Progressive Landslide Analysis with Bernander Finite Difference Method

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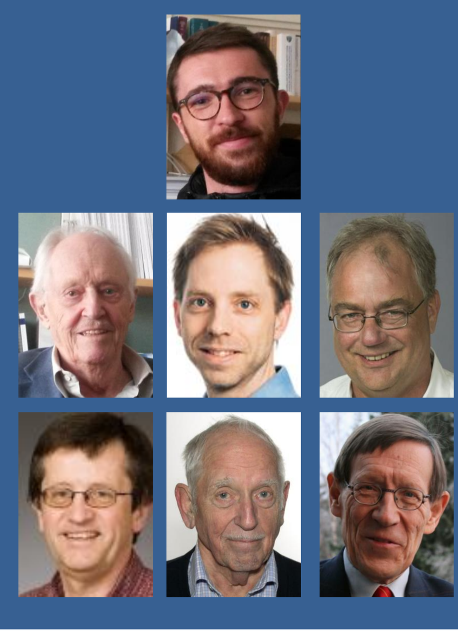


Introduction

- A spreadsheet is presented of the Finite Difference Method (FDM) by Stig Bernander et al. (1981, 2011, and 2016) and Dury (2017)
- Contrary to the classic Limit Equilibrium Method (LEM) the softening of the soil is taken into consideration.
- The method is illustrated in Fig. 1-3, Dury (2017).

