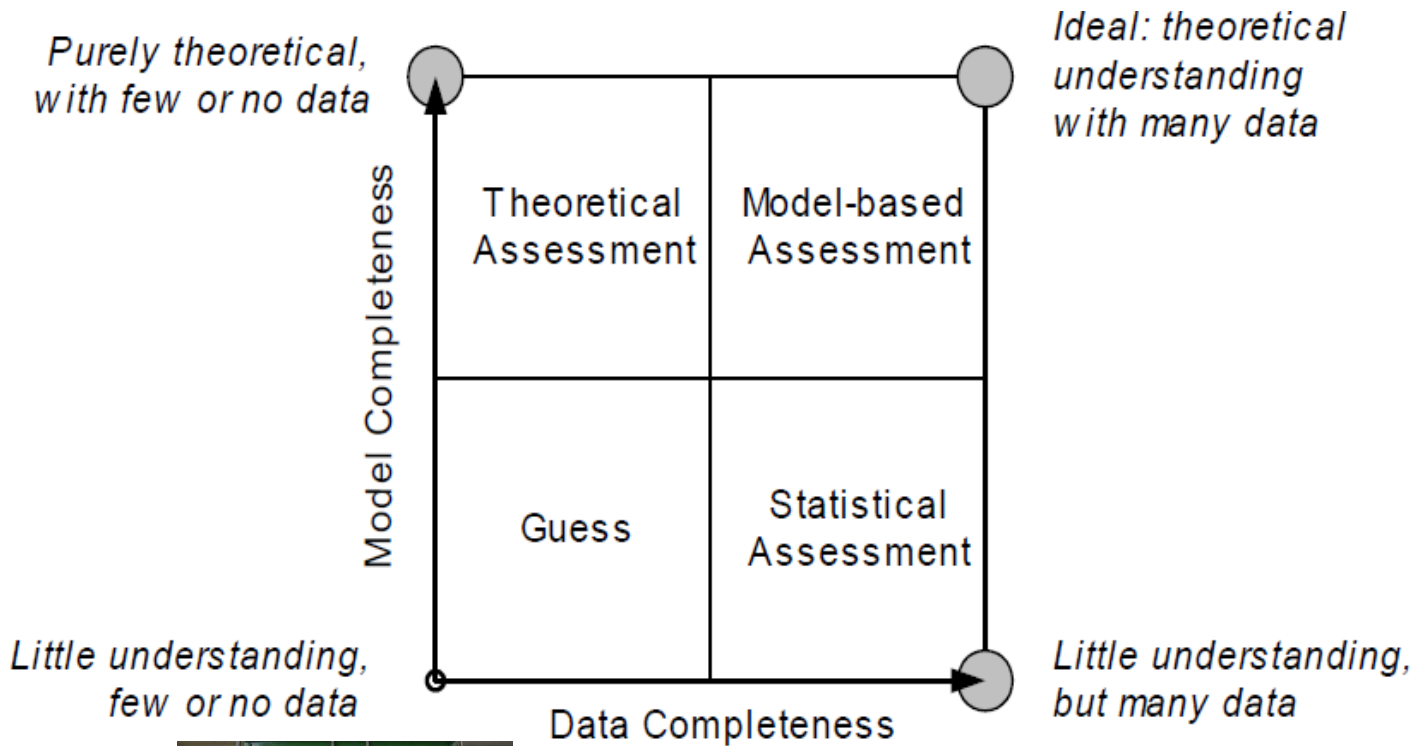
### Internal Instability - Suffusion, and Suffosion:

Both are internal erosion mechanisms that can occur with internally unstable soils. It is possible that these mechanisms as well as internal migration (stopping) 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.

