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A40 Brecon Bypass Landslide: investigation, remediation and asset management for climate resilience

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Abstract February 2020 saw three named storms, record-breaking rainfall, widespread flooding and multiple landslides impacting transport infrastructure in Wales. Between 15th-16th February 2020, a 300m^3 failure of part of the westbound A40 Brecon Bypass cutting occurred, leading to the initial closure of all four lanes of the dual carriageways. As part of Welsh Government's strategy for climate resilient infrastructure and in accordance with the CD622 Managing Geotechnical Risk framework, the landslide and wider earthwork were investigated and remediated between 2020 and 2022. This paper discusses the approach to management of geotechnical risk for the scheme, from desk study through implementation of an on-slope ground investigation and interim risk mitigation, to design and implementation of the remedial measures. The paper describes the nature and trigger of the failure, adaptations in the design phase to provide resilience to geohazards and future climatic conditions, the constraints that were overcome during the site works by collaborative working and finally measures taken to manage residual risk and ensure ease of maintenance during future asset management.

Keywords: Slope Stability, Landslide, Geotechnical Risk Management, Geotechnical Asset Management

1. Introduction and background

The A40 Brecon Bypass is a 4.2km length dual carriageway located 1.5km south of Brecon, Wales (Figure 1). North and Mid Wales Trunk Road Agent (NMWTRA) is responsible for managing the infrastructure on behalf of the Welsh Government. The bypass is largely constructed on side-long ground within the north facing Usk valley side. The westbound lanes are largely formed in cutting whilst the eastbound is on embankment. The highest cuttings are located in the central part of the bypass, where the route passes through the Coed Nant-y-ceiliog woodland. The cuttings are between 1v:2h (27°) and 1v:1.75h (30°), up to 23m high and vegetated with semi-mature pine trees and dense scrub. At the cutting toe, an up to 7m high concrete cribwork wall is present.

Following heavy rainfall, during the night of 15th-16th February 2020, a landslide occurred in the cutting at the western extent of the woodland [305030, 227383]. The part-rotational, part-translational cutting failure with a debris flow run-out, shed material onto the lower slope and road. 400m east, a further slope failure into the Nant-y-Ceiliog (outside of the highway boundary) led to blockage of a culvert and carriageway flooding. As part of Welsh Government's strategy for climate resilient infrastructure and in accordance with CD622 'Managing Geotechnical Risk', investigation of the landslide site and wider earthwork was commenced. Mott MacDonald were appointed by NMWTRA to design the investigation and remediation.

Immediate risk mitigation following the landslide involved closure of all four lanes of the bypass, with one eastbound lane re-opened on the afternoon of 17/02/2020 and lane two of the westbound carriageway re-opened on 18/02/2020, following a phase of inspection and clearance of 300 tonnes of debris. Lane one of the westbound carriageway remained closed as water continued to flow from the landslide backscar and over the cribwork wall (Figure 2) and further adverse weather (Storm Jorge) was forecast for late February 2020.

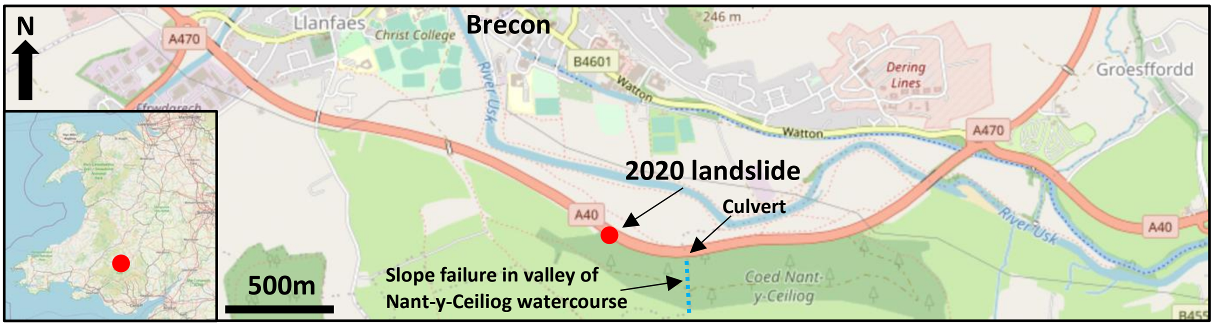

Figure 1: Location of the landslide, inset: Wales context. Background map source: OpenStreetMap 2022.

