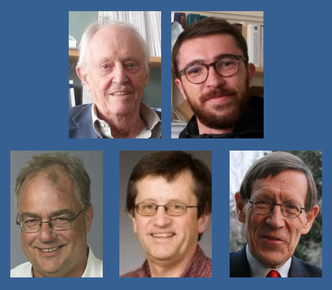
Progressive Landslide Analysis in Canadian Glacial Silty Clay in Churchill River

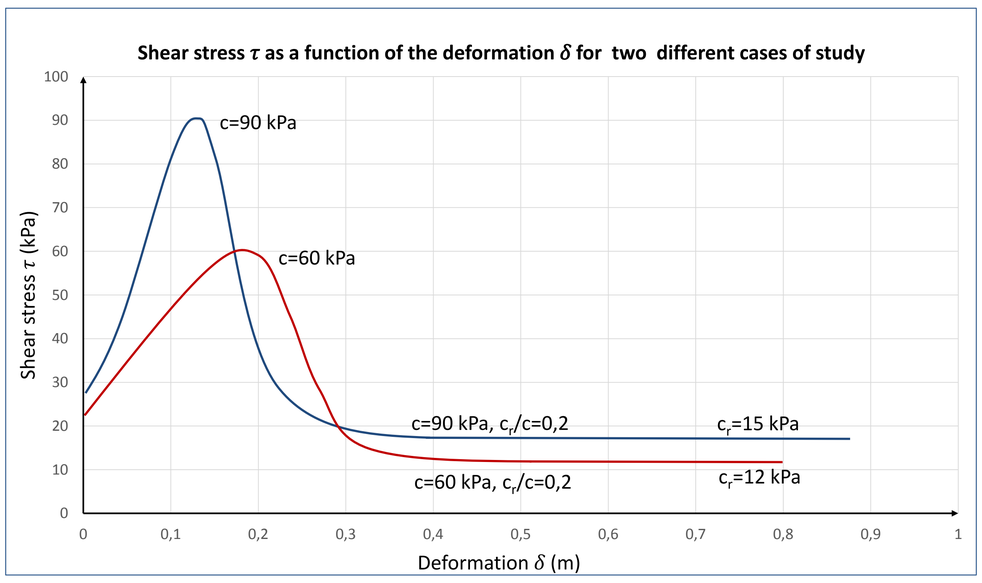
S. Bernander[1], R. Dury[1], J. Laue[1], S. Knutsson[1], L. Elfgren[1]

[1]Luleå University of Technology, Luleå, Sweden



Introduction

- At Muskrat Falls in Newfoundland, Fig. 1-2, a large hydro power plant is built.
- A land ridge composed of loose layers, the North Spur, will be used as a natural dam.
- Three different failure surfaces have been studied for different soil properties, Fig. 3-4.



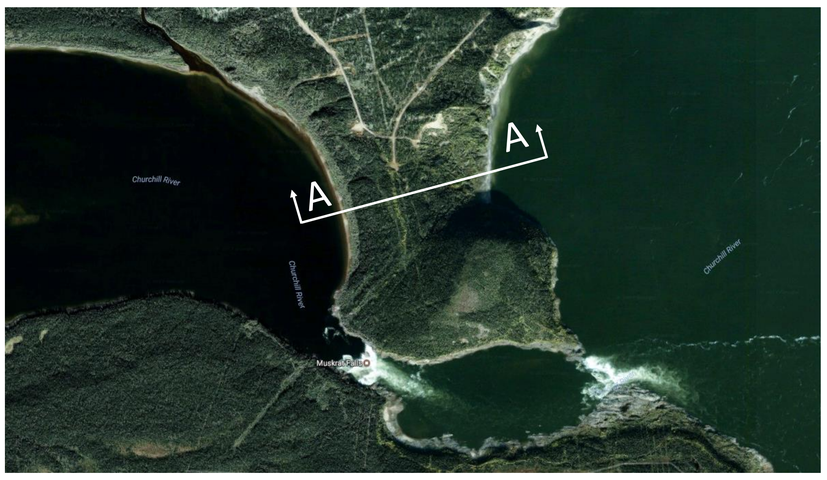


Fig. 1. Satellite view of the North Spur at Muskrat Falls

Fig. 2. Construction site at Muskrat Falls
http://muskratfalls.nalcorenergy.com/

Method

Failure analyses have been performed for three cases:

- **Case 1**: A traditional Limit Equilibrium Method (LEM) for a **horizontal** failure surface
- **Case 2**: A Progressive Failure Analysis (PFA) with a Finite Difference Method (FDM) for an **inclined** failure surface (4%) in the upper clay layer, Bernander et al. (2011, 2016), Dury (2017)
- **Case 3**: As Case 2 for a **curved** failure surface in the lower clay layer

Fig. 3. Softening behavior of materials for two different cases of study

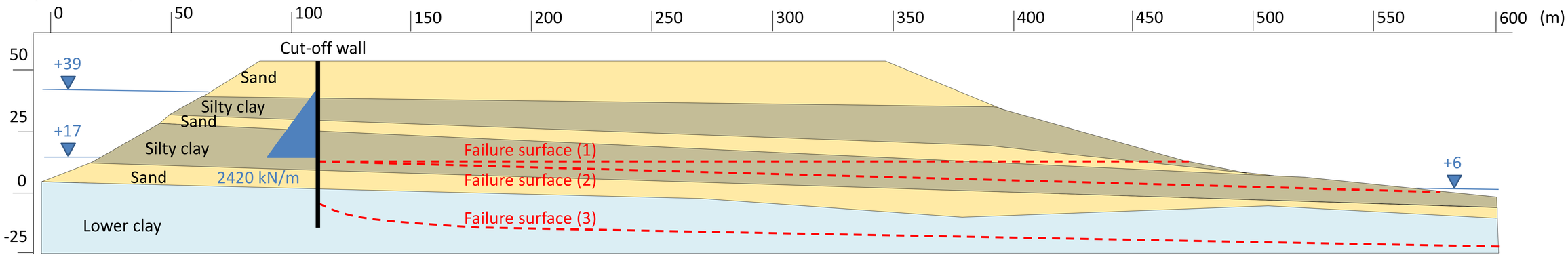


Fig. 4. Section A-A of the North Spur at Muskrat Falls. In red, the failure surfaces corresponding to the three cases studied. The blue triangle represents the additional pressure on the cut-off wall due to the rising water.

Results

- The horizontal failure surface in Case 1 is safe (both with LEM and PFA)
- The inclined and curved failure surfaces in Cases 2 and 3 are unsafe for many material properties according to the Progressive Failure Analysis (PFA).