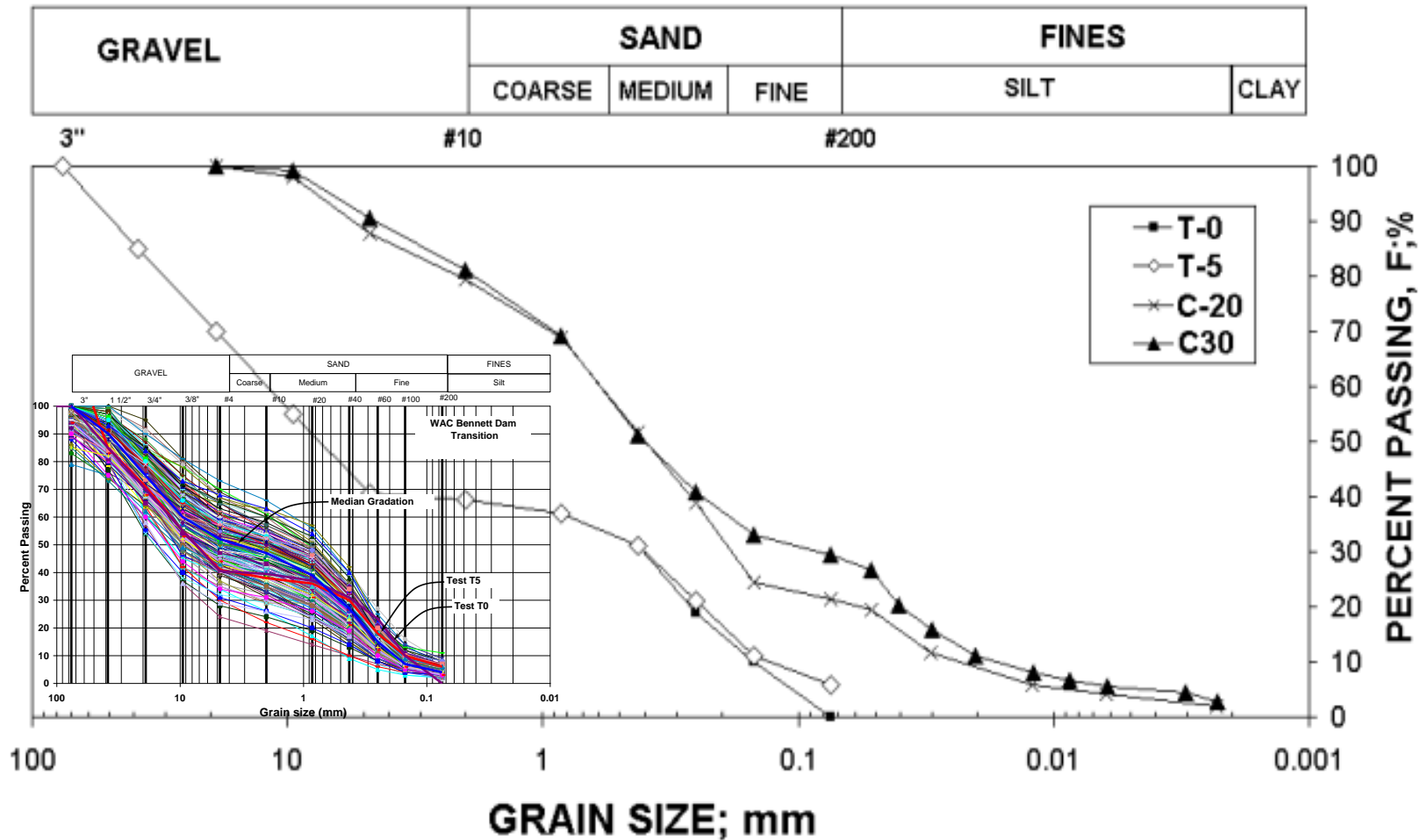
**Suffosion** is a similar process, but results in volume change (voids leading to sinkholes) because the coarser particles are not in point-to-point contact. Suffosion is less likely under the stress conditions and gradients typically found in embankment dams. Note: This

The screenshot shows a web browser window displaying the USBR website. The browser tabs include 'Hotel Features and...', 'IV-4-20150617.pdf', and 'Dam Safety Office'. The address bar shows 'www.usbr.gov/ssle/damsafety/risk/methodology.html'. The website header features the 'RECLAMATION' logo with the tagline 'Managing Water in the West' and a search bar. A navigation menu includes 'Water & Power', 'Resources & Research', 'About Us', 'Recreation & Public Use', and 'News & Multimedia'. The main content area is titled 'Security, Safety and Law Enforcement Office - Dam Safety'. A sidebar on the left lists 'SSLE', 'SSLE Home', 'Documents', 'Dam Safety', 'Contacts', 'Funding', 'Links', 'References', and 'Risk Management'. The main content area is titled 'Risk Management' and 'Best Practices and Risk Methodology'. The text below this title states: 'The Bureau of Reclamation has been using risk analysis as the primary support for dam safety decision-making for about 15 years, and has developed procedures to analyze risks for a multitude of potential failure modes. Manuals, guidelines, standards, and practical reference material on how to perform risk analysis for dam safety applications are lacking. The Best Practices Training Manual contains what are considered the "Best Practices" currently in use for estimating dam safety risks at the Bureau of Reclamation. Risk analysis at the Bureau of Reclamation has evolved over the years and will continue to evolve. Therefore, updates to this manual are planned in the future as significant improvements are developed.'

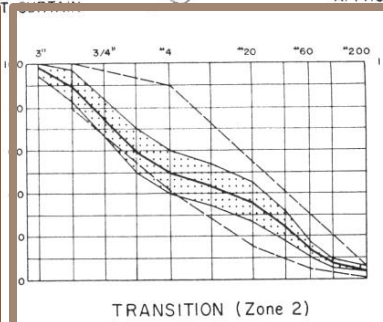
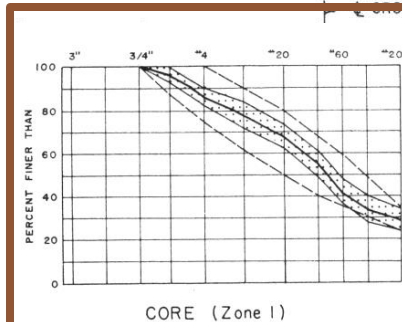
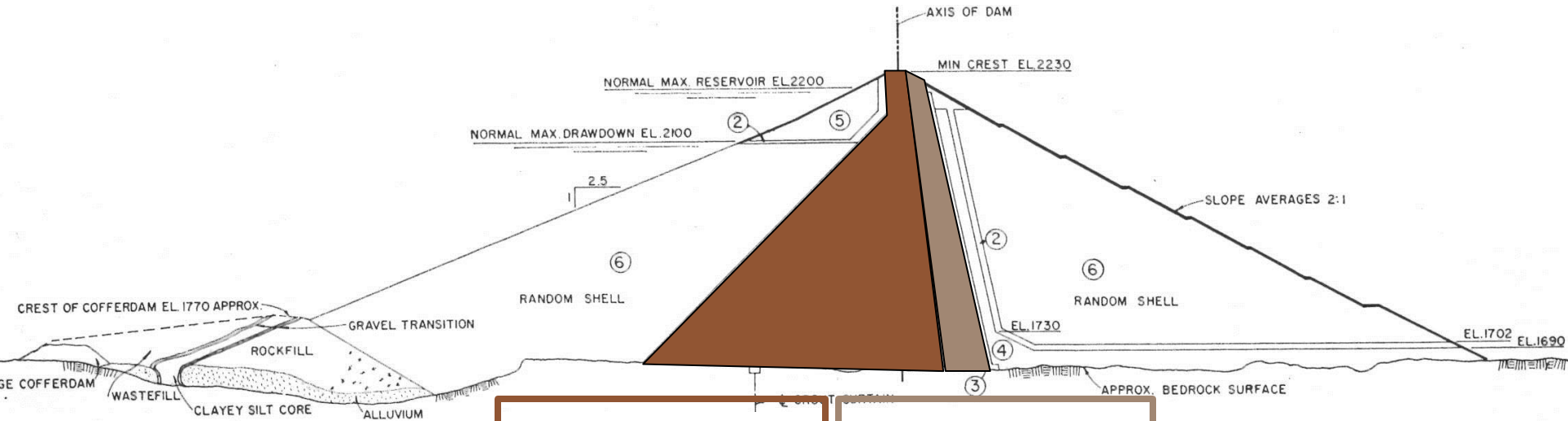
# Experimental Research