2. Investigation and ground conditions

A 15m long, up to 3m high 30-50° backscar was left by the failure, below which a bowl was present in the mid slope (Figures 2 and 3). Water was issuing from the bowl and saturated debris had accumulated in the mid slope. A green plastic-coated mesh was identified on the slope, damaged by the landslide. At the crest of the cutting, a fence forms the highway boundary, parallel to which is a gravel drain. The drain was obscured by soil and vegetation and surface water flows from third party land were seen to flow over the drain and onto the cutting.

The geology of the site comprises bedrock of the St Maughans Formation; purple, brown and green sandstones and red mudstones with conglomerates (Barclay et al., 2005). No superficial deposits are mapped. Historic mapping shows a track on the route of the current A40 within the Coed Nant-y-Ceiliog on the approximately 20° north-facing valley side, remaining unchanged from at least 1885 until the bypass construction in the 1970s.

As-built drawings dated 1980 show a crest filter drain and slope netting in the 1v:1.75h (30°) area of the 2020 landslide, with downslope drains either side of the landslide. Within the cutting to the east of the landslide, herringbone drains, downslope drains, netting and rockfill 'stabilising layers' are shown, indicative of groundwater and/or slope stability challenges during design and construction. Anecdotal evidence and 1980 photographs indicated that slope failures may have occurred during construction. 2016 HD41 (now CS641) earthwork inspection records largely corroborated the drawings; however, the slope was locally recorded as up to 34° and the drainage at the slope crest was undetermined, possibly reflecting dense vegetation cover.

At least 3m of superficial deposits was exposed in the backscar, comprising red-brown clayey gravelly sand or silt. Within the central area of the bowl, exposures of red-brown weak siltstone and medium strong micaceous sandstone were identified, interpreted as the St Maughans Formation. At the interface of the superficial deposits and bedrock, a dominant groundwater egress was observed, with further egresses from the backscar (Figure 3).

Figure 2: The landslide site following initial clearance of debris from the A40.

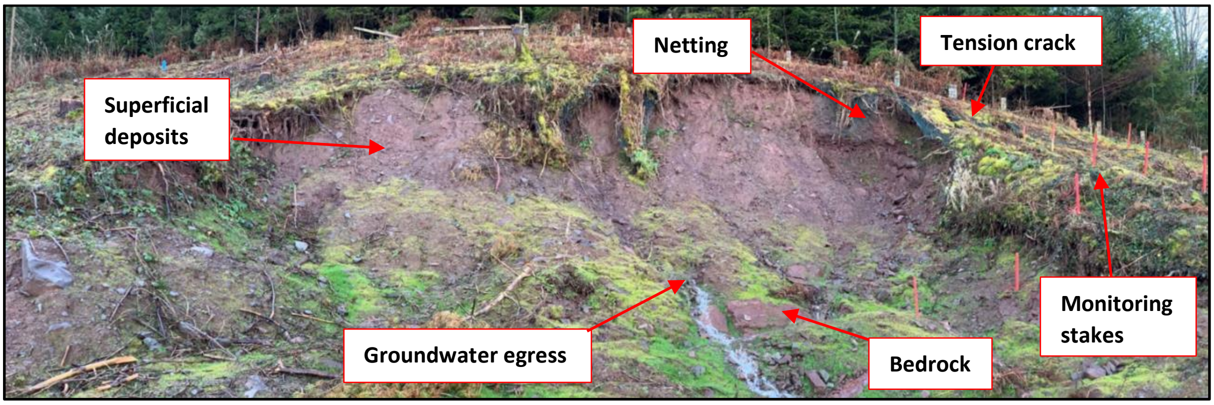

Figure 3: Detail of the landslide backscar, showing groundwater egress and monitoring stakes.

Following heavy rainfall, seepage was identified on the lower slope. Bedrock outcrops in the Nant-y-ceiliog watercourse provided rock strength and discontinuity data – indicating a favourable southward bedding dip. The desk study and site visit information was documented in the CD622 Preliminary Sources Study Report.

Ground investigation was undertaken by Geotechnical Engineering Ltd as subcontractor to Alun Griffiths Ltd in October 2020. Interim risk mitigation included monthly and reactive inspections triggered when thresholds were exceeded, namely 70% of the 7-day and 24hr rainfall pre-landslide, equivalent to 100mm and 50mm, respectively. On clearance of vegetation, tension cracks were identified at the backscar extents and a series of stakes were installed and their relative offset and tilt monitored to identify any further movement (Figure 3).

