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The Horncliffe landslide, Berwick-upon-Tweed, December 2008

Land Use and Development Programme

Open Report OR/08/071

BRITISH GEOLOGICAL SURVEY

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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 at Horncliffe, near Berwick-upon-Tweed, on Saturday 6th December 2008. The report is based on data collected during a two hour investigation of the site, as well as an assessment of existing data held in BGS archives. The sites lies on 1:50 000 scale Geological Sheet 26 (Berwick). Survey of the superficial deposits of this area was compiled at 1:63 360 scale in 1969. 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

BGS acknowledges with thanks the assistance and cooperation of Northumberland County Council, in particular Steve Clark and Warren Simpson. All photographs were taken by Brian McIntyre, BGS Photographic Services.

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FIGURES

Summary

This report describes the geological context, form and composition of a small rotational failure and debris flow in unconsolidated sediments in the bank of the River Tweed at Honey Farm, Horncliffe, approximately six miles west of Berwick on the Union Bridge road. Slippage of the bank resulted in undermining of the road, cracking and subsidence of the tarmac, rupture of a water main, and tension cracking across some of the remaining road adjacent to the failure. Consequently the road was closed, and may need to be rerouted to avoid potential future hazards. The road at this locality was previously re-routed (1954) as a result of a similar failure, thus it seems likely that the sediments here are inherently prone to failure, given a sufficient trigger. This recent slippage probably occurred as a result of saturation of the ground either by seepage from a buried culvert, or from the water main, that locally raised pore water pressures. The slippage was possibly exacerbated by maintenance works that had removed natural materials and backfilled holes with gravel and cobble aggregate, which disrupted natural drainage and increasing normal stresses on the underlying sediments.

Date of failure: 6th December 2008

Location: Honey Farm, Horncliffe, near Berwick-upon-Tweed, NE England.

Type of failure: rotational slump in unconsolidated deposits

BGS landslide ID: 16346

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1 Introduction

A section of the bank of the River Tweed, near Berwick (Fig. 1), collapsed during the weekend of the 6th December 2008. Undermining of the road and associated tension cracking rendered the road unsafe and prompted its immediate closure. The following was published on the Berwick Advertiser website, 10th December 2008:

> **Landslide hits road close to historic bridge**
>
> A LANDSLIDE at Horncliffe at the weekend has forced the closure of the road to the Union Chain Bridge from the Horncliffe side. The slip, just below the Chain Bridge Honey Farm, occurred at about 7am on Saturday, and a substantial footbridge recently restored by the county council and several mature trees were swept into the River Tweed below, while a section of the road has also collapsed. The road below the honey farm is now closed to traffic and pedestrians until the route is repaired and made safe, but the bridge is open to traffic and pedestrians from the Scottish side. Willie Robson, owner of the Chain Bridge Honey Farm, emphasised that although the road to the chain bridge is closed, the honey farm is still open for business as usual. And, although he was concerned by the landslide and the time the road will be closed for, he believes it should be relatively easy to repair.
>
> Edward Cawthorn, who lives at Chain Bridge House, said: "It has completely swept away the footbridge from the riverside path, which was only just restored some six weeks ago. The riverside is impassable from the bridge to Horncliffe." Mr Cawthorn added that a crack has appeared in the surface on the opposite side of the road to that which subsided, and the section of road that has collapsed was newly laid with Tarmac following a repair to a small hole about eight weeks ago.
>
> A Northumberland County Council spokeswoman said: "The C2, Horncliffe Road near Union Chain Bridge has been closed on an emergency basis due to a landslip. The road became dangerous to motorists from December 7 and will remain closed until further notice. A regular temporary road closure order has been requested, this is expected to be in place for up to and possibly in excess of six months." A spokeswoman from Northumbrian Water added: "Northumbrian Water is aware of a collapsed roadside bank near the Union Chain Bridge. The collapse has, unfortunately, damaged a small diameter water main and the few customers supplied by that water main are now on a temporary supply. "We are waiting for Northumberland County Council to make the area safe so we can carry out a repair."