# WAC Bennett Dam: core and transition materials



# Rigid-wall permeameter I

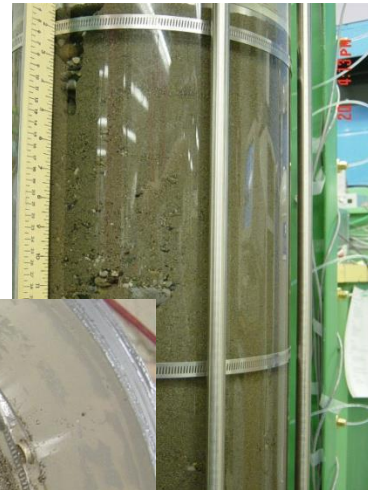


# Rigid-wall permeameter I

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



$t = 1180$  s



60 s



# Rigid-wall permeameter I

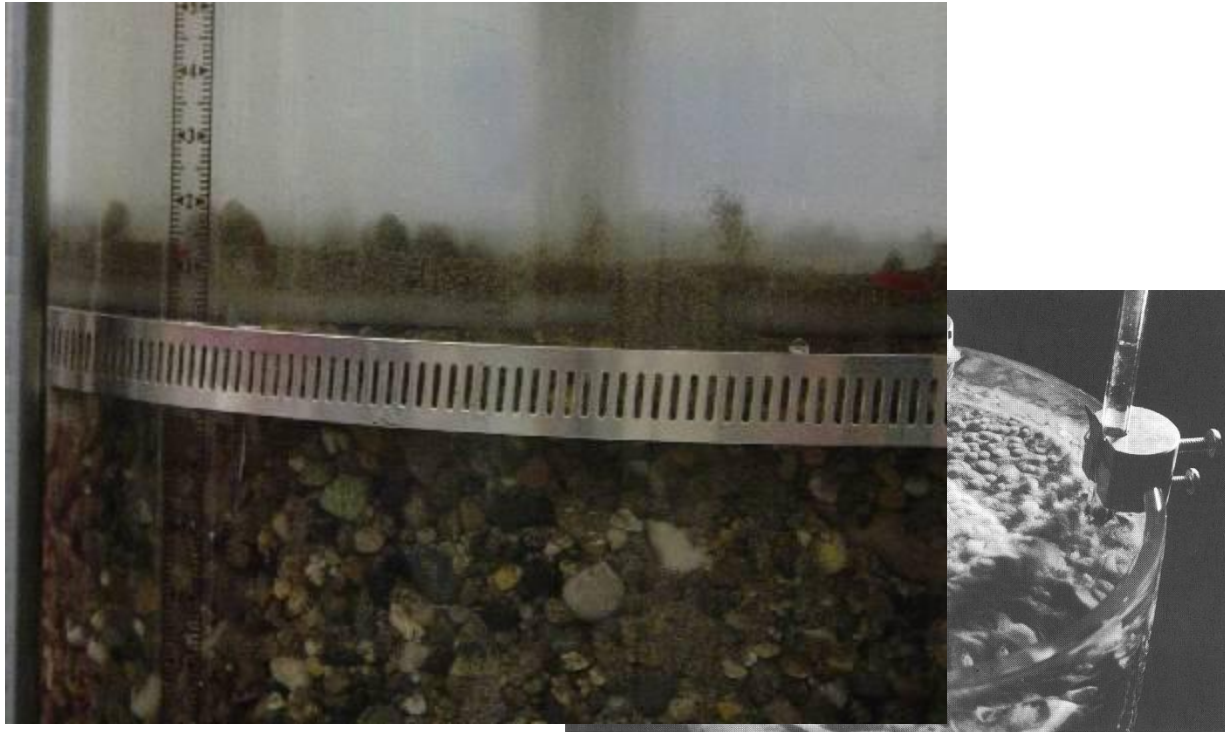


Fig. 9. Material A: strong general piping of fines ( $i = 0.22$ ,  $v = 0.27$  cm/s)