An investigation options appraisal was undertaken as part of the CD622 Ground Investigation Scoping Report. To understand the slope ground conditions, nine dynamic sampling with rotary coring follow-on boreholes were sunk using a 'slope-climbing' rig (Figure 4) which was lifted over the cribwork wall and onto the slope during a night road closure. Ground anchors were used to support the rig in the event of loss of ground contact. Dual-depth standpipe piezometers with dataloggers were installed within the boreholes to understand the groundwater regime. A 'flashy' response to rainfall events was observed for installations within the coarse superficial deposits and fractured bedrock. Deeper installations showed a less pronounced response. As exposed on site, a cover of superficial deposits was encountered and is interpreted as hill-wash (Figure 5). The ground model (Figure 6) and material parameters were documented within the CD622 Ground Investigation Report.

Figure 4: On-slope ground investigation, showing crest anchor system.

Stratum	Top (mbgl) [mOD]	Base (mbgl) [mOD]	Thickness (m)	Typical description and notes
Superficial Deposits – Sands and Silts	0.0 [169.0]	4.0 [165.0]	4.0	Firm to stiff slightly gravelly slightly sandy to sandy clayey SILT or medium dense gravelly to very gravelly clayey to very clayey fine to coarse SAND, with a low to medium cobble content
Superficial Deposits - Gravel	4.0 [165.0]	5.0 [164.0]	1.0	Dense to very dense slightly sandy GRAVEL with low cobble content
St Maughans Formation – Weathered	5.0 [164.0]	9.0 [160.0]	4.0	Extremely weak to weak very thickly laminated to thinly bedded MUDSTONE and SILTSTONE. Locally disintegrated to clay-bound gravel. Occasional sandstone bands
St Maughans Formation	9.0 [160.0]	>13.0 [<156.0]	>4.0	Weak to medium strong thinly to medium bedded SILTSTONE and SANDSTONE

Figure 5: Summary ground model (below the crest of the backscar) and borehole core sequence.

3. Failure trigger

Daily rainfall data from the NRW raingauge 1km west of site spans from 1961 through the 2020 landslide. Between 15th-17th February 2020, during Storm Dennis, 99mm of rain fell, compared to the whole-February average of 111mm. Storm Dennis represents the second highest daily rainfall recorded since construction of the bypass, with Storm Callum (October 2018) representing the highest, at 106mm. 199mm rain fell over a nine-day period up to the end of Storm Dennis, compared to 151mm over the equivalent period to the end of Storm Callum. Higher magnitudes of rainfall had been experienced at the site prior to the failure event, however it is interpreted that the cumulative antecedent conditions led to the landslide. The prolonged heavy rainfall, large catchment, inefficient crest drainage and presence of the spring are interpreted to have contributed to progressive saturation of the slope and initiation of a groundwater ‘burst’ type failure.

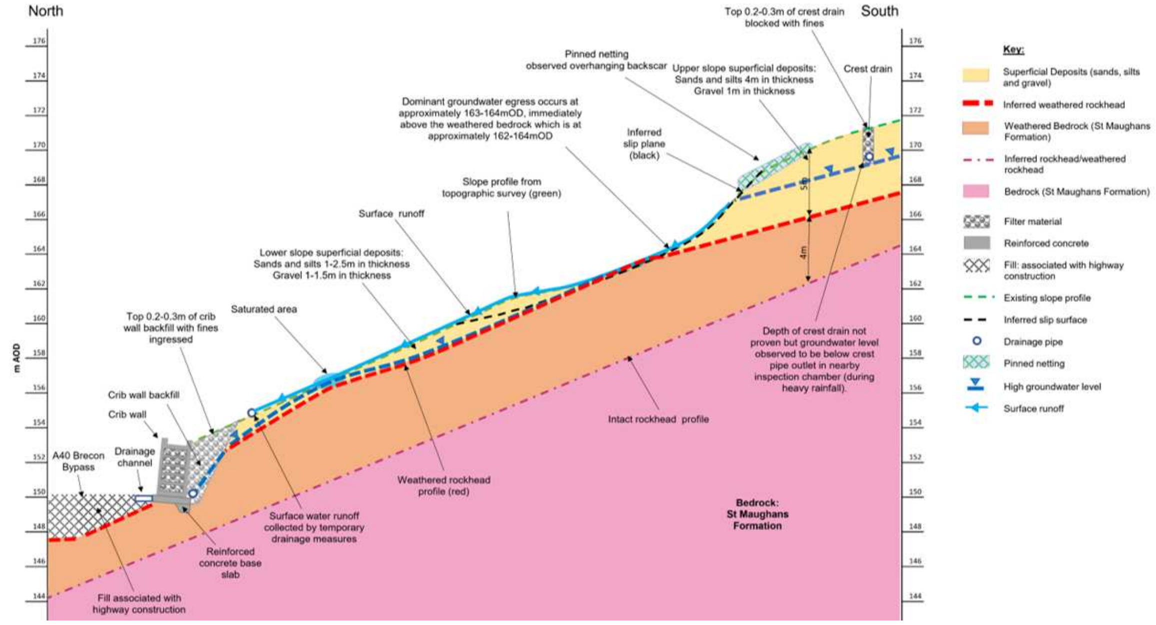

Figure 6: Conceptual ground model cross section.

