MODELLING EVOLUTIONARY CONTACT IN PLOUGHING AND CUTTING OF SOILS

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Numerous applications in civil engineering revolve around displacement or removal of soil by means of ploughing and cutting. The terms "ploughing" and "cutting" both refer to processes by which deformation is induced by sliding contact with a rigid or flexible object, an example of which is shown in Figure 1.

Ploughing and cutting are differentiated, however, by whether or not separation of the material occurs, as shown schematically in Figure 2. Both processes play direct roles in earthmoving, mining, dredging, trenching, tunnelling and similar areas, and they are also relevant on the micro-structural level in soil-structure interaction, as sliding of asperities on interfacing materials (e.g. concrete and soil) can be a significant source of friction and wear.

While ploughing and cutting in metals have been investigated extensively, studies dealing with soils are limited. For both metals and soils, there is a basic lack of understanding of the unsteady regime in which the object (plough or cutter) first makes contact with the soil and then begins to slide with prescribed force or penetration. In this transient regime, the shape and location of material boundaries, as well as the stress and strain fields, evolve in time. As a consequence, basic quantities of interest such as horizontal (drag) force and penetration also change in time. Furthermore, previous studies focus heavily on ploughing and

FIGURE 1: Ploughing of soft clay by a flat, inclined plate of narrow with.

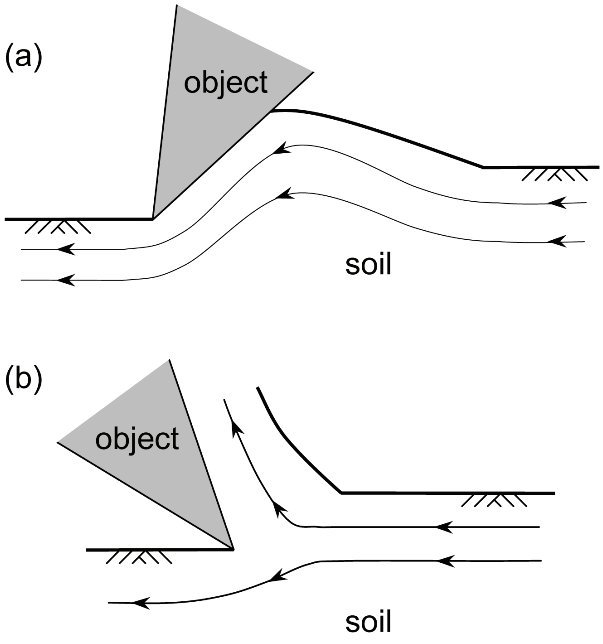

FIGURE 2: (a)Ploughing and (b) cutting as distinct modes of deformation as an object slides over a surface.

cutting under plane-strain conditions despite the fact that the deformation is typically three-dimensional. As compared to metals, analysis of soils is also complicated by the presence of pore water, which plays an important role in offshore applications such as pipeline ploughing.

Through the use of state-of-the-art experimental methods and computational techniques, this project aims to build an understanding of the

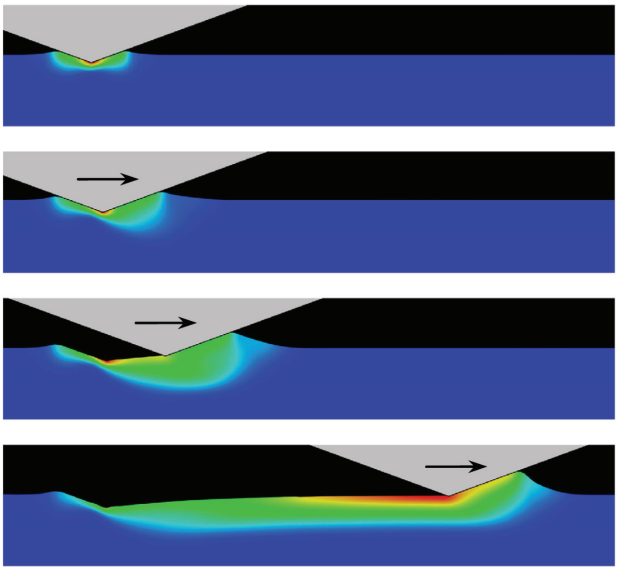

FIGURE 3: Results of two-dimensional (plane strain) finite element simulations of a smooth, rigid wedge sliding over cohesive material. In the first stage (top), a normal force is applied without translation (i.e. indentation), and the wedge then slides from left to right. Contours show equivalent plastic strain.

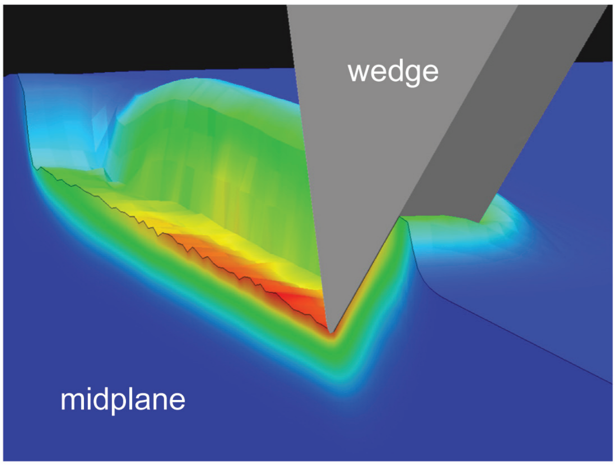

FIGURE 4: Pattern of deformation observed in a three-dimensional finite element simulation of a smooth, rigid wedge of narrow width sliding over cohesive material.

evolutionary deformation occurring in ploughing and cutting of soils. In experiments, quantitative analysis of the evolving displacement field is performed using particle image velocimetry (PIV), and centrifuge testing is employed to reproduce full-scale behaviour, especially for investigation of applied problems relevant to industry. Observations from experiments are subsequently used as the basis for developing analytical models and validating results from comprehensive numerical simulations. In numerical simulations, attention is directed at implementing methods that effectively accommodate extreme deformations. These include adaptive finite element methods, meshless continuum-based approaches, and particle-based methods. Special emphasis in both analytical and numerical modelling is placed on accounting for three-dimensional deformation and the effects of pore pressure.

Figures 3 and 4 show typical results from two- and three-dimensional finite element simulations of quasi-static ploughing in cohesive material by a rigid wedge. Figure 3 highlights the evolutionary nature of the ploughing process as the wedge initially indents the material and then slides from left to right under prescribed normal force.

One can observe basic similarities and differences between plane strain (Figure 3) and the three-dimensional configuration for a wedge of narrow width (Figure 4). A significant difference is that material flows to the sides of the wedge in three dimensions, and as a consequence, relatively large penetration is maintained as the configuration approaches steady state. In plain strain, penetration in steady state is practically zero.