Engineering Geology 116 (2010) 109–116

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Analysis of a retrogressive landslide in glaciolacustrine varved clay

Kohv Marko [a,*], Hang Tiit [a], Talviste Peeter [b], Kalm Volli [a]

[a] Department of Geology, University of Tartu, Ravila 14a, 50411, Tartu, Estonia
[b] IPT Projektijuhtimine OÜ, Kopli 96, 1, 10416, Tallinn, Estonia

ARTICLE INFO

Article history:
Received 8 April 2010
Received in revised form 20 July 2010
Accepted 30 July 2010
Available online 11 August 2010

Keywords:
Landslide
Liquefaction
Slope stability
Glaciolacustrine clay
Varve correlation
Estonia
Eastern Baltic

ABSTRACT

The largest landslides in Estonia are associated with glaciolacustrine varved clays. One of the recent slope failures, Audru landslide, was chosen for detailed investigation. Landslide morphology was instrumentally measured and the underlying geological setting investigated with eight boreholes penetrating the varved clay. Varve correlation was used to localize the failure zone and estimate the extent of the displaced material within the landslide body. Field measurements and limit equilibrium models displayed a retrogressive complex of three separate sliding events. The first stage of Audru landslide was initiated by the river undercutting and was followed by retrogressive slides that caused partial liquefaction of the landslide body. The influence of the various modeling parameters on the overall slope stability was also investigated.

1. Introduction

Estonian territory, lying at the southern slope of the Fennoscandian Shield, is characterized by tectonic stability and flat topography. Low altitude (<20 m asl) coastal areas are smoothed to even topography by deposits of proglacial lake and bottom deposits of marine and lacustrine stages of the Baltic Sea. In such conditions landslide hazard is usually a rare occurrence (Miidel and Raukas, 2005). However, recent inventory (Kohv et al., 2009) reported a growing number of sliding events at the valley slopes cut into low laying coastal plain. Three types of landslides were distinguished based on sediments and failure mechanisms involved. The largest slides developed in the glaciolacustrine clay are retrogressive complexes of the individual slides. The second group are landslides in marine sand and silt triggered by groundwater-generated shear stresses inside the slope. The third group are small landslides occurring at the river bank caused by the river undercutting.

The aim of this study was to obtain detailed description of the landslide morphological and geological setting and to investigate failure mechanism and influence of the various modelling parameters to the slope stability.

2. Regional background and geological setting

The Audru landslide occurred on May 11–12-th 2002 at the valley slope of the Audru River (Fig. 1). Audru River flows from the Lavassaare peat bog at an altitude of 16.4 m (mean gradient 0.55 m/km) and drains into the Pärnu Bay eastern Baltic Sea. The 5–6 m deep valley of the Audru River is eroded into a former marine plain with flat, slightly undulating topography with altitudes between 2 and 15 m (Fig. 1). Geologically the Audru valley is a young valley while its development due to fluvial erosion started only after Litorina Sea transgression (ca 7400–7200 yrs BP) and progressed in accordance to the lowering base-level and regression of the Baltic coastline (Veski, 1998). The Audru landslide occurred in the outer bend of the river meander, where river erosion is strongest.

Depth of the river channel at the investigated section of the valley is 2–2.5 m. The waterlevel in the channel fluctuates within 2 m, highest waterlevel occur in spring after the snowmelt and is lowest usually during the drier summer months. The climate in the area is temperate marine. Temperatures vary between −43 °C and 35 °C, with an annual average of 5.8 °C. Mean annual precipitation is ca. 700 mm/yr and evaporation from 400 to 500 mm/yr during the ice-free season (Arold, 2005). Snow cover typically lasts around 100 (max. 140) days and melts in March, causing high water levels in both soil and rivers (Jaagus, 1999).

The surface of bedrock from Devonian sandstones at the study area lies at an altitude of −10 to −15 m (Tavast and Raukas, 1982). It is

* Corresponding author. Tel.: +37 256663752; fax: +37 27375836.
E-mail address: marko.kohv@ut.ee (K. Marko).

0013-7952/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.enggeo.2010.07.012

