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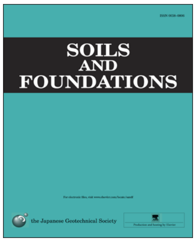

Loss of slope support due to base liquefaction: comparison of 1g and centrifuge landslide flume experiments

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Abstract

Recent physical model studies of landslide behaviour in loose, granular slopes have illustrated that the soil at the base of a slope may be of heightened risk of liquefaction as this area is located directly in the path of monotonic shearing events (i.e. localised toe failures) and is often saturated by groundwater. The objective of this paper is to further investigate the factors that influence the possible transition of a small toe slide to a larger and higher mobility liquefaction flow failure. Specifically, this paper investigated the influence of stress-level and soil-layer thickness between two different laboratory testing methods in controlling whether a slide transitions to a flow in physical model flume tests. Observations from two flume experiments were contrasted: one in which suction stresses were designed to dominate (a 0.33 m soil layer in a large-scale 1 g test) and a second enhanced gravity test performed in a geotechnical centrifuge where the body stresses are more representative of field scale landslides (i.e. behaviour representative of a 1.5 m thick soil layer). While the centrifuge test was brought to widespread liquefaction failure under increasing seepage flow, the 1 g flume test experienced liquefaction, but only displaced 25 mm. The results from this study highlight the dominant effect matric suction can have on the mobility of landslides, and provides a clear demonstration of the danger of misinterpreting the behaviour observed in small scale 1 g models as being fully accurate representations of larger field-scale landslide behaviour.

Keywords: Landslide; Large-scale flume; Centrifuge; Liquefaction; Physical model comparison

1. Introduction

Rainfall-induced landslides pose a significant geohazard in many regions of the world (Petley, 2012). The process of triggering this class of landslide is typically considered to be a drained shearing event in which a transient loss of matric suction and/or rise in pore water pressure due to rainfall infiltration and increased groundwater flux leads to a reduction of effective stress and frictional resistance available to counteract the downslope component of gravity. In certain circumstances this initial drained failure can transition into a widespread undrained shearing event characterised by the development of significant shear induced transient pore water pressures, deviatoric strain-softening, and the rapid accumulation of large soil strains under undrained conditions. This process, called static liquefaction, can significantly and often unexpectedly increase the kinetic energy of the unstable soil mass, the distal reach of the landslide debris, and the resulting hazard posed by the landslide event (e.g Knill et al., 1976; Eckersley, 1990; Lade, 1992; Wanatowski and Chu; 2007; Ng, 2007, 2008; Take et al., 2014).

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Given the possibility of static liquefaction greatly amplifying landslide risk, considerable research effort has been undertaken in the geotechnical element testing and physical modelling communities to investigate the conditions under which static liquefaction may occur. Element test results have led to the development of Lade's instability line conceptual framework for static liquefaction (Lade, 1992) and clear demonstrations of the role of void ratio, confining stress and state parameter (e.g. Yamamuro and Lade, 1997, Chu et al., 2003), fines content (e.g. Yamamuro and Lade, 1997, Monkul and Yamamuro, 2011, Baki et al., 2012), stress path and intermediate principal stress (e.g. Wanatowski and Chu, 2007, Chu and Wanatowski, 2008, Wanatowski et al., 2010) on the observed susceptibility of loose granular soils to static liquefaction. Further high-speed ring-shear tests have brought clarity to the rheological behaviour of granular materials under high-strain rate conditions (e.g. Sassa et al., 2004; Fukuoka et al., 2006) which is pertinent to understanding the mobility of the slide once triggered.

Physical modelling has been used to investigate hydraulically-induced landslide triggering in reduced-scale flume tests, centrifuge model experiments (e.g. Zhang and Ng, 2003; Take et al., 2004; Ng, 2008; Lee et al., 2008; Askarinejad et al., 2012), and in a small number of large-scale flume tests (e.g. Moriwaki et al., 2004). Recognising that static liquefaction was surprisingly difficult to trigger in physical models (e.g. Take, 2014a). Take and Beddoe (2014) hypothesised that the slope geometry often modelled in these experimental studies may have had the unintended consequence of making liquefaction less likely.