Material Properties

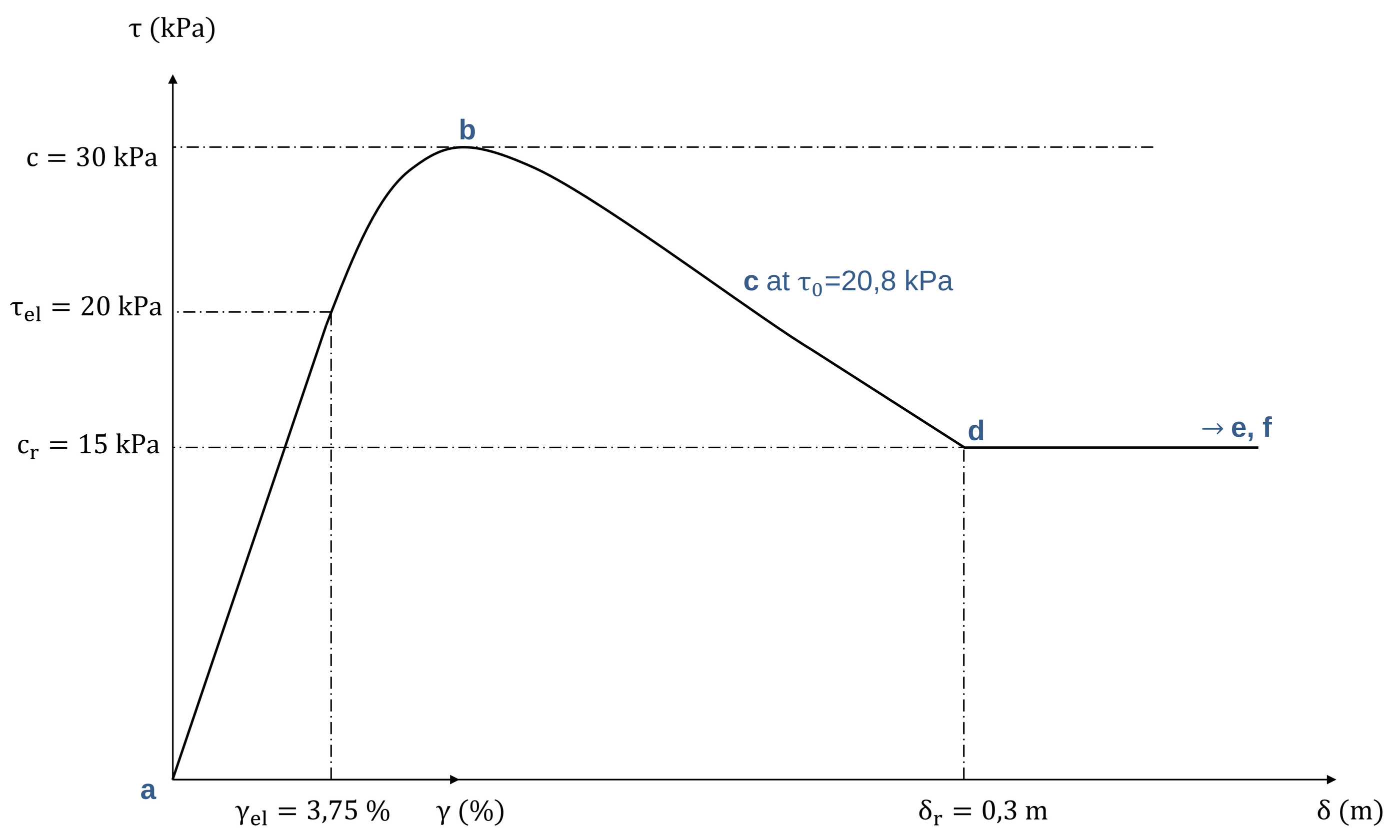


Figure 1. Stress-strain deformation relationship of a typical 'deformation softening' clay from southwestern Sweden. The letters a to f refer to Fig. 3 for L=0.

Finite Differential Method

- The mean deformation δ in each element caused by normal forces N is maintained compatible with the deformation generated by the shear stresses τ.

