Recent landslide activity in Manaihan, East Belgium

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ABSTRACT : Past landslides have been recognized in the Battice area of E Belgium. In contrast to the other inactive landslides, the Manaihan landslide was reactivated dramatically on September 14, 1998. This study aimed to map the spatial extent of the Manaihan landslide; to measure surface displacement using GPS; to investigate subsurface structure; and to determine the depth of the current shear surfaces. We monitored the ground displacements by repeated GPS surveys from 1999 to 2005. We also produced DEMs of the landslide at two different epochs (1953 and 1999). Mapping the height changes by DEM subtraction, we identified a partial landslide reactivation with episodic movement since 1980, at a mean rate of ~20 cm/yr. Most observed displacements occur around the winter's end. Penetration test results give clear boundaries between the landslide mass and the undisturbed bedrock in the upslope part of the slide. The landslide reactivation and the spatial distribution of motions are caused mainly by seepage from a broken sewage pipe, locally inducing high pore pressures, possibly also by anthropogenic loading of some parts of the headscarp.

KEYWORDS : landslide reactivation, GPS survey, East Belgium

1. Introduction

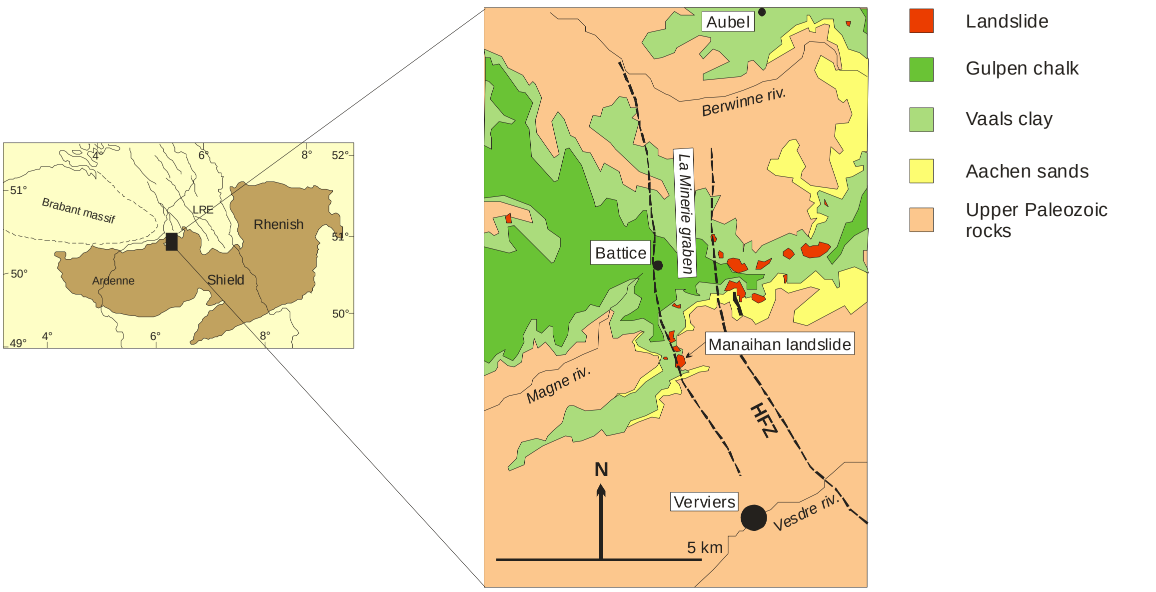

Fig. 1. Location map

Several large ancient landslides extend over the slopes of the main ridges of the moderately dissected Herve tableland, in the Battice area of E Belgium (Demoulin et al., 2003) (fig. 1). Although most of them are inactive for many years, one landslide near Manaihan was dramatically reactivated by the heavy rainfall of September 14, 1998. This landslide suddenly moved ~2m downslope, creating a ~1 m high new scarp at the top of the old headscarp.

The ridges on which the landslides, and notably the Manaihan slide, are located expose subhorizontal upper Cretaceous strata unconformably resting on the upper Carboniferous shales of the basement. The sands and silts of the basal Aachen Formation are 0 to 10 m thick. They are overlain by the 20 to 30 m thick Vaals Formation displaying here its typical clayey facies, and by some meters of chalks of the Gulpen Formation, locally weathered to clay-with-flints but absent in Manaihan. The landslides mainly disturb the clays of the Vaals Formation, on slopes ranging from 4 to 10°.

This study aims to map the spatial extent of the Manaihan landslide and its dominant surface features; to measure surface displacement using GPS; to investigate subsurface structure with penetration tests (PT) and corings; and to determine the depth of the shear surface by inclinometers.

2. Methodology

2.1. Topography and displacements

First, a geomorphic map was realised. Mapping was carried out both from aerial photographs and by field surveys.

