HR Wallingford
Working with water

Erosion of coarser materials

Literature Review

11th December 2017 International Workshop, Aussois Mark Morris

Structure

1. Context for this review
2. Approach
3. Findings: Factors affecting soil erodibility

   Findings: Soil erosion processes

   Findings: Shear stress and erodibility measurement / estimation techniques

   Findings: Modelling methods and approaches

   Findings: Experiments and investigations
4. Overall conclusions
5. Where next?

[1] Context for this review

- Aim: Reliably predicting breaching processes...
- Goal: Providing industry engineers with a practical, usable, reliable breach prediction tool

- Focus on prediction of erosion of coarser materials – complementing the rigorous work undertaken by USDA HERU on headcut erosion
- This presentation picks out key issues rather than citations
- May well have already been explained during the 16 preceding sessions!

[1] Context for this review

But, just what does “Coarser grained materials” mean?

- From finer materials such as silts / clays through sands to gravels / cobbles
- Sufficient to span from headcut to surface erosion processes
- Not forgetting mixed materials
- Trying to reflect materials typically found in levees (and dams)
- but NOT rocks

[2] Approach

- **Scope**
  - Tried to cover topics / areas related to prediction of breach through coarser grained materials
- **Process**
  1. Literature review search terms
  2. Online search plus expert suggestions (many people here today...)
  3. Long list references – rated
  4. Relevant papers reviewed in more detail
  5. Conclusions

- **Mohamed Hassan / Mark Morris undertook the review**

[2] Approach – Topic Structure

- **Approach**

- **Findings**
  - i. Factors affecting soil erodibility
  - ii. Soil erosion processes
  - iii. Critical shear stress and erodibility measurement & estimation techniques
  - iv. Modelling methods and approaches
  - v. Experiments and investigations

- **Conclusions**

[i] Factors affecting soil erodibility

- **We are not alone... Research into soil erodibility covers a variety of areas including:**
  - **Erosion of soil from fields (agricultural sector)**
  - **Erosion of river banks (morphological analyses)**
  - **Erosion of mountainous areas (soil loss; slope stability)**
  - **Erosion of river beds (bridge scour)**
  - **Erosion of river and port beds (navigation)**
  - **Erosion of seabed (buried structures; pipelines)**
  - **Erosion of levees and dams**

[i] Factors affecting soil erodibility

Key observations:

- **No simple or clear method for predicting soil erodibility. No single solution found...**

- **Many approaches use the excess stress equation – or some variation thereof**
  - **Suggestion that use of linear excess stress has consensus and acceptance as best currently available method**
  - **Wilson model proposes non linear relationship – reducing rate of increase in erosion at higher stress levels. This matches some observations – but needs investigation / validation.**

[i] Factors affecting soil erodibility

Key observations:

- **Many efforts to determine what factors affect or determine soil erodibility**
  - **Relative importance varies according to soil grading**
  - **Example...**

Table 3.1: Soil properties influencing erodibility

Soil water content	Soil dispersion ratio
Soil unit weight	Soil cation exchange cap
Soil plasticity index	Soil sodium absorption rat
Soil undrained shear stress	Soil pH
Soil void ratio	Soil temperature
Soil swell	Water temperature
Soil mean grain size	Water salinity
Soil percent passing #200	Water pH
Soil clay minerals	

Source: Briaud, 2008

[i] Factors affecting soil erodibility

Given the complexity of parameters, attempts made to simplify:

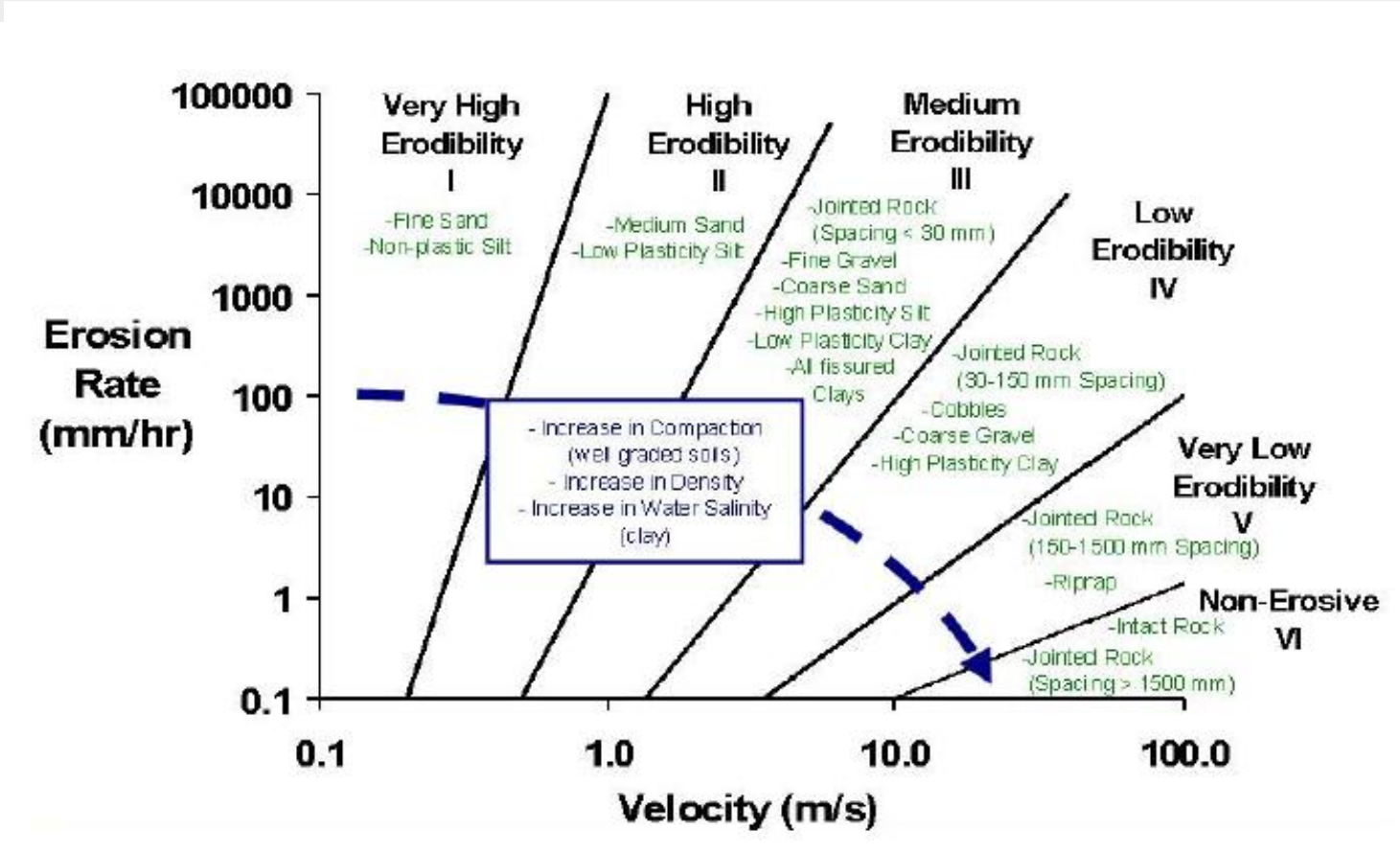


Figure 3.1: Example plot showing zones of erodibility

Source: Briaud, 2008

[ii] Soil erosion processes

Condensed into:

- **Macro processes**
  - Headcut
  - Surface erosion
  - Block failures
  - Internal erosion
- **Micro processes**
  - Cohesive forces (clays / fines)
  - Pore pressures
  - Geometric locking