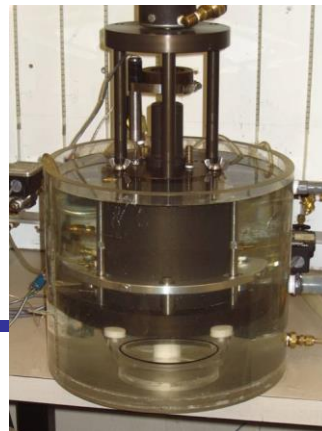
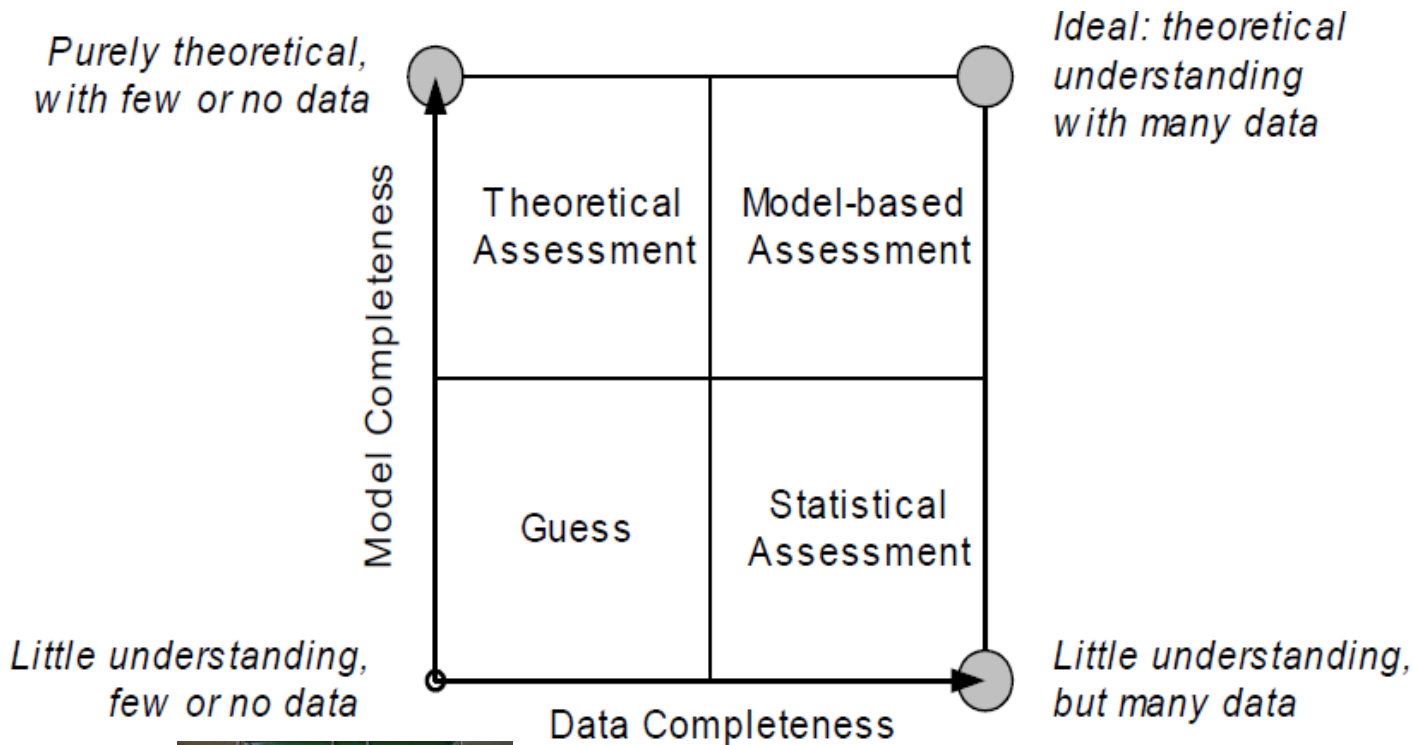
$$i_{cr} = \alpha i_c$$

