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The Penicuik landslide, Midlothian, January 2007

Physical Hazards Programme

Internal Report IR/07/036

BRITISH GEOLOGICAL SURVEY

PHYSICAL HAZARDS PROGRAMME

INTERNAL REPORT IR/07/036

The Penicuik landslide, Midlothian, January 2007

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Foreword

This report is the published product of a short study by the British Geological Survey (BGS) of the landslide that occurred in South Bank Wood, Penicuik, on the 11th January 2007. The report is based on data collected during two visits to the site, as well as an assessment of existing data held in BGS archives. The sites lies on 1:50 000 scale Geological Sheet 32E (Edinburgh) (British Geological Survey 2006). Survey of the superficial deposits of this area was conducted 1981-2000. This report does not include any assessment of geotechnical properties of the failed material, and should not be used in place of a full geotechnical review.

Acknowledgements

Photographs were taken by Brian McIntyre (BGS Photographic Services), and the authors.

Contents

FIGURES

Summary

This report describes the geological context, form and composition of a substantial rotational failure in artificial deposits on the southern bank of the River North Esk, approximately 0.5 km southwest of Penicuik town centre. Slippage of buried industrial waste resulted in collapse of a substantial volume of made ground, and associated tension cracking. Consequently the area was closed until the level of potential hazard could be assessed and remedial measures put in place. Slippage probably occurred as a result on prolonged and intensive rainfall in the weeks leading up to, as well as immediately prior to, the eventual failure. Elevated pore water pressures throughout the substrate, a raised water table, and slope-parallel stratification in the unconsolidated waste are likely to have combined to initiate the collapse.

Date of failure: 11th January 2007

Location: South Bank Wood, near Penicuik, central Scotland

Type of failure: rotational slump in artificial deposits

BGS landslide ID: 15470

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1 Introduction

This report documents a new active landslip at South Bank Wood, Penicuik Estate, Midlothian (NT 23090 59220). Visits to the site by BGS geologists took place on 27th January and 9th March 2007. According to local sources, movement on the site of a former mill landfill was first noted on Thursday 11th January 2007, with the main failure during the night of the 12th January. Open fissures seen on 27th January by BGS staff suggest that gravitational movements are likely to continue. The site is on 1:10 000 scale geological sheet NT25NW (Penicuik) which is included in 1:50 000 Scale Geological Sheet 32E (Edinburgh).

Penicuik is a small town, developed as a planned village in 1770 by its Laird, Sir James Clerk of Penicuik. Its industries included mining and later, paper-making. This industry was centred on Valleyfield Mills, just downstream of the landslip site, that operated from 1709 to 1966, firstly by Agnes Campbell and by the Cowan family from 1770.