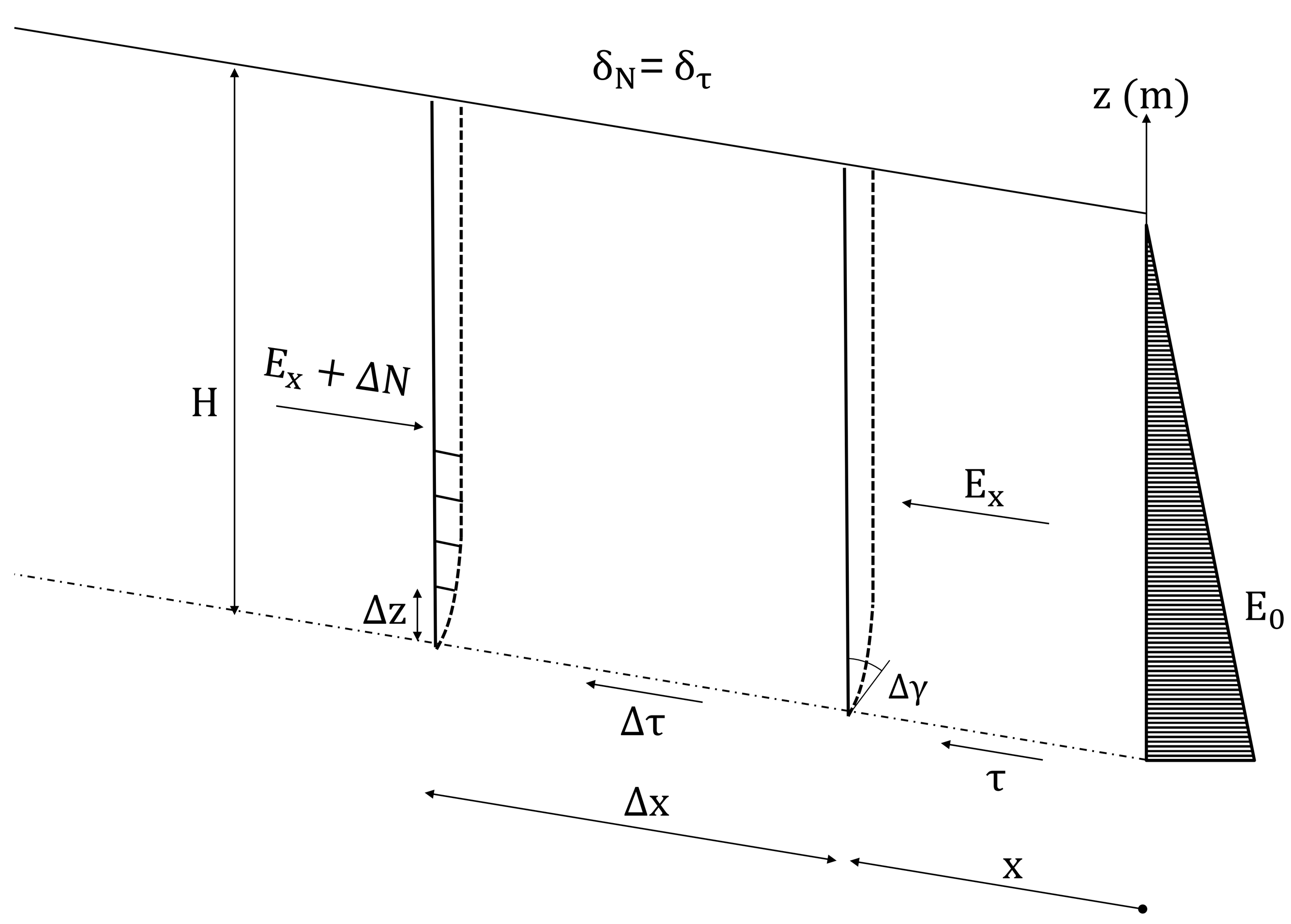
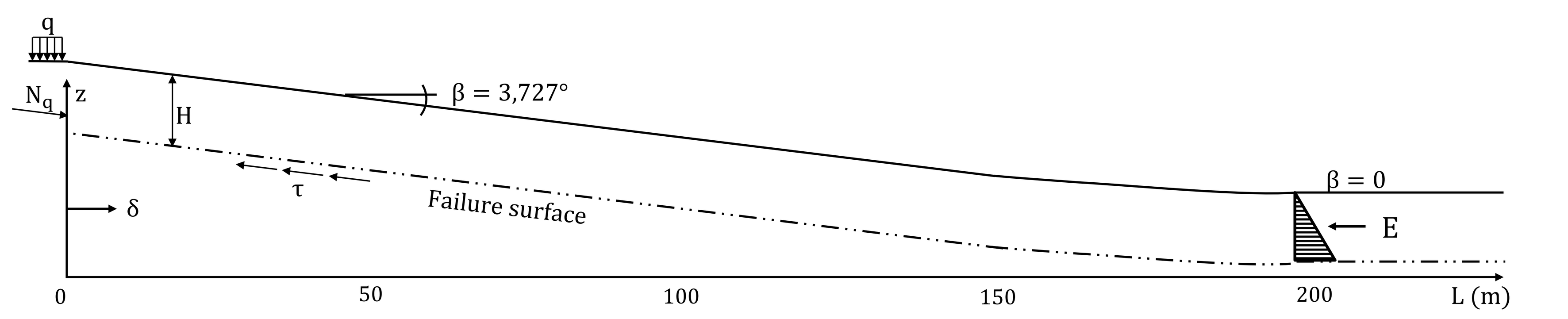