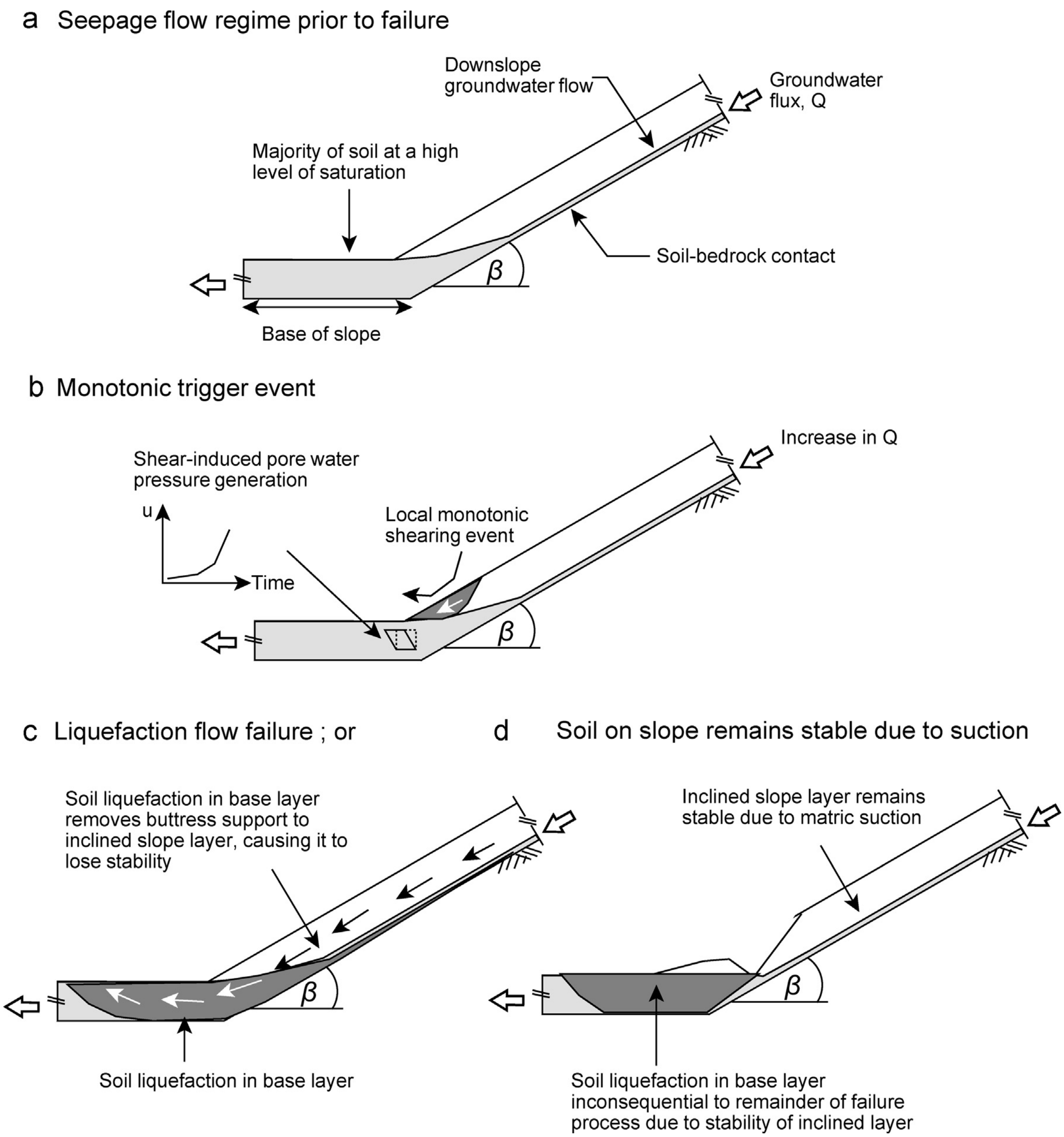

Fig. 1. Potential consequences of matric suction on the transition from slide to flow due to base liquefaction in which the (a) high degree of saturation at the base of the slope, combined with (b) a monotonic triggering event could cause liquefaction and transition to a (c) widespread liquefaction flow failure, or (d) cessation of failure due to the soil on the inclined portion of the slope remaining stable under suction.

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