- **Closer look at the effects of:**
  - Soil grading
  - Seepage
  - Dilatancy

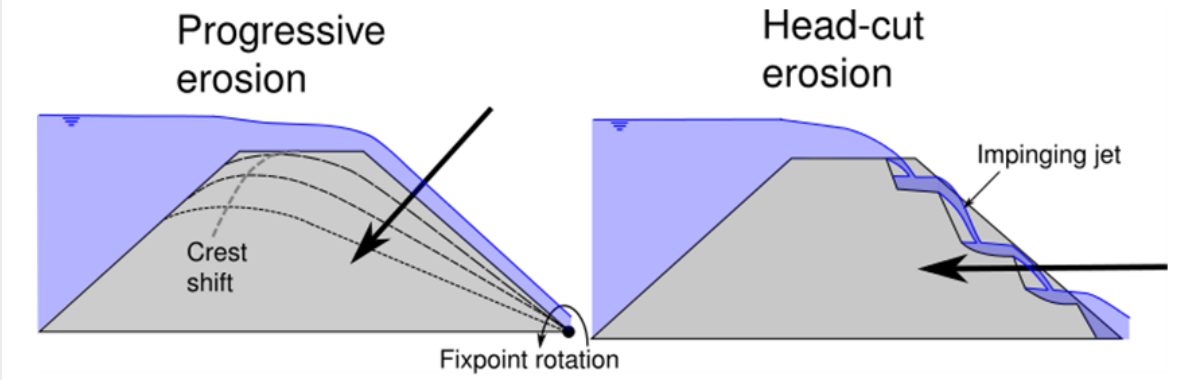
[ii] Soil erosion processes

Surface erosion processes:

...as the material becomes more erodible transition from headcut to surface erosion

Researchers report:

1 Parallel slope retreat
2 Steepening of the slope
3 Flattening of the slope



Source: Christian Volzt

Various pivot points – various materials / gradings etc.

[will be mapping the observed processes against grading / material type/state – we lack the big picture of processes across the material grade spectrum]

[ii] Soil erosion processes

Soil grading:

- **Levees / dams are rarely constructed from uniformly graded material**
  - **We need to understand erodibility of clean samples as well as mixed soils**

- **Key research by Wahl into the effects of fines on overall erodibility**
- **Key research by ERDC into coarser grain soil erodibility and macro erosion process changes**

[ii] Soil erosion processes

Erosion models:

- **Whilst there are various studies and concepts looking at critical shear stress for coarser materials (e.g. Shields; failure of riprao etc), there seems little on rate of erosion.**

- **River transport models?**
  - **These are typically based on shallow slope, equilibrium sediment in / out, long term, slow changes → not what is normally seen in breach.**

- **We need reliable data to assess whether excess stress formulation remains usable for breach erosion of coarser materials**

[ii] Soil erosion processes

Seepage:

- **Where significant seepage can occur (clean graded, coarser soils) this affects erodibility**