A visit to the site by a BGS team of geologist and photographer was arranged for 17th December 2008 through Mr. Steve Clark at Northumberland County Council. Mr. Warren Simpson and the council's geotechnical consultant met us at the site.

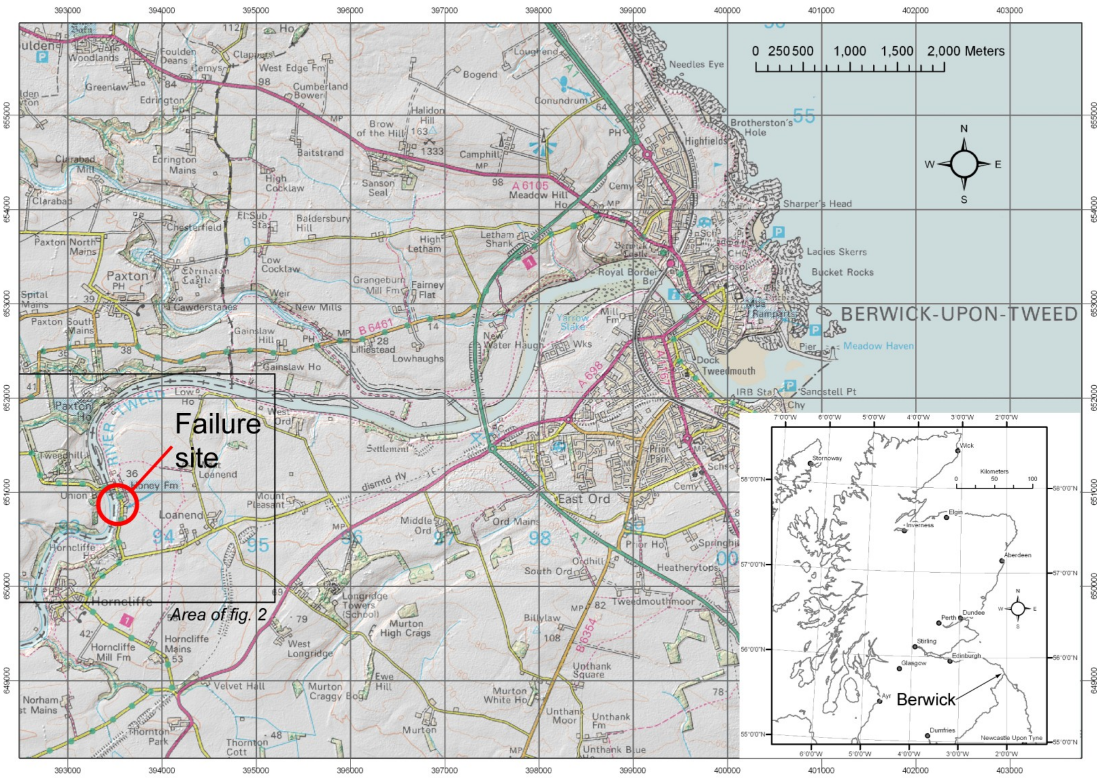

Figure 1. Location of site in relation to wider area. Box shows area covered in Fig. 2.

1.1 FAILURE SITE

The failure took place at [NT93543 50854], on the eastern bank of the River Tweed between the Honey Farm and the Union Chain Bridge that crosses the Scotland – England border. There were reportedly maintenance works carried out to a fractured water main at the site 6 weeks prior to the failure, and evidence seen during the site visit suggested that repair had been effected and the hole backfilled with a coarse gravel aggregate. Locals also informed us that a culvert was thought to flow beneath the road at this location, though it was unknown whether or not it was still functional. During the site visit, a small stream was seen emerging beneath slumped and in situ material near the top of the failure gully, which may be the one reported to have been previously culverted.