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

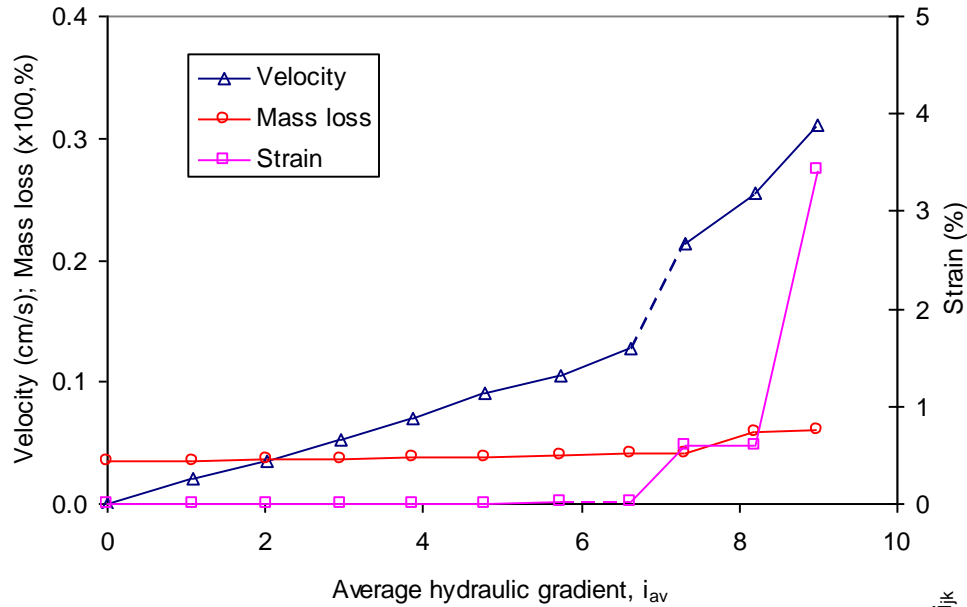
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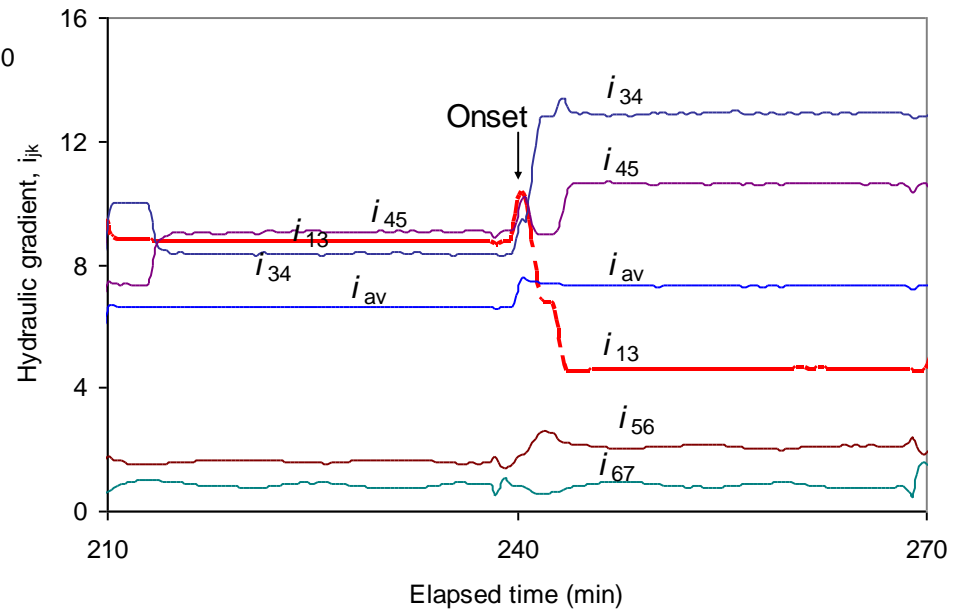
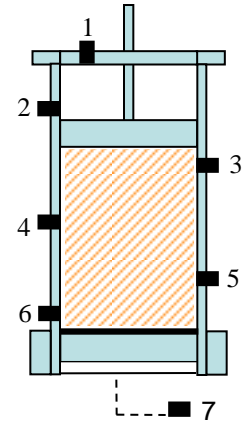
# Experimental Research