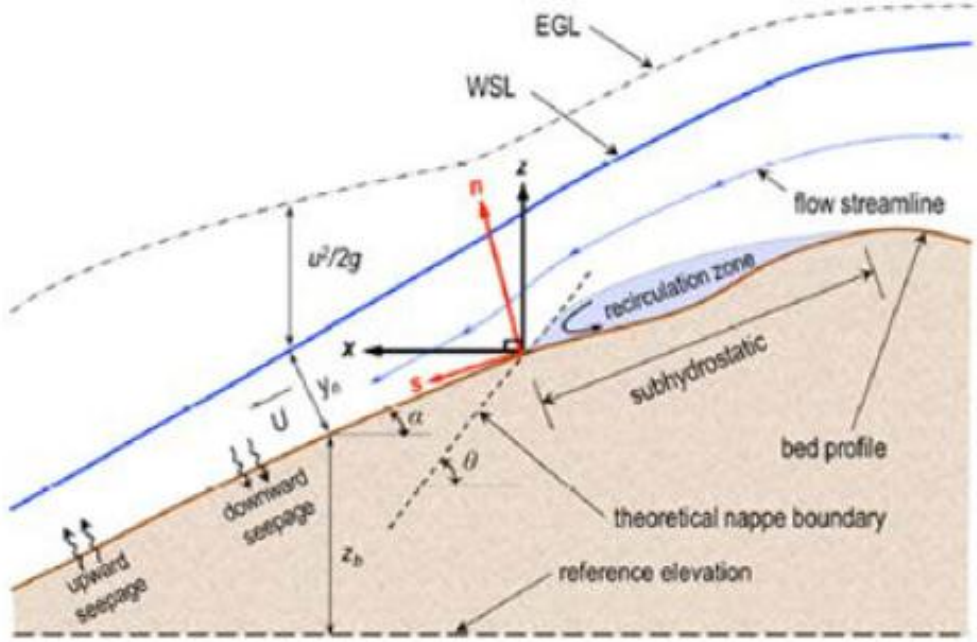


Figure 3.2: Hypothetical flow overtopping a steep non-cohesive bed showing recirculation zone, water surface levels and bed elevations, flow parameters, energy grade line and upward / downward seepage

Source: Al-Riffai et al, 2013

- **Tests need to consider internal seepage, drainage effects...**

[ii] Soil erosion processes

Dilatancy:

- Van Rhee argues that dilatancy can occur for some specific soil grades (sands), whereby soil expansion / seepage inflow reduces erodibility

- Specific ‘window’ of conditions

[Again – we need to put this process in context with others / soil grade/state etc]

[iii] Critical shear stress and erodibility measurement & estimation techniques

Equipment:

- Jet erosion test — JET
- Hole erosion test — HET
- Erosion function apparatus — EFA
- Internal erosion apparatus — IEA
- Cohesive strength meter — CSM
- Block puller device

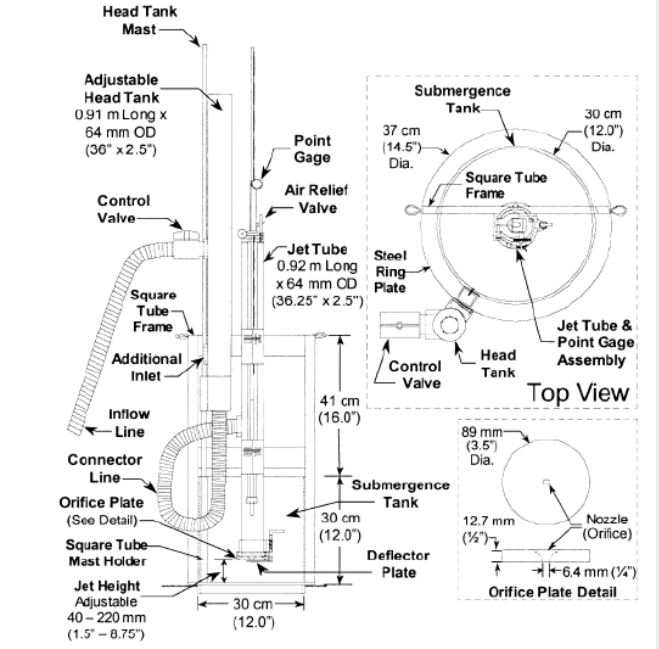


Figure 3.4: Schematic of the JET in situ apparatus

Source: Hanson and Cook, 2004

Which for what? Match equipment to process?

Tc and Kd of coarse grained materials → JET and EFA

(neither requires drilling into sample...)

[iii] Critical shear stress and erodibility measurement & estimation techniques

BUT

1. **Noted differences between laboratory and field sample analyses**

2. **Unresolved differences of measurement using different systems**

How do we resolve this?