Figure 2. Illustration of the Finite Differential Method

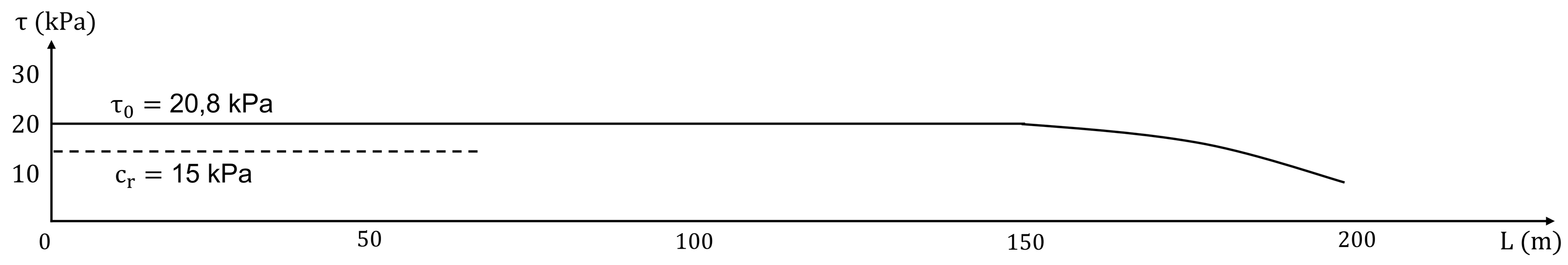
Discussion

- An easy to use spreadsheet has been developed, Dury (2017)
- Different geometries and material properties can be studied
- The method may readily be applied by Consultant Engineers

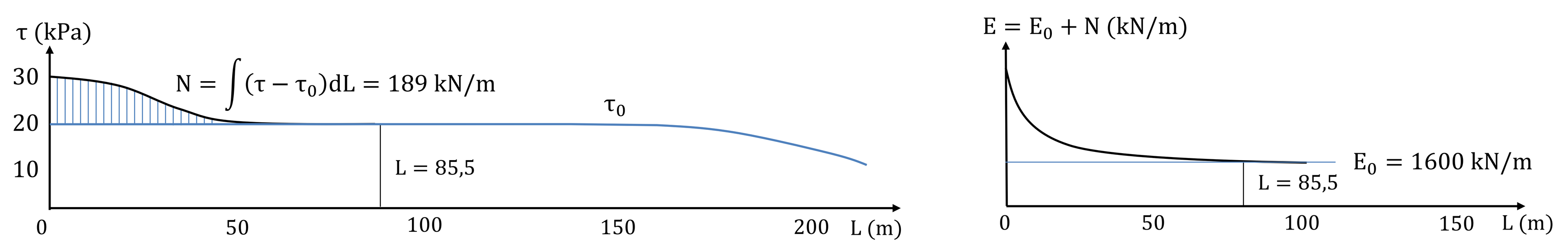
Progressive Failure Process



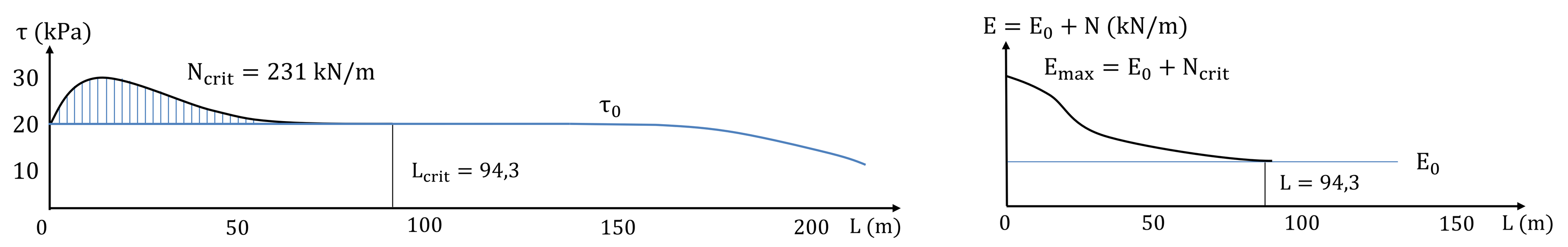
Downhill progressive failure triggered by an additional load q can be divided in 5 different phases :



