Slot stability of diaphragm walls during construction – possibilities and limitations of centrifuge modelling

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ABSTRACT: Excavations for diaphragm walls are an ongoing challenge for contractors, as slot stability depends on many parameters, including bentonite composition, soil stratification and behaviour, applied loads, and groundwater conditions. Centrifuge modelling could be a viable option for optimising the construction process, particularly for large diaphragm walls and high-risk excavations. This contribution discusses possible test setups for modelling slot excavation processes and investigating key parameters. The aim is to assess whether centrifuge modelling is a viable approach for studying diaphragm-wall construction processes, with a view to process optimisation, improved understanding of load-bearing behaviour during construction, and reduced risk of slot collapse.

1 INTRODUCTION & OVERVIEW

Slot stability of diaphragm walls depends on a variety of boundary conditions and remains an ongoing challenge for contractors during construction. Moeller (2012) describes the different aspects of the slot stability based on the following failure modes:

- Groundwater ingress into the slot
- Sliding of discrete soil particles into the slot ("inner stability")
- Failure mechanisms in the adjacent soil near to the slot ("outer stability")

Occuring slot instabilities during construction, or defects in the diaphragm wall (e.g. Moormann, 2023), are difficult to recognise but pose significant safety risks. Therefore, physical modelling of slot stability under specific conditions – such as complex geology combined with groundwater occurence - could improve understanding of soil behaviour near the slot (e.g. „outer stability“) and within the slot itself (e.g. „inner stability“; groundwater ingress), thereby improving construction safety.

Outer stability: The outer stability of a diaphragm-wall slot is generally analysed using distinct failure mechanisms associated with active earth pressure, as described in Moeller (2012). The failure mechanism is represented as a three-dimensional earth body, whereas DIN (2013) and Kilchert (1984) propose an idealised earth-wedge model. The earth pressure depends on the adjacent soil and its strength parameters (φ‘; s_u) and on the pore-water pressure (u).

Inner stability: Inner stability is ensured as long as individual soil grains or thin clods of soil are prevented from sliding into the slot. Details are given in Moeller (2012). One important parameter is that the effective weight of the soil is influenced by buoyancy in the supporting bentonite fluid.

Zhuo et al. (2014) describe centrifuge modelling to investigate the stability of long trenches in soft soil using bentonite-water slurry. Bentonite support fluids were tested at 1*g*-conditions to indentify an optimum bentonite-water mix. However, no additional information is provided on scaling effects for the bentonite slurry. Trench stability was analysed by increasing the *g*-level up to trench failure. Li and Zhang (2019) analysed the stability of a slurry trench through analytical and numerical modelling. The study focuses on the load-bearing behaviour of a weak soil layer located between two stiff soil layers (above and below). In the analytical model, a rotational failure mechanism associated with local failure of the weak layer into the trench is analysed. For the numerical modelling, an elastic-perfectly plastic constitutive model was used. The factor of safety against collapse of weak layers appears to correlate with the thickness of the weak layer. Ohno et al. (2006) investigated the influence of clay ground conditions on slurry-trench stability using centrifuge modelling. A typical centrifuge test setup is presented. They report ground-surface settlements in relation to decreasing slurry level and the formation of failure mechanisms.

2 ANALYSIS OF A PRACTICAL TASK

The following example (Figure 1) is based on practical issues related to slot stability during diaphragm-wall construction. A diaphragm wall is being constructed in fine-grained soil with an artesian groundwater level beneath the excavation. Slot stability must be ensured with respect to the failure modes listed in Section 1. Practical experience shows that artesian groundwater levels can trigger local slot instabilities. In addition, variations in the depth of soil layers beneath the slot may increase the risk of instability through increased water pressures around the slot, as the hydraulic gradient depends on the thickness of the most impervious soil layer.

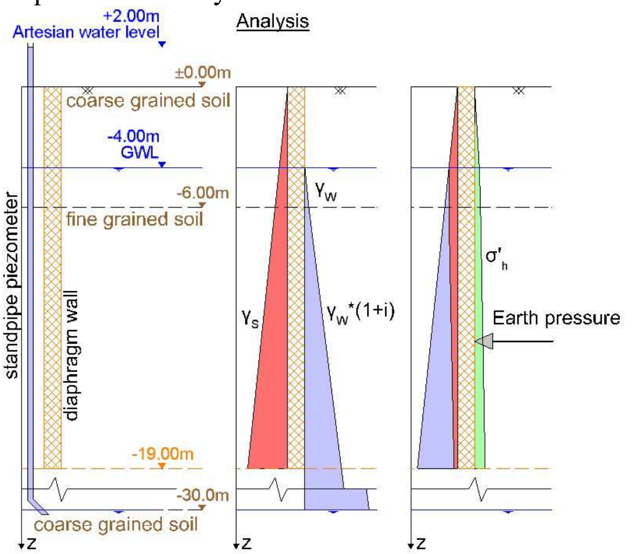

Figure 1: Situation of a 19 m deep slot diaphragm-wall construction in fine-grained soil with an artesian groundwater level beneath. Analysis: pore-water pressure in the soil (given in blue) and bentonite suspension pressure (given in red); right-hand side: net suspension pressure for slot stability compared with earth pressure.

Boundary conditions such as variability in the elevation of the top of the coarse-grained layer with artesian pressure, as well as the artesian groundwater level itself, play an important role for both inner and outer stability of the slot under construction. Moreover, slot stability relies on the counterbalance provided by the net supporting bentonite fluid pressure, shown in red on the right-hand side of Figure 1. Due to the high pore-water pressure, it may be difficult to achieve sufficient supporting pressure from the bentonite fluid to stabilise the slot against earth pressure. Therefore, potential inner- and outer-stability problems are of particular interest, but are difficult to investigate on site.

3 OUTLOOK

Centrifuge modelling of slot stability under changing boundary conditions, such as artesian groundwater level or soil layering, is of particular interest. Based on the studies by Ohno et al. (2006) and Zhuo et al. (2014), a test setup for this specific boundary problem may be developed as a next step. Key aspects include scaling of grain size and bentonite fluid properties in relation to inner stability, as well as provision of an artesian groundwater condition in the model setup. Excavation of the slot itself could be a limitation. However, this step may not be necessary if the artesian groundwater condition governs stability regardless of the excavation process. Therefore, the artesian pressure in the lower layer needs to be controlled during the test to study the slot-stability mechanisms relevant to the construction site condition shown in Figure 1. The monitoring of load-bearing behaviour and occurence of slot collapses require appropriate measurement technologies. Subsequently, suitable methods will be identified. Finally, different bentoninte slurry mixtures may be tested with respect to inner and outer slot stability.

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