Calgary Geotechnical Society Presentation

Topic: Numerical Analysis of the Brumadinho Tailings Dam Failure
Speaker: Dr. Marcos Arroyo
Date: Wednesday, November 24, 2021, 10:00am - 11:15am (MST)

Questions from the audience:

1. **If there is an increase in fines (clay) content, will viscous behavior become more influential in peak undrained shear strength? if so, will the rate dependency possibly delay the time that confined liquefaction can occur in the tailings material?**

A: CASM-visco predicts that an ideal material with viscosity that is typical of clay but permeability that is typical of sandy silts will be less sensitive to sudden shocks and less easily triggered into liquefaction. This was explained in detail in our recent paper to T&MW.

I am afraid that a material combining those two properties will be difficult to find. Rate effects (viscosity) are more dependent on plasticity that on fine content. Note also that, from this point of view, If you have a lot of non-plastic fines you are in the worst possible scenario for triggering.

2. **How do you choose the initial state parameters in your models to end up at the end of construction with the characteristic state parameter inferred from CPT data?**

A: We cannot control how state parameter evolves during construction, but only specify the initial value. This is related to other parameters in the model as detailed in the report (see Appendix A.2). The indications of state that are inferred from CPT data are one source of information amongst others to be considered when selecting parameters and initial values. This is particularly so when you use -as we did- a method such as Plewes that carries large uncertainty, even if it is likely to be unbiased in its central estimate.

3. **The video shows that failure occurred simultaneously over a length of around 300m. Your '3D' analyses was only 15m wide. How do you justify your statement that liquefaction from drilling at section 3 would propagate laterally when your other analyses at section 2 showed that liquefaction would not propagate? The EPR used a 3D Model of the full dam that showed that liquefaction from drilling would not propagate laterally due to the drilling?**

A: The plane strain triggering simulations indicate

   1. *that if a structure with the geometry and disposition of materials assigned to section 3 would have extended indefinitely in the out of plane direction a localised trigger at the last borehole would have failed it. On the other hand,*
   2. *if a structure with the geometry and disposition of materials assigned to section 2 would have extended indefinitely in the out of plane direction a localised trigger at the penultimate borehole would not have failed it*

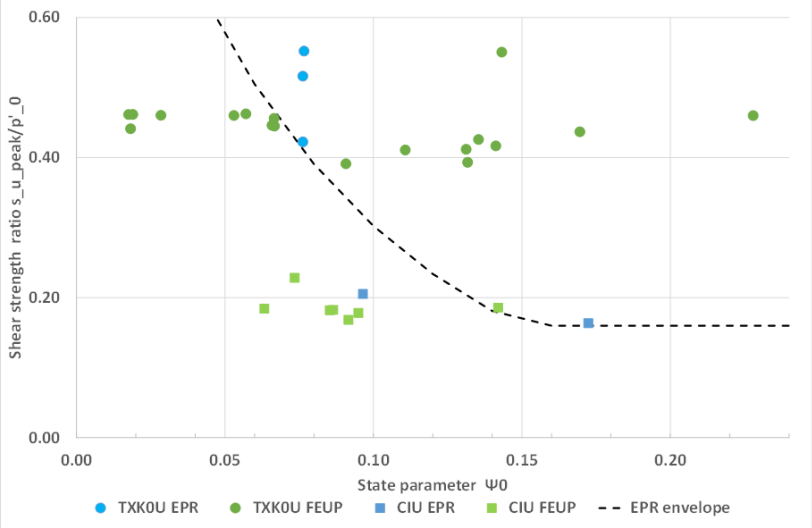
Those two statements are not contradictory. A failure front that initiates at section 3 at a very localized position (1m x 3 m) does not need to arrive at section 3 with the same width; on the contrary it is more likely that the plastic wavefront (a.k.a. liquefied zone) has expanded

substantially when it arrives at section 2. We think that such expansion upon lateral propagation is possible because this is what happens, at a lesser scale, on our 3D slice model.

The geometry assigned to section 2 does withstand a trigger of 1mx3m. I doubt that it would withstand a much larger lateral trigger. As a matter of fact, we found in our analyses that changing the conditions in the soil around the borehole in Section 2 by very modest amounts, liquefaction was triggered; the situation was close to critical.

Still, it would be worth checking this hypothesis when (and if) a proper coupled hydromechanical 3D model of the full dam is built. I am afraid that the uncoupled models presented by the EPR do not qualify, as they are based on a number of flawed assumptions about the tailings behaviour, including, but not limited to, a highly underestimated undrained peak resistance, as evidenced by the results presented in my talk and reproduced below, for ease of reference

Triaxial peak undrained strength (2)



- There is no common envelope for TXCIU & TXK0U

4. For the design of new tailings dams, should it be necessary to consider the possible propagation of very localized liquefaction?

A: New tailings dam should be designed to avoid the presence of potentially liquefactable materials in structurally critical locations.

5. What evidence do you have that the drilling caused an over-pressure condition?

A: A static overpressure can be estimated from geometry of the simulated water table and drill position and corroborated -if available- by piezometric information and water observations from the drilling logs. Pages 66 to 68 of our report discuss this in detail. Please note that a wireline system

might have induced some dynamic overpressures as well, although those have not been accounted for in our computations.

6. **Do you think Norsand can be suitable to model creep of tailings?**

A: I am not an expert in Norsand, but I think it is likely that the model may be extended to viscoplasticity using a similar approach to that we used for CASM.

7. **Did previous data identify the liquefiable material within the dam or where they unknown at the time of the drill? Do you think in the future this will be required to locate so no drills will occur?**

A: The presence of liquefiable materials in the dam was known in general. The CPTu that was executed close to the last borehole was part of the same site investigation campaign. It I my impression -but I may be mistaken- that, perhaps, the results of that last CPTu campaign had not been properly released and/or given appropriate consideration yet by the time of the failure.

In the future, it may be advisable to look in detail at the CPTu results before drilling in a similarly dangerous material.