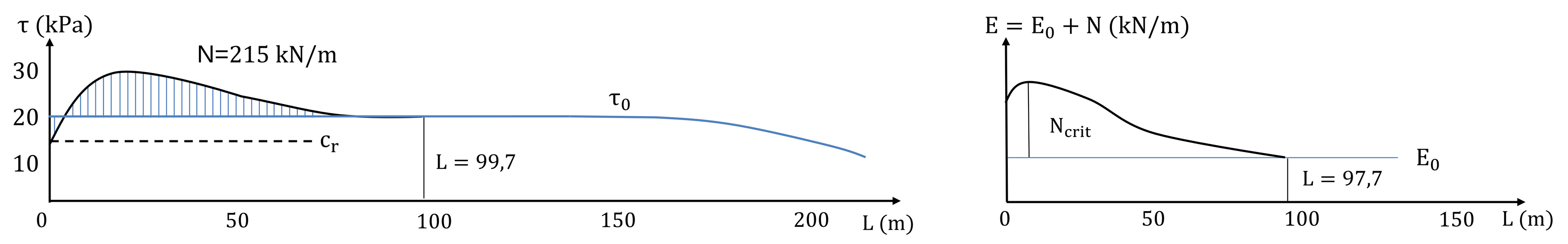
Phase 1, Moment **a:** In-situ conditions. No load q or N_q and in situ stress τ_0 = 20,8 kPa



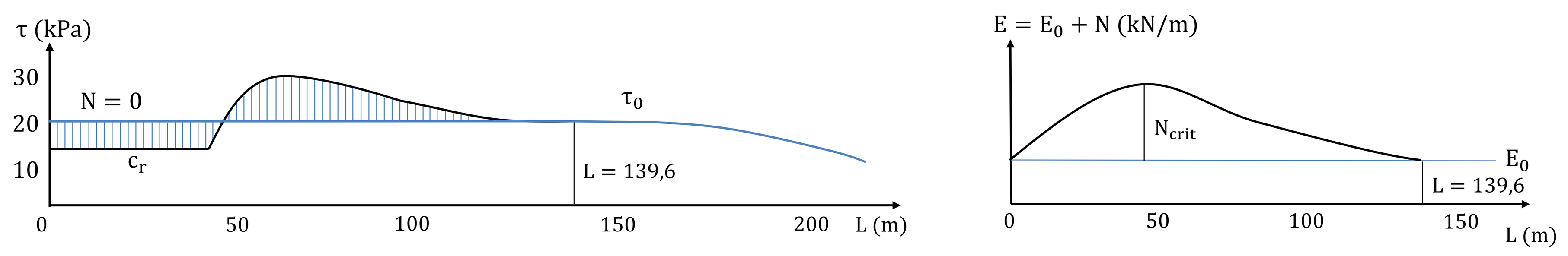
Phase 2, Moment **b**: A load q is applied giving τ = c = 30 kPa. The shear stresses can be integrated to the force N_q = 189 kN for an influence length L_b = 85,5 m.



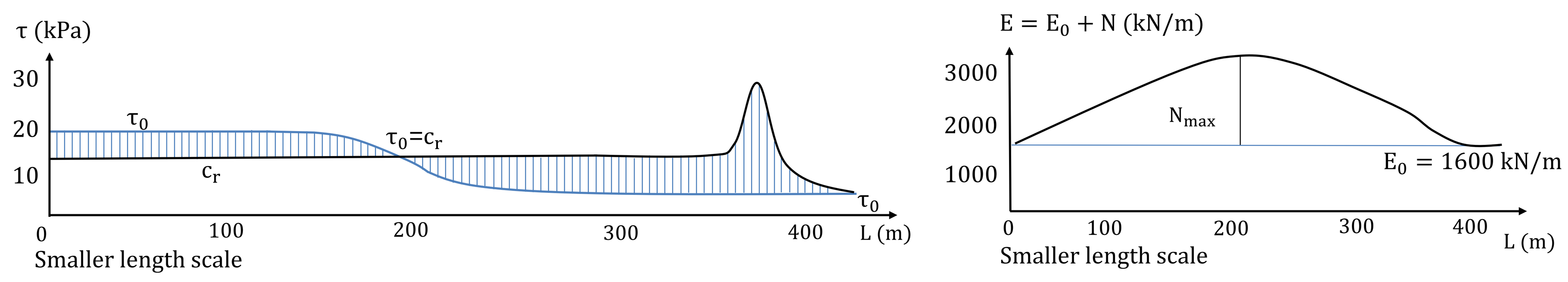
End of Phase 2, start of Phase 3, Moment **c**: The shear stress has now decreased to τ_0 = 20,8 kPa at the point of the application of q and the load has reached its maximum value N_{crit} = 231 kN for an influence length L_{crit} = 94,3 m.