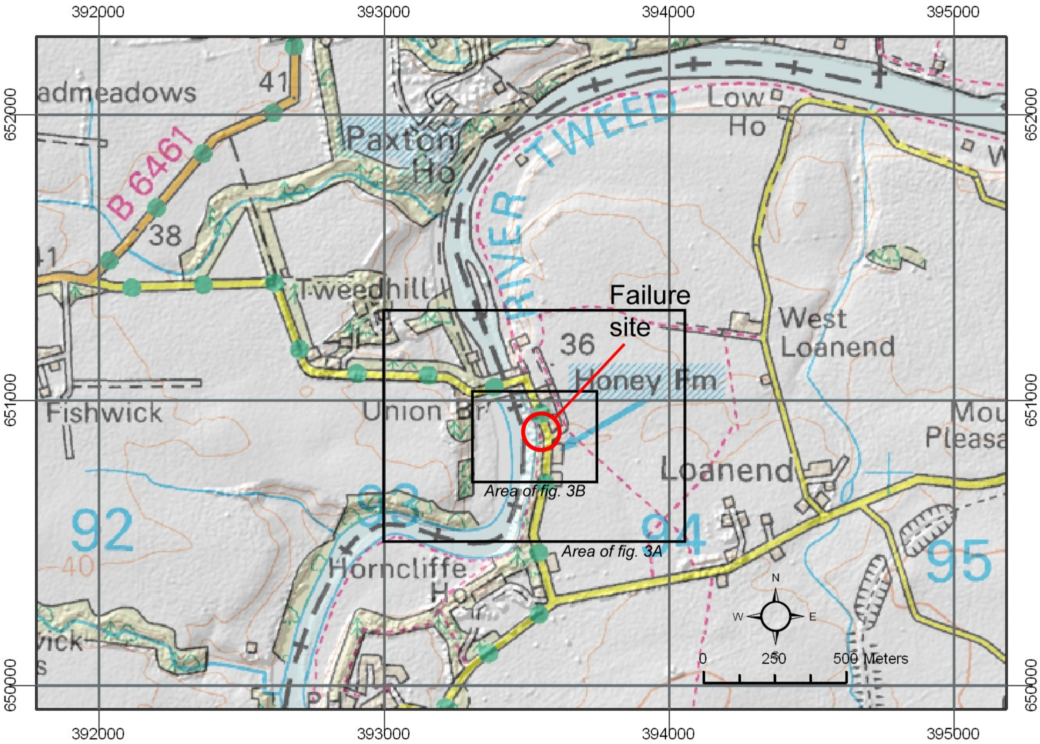

Figure 2. Detail of landslip site.

1.2 GEOLOGICAL CONTEXT

Bedrock thought to underlie the site is sandstone, siltstone and mudstone of the Balaggan Formation. Outcrops at the eastern end of the Chain Bridge revealed this to be a cross-bedded medium to coarse-grained red sandstone. No bedrock was seen at the failure site, however. The failure appears to have occurred in the overlying Superficial deposits, comprising principally a soft, red and grey mottled, silt and sand-dominated weakly cohesive diamicton. The matrix becomes increasingly firm with depth, particularly below 1.7 m. The matrix contains sufficient clay-grade sediment to impart a slight tendency to cleave or fracture when dug, particularly where it is more consolidated. The diamicton contains sub-angular (SA) and sub-rounded (SR) cobbles of the local red sandstone, as well as more angular, but weak, blocks of grey mudstone.

Other mapped deposits in the surrounding area (Fig. 3A) include alluvial and river terrace deposits associated with the River Tweed. These were not investigated during the site visit since they occur only to the west and north of the site, but are likely to be composed of gravel, sand and silt, in variable proportions. The road at the failure site occurs at the top of a steep bank (Fig. 3B). The road was underlain by at least two units of different types of fill (Fig. 4). To the south of the site, the exposed sequence revealed a red unit overlying a black unit, which in turn overlay the upper (possibly disturbed) part of the reddish diamicton. The red and black fills appeared to be composed of brick and coal rubble respectively, and were laterally continuous from south to north except in the central portion of the backscarp where the recent water mains maintenance had excavated through the sediments and been backfilled with gravel. Both red and black units were relatively thin (0.15-0.3 m thick), but of more-or-less constant thickness.