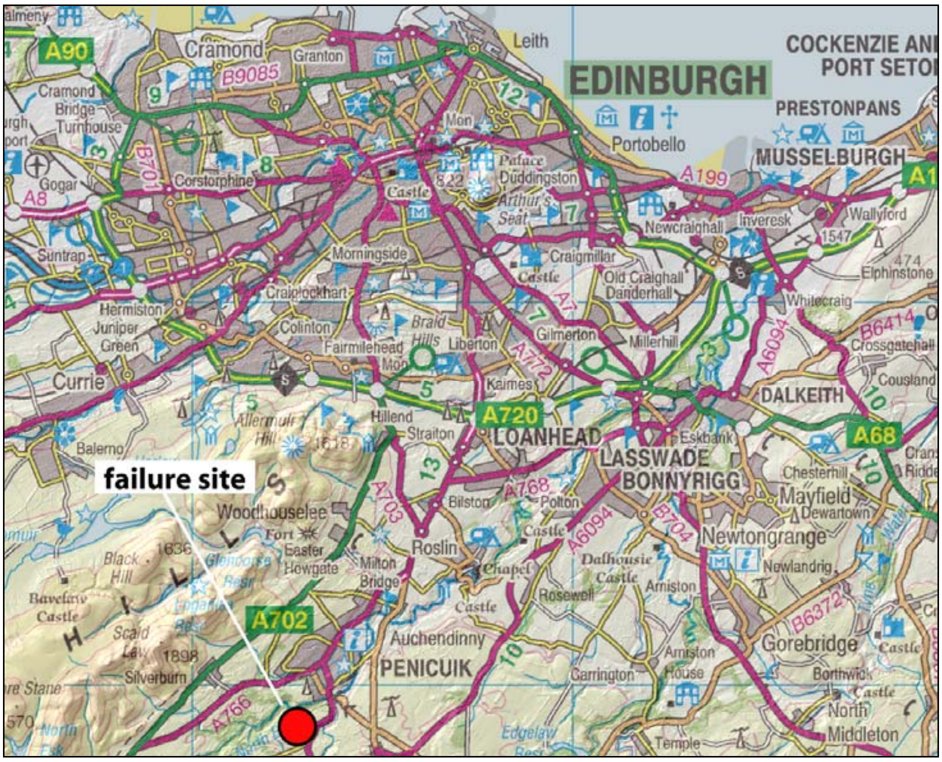

Figure 1. Location of site in relation to wider area. Red spot shows failure site shown in Fig. 2.

1.1 FAILURE SITE

The main part of the landslip is located on what was a small part of an area of gently sloping ground above the incised postglacial gorge of the River North Esk. Topographical maps pre-dating formation of the made ground show that a small stream, occupying a narrow and short side valley, formerly existed on the site. Recent maps indicate that water still emerges at the base of the slope on the line of the old valley and burn. This emergence is via a c. 10 mm thick, c. 0.5

m diameter steel pipe housed in 0.3-0.4m thick concrete. The source of this water is thought to be two culverted streams that enter buried pipes above, and to the south, of the failure site and the made ground, at NT 23070 59118 and NT 23097 59075. It is assumed that the pipes were laid beneath the made ground, and that they are continuous.