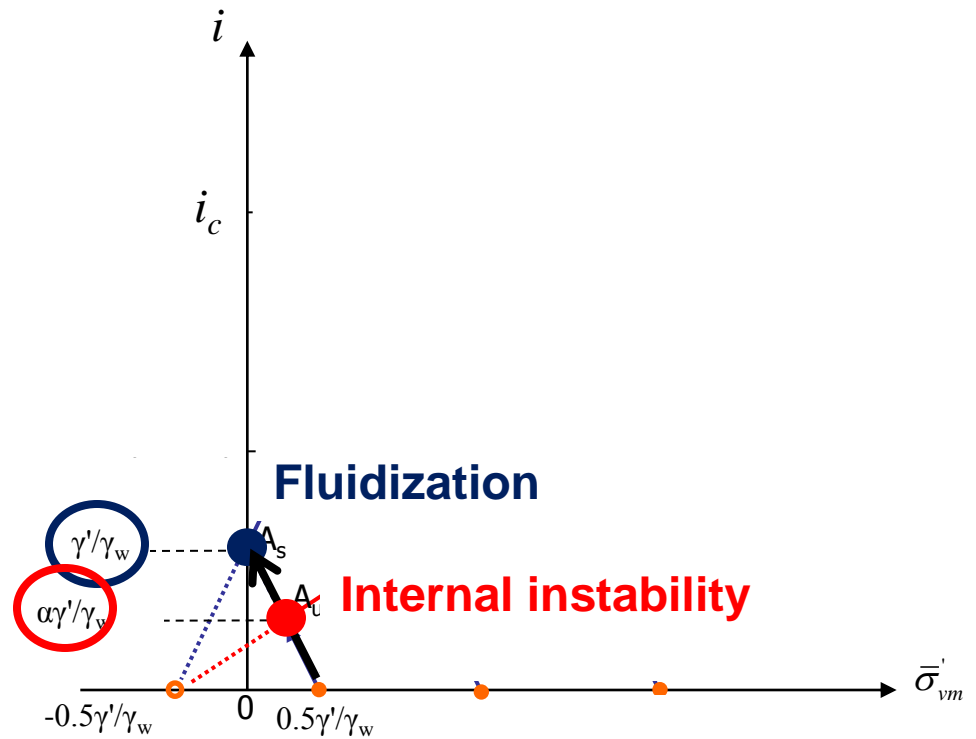
# Rigid-wall permeameter II



$i_{av} = 6.6$  and  $7.3$

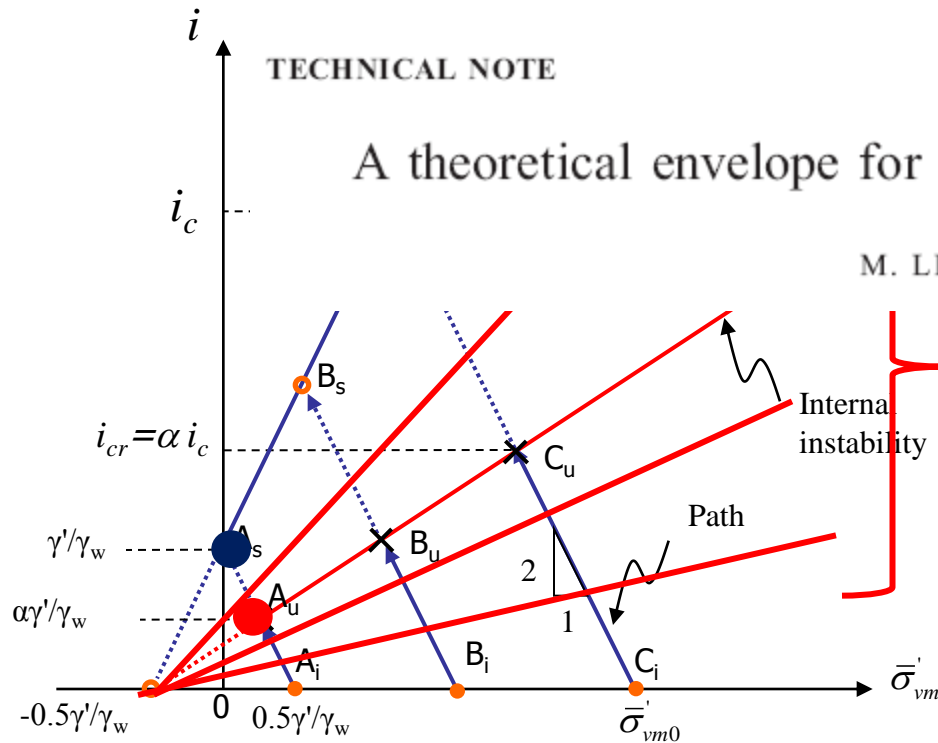


# Stress reduction $\alpha$ -concept:

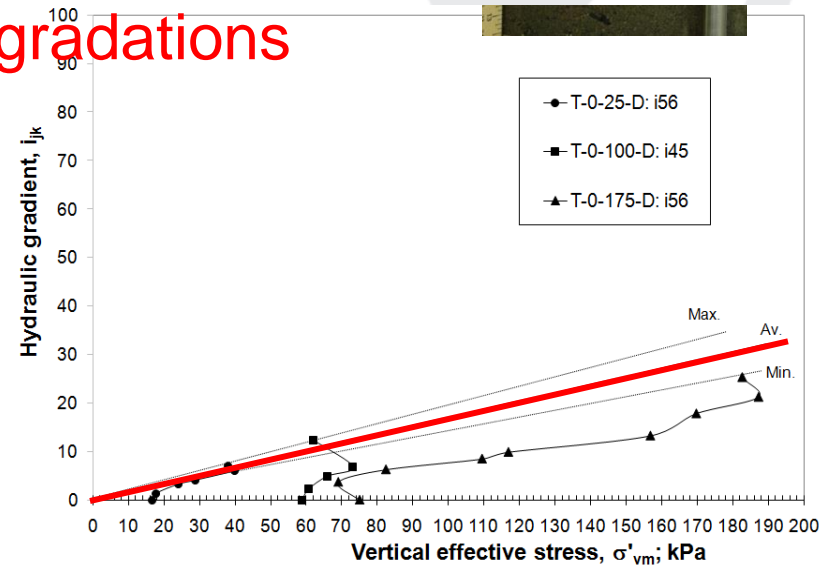


# Expanding the $\alpha$ -concept in stress-gradient space:

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



gradations

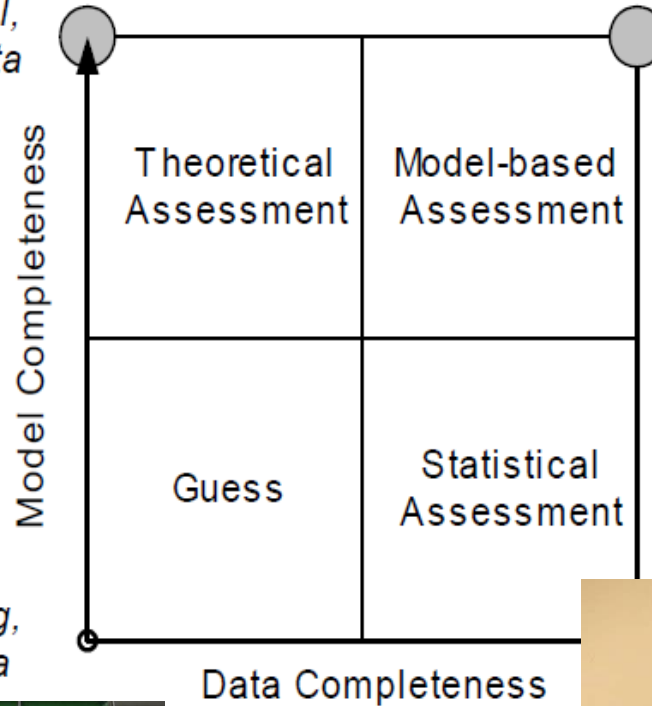


Constantinople (1922) – London (1994) – Vancouver (2011)

# Experimental Research

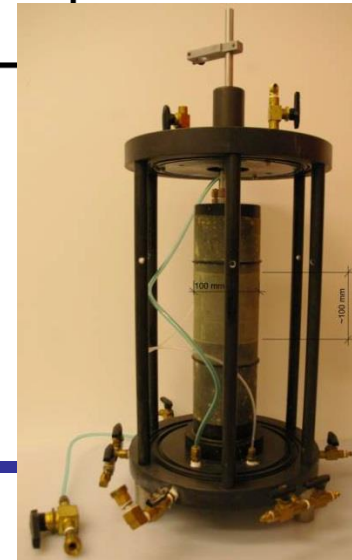
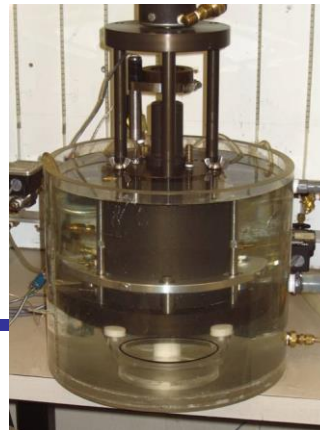
*Purely theoretical,  
with few or no data*