The recent maintenance work carried out on the fractured water main at the site had required excavation of a substantial hole (diameter c. 5 m) in the roadside verge. The excavation was subsequently backfilled with loose, c. 50 mm-grade gravel aggregate, to a depth of >1.5 m. Following bank failure, the new tarmac laid over the aggregate had slumped (c. 0.3 m drop) and buckled and detached from the older portion of the road (Fig. 4 and Appendix).

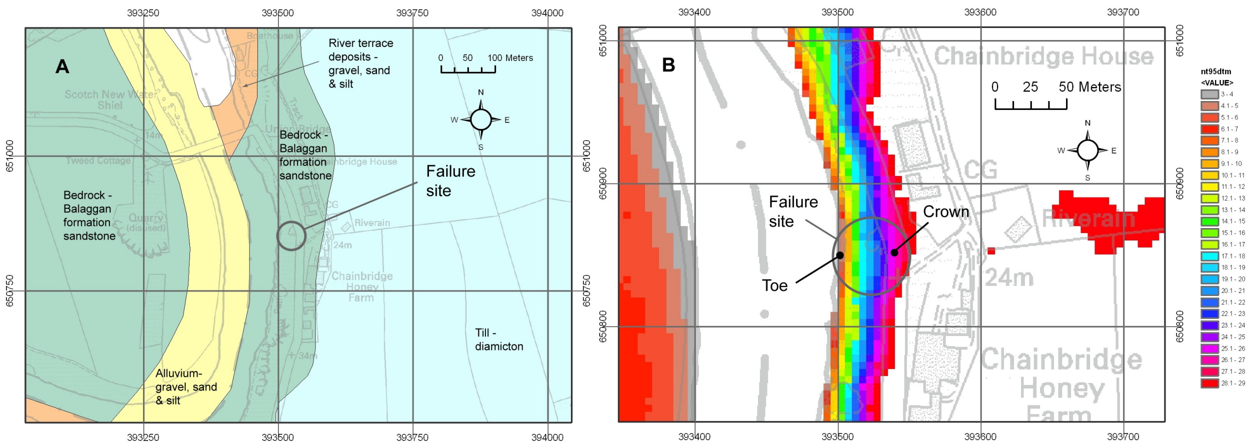

Figure 3. A. Geological map of the area surrounding the failure site, based on BGS 1:50 000 scale Sheet 26 (Berwick), and B. digital terrain data for the river bank at the failure site, from NEXTMap. Note the different scales of A & B.

2 Description of failure

2.1 SITE

The failure site is a steep, wooded bank. Several of the trees on the foundered material had fallen and lay in the gully overlying much of the slipped material. Access to the slide was only possible at the mainscarp and at the toe, but it was possible to climb up the central gully of the failure in the path of the present burn.

2.2 MORPHOLOGY

The c. 20 m wide mainscarp (Fig. 4, 5, 6A) displaces a c. 7 m-long section of tarmac from the road, with tension cracks in the road evident to the south. The gradient of the slip surface tends from initially sub-vertical to flat within the top few metres, where semi-intact blocks of the failed material formed a bench. Below this bench a secondary scarp marks the top of the debris flow gully, which drops initially sub-vertically before grading to an average slope of c. 26.6°. Failure appears to have occurred in the upper 3-5 m of the red-brown silty diamicton (subglacial till) that makes up much of the area. In total the failure site is 21.8 m high from scarp to toe, and is 48.75 m in length (Fig. 6B). In plan, the failure has an inverted 'teardrop' shape, with the widest part at the top. The failed area beneath the centre of the primary failure plane is delimited by an arcuate backscarp, undercut or oversteepened striated and grooved flanks, and a central area of displaced vegetation, rock (aggregate) debris, and liquefied sediments. This contrasts with the area of river bank to the south, where it is still wooded and where the slope remains relatively intact. Below the mainscarp in this area are several minor scarps, hidden amongst the trees, identifying rotational blocks that have slipped only a short distance. No evidence was seen in this area that failure had resulted in a debris flow.