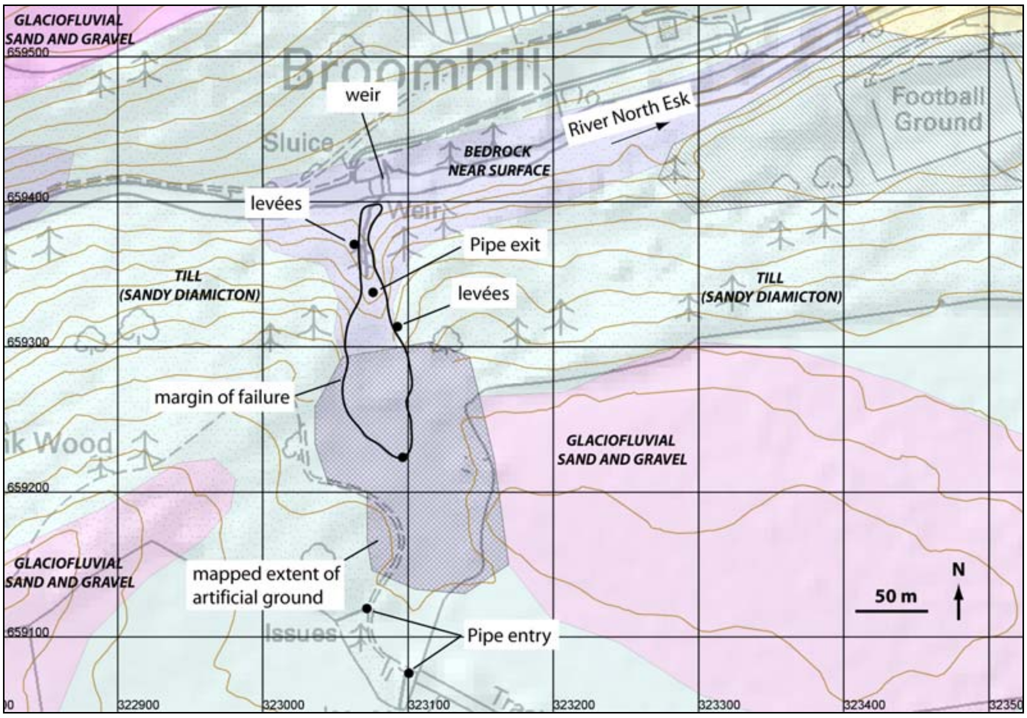

Figure 2: Geological context of failure site

1.2 GEOLOGICAL CONTEXT

1.2.1 Bedrock Geology

Sedimentary strata belonging to the Passage Formation (Clackmannan Group) of Upper Carboniferous age form the bedrock underlying the site of the landslip. These rocks consist mainly of sandstones, siltstones and mudstones. These strata dip at about 10 degrees towards the ENE. They are exposed in the bed and banks of the River North Esk hereabouts and are visible also in the lower part of the minor side valley in which the landslip is located. A hard bed of sandstone was used as the foundation of the mill weir in the river at the bottom of this side valley. The bedrock is not affected by the landslip activity.

1.2.2 Quaternary Geology

The River North Esk flows through a postglacial gorge with steep banks cut in glacial till resting on bedrock. The till is typically dark brownish grey to black if unweathered, and is a stiff to hard sandy, gravelly, silty clay diamicton. The till weathers from grey to mottled orange. There is a long history of minor landslips along the North Esk valley associated with the steep incised slopes and their Quaternary deposits including glaciofluvial sand and gravel elsewhere seen resting on the glacial till. Where bedrock occurs as cliffs, small rockfalls have also been recorded. The Quaternary deposits were not significantly affected by the landslip, being only slightly incised at the base of the gully by the down-slope flow of failed material and water.

1.2.3 Man-made deposits

At the site of the landslip, the surface material is shown as man-made deposits (made and worked) on the current superficial map edition. The area of deposit covers approximately 190 m (north-south) x 70 m to 110 m (west-east). Prior to the landslip event, the lithology of the fill was not recorded on BGS maps. New exposures reveal that the waste materials consist of assorted rubbish from the now demolished Valleyfield (paper) Mill, as well as chimney soot and boiler ash. Paper waste, and what appeared to be wood or paper pulp, are the most abundant materials, whilst the upper layers also contain plastic sheets and large rubber bands.

2 Description of failure

2.1 SITE

The failure site is densely wooded, and although paths exist through the wood, both upper and lower paths had been breached by the failure. The floor of the failure was saturated and appeared to be composed of industrial waste, and was considered unsafe for close investigation. Therefore, access to the slide was only possible along its sides.

Figure 3: View west across headscarp of failure, figure (left) for scale

Figure 4: View north (downslope) from headscarp

2.2 COMPOSITION

The eastern wall of the landslip displayed the stratigraphy of the landfill with steeply dipping slope-parallel fore-sets and horizontal top-sets.

Figure 5: Stratified and steeply-dipping waste in eastern wall of failure

The total amount of landfill that failed is estimated to represent approximately 25% of its total volume. There was a distinct sulphide odour on site, perhaps due to the presence of wood pulp in the waste. The failure gully is partially occupied by failed material, including slumped vegetation, and is saturated. Broken pipe debris and a concentration of bricks at the toe of the tip were noted. Running water and orange-stained pools of water were seen.

2.3 MORPHOLOGY

The head of the failure is located at NT 23093 59226, at around 212 m O.D. The River North Esk (at the base of the failure) is at 178 m O.D. The elongate gully produced by the collapse has a northerly aspect (358°), and occurs within landfill material as far downslope as NT 23083 59339. Below this point, the gully appears to be the pre-existing stream channel, slightly enlarged by bed erosion and bank collapse. At the most recent visit, the landslipped area measured 114 m from tip (head wall scarp) to toe (down-slope limit of slipped material), approximately 40 m across at its maximum, and up to 15 m deep.

