Engineering Geology 105 (2009) 171–185

Contents lists available at ScienceDirect

Engineering Geology

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

Site and laboratory investigation of the Slano blato landslide

Karmen Fifer Bizjak [a,*], Andreja Zupančič [b]

[a] Slovenian National Building and Civil Engineering Institute, Dimičeva 12, Ljubljana, Slovenia
[b] Faculty of Chemistry and Chemical Technology, Department of Chemical Engineering, University of Ljubljana, Aškerčeva 5, 1001, Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 25 September 2007
Received in revised form 19 September 2008
Accepted 16 January 2009
Available online 13 February 2009

Keywords:
Earth flow
Landslide
Geotechnical engineering
Rheological properties
Numerical modeling
Burger model

ABSTRACT

The Slano blato landslide is situated above the village of Lokavec, in the western part of Slovenia. This area is one of the seismically most active parts of the country. Considering just the last decade, movement of the landslide was observed in November 2000, when the displaced material reached a velocity of 60–100 m/day. Silty and clayey gravel above flysch layers of marl and sandstone formed the landslide mass.

Geotechnical investigations of the landslide were performed in 2003 and 2004, when the depth of the landslide was determined, as well as the geotechnical parameters and the sliding mechanism. Rheological tests were also carried out for further analysis. Based on the investigation results and the observed landslide velocity, the landslide was classified as an earth flow. Inclinometer measurements showed that the landslide has two shear surfaces, with different behaviour shown as each.

A stability analysis was carried out numerically by applying the Mohr–Coulomb and Burger elasto–plastic models. The Mohr–Coulomb model indicated that the high water level influences the landslide instability. In the case of the Burger elasto-plastic model, a higher velocity was calculated, at a water content of between 35 and 40%.

1. Introduction

Rainfall, earthquakes and human activities are the most relevant factors, which cause triggering of large landslides in mountain regions. When there are inhabited areas in the vicinity of a landslide, it can be very important to estimate the level of hazard and risk.

The Slano blato landslide is situated in the west of Slovenia (Fig. 1), above the village of Lokavec (Fig. 2), on the border between the Alps and the Mediterranean region. It has a relatively long movement history and was first documented in 1887. At that time it destroyed part of a main road, after which reconstruction works took 17 years to complete. A series of retention dams and drainage systems were built on the Grajšček stream, which springs at the upper part of the landslide. Unfortunately, in the area of landslide the old drainage system had not been maintained for a long time.

Taking into account the last decade movement of the landslide was reactivated in November 2000. In first days the estimated velocity of the displaced material was 60–100 m/day. In the worst scenario, at least 30 houses belonging to the nearby village of Lokavec were in danger. The Slano blato landslide was reactivated as an earth flow by a combination of several events.

Landslides are often caused by earthquakes, which may affect large areas, their size being a function of the earthquake magnitude (Keefer, 1984, 2002). In 1998, the strongest earthquake to have occurred over the last 100 years in the Upper Soča River Valley (M_L 5.7) took place (Vidrih et al., 2001), with its epicentral area near Bovec (Fig. 1). The Soča River valley is situated near the Slovenian–Italian border. The area of NW Slovenia is one of the most seismically active parts of the country. Earthquakes can reach intensities higher than IX on the MCS scale (Ribarič, 1980, 1987), whereas the maximum observed historical event was estimated to had a magnitude of $M_L = 6.8$ (Lapajne et al., 1997). During this earthquake about 70 rock falls were identified (Vidrih et al., 2001). An approximately 100 m long section of the shore of Lake Bohinj, about 20 km from the epicentre, collapsed due to liquefaction (Lenart, 2006).

Four large landslides triggered in Slovenia after the earthquake. The Stože landslide, which was located about 10 km from the epicentral area, was the first to trigger in November 2000. The Slano blato landslide, which is located at a distance of 50 km from the epicentral area, triggered in the same month. The Macesnik landslide was the most distant, 90 km from the epicentre; it triggered in the same year. The following year the Strug landslide was activated, at a distance of 20 km from Bovec. The Stože and Strug landslides were associated with debris flow events (Mikoš et al., 2006), whereas the Slano blato landslide was associated with an earth flow. The whole region has a high risk of landslides and rockfalls (Komac, 2006). In the Upper Soča River Valley for some months before the earthquake, as well as after the earthquake, there was no significant rainfall until November 2000.

If surface strata are disturbed, heavy rainfall may trigger more landslides than the earthquake itself or may enlarge some existing landslides (Lin et al., 2006) Earthquakes can affect the stability of slopes for a long period of time. The reactivation of landslides by earthquakes is rare, but there are a few reports about such occurrences (Lin et al., 2006; Gallousi

* Corresponding author.
E-mail address: karmen.fifer@zag.si (K. Fifer Bizjak).