Secondly, the monitoring of the landslide displacements was performed by repeated GPS surveys. A first set of 14 marks covering the southern half of the landslide was repeatedly measured in 1999-2000. Measurements were then carried out in 2001-2002 for 30 marks installed in the northern half of the slide, together with further measurements of 4 marks retrieved from the first network. A last survey of a limited set of remaining marks took place in June 2005. Assumed fixed reference points were chosen outside the landslide, one of these marks belonging to both sets and allowing their connection. The measurements were carried out in rapid static mode with Leica SR95OO dual-frequency receivers, the field conditions and the data processing jointly accounting for an uncertainty of ~3cm in all three components (N, E and Up) of relative motion.

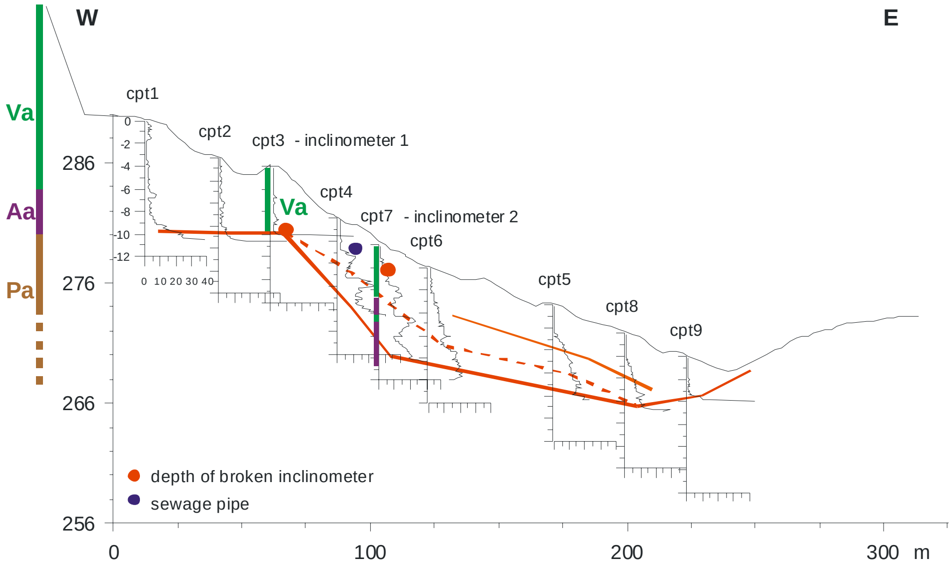

Fig. 2. Section of the landslide inferred from penetration tests, corings and inclinometer readings (Va: Vaals Fm; Aa: Aachen Fm; Pa: Paleozoic)

Finally, in order to gain a longer-term insight into the displacement history, precise DEMs of the landslide topography at epochs separated by ~50 years were compared. A first DEM was produced by digital stereophotogrammetry from aerial photographs of 1953 and was compared with another one interpolated from a kinematic GPS survey of the landslide performed in 1999. After common referencing, the model of 1953 was subtracted from that of 1999 to map the changes in z over the 1953-1999 period. The error of the final map of z change is <70cm in ground plan and ~25cm in height variation.

2.2. Landslide structure

Subsurface investigations were based on drop penetration tests (PT) along the slope profile and on the installation of two inclinometers. The drop penetration tests were performed with a heavy drop-hammer (50kg) using the portable equipment manufactured by ABOVO Geotechnics. The tests were carried out according to the German Industrial Norm DIN 4022. The inclinometers were installed along the same profile in two locations up- and downslope of a sewage pipe crossing the landslide. Plastic inclinometer tubes manufactured by GLÖTZL geotechnics reached depths of 9.5m and 6.0m respectively. Both inclinometer tubes were repeatedly surveyed until the tubes were broken.

3. Results

3.1. Landslide structure

PT results give clear boundaries between the landslide mass and the undisturbed bedrock in the upslope part of the slide (fig. 2). The inclinometers have shown the existence of distinct shear surfaces with measured displacement rates up to 15.8 mm in 21 days. Upslope of the sewage pipe, the shear surface is located at a depth of 5.5m to 6m, which corresponds to the depth of the bedrock as determined by PT. Downslope of the pipe, the present-day shearing occurs at a depth of about 2.5 m (Demoulin & Glade, 2004).