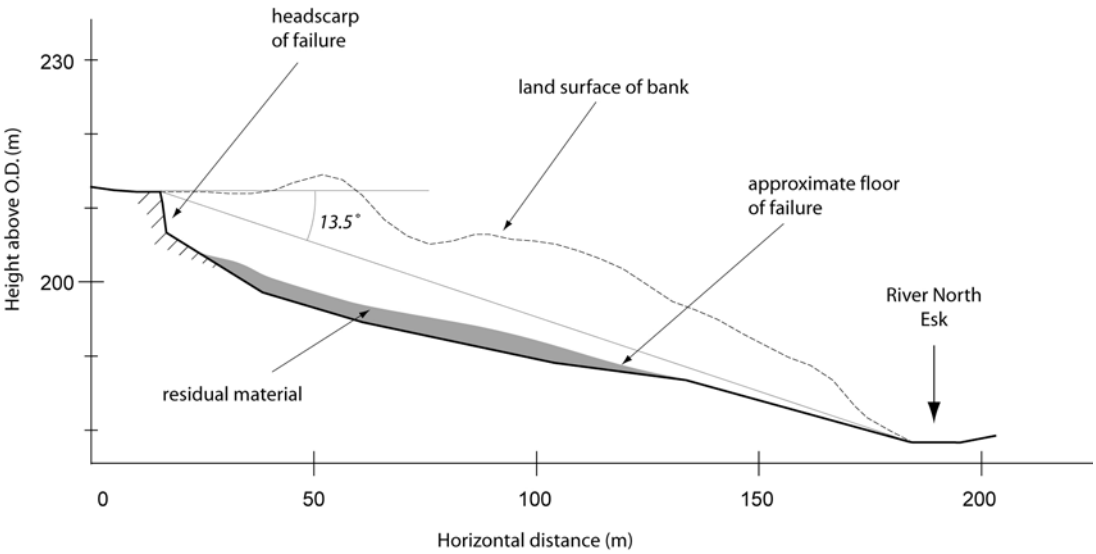

Figure 6: Profile of failure site, based on high-resolution digital elevation data from Intermap Technologies

The headwall scarp is arcuate in plan, whilst in profile the exposed faces are sub-vertical (in places almost overhanging) (Fig. 7 a). The c. 350 m perimeter of the failure is crenulate, with two major lateral slump scarps along the western margin, and many subsidiary collapse scars on both western and eastern sides. On the western fringes, tension cracks and ‘potholes’ were observed up to 12 m from the main western failure edge. One such tension crack exposed a near-surface drainage pipe culverting surface runoff beneath the footpath.

