Photographic feature: Monitoring of negative porewater pressure in silt slopes

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In the northern part of Sweden there are several natural silt slopes adjacent to local roads or highways. These slopes may have a height of 40–50 m and an average inclination close to the friction angle of the material (Fig. 1). One reason that these slopes relatively seldom fail is related to negative porewater pressures (suctions). As knowledge on the size and seasonal variations of negative porewater pressures is limited in Sweden, as well as internationally, conservative values of these pressures have been used in stability calculations. To enhance our knowledge of porewater pressure distribution and its seasonal variations, an investigation was carried out in two selected slopes with the main focus on long-term monitoring of negative porewater pressures (suctions) in slopes related to their stability. The overall aims of the project were to increase the knowledge of seasonal variations of negative porewater pressures, to develop an improved method for field and laboratory testing of silt, and to form the basis for more reliable stability calculations (Westerberg et al. 2014).

Test sites

Two slopes along the river Ångermanälven in the municipality of Sollefteå (see Fig. 2) were studied. During the years 2009–2012 porewater pressures were measured at depths between 2 and 25 m below ground surface at the Nipuddsvägen slope and between 2 and 30 m at the Väst Remsle slope. At Nipuddsvägen, which was the main slope of the project, extensive field and laboratory investigations were conducted to determine geotechnical properties and stratigraphy, in addition to in situ measurements of porewater pressures, moisture content and precipitation.

The slope at the Nipuddsvägen road is about 50 m high with an average slope angle of 35°. The main part of the slope is vegetated with deciduous trees (Fig. 3). The slope is situated on the river Ångermanälven and behind the crest of the slope is a residential area with local streets. The soil at the Nipuddsvägen test site consists of 2.5–3 m sand at the top, and thereunder sandy silt, silt and clayey silt. The topography of the Väst Remsle slope is similar, but the soil consists mainly of sand.

Investigations and measurements

At the Nipuddsvägen slope the investigations carried out included soil–rock sounding, weight sounding, cone penetration test (CPT) and dilatometer tests. Disturbed and undisturbed samplings were...
carried out with screw auger and piston sampler respectively and the samples were analysed in the laboratory. The slope was instrumented with groundwater pipes, pore pressure transducers and moisture sensors. Climatological data such as temperature, air pressure and precipitation were recorded.

The BAT piezometer can be used for pore pressure measurements in both the saturated and unsaturated zones of the soil. Although tensiometers are commonly used outside Sweden for measurement of negative pore pressures, the BAT piezometer is the only type used in Sweden for this purpose. Therefore, BAT piezometers were also used in this project, and were mainly of the Vadoze type. The BAT piezometer consists of a filter tip, a measuring body with a pressure sensor and a read-out unit (see Fig. 4). The filter tip is a closed system with a ceramic filter at the bottom that after saturation does not let air through, and at the top has a double rubber membrane. During measurements, a needle installed through the stem penetrates through the rubber membrane and connects the water in the pressure chamber to the pressure sensor.

Measurement of variations in moisture content was carried out using ThetaProbe ML2x soil moisture sensors. The sensor measures changes in the dielectric constant of a soil volume. As the dielectric constant of water is much higher than that of soil and air, the dielectric constant is mainly determined by the water content.

At Nipuddsvägen piezometers were installed and pore pressure measurements carried out at three locations above the crest of the slope, at three locations in the upper part of the slope and at one location at the toe of the slope. At the locations above the crest piezometers were installed at six levels between 2 and 25 m below ground surface (see Fig. 5). In the upper part of the slope the piezometers were installed at one level and at the toe at two levels. Standpipe piezometers were installed at one location above the crest and at two locations at the toe of the slope. Moisture sensors were installed at five levels, between 0.5 and 4 m depth, at one location above the crest of the slope.

**Results**

The results of the measurements carried out during more than 3 years show a seasonal variation of (negative) porewater pressures...
during that time in the upper part of the soil profile; that is, down to 6 m depth (Westerberg et al. 2014) (see Fig. 6). Also, the lowest negative porewater pressures were measured in this part of the profile at Nipuddsvägen. They occur during either the thawing period or during the autumn or beginning of winter. The moisture content measurements in the upper part of the soil profile show clearly how the moisture content varied with time of the year, rainfall and during the thawing period. The stability analyses show the importance of considering negative pore pressures in the calculations.

Further work

The measurements of porewater pressure and moisture content have continued after the finalization of the project, but no detailed analysis of the data has yet been carried out. A deeper analysis of these measurements is planned to the year 2017 as the basis for a decision on continuation of the measurements. However, as a result of the Göta River Investigation (SGI 2012) the Swedish Geotechnical Institute received a continued allocation from the Government for climate adaptation in 2013, to be used for overview landslide risk mapping in a changing climate along other rivers in Sweden. One of the three rivers given most priority is the Ångermanälven. As the size and changes of negative porewater pressures in silt slopes along this river are crucial for slope stability, some existing piezometers have been replaced and further piezometers have been installed in the slope at Nipuddsvägen. Groundwater pipes at a deeper level will also be installed. Both BAT piezometers and UMS tensiometers have been installed to allow evaluation of the two systems and comparison of the results.

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