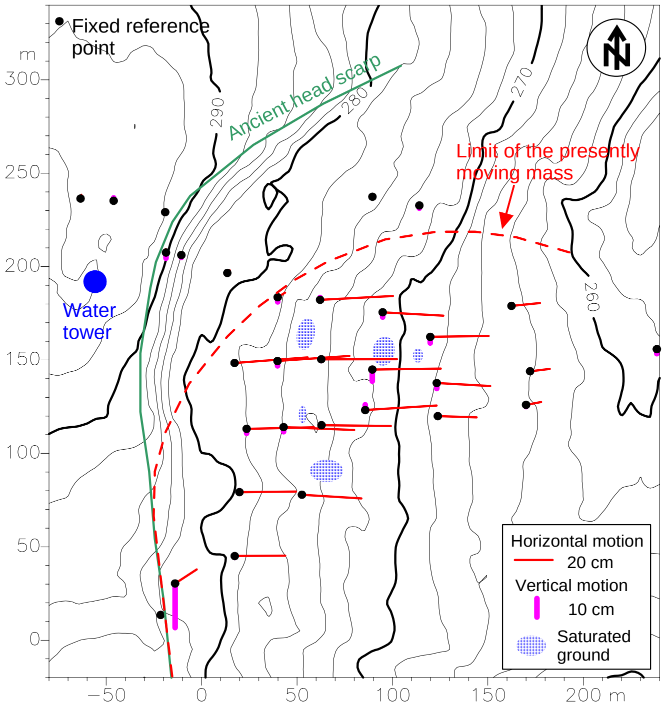

Fig. 3. Ground displacements recorded by successive GPS surveys during the winter 2001-2002.

3.2. Landslide displacements

Geomorphic mapping and GPS measurements both show that not the whole landslide is moving at present. Its northern part, separated from the central mass by overstepping scarplets and a small graben developed in September 1998 oblique to the headscarp, has not been reactivated (fig. 3). In this area, the old headscarp shows no significant displacement. To the south of this limit, the landslide mass moves downslope as a whole, with highest amounts of motion in its upslope half progressively decreasing towards the valley bottom. Only minor vertical displacements are observed within the landslide. By contrast, the southern part of the old headscarp is clearly rejuvenated, inducing a strong subsidence (~25 cm during the winter 2001-2002) of the uppermost slipped blocks.

In the longer term, the height change map obtained by comparing the terrain models of 1953 and 1999 shows prominent N-striking elongated zones of high apparent uplift running across the landslide, parallel to the headscarp. The motion locally exceeds +1.7m whereas in between are zones of subsidence (up to –0.7m) or sometimes no motion. However, this is not a true vertical movement of the ground but mainly the effect of the downslope displacement of ~2m-high ridges corresponding to the uplifted edge of tilted blocks (fig. 4). In the central part of the landslide, this displacement amounts to 6-7m and it decreases to ~4m near the lateral margins of the reactivated area. The current landslide motion is thus mainly translational above the distal part of the surface of rupture, involving void creation and block subsidence at the foot of the scarp, with a minor component of rotation which sharpens the ridges.

All measurements indicate that, beyond the sudden ~1.5 m slip of September 1998, the reactivated area moves episodically since 1980, at a mean rate of ~20 cm/yr (Demoulin, 2006). Most observed displacements occur around the winter's end, when episodes of heavy precipitation combine with minimal evaporation and occasional intense daily rainfall.

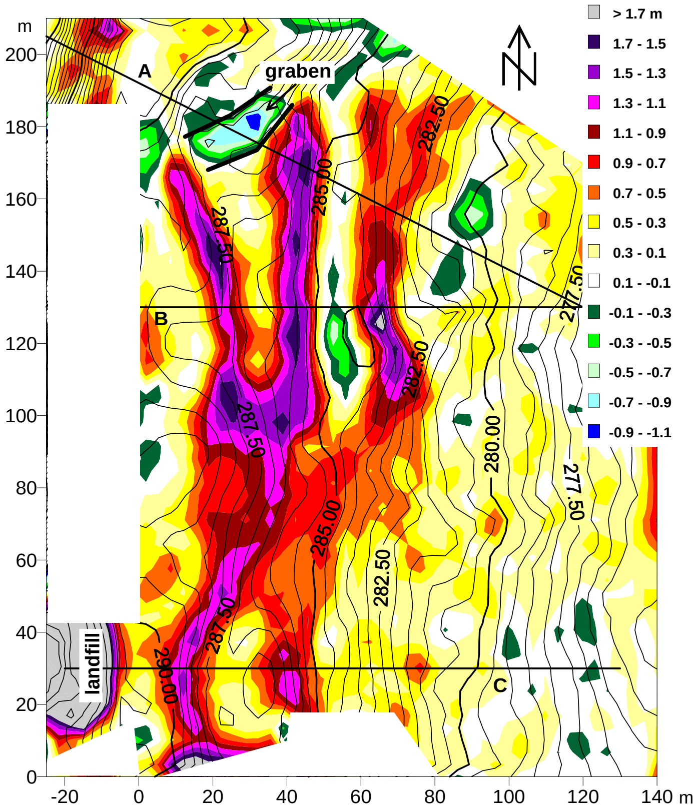

Fig. 4. DEM-based map of height changes within the landslide between 1953 and 1999.

4. Conclusion

We showed that the Manaihan landslide is approximately 5-10 m deep and initially filled a pre-existing valley. The current landslide reactivation and motion distribution seem to be determined mainly by seepage from a broken sewage pipe, locally inducing high pore pressures, possibly also by anthropogenic loading of some parts of the headscarp. To mitigate the hazard linked to the Manaihan landslide would thus especially, and simply, imply disabling the sewage pipe or at least deriving it out of the landslide.

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