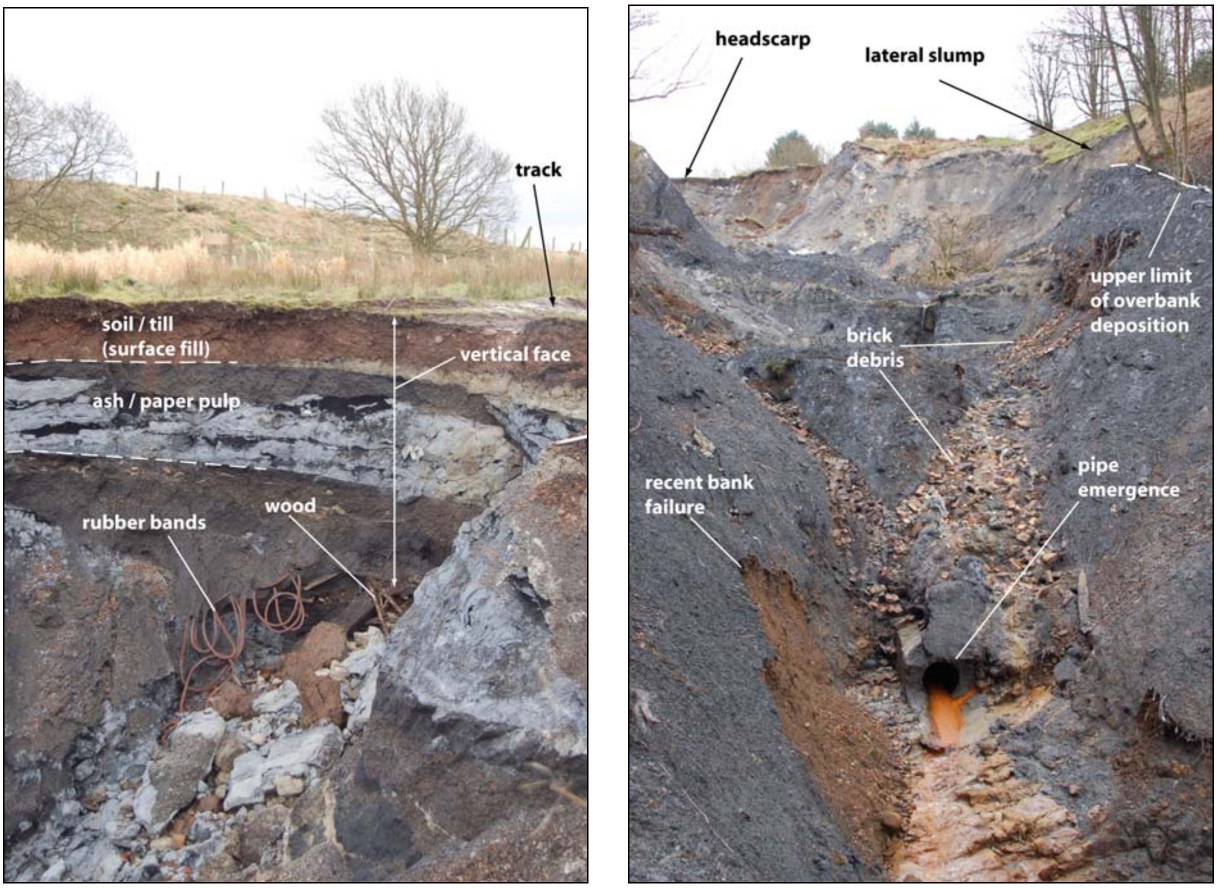

Figure 7: a) Stratified waste exposed in vertical face of headscarp b) view up gully from toe of failure

Overbank material (reworked landfill) is present along the lower margins of the failure gully (Fig. 7b), to a width of about 40 m. There is a notable cross-gully asymmetry in the height of overbank deposition, the highest areas marked by debris levées up to 2 m high (e.g. at NT 23090 59310 on the eastern flank, and at NT 23065 59374 on the western flank) (Fig. 8). Behind these levées are hollows where the original slopes are visible, and where no failed material was seen overlying the *in situ* orange-red sandy till. The lateral margin of overbank deposition is generally abrupt and continuous (Figs. 7, 8, 10). Standing water was seen trapped in pools between the new levées and the pre-existing slopes. Failed material was also seen capping fallen tree limbs protruding the gully side (Fig. 9). On parts of the lower slopes, sub-horizontal flow lineations were observed in the overbank debris, as were flow-aligned trees (Fig. 8).