4. Remedial design

An adaptable, robust and low-maintenance solution was sought. Other factors included how the slope would be accessed, how road user impacts could be minimised as well as the environment and visual impact given the site’s visibility from Brecon. Analysis of the post-failure slope stability showed that the factor of safety was well below satisfactory, confirming the backscar was unstable. Remedial options were considered at outline design stage. A do-nothing scenario was discounted due to the risks. A do-minimum scenario, comprising inspections, lane closure and maintaining temporary drainage was ruled out due to poor long-term management of risk.

Three repair approaches were appraised: reprofiling, reinforcement and retention. All solutions included extensive drainage works, which were identified early in the process as a key requirement. Reprofiling and filling with compacted free-draining stone was concluded to provide fair geotechnical risk management however analysis showed that crest excavations were required as well as potential encroachment on third party land. A reinforcement solution was ruled out based upon the problems anticipated for soil nailing arising from the coarse soils, high groundwater and potential for clashes with the highway drainage and third-party land.

A retention solution was selected, comprising a 2m high gabion wall retaining SHW Class 6N well-graded granular fill. A cellular topsoil retention system was proposed upon the 6N to enable vegetation establishment after seeding. A concrete cascade permits outflow of the gabion wall drainage which captures and diverts the spring, the ultimate outfall of which is a pipe over the cribwork wall and into a modified channel. A 750mm thick SHW Class 6G rock blanket was proposed on the lower slope to manage groundwater seepages. A single-basket high gabion wall was included in the west of the site to retain an inspection path. It was proposed to replace the crest drain over a 500m length, comprising excavation of the existing and replacing with a twin-wall plastic pipe with additional resilience in the form of an impermeable membrane on the downslope side and separator geotextile wrapping the trench. Other measures included clearance of ditches and repairs to the cribwork wall. The design and construction stage risk mitigation were presented in the CD622 Geotechnical Design Report.

5. Construction

Alun Griffiths Ltd was awarded the construction contract. Managing geotechnical risk was recognised at tender stage via 60/40 technical/commercial tender scoring. Construction started in autumn 2021, with full-time site presence from a geotechnical engineer to aid residual risk management. A barrier was installed to isolate lane one for the works, with lane two open to traffic. Access for the works was formed from the slope toe via haul roads to the crest in addition to a fill platform within the closed lane. Renewal of the crest drain was commenced first (Figure 7). Due to fines presence throughout the filter media, clean stone backfill was imported for the new pipework. The undermined brick headwall at the Nant-y-Ceiliog outfall was replaced with a gabion solution. A 130m length of crest drain was found to have no outfall into a downslope drain where expected from the as-built drawings so modifications were made to help capture surface water and reduce infiltration.

Figure 7: Renewal of the crest drain. Left: replacement of pipework and filter media. Right: completed works.

Excavations for the gabion wall were formed in bays to manage temporary slope stability. Baskets were braced externally and hand-filled to minimise voiding and post-construction distortion. A backfall on the blinding was constructed to aid wall stability and direct water into the back of wall drainage. The drainage comprised a perforated twin-wall pipe with Type B filter media wrapped in a separator geotextile to minimise fines ingress (Figure 8). Rodding eye accesses were used in place of chambers where possible to aid constructability.

Remote-controlled plant was used to compact the Class 6N backfill, reducing the risk of vibration injuries and limiting the requirement for person-operated plant on the slope. A 150mm thickness cellular topsoil retention system with underlying fines separator geosynthetic was installed upon the 6N backfill, with additional resilience in the form of embedment of the system at the crest within an anchor trench. In front of the gabion wall, a 0.5m thickness of geogrid-reinforced fill provides embedment and an access path for inspection and maintenance.

The gabion drainage discharges into a cascade via a headwall (Figure 8). A concrete apron was formed upstream of the headwall and weepholes were installed into the headwall to direct and discharge, respectively, flows in the pipe bedding from groundwater seepage. The cascade is a proprietary segmental concrete stairs product, reducing the need for formwork. The step treads were infilled with concrete and natural stone side walls were formed. The adjacent steps comprise the same product as the cascade. For additional sliding resistance, min. 1m length 25mm diameter high yield strength bars were driven into the slope and embedded within the concrete of the step treads. The cascade discharges into a PVC pipe which passes over the cribwork wall and into a channel which was enlarged to manage the increased flows (Figure 8). After a very dry early-mid 2022, water flow was observed in the drainage measures in November 2022 after heavy rainfall.