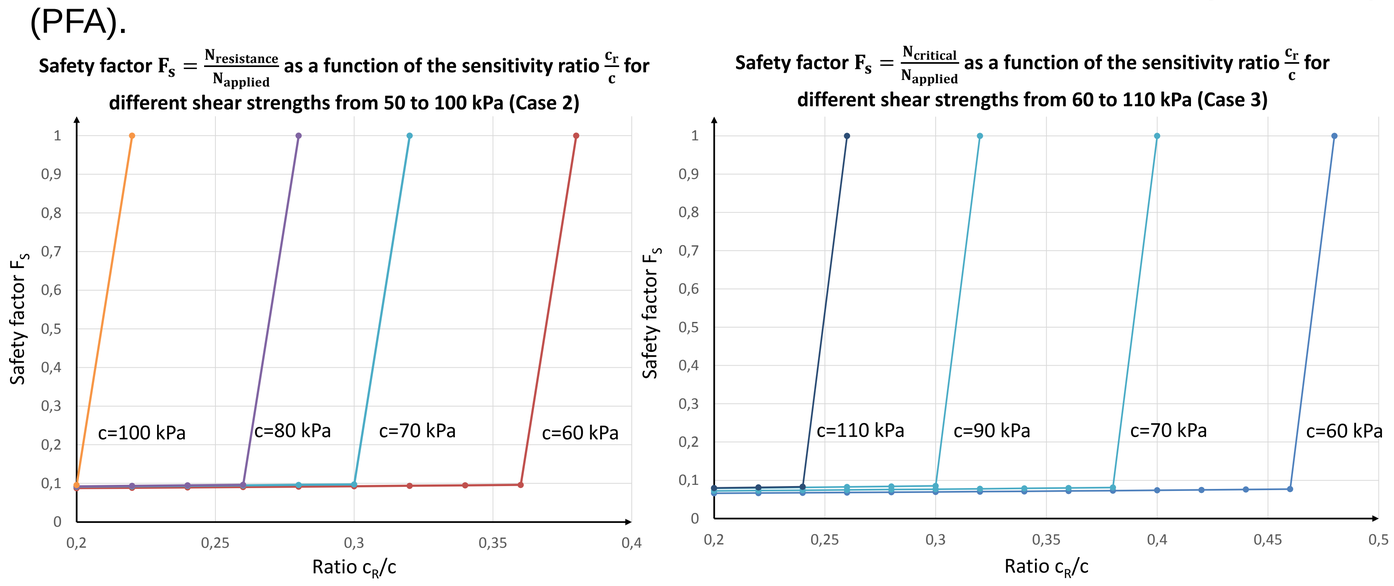


Fig. 5 and 6. Safety factors as a function of the sensitivity ratio for different shear strength for case 2 and 3

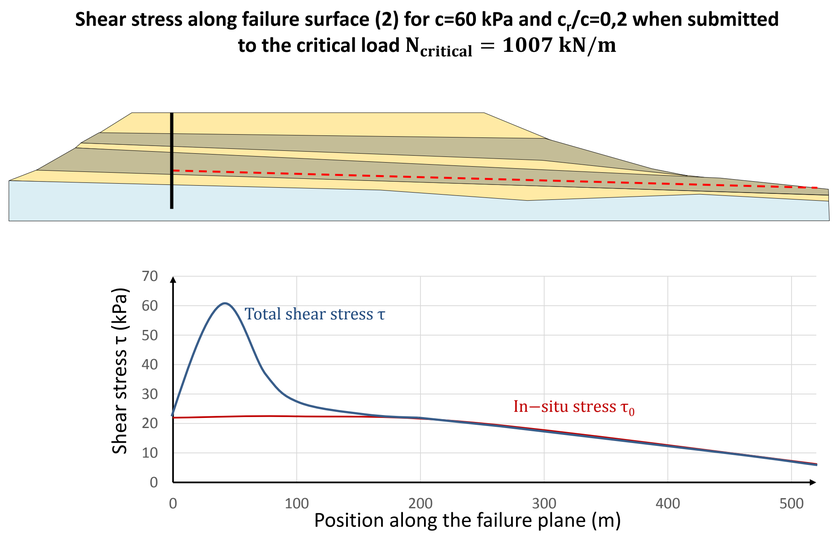


Fig. 7. Shear stress along the failure plane for for c=60 kPa and c_r/c=0,2

- For a pressure on the cut-off wall by rising water of $N_w = 0{,}5\rho_w H^2 = 0{,}5 \cdot 10 \cdot (39\text{-}17)^2 = 2420$ kN/m, the safety factor for the inclined surface in Case 2 for a clay with c = 60 kPa and c/c_R = 0,2 kPa will only be $F = N_{resistance}/N_{applied} = 1007/2420 = 0{,}4$. This is very unsafe.
- Fig.5 illustrates a case taking also the earth pressure on the cut-off wall into consideration. This gives safety factors <1 for clays weaker than c = 100 kPa with $c_R/c \leq 0{,}2$ to c = 60 kPa with $c_R/c \leq 0{,}45$ kPa.
- Fig.6 illustrates the inclined failure surface in Case 3 in a similar way as in Fig. 5.

Discussion

- Tests ought to be carried out to check the real properties of the soil (stress – deformation relationships as in Fig. 1).
- One way could be to drive groups of piles into the soil and to check the settlements for possible liquefaction in the areas around the assumed failure planes.
- If the tests indicate materials that give unstable results, the North Spur ridge ought to be stabilized, Bernander (2016), Dury (2017).

Contact

Robin DURY
Luleå Tekniska Universitet
Email: robdur-6@ltu.student.se
Phone: + 33 6 80 38 87 19

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