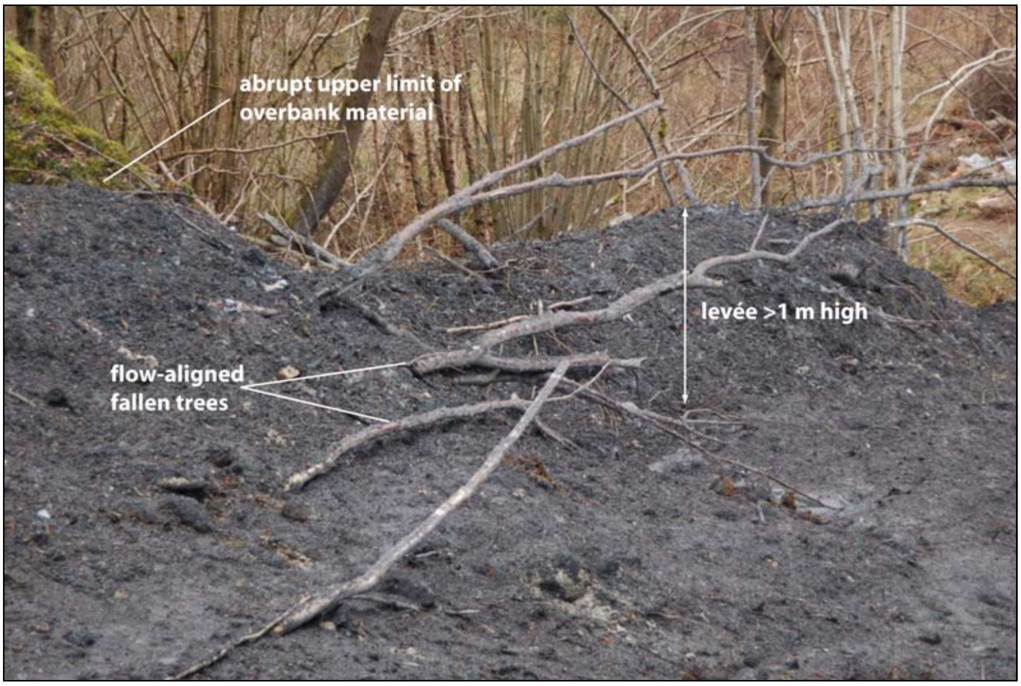

Figure 8: Levée of overbank material near base of slope, western margin

Figure 9: Debris flow material capping fallen tree limb

At the weir, considerable erosion has taken place against its southern abutment, and the stream draining the failure site now discharges via a gully to the river. In the main river channel, large amounts of debris from the landfill had been transported downstream with bricks conspicuous in places. Boulders of pale grey waste up to 1 m^3, had been transported downstream for at least 550 m to the main road bridge over the river in south Penicuik. The most distinctive feature of the channel upstream of the road bridge over the North Esk in Penicuik, is the ‘trimline’ of the clean banking against the dark grey waste covering the lower sides to a maximum height of about 1.8 m above the normal river level. The trimline could indicate the passage of a debris flow downstream from the weir area as the river was temporarily dammed and in the subsequent dam failure. Farther downstream, the lower debris line records the passage of the flood event caused by failure of the temporary blockage. Grey and black waste sands have been located in slack water areas in the River North Esk in Roslin Glen near Hawthornden Castle (NT 27980 63160), about 6 km downstream.

2.4 MODE OF FAILURE

2.4.1 Landslip

The vertical and overhanging headscarp faces suggest that catastrophic (rather than incremental) failure occurred in the made ground at the Penicuik site. Tension cracking in the substrate still visible in the surrrounding area attests to tensile stresses related to extensional deformation resulting from debuttressing (slope collapse). The steep headwall, deep gully, and lack of visible slide plane at the gully base indicate that initial failure was probably rotational rather than translational. The volume of the initial failure is not known, but the very limited amount of remaining debris in the gully suggests that disaggregation and possible liquifaction occurred soon after failure, producing a cohesionless debris flow that flowed downslope and was highly effective at removing debris.

Evidence of extensive overbank deposition from mid-slope downwards indicates that the volume of the debris flow was sufficiently great to overwhelm the confines of any existing channel. Limited evidence of bed erosion in the lower gully suggests that the debris flow was not particularly erosive – perhaps due to its composition of principally weak materials (paper pulp, ash etc). Undercutting and slumping of the stream banks in the lower gully did occur, however, but the exposed faces were not covered in the grey ashy failure material indicating that their formation occurred after the debris flow event, most probably as a result of turbulent stream flow.