*Ideal: theoretical  
understanding  
with many data*



*Little understanding,  
few or no data*

*Little understanding,  
many data*



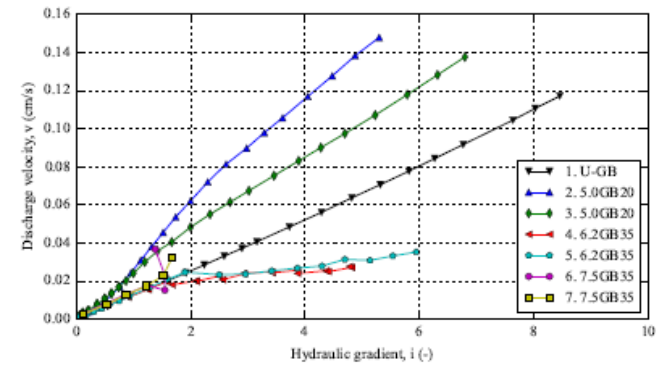
# Flexible wall permeameter



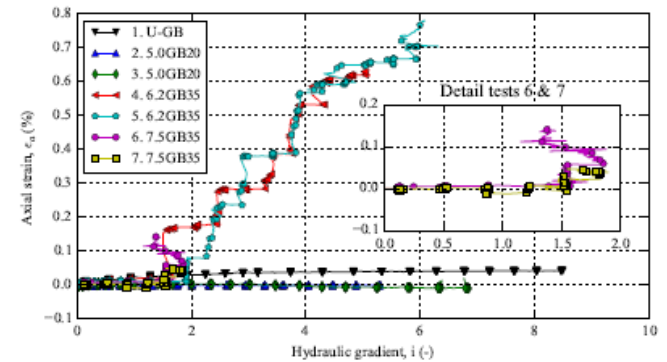
Discharge velocity  
Axial strain  
Volumetric strain

vs.

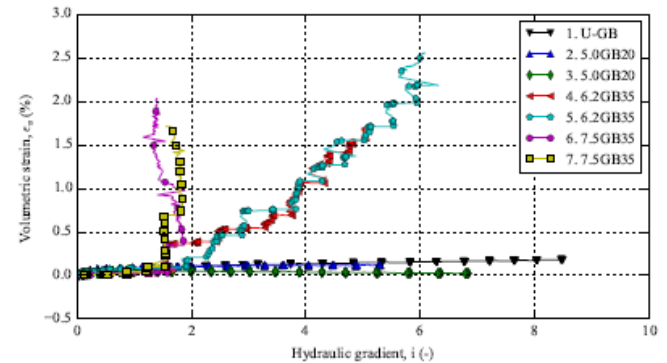
Hydraulic gradient



(a)

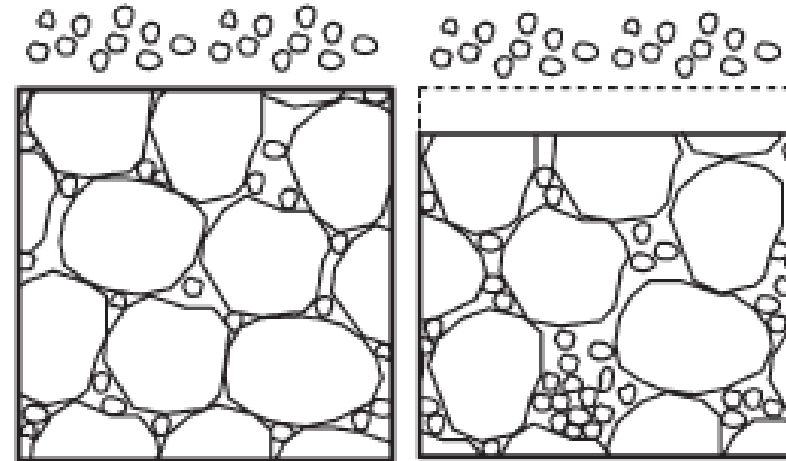
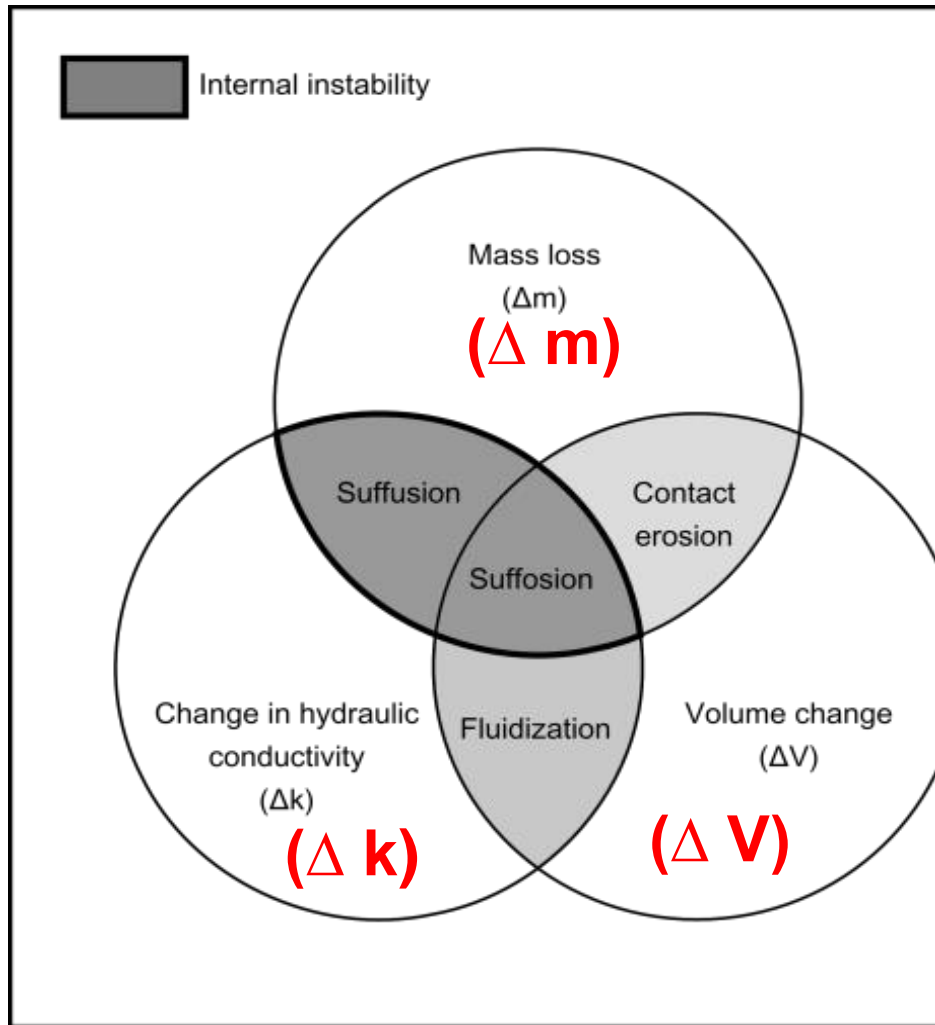