Figure 8: Left: gabion wall and associated drainage construction, right: cascade and over-wall drainage pipe.

The cribwork wall repairs comprised replacement of missing elements that had been entrained in the landslide and repairs to damaged elements. Damaged elements were deconstructed to ascertain the reinforcement details and the additional elements were cast for potential future works. To avoid deconstruction of the wall to replace damaged elements in the lower part of the wall, the elements were broken back to fresh concrete, reinforcement added and formwork used to cast the repair. Where damage was extensive, no-fines concrete with weep pipes was used as infill to ensure continued drainage.

6. Future asset management

The scheme was designed to be as simple and easy to maintain as possible since residual risk requires inspection and maintenance of the measures (Figure 9). Recommendations for maintenance were made within the CD622 Geotechnical Feedback Report. Key objectives are ensuring free-flow of drainage and visibility and serviceability of retention measures. A risk-based approach to inspections was recommended, with the frequency decreasing over time to the baseline DMRB CS641 requirements as the performance of the remedial measures is observed and response to weather events understood in the context of the expected behaviour. The open cascade and discharge of water into the verge channel permits immediate visual confirmation of the drainage effectiveness. Shallow gradient dedicated paths and inclusion of steps with guard rails allows safe and robust access for long-term inspection and maintenance of the retention measures, chambers and crest drain.

Future challenges for management of the wider cutting asset include potential future instability of the ageing earthwork and cribwork wall as well as management of slope vegetation. The simple solution implemented at the landslide is intended to be suitable for replication at other sites of instability on the cutting, if identified.

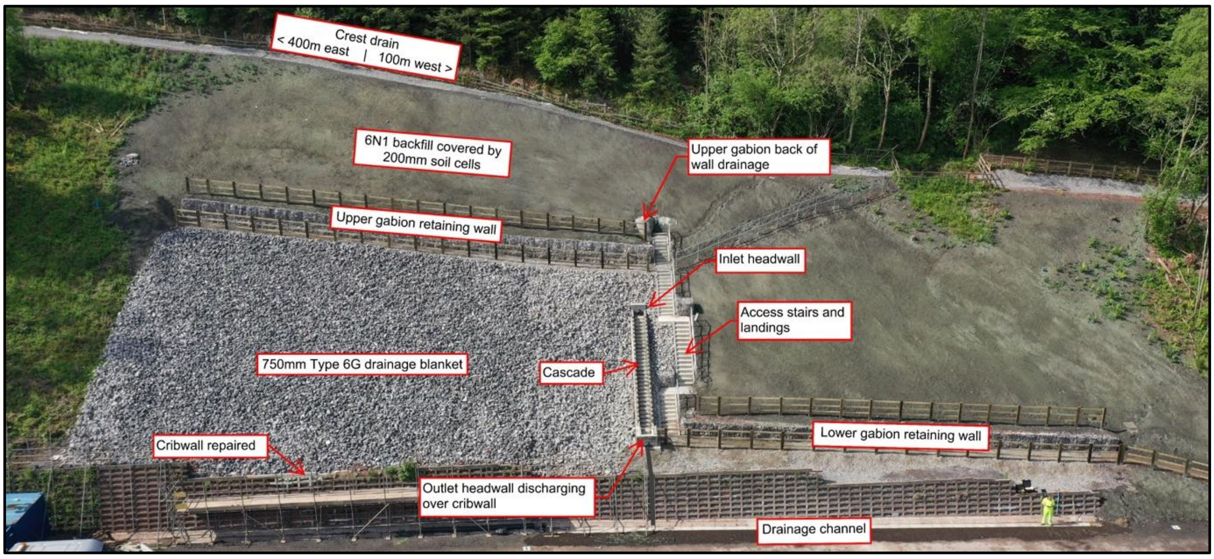

Figure 9: Drone photograph of landslide remedial works at the end of the construction phase.

7. Conclusions

The CD622 'Managing Geotechnical Risk' framework from desk study through to Geotechnical Feedback Report was effectively implemented for the investigation and remediation of an earthwork failure on the Wales strategic road network following extreme weather. The failure mechanism is interpreted to be a groundwater 'burst' from an ephemeral spring which resulted in a debris flow of saturated superficial deposits. The scheme provided an asset which can be easily and safely maintained and included multiple adaptations to provide resilience to geohazards and future climatic conditions. Collaboration between all parties during the difficult circumstances of the COVID-19 pandemic enabled the design, construction and operational and maintenance challenges to be considered and overcome, resulting in a scheme which is more resilient to climate change.

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