Larger lateral bank collapses are also thought to have taken place subsequent to the main failure, particularly the two arcuate slumps on the western margin. These scars truncate a clear lateral limit of overbank material, and material from them is still present at their bases (Fig. 10). The southernmost of the two slumps exposes upper fill material resembling soil and till, which supports vegetation. The inward-dipping grassy tops of slumped but intact blocks of this material show that this collapse was a rotational failure, and that it occurred after the main debris flow. Similarly, the inward-dipping block supporting an intact tree at the base of the northermost of these two slumps suggests the same. It is likely that much of the perimeter of the initial failure has subsequently, and incrementally, collapsed, as the exposed faces attempt to readjust to a new angle of repose. This process may continue for some time.

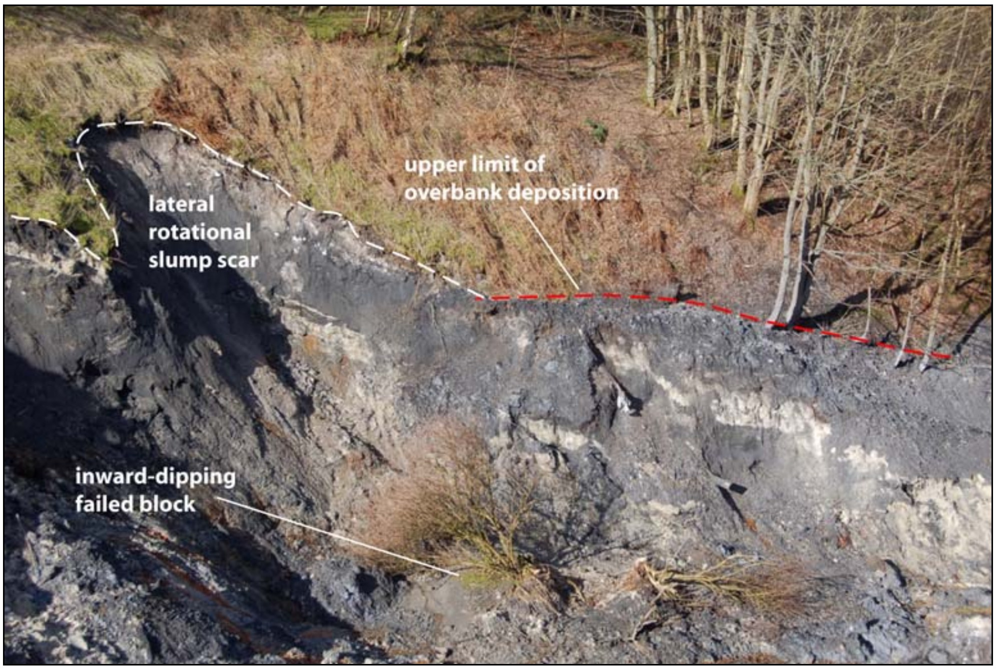

Figure 10: Lateral slump truncating overbank deposition, western margin of failure

2.4.2 Debris flow

Following the initial slump, disaggregation of the material ensued, most probably aided by a high water content. This is likely to have occurred as a result of higher than normal volumes of surface runoff resulting from heavy rainfall, which also led to a locally elevated water table. The failed material (paper, pulp, ash, plastic sheets etc) was heterogeneous, stratified, and had limited cohesion. Combined with the abundant water present in the substrate that further lowered its effective shear strength, mass movement of the material produced a cohesionless debris flow that by 75 m downslope of the headscarp had breached its confines. Mass transport in this way led to the formation of levées, the deposition of overbank material, and re-alignment of fallen trees parallel to flow. It is possible that undercutting propagated further bank collapses, thereby maintaining the flow. That the height of overbank deposits and the distribution of levées is asymmetric, may hint at a slight sinuosity to the path of the debris flow (Fig. 11).

