Assessment of field measurements of two deep excavations from Copenhagen's Sydhavn metro line.

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The case studies presented hereafter are the Enghave Brygge (EBR) station and the Ørstedværket (ØVK) shaft which were constructed as a part of the extension of Copenhagen's metro line to Sydhavn by the bottom-up construction method in stiff over-consolidated deposits as well as soft rocks in Copenhagen.

Figure 1: Southern part of EBR, looking in northern direction.

Description of case studies

Ground conditions: The geological conditions of the Copenhagen area consist of Quaternary deposits overlaying the Paleogene deposits, mainly consisting of Danian Limestone and locally of Selandian greensand (South Copenhagen). **Figure 2** illustrates a typical cross section of the excavation at EBR and ØVK, including the soil design profiles and mechanical properties of soil and rock units.

Excavation characteristics: The excavations are retained by secant pile walls with 1.2 m diameter piles, supported by ground anchors and struts in the temporary case, as shown in **Figure 2**. The length of the piles is 24.5 m, the primary pile spacing is 1.8 m and the bending stiffness of the wall is 1745 MNm^2. The free length of the anchors is 11 m while their fixed length is 8.5 m. The anchors have been installed at an inclination of 30^o at EBR shaft and 35^o at ØVK shaft and pre-stressed at a force of 1 MN. The ground water control inside the excavation consists of pumping wells, where the subtracted water is recharged back to aquifer through re-infiltration wells that are situated outside the excavation.

Instrumentation: The horizontal displacements of the secant pile wall are monitored by inclinometer casings that are fixed to the steel reinforcement cages. The anchor and temporary strut loads are monitored by load cells that are installed on anchor heads and struts respectively. Strut loads are measured by three sets of strain gauges that are installed on each side of the selected struts. An illustration of the instrumentation layout at EBR and ØVK is presented in **Figure 3**.

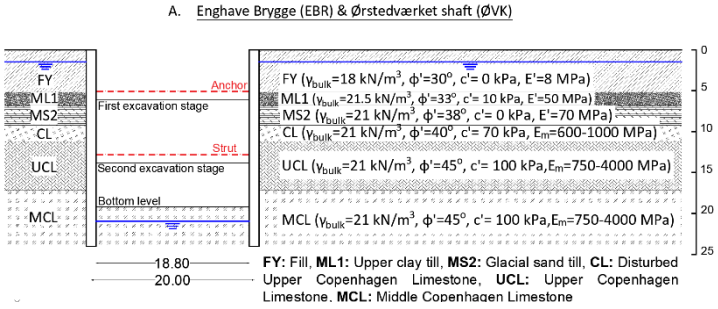

Figure 2: Typical cross section of the excavation carried out at EBR and ØVK, showing design soil profile.

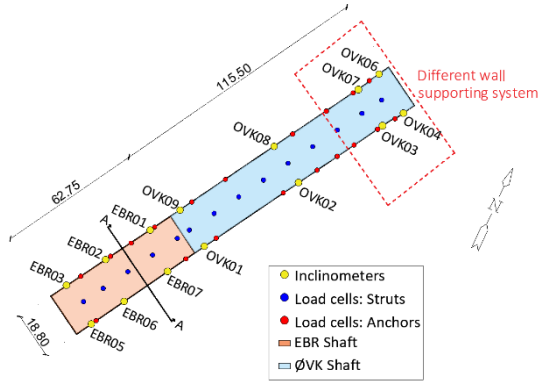

Figure 3: Plan view of EBR and ØVK excavations with the instrumentation layout.

Field observations

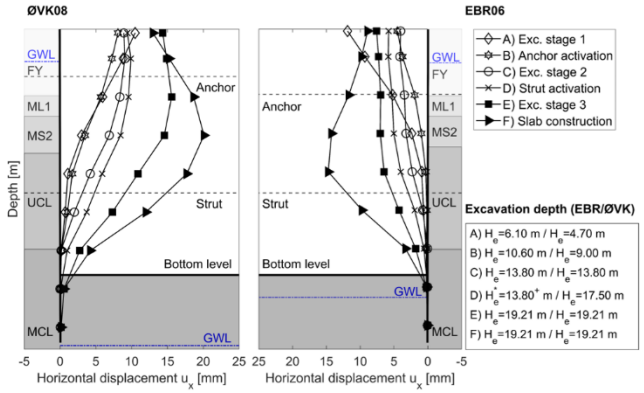

Figure 4: Lateral deflections measured at ØVK and EBR shafts from inclinometers located at the center of the shafts (considered representative of plane strain conditions) for different construction stages.

The different performance observed between the two shafts, even though the stratigraphy and the system stiffness are similar, is attributed to the fact that:

i. higher pumping occurred as the excavation progressed at ØVK and consequently there is a bigger difference in water head inside and outside the excavation
ii. the anchors at ØVK were prestressed at a higher force that the desired (1.2 MN).

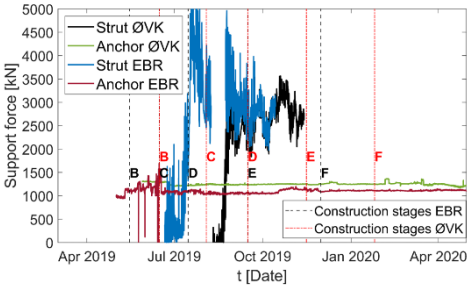

Figure 5: Time history of strut and anchor forces measured from load cells that are located close to inclinometers shown in Figure 4 at EBR and ØVK shafts. Construction stages for each case are also displayed.

Conclusions:

i) Linear increase of wall deflections with the excavation depth after the installation of the anchors.
ii) Influence of groundwater control on wall deflections.