[iii] Critical shear stress and erodibility measurement & estimation techniques

In the absence of testing equipment, use of some estimation techniques has developed:

- **T_c in relation to D_{50}**
- **Still lacking K_d – significant variation related to particle size**
- **Work is needed...**

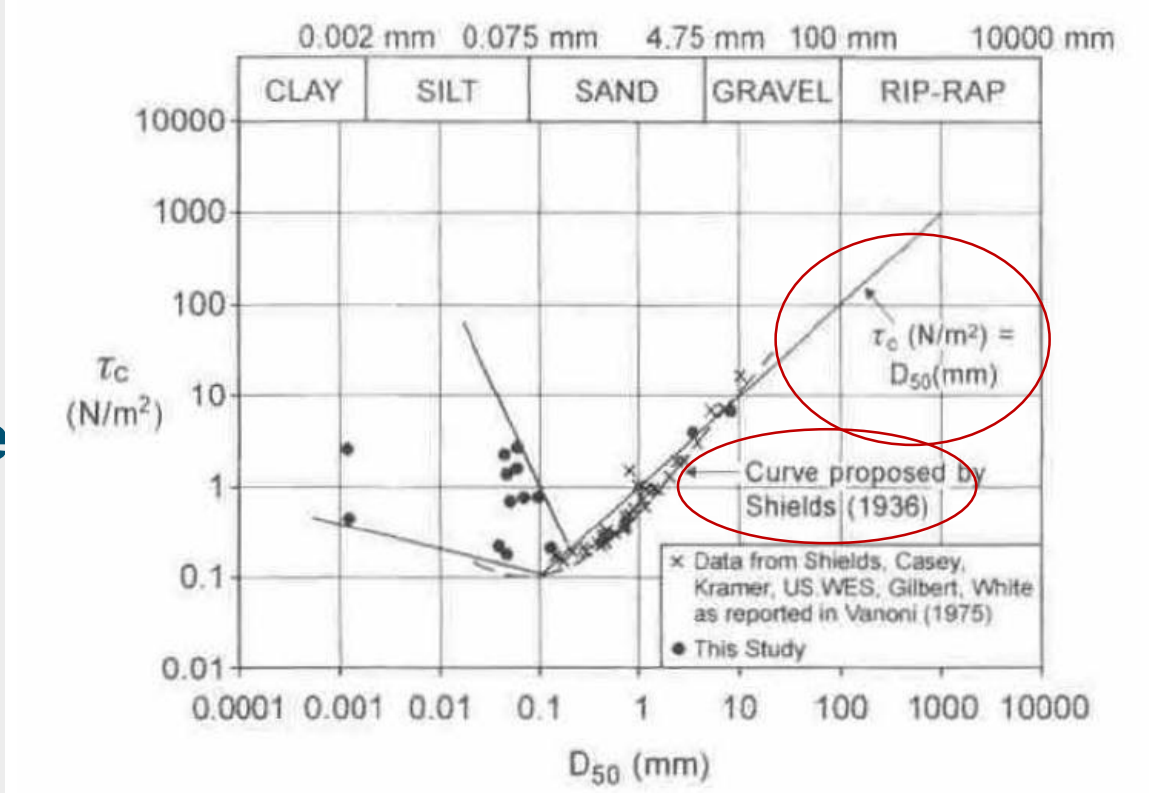


Figure 3.10: Critical Shear Stress versus Median Soil Grain Diameter

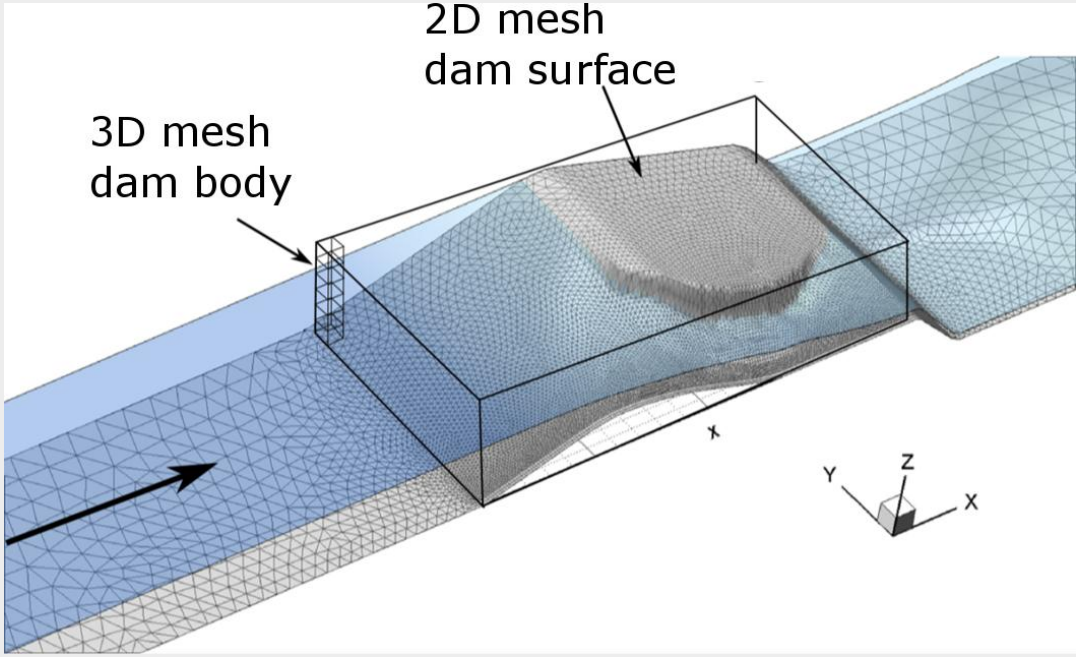
Source: Briaud et al (2001)

[iv] Modelling methods and approaches

- We've heard from Tony about the DSIG breach modelling project. Researchers continue to develop, refine and extend breach models
- Breach models of varying complexity exist – 1D/2D/3D.
- Open source software plus increased computing power allows for complex 2D/3D models integrating flow, erosion, seepage, slope stability etc. BUT, the issue of soil erodibility and homogeneity remains for all!
- Another practical consideration, is balancing the usability / complexity (time to learn, run; data needs etc) against accepted uncertainty in outputs