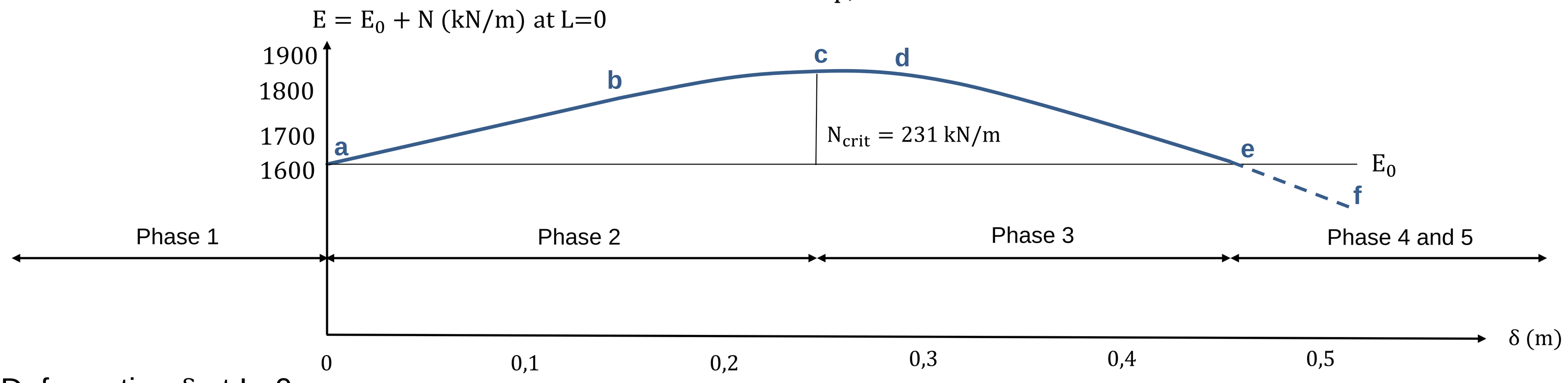
Phase 3, Moment **d**: Now an unstable dynamic phase starts and the load that can be taken is reduced to N = 215 kN for an influence length of L_d = 99,7 m. The shear stress is reduced to its minimum value c_r= 15kPa



End of Phase 3, Moment **e**: The negative shear forces balance the positive forces so that N = 0 at the point of load application. The maximum shear force 231 kN has travelled downslope for a total influence length of L_e = 139,6 m



Phase 4 (and 5), Moment **f**: The in situ shear stress τ_0 decreases from **L** = 150 m where the slope turns horizontal. The pressure **N** is caused by the weight of the sliding mass, $N = L * H * \rho * g * \sin(\beta)$. The residual shear stress c_r is reduced due to dynamic action. The pressure is "permanently" or "temporarily" balanced by passive resistance if $(E_0 + N)_{max} < E_{p,Rankine}$. The failure plane develops far into the unsloping ground before equilibrium is reached. If $(E_0 + N)_{max} > E_{p,Rankine}$ a final collapse will occur in **Phase 5.**



Deformation δ at L=0

Figure 3. Illustration of the progressive failure process

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References

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