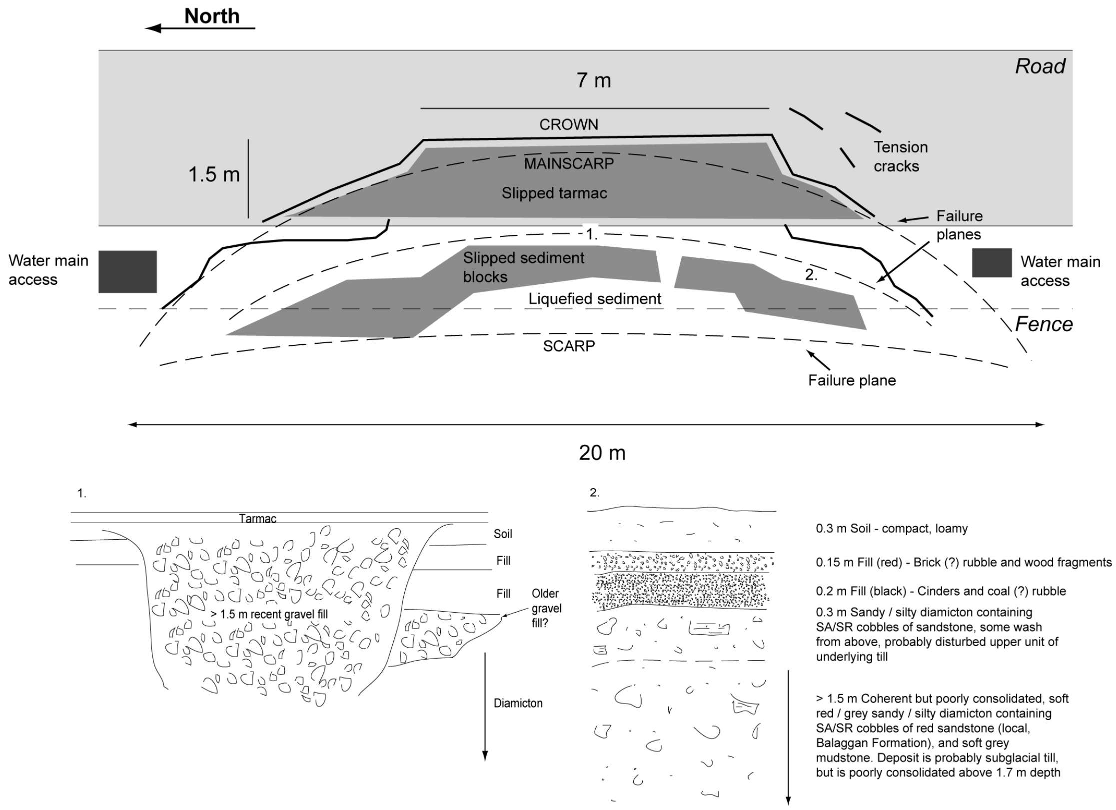

Figure 4. Schematic plan drawing of the mainscarp of the failure, showing locations of principal failure planes, backscarps, slipped material and the two vertical sections (1 & 2) shown below. Not to scale. 1. Vertical section through recent gravel infill at the centre of the mainscarp, and 2. Vertical section through in situ sediments and fill at southern end of mainscarp.

Figure 5. Panorama of the mainscarp of the failure, showing the central area where recent gravel fill has been washed out, leading to undermining and collapse of the road. Note the reddish diamicton overlain by black and red fill to either side of the grey gravel. Grit bin (right) and hammer (centre) for scale.

The toe of the failure was at river level, although there were no signs of undercutting of the bank either at the toe, or elsewhere along this section of the river. The main debris flow gully narrows to a minimum c. 4 m above the river, below which it widens slightly. At the narrow 'neck' of the gully (c. 5 m wide), a small overbank debris lobe consisting mainly of liquefied sediments and displaced vegetation has been deposited on the northern flank of the channel (Fig. 6A). The central part of the main gully above this point is filled with rock debris, displaced vegetation, and liquefied sediments. At the toe of the failure, a small debris fan has developed, probably subsequent to the initial failure, as a result of continuing down-wash of unconsolidated sediment by the extant stream or water from the ruptured mains pipe. To the south of this lobe, a small, arcuate failure is present, marked by a semi-elliptical backscarp and an infill of liquefied sediment. There is no apparent physical connection between this hollow and the main failure gully; however, there are signs that water, and / or debris have flowed over the ridge between the two, from the main gully into the smaller hollow.