[iv] Modelling methods and approaches

- **The result is that we tend to have parallel model development and use, comprising:**
  - **Simpler models that are relatively quick and easy to use being applied within industry**
  - **More complex 3D models being developed in academia testing the limits of ever more complex numerical solutions**



Source: Christian Volzt

[iv] Modelling methods and approaches

BUT Without a solution to the soil erodibility / variability issue and without reliable validation data across a range of soil grades, the model performance (whether simple or complex) will always be questioned.

[v] Experiments and investigations

- One off studies versus longer term research into specific aspects
- Narrow glimpses of specific processes for specific soils under specific conditions
- Typically at a small scale →
  - scaling of all processes not necessarily correct
  - Accurate construction / analysis of soil state difficult

[v] Experiments and investigations

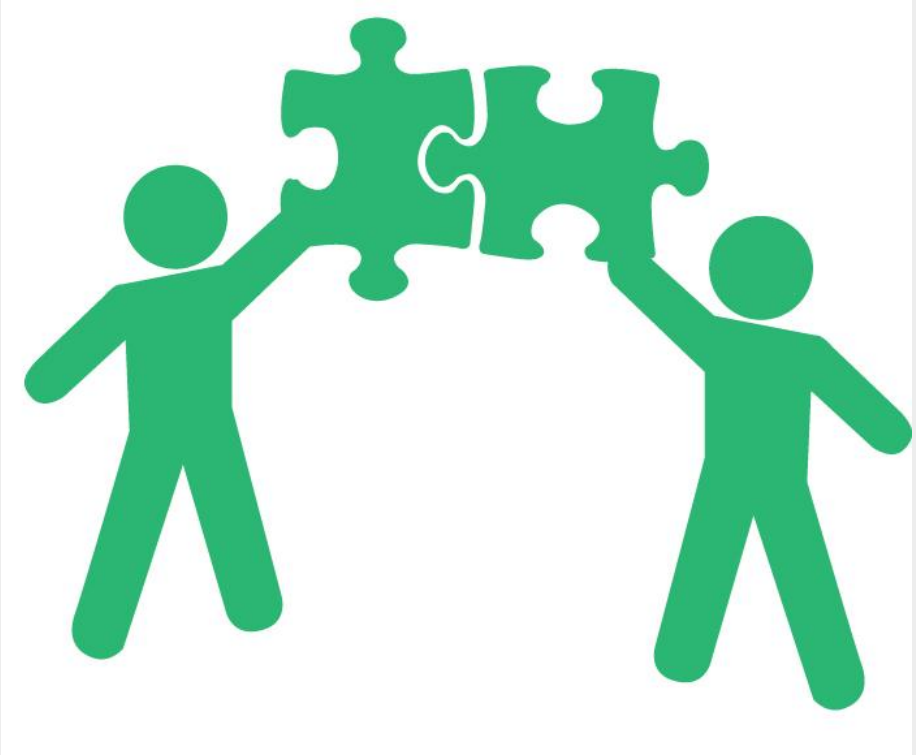
Some of the longer term researchers include:

Univ Ottawa	Al Rifai
TU Delft	Paul Visser / Myron van Damme
ERDC, Vicksburg	Johannes Wibowo / Ghada Elithy
Oklahoma State Uni	Criswell
USDA-ARS / HERU Temple)	Sherry Hunt (Greg Hanson / Darrel
USBR	Tony Wahl
HR Wallingford	Mark Morris / Mohamed Hassan
ETH, Zurich	Schmocker

[v] Experiments and investigations

Perhaps maintaining some form of schedule of research interests and programmes (past, present, planned...) would help allow the bigger picture / gaps in knowledge to be more easily seen?

[Problem is always money, motivations for collaboration etc...]



[4] Conclusions

Factors affecting soil erodibility

- No simple or clear method for predicting soil erodibility. No single solution found...
- Many approaches use the excess stress equation – or some variation thereof. Unclear whether linear or more complex form (or different form altogether) is more appropriate

[4] Conclusions

Soil erosion processes

- We still do not know when the transition from headcut to surface erosion macro processes occurs or when surface erosion of slopes flattens, steepens, parallel retreat etc
- Research has focussed on narrow windows of soil type and state – missing the big picture
- Starting to look at the role of seepage in relation to erodibility (including dilatancy)
- Starting to look at the role of fines in relation to erodibility

[4] Conclusions

Shear stress and erodibility measurement / estimation techniques

- We have a variety of methods developed in relation to specific, observed processes (jets, holes, surface erosion etc). BUT, we have not resolved why we estimate different values for erodibility and critical shear stress when applying each test to the same soil

- Systems are typically applicable to fine material rather than coarse grained and larger – we need a solution for representing / measuring erodibility of larger sized material

[4] Conclusions

Modelling Methods and Approaches

- Computational models are advancing → 2D / 3D models of breach are becoming a reality
- BUT we are lacking reliable, large scale data for a variety of soil types and conditions (as found in dams and levees) that allow us to validate those models
- As we learn more about breaching processes we learn more about what data we need, and what processes we should be watching as part of future large scale tests / data collection

[4] Conclusions

Experiments and Investigations

- There is a scatter of experiments, looking at different aspects of breach for different soils. However, most are narrowly focussed
- We miss the big picture – an overview of processes by soil type and state – from clay to cobbles!
- Too many tests are undertaken at too small a scale meaning that processes are not correctly recreated

[5] Where next?

Address:

1. Differences between erodibility measurement equipment
2. Develop solutions for erodibility measurement of coarser material
3. Investigate and map macro erosion processes – from headcut to surface erosion (and variations thereof)
4. Collate large scale, quality data for model validation (from clay to cobbles
   - This may be to support deterministic models or probabilistic approaches (which may be the best way to address soil variability)
5. Continue investigation into specific processes (internal seepage; dilation; effect of fines)

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