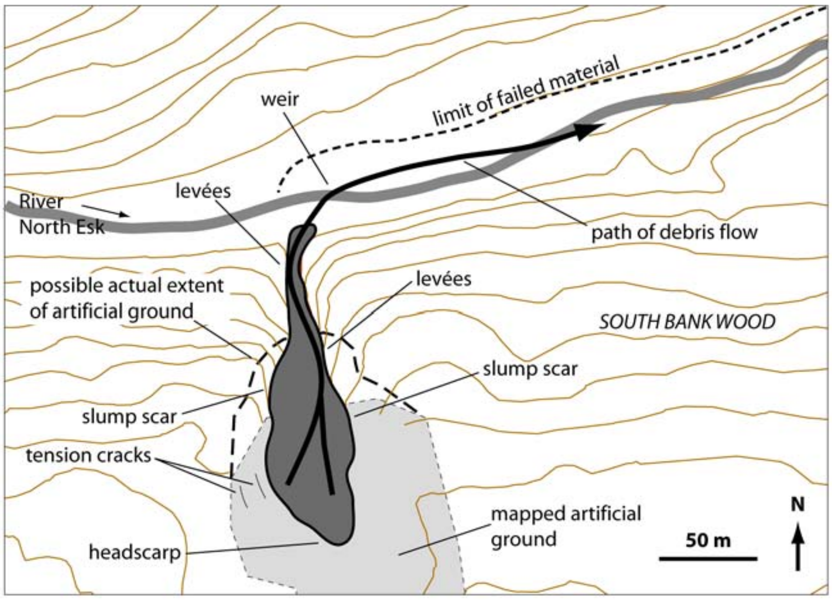

Figure 11: Schematic illustration of likely flow path of landslip / debris flow

2.5 CLASSIFICATION

BGS adopt the classification scheme for landslides suggested by the World Landslide Inventory, largely based upon Varnes (1978) and Cruden & Varnes (1996). This is a morpho-genetic scheme – classifying according to material, failed morphology and (often inferred) mechanism. Failures may occur within rock, debris or earth, and may be composite in form. This scheme allows for over 20 categories of failure to be recorded. The Penicuik landslide shows an oversteepened headscarp typical of rotational failures, but evidence that the material disaggregated suggests that liquifaction occurred soon after initial failure, and that transport by debris flow processes was dominant. This landslide may be best described as an initially rotational slide in unconsolidated artificial substrate that quickly developed into a cohesionless debris flow. Thus classification as a complex failure may be most appropriate.

2.6 TRIGGERS OF SLOPE FAILURE

The most likely trigger for the Penicuik landslide is the prolonged and intense rainfall that occurred prior to failure. This led to several changes in the immediate area that each formed a component trigger. Prolonged rainfall leading up to failure would have saturated the substrate, raising pore water pressures beyond normal values, and would have led to increased surface runoff. Channelised flow at the surface perhaps incised the underlying, poorly-consolidated substrate of industrial waste, which would have been weakened, and more likely to deform under self-weight stresses as a result of saturation. Channel incision would have been rapidly followed by bank collapse, with self-propagating results due to debuttressing. The slope-parallel stratification in the waste would have facilitated its downslope movement. Therefore, it is likely that ground failure occurred as a combined result of fluid-weakened substrate, an elevated local water table, increased surface runoff, and the slope-parallel stratification of the material.

3 Impacts

According to local sources, the landslide very temporarily blocked the River North Esk, here around 15 m wide. Inspection on the lower, flatter ground on the north bank of the river, despite clean up operations, suggests that this happened. At the weir, there is a sluice leading into a mill lade on the north bank. In the bed of the mill lade immediately east of the weir, there was clear evidence of sand ripple trains consistent with significant recent river water flow along it. However, debris from the landslip (including plastic) floored the lade 100 m further downstream, and also occurs beyond its banks forming low fans of reworked landfill on to lower ground to the south, on the floodplain above the river channel.

The area is currently unsafe, and consequently is closed pending remedial works. Debris from the slip has been recently reported as far as Musselburgh (c.20 km downstream), where anglers have also commented on a lack of fish in the river.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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