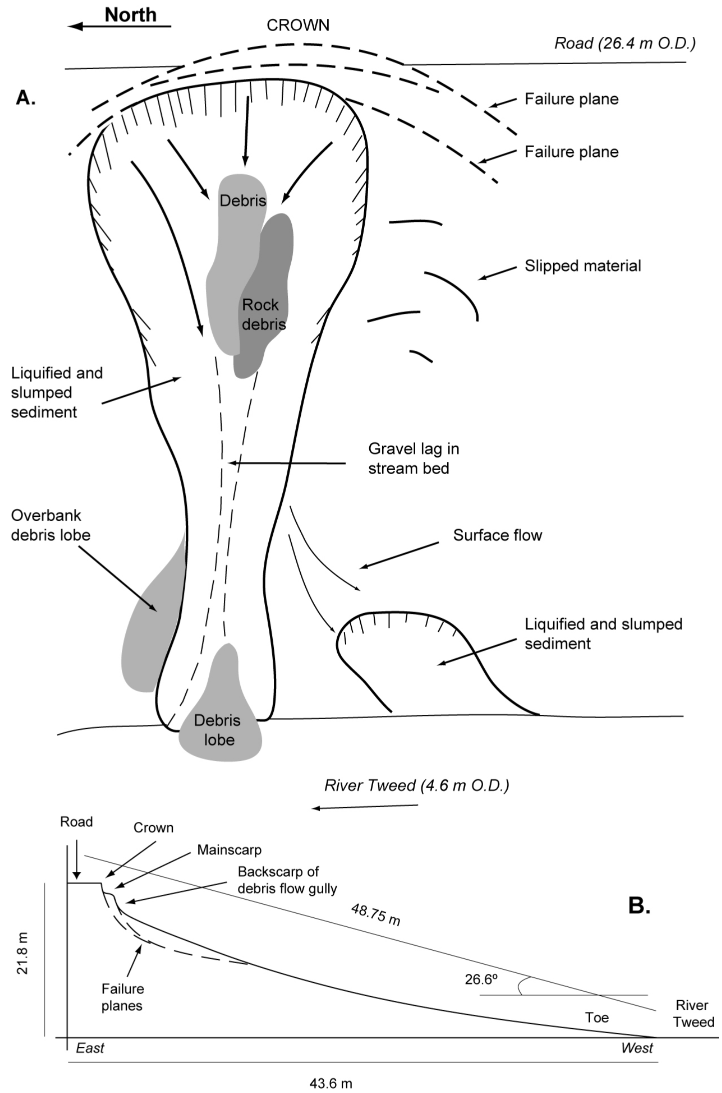

Figure 6. A. Schematic plan drawing of the failure site showing locations of principal failure planes, backscarps, and residual material. Not to scale. B. Cross-profile of the failure, showing length, height, and mean slope angle.

2.3 GEOLOGY

As described above, the failure site is predominantly composed of reddish, soft, silty diamicton that is variably well consolidated. The site is not bedrock at surface, as indicated by the existing geological map. The thin, surface veneers of road hardcore material (red and black fill) are relatively coherent and appear to have failed in a similar manner to the underlying diamicton. The coarse gravel used to backfill the water main excavation, however, is considerably less cohesive than any of the materials either side, and a significant amount has collapsed or been washed out, leading to undermining and collapse of the overlying road section. A concentration of large, angular blocks c. 0.3 – 0.5 m in diameter occurs in the upper reaches of the gully, mainly on the southern side of the central channel. These blocks are basaltic, and appear to have derived from previous fill beneath either the road or the verge. Some of these blocks were also seen at the failure toe. The present stream emerging at the top of the gully exposes gravel and cobbles along its length, in contrast to the liquefied sediments along its flanks, but nowhere was bedrock seen at surface.