(b)



(c)

# Suffusion vs. Suffosion



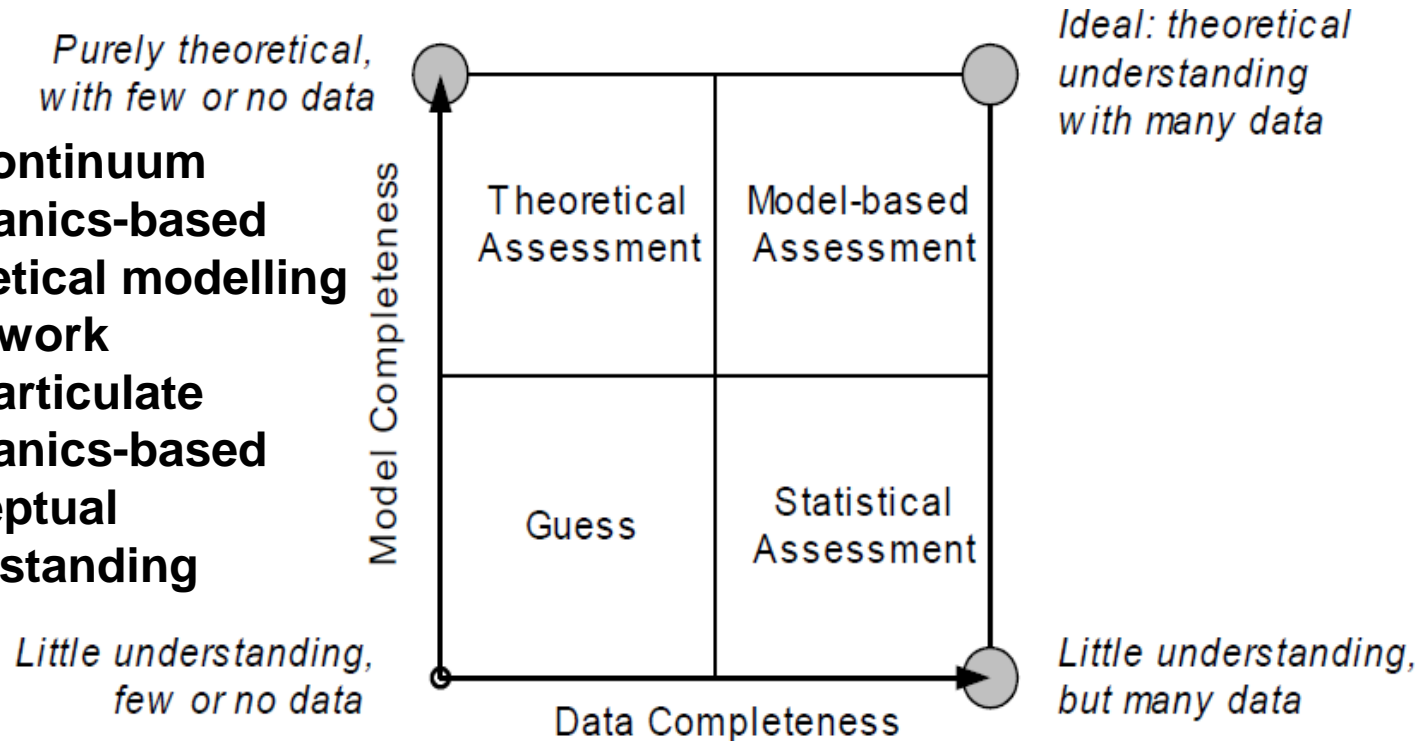
Suffusion

Suffosion

# Summary remarks: experimental research

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

- model-informed experimental investigations



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