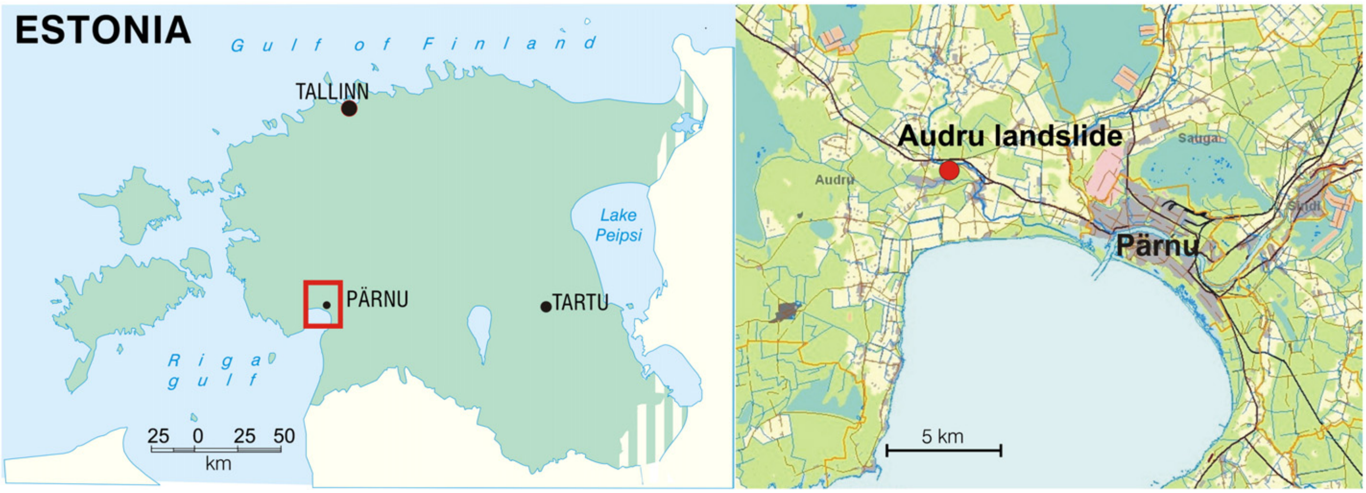

Fig. 1. Location of the Audru landslide at the coastal plain of western Estonia.

covered by bluish-grey loamy till of the Late-Weichselian age. The latter is capped by 10 m thick glaciolacustrine varved clay and silt. Fine-grained marine sand, which is in average 2–4 m thick, usually covers the varved clay and has been accumulated during the transgression phases of the Baltic Sea (Veski, 1998). The varved glaciolacustrine clay is geotechnically the weakest sediment type in the area and large landslides here occur in this soil type (Kohv et al., 2009).

The glaciolacustrine varved clays in Pärnu area has been deposited in a vast proglacial sedimentary basin (Pirrus, 1968; Hang et al., 2007). Laterally, within the limits of this proglacial basin, the geotechnical qualities of the clay do not change notably (Vilo, 1986; Saarse, 1992). A clay fraction (<0.002 mm) is dominant in varved clays, in the upper portion where it constitutes 69–79% (Hang et al., 2007) and towards the depth the clay content decreases (down to 46–51%) and the silt fraction increases. Thickness of individual varves increases steadily from 1 to 2 mm in the upper portion to 20–30 cm in the lower part of the varved clay section (Hang et al., 2007). In the clay fraction (<0.002 mm), illite (70–80%), smectite–illite (9–19%), kaolinite (6–8%), and chlorite (2–5%) dominate; the silty summer layers are composed primarily by quartz (46–59%), feldspars (14–18%), and carbonate (11–21%) (Kattel, 1989). According to the Casagrande plasticity chart (Coduto, 1998) the upper portion of the clays is classified as CL (fat clay) and the lower as CH (lean clay). Water content of the clay decreases towards depth, being 70–85% in the upper portion and decreasing downward to 30–60%. The over-consolidation ratio (OCR) is 1.3–1.6 (Kohv et al., 2009).

Two groundwater aquifers are located within Quaternary sediments in the Pärnu area (Kohv et al., 2009). The upper, unconfined aquifer is bound to marine sands, and the lower, confined aquifer is bound to the till capped by the glaciolacustrine clay. The glaciolacustrine clay acts as an aquiclude between the two groundwater aquifers. The upper aquifer is controlled by precipitation, transpiration, evaporation and by the water level in adjoining rivers and mires. Groundwater level in the surface sediments is changing according to weather conditions: during droughts there may be no water at all in sediments above the clay, while during thaw or heavy rains the water level rises up to −1 m from the surface.

The confined groundwater aquifer has been monitored from 1992 to 2004 in the town of Pärnu, seven km SEE from the Audru landslide (Figs. 1 and 2). Both places are located on the same glaciolacustrine-marine plain with a similar geomorphological and geological setting (Hang et al., 2008) therefore similar groundwater level is assumed. The piezometric level over the last 7 years has been between 0 and 1.5 m asl, a considerable rise (mean 5 m, max. 12 m) occurred from 1991 to 2001 (Kohv et al., 2009) due to significant decrease of the consumption and opening of the new groundwater wells outside the Pärnu, lessening water outtake from the wells situated within the town.

3. Methods

The geometry of the Audru landslide was mapped with theodolite (Dhalta 010B, angle measurement error ± 10″) and the riverchannel morphology with the measuring stick along the cross profiles.

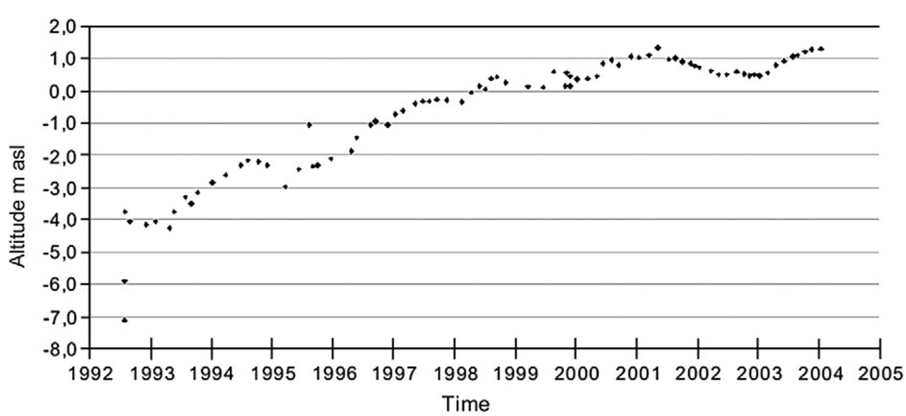

Fig. 2. Median (14 wells) piezometric level of confined aquifer situated in till deposit under the varved clay unit in the town of Pärnu during 1999 to 2004.