2.4 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 Horncliffe landslide shows a crown composed of three oversteepened mainscarps, typical of rotational failures, with displaced vegetation and liquefied sediments lower down the slope typical of transport by a debris flow. Thus the landslip may be best described as a shallow rotational slide in an unconsolidated substrate that gave rise to a subsequent cohesionless debris flow.

2.5 TRIGGERS OF SLOPE FAILURE

It is likely that many factors exerted an influence on the location and nature of the Horncliffe failure, and that the exact circumstances leading to the bank collapse will remain ambiguous. Nonetheless, several possibilities exist.

That the failure scarp is centred on the location where recent excavations and backfilling occurred may indicate some connection between the two. However, it is also reported than an old culvert used to flow under the road at this point. The failure of the bank has removed or disguised much of the evidence of both, thus a causal link is hard to establish. Nonetheless, it is most likely that this failure was precipitated in a similar manner to bank collapses in similar materials elsewhere (e.g. Golledge 2006). The overriding trigger in such cases is elevated pore water pressures within unconsolidated substrates, which reduce sediment cohesion and their load-bearing ability. Where such pore pressure changes are localised, the contrasting shear strength of adjacent sediment masses preferentially focuses failure into the weakest area. That the bank to the south of the failure slipped, but did not liquefy into a debris flow, suggests that hydraulic conditions at the site were markedly different to those in the surrounding area. Rainfall was not reported to have been particularly heavy in the days before the failure, thus it seems likely that liquefaction of the sediments occurred as a result of localised build-up of water within the substrate near the recently excavated area. The free-draining gravel used to backfill the excavation may have aided natural drainage of the hole, but may have resulted in a water-table anomaly that increased the fluid content of the substrate immediately below, thereby raising pore water pressures in the sediments and leaving them prone to collapse initially in a rotational manner, followed by liquefaction of the mobilised sediments. The water may have been sourced from the culverted stream or from the ruptured water main prior to its repair.

Following its initial failure, the collapsed part of the bank liquefied and generated a debris flow. This flow removed a considerable volume of bank material and presumably deposited most of it in the River Tweed, since only a small proportion of the sediment was remaining in the gully. The depth of the flow was evident from overbank 'trimlines' of mud draping vegetation at the toe up to 2 m above the height of the extant stream. The debris flow probably breached the southern margin of its confining gully and may have triggered the minor failure adjacent to the toe, by saturation and loading of the sediments. Subsequent to the initial failure and debris flow events, oversteepened banks along the margins of the slip started to slump in order to regain stability. This process may be still taking place.

3 Impacts

The road is currently unsafe, particularly for the oil lorries that serve the local houses. The road is currently closed pending a decision on the nature of remedial works, although a temporary diversion around the affected area is expected to be implemented by January 2009. Full remediation may take up to six months.

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.

CRUDEN, D. M. AND VARNES, D. J. 1996. Landslide types and processes. In *Special Report 247: Landslides: Investigation and Mitigation,* Transportation Research Board, Washington, D.C.

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Appendix 1

i) View of landslip from west bank of the River Tweed. The road can be seen in the centre top, the mainscarp beneath, and the debris lobe entering the river at the toe.

ii) The failure site, looking north. Note the temporary blue pipe diverting the water main.

iii) The collapsed section of road at the crown of the failure. Note the grey gravel used as backfill material after recent maintenance work on the water main.

iv) View south showing the crown of the failure, and the flat 'bench' of slipped and liquefied material. To the right is the top of the main failure gully and its backscarp.

v) The mainscarp of the landslip and the flat bench of slipped material. Note the in situ diamicton composing the majority of the scarp, and the washed-out grey gravel backfill to the left.

vi) Backscarp of the debris flow gully. Note emergence of the small stream from beneath c. 1 m sediment, left of centre.

vii) Panorama of the failure scar from the mainscarp, looking down to the river.

viii) Stream and debris fan at toe of landslip. Note the displaced vegetation and mixed lithologies of rock debris.