0013-7952/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.enggeo.2009.01.006

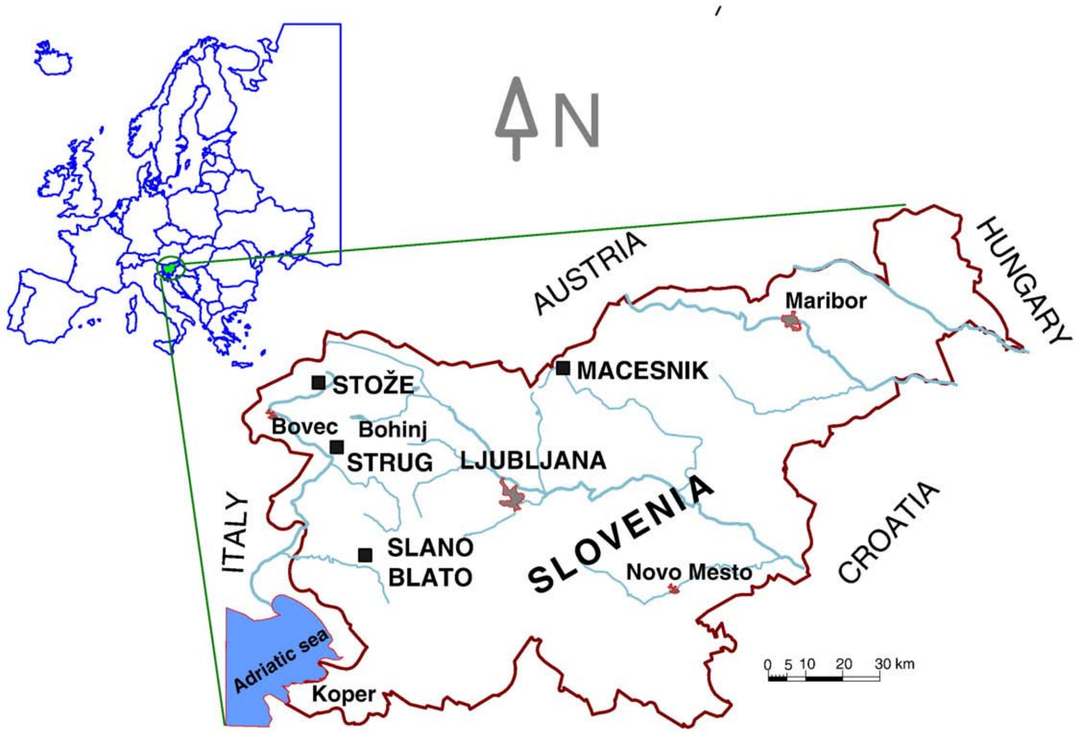

Fig. 1. Locations of the Slano Blato landslide and another three large landslides.

Fig. 2. The Slano Blato landslide, above the Lokavec village.

and Koukouvelas, 2007). The epicentral distance of the Slano blato landslide is near the margin of data for other worldwide earthquakes of this magnitude, as determined by Keefer (1984) and Rodriguez et al. (1999).

The aim of this paper is to present the results of geomechanical investigations, and to analyse the processes which influenced landslide triggering. In the year 2000 precipitation was more intense than had been recorded over the previous 10 years. With an average annual precipitation of 2000 mm, the region of Slano blato is the one of the wettest sites in Slovenia. In November 2000 the maximum precipitation was 59 mm per day. By comparison, the average maximum monthly precipitation in the previous decade was only 34 mm.

The Slano Blato landslide has been classified as an earth flow on the basis of its movement type according to the system of Hungr et al. (2001) which considers genetic and morphological aspects rather than arbitrary grain-size limits. Movement is usually initiated in the upper part of the landslide. Wet displaced material then moves down the landslide and accumulates on the lower, less-steeply angled parts of the slope. Intense precipitation of long duration many times causes changes to the surface of the landslide.

The triggering of landslides due to intense rainfall is well known in the Alpine regions of Italy, (Crosta et al., 2003; Guzzeti et al., 2004), Switzerland and Austria (Moser, 2002). Rainfall does not directly trigger failure, but it increases pore pressures by changing the hydraulic, physical and mechanical properties of the soil and the vegetation cover. Unfavourable combinations of these features can trigger slope failure (Alleoti, 2004). For the prediction of landslide movements rainfall threshold models (Lehmann et al., 2007), hydrological models (Sirangelo and Braca, 2004), and coupled models (Duan, 1996) have been developed.

The constitutive soil models that are usually used for the geotechnical analysis of landslides are the Mohr–Coulomb model, the Drucker Prager model, and the von Mises model. In the case of the Slano blato landslide the Mohr–Coulomb and Burger numerical models were used.

The application of a Burger analysis allows prediction of the displacement in time based on the results of rheological measurements,