Successful Remediation of Dual Pipeline Stress Within a Complex Landslide

C. Watson[1], D. Poh[2] and R. Satrasala[3]

[1]Engineering Geologist, Pattle Delamore Partners Ltd., Level 5, PDP House, 235 Broadway, Newmarket, Auckland; PH (+64) 27-376-4063; email: cam.watson@pdp.co.nz
[2]Geotechnical Engineer – Service Leader, Pattle Delamore Partners Ltd., Level 5, PDP House, 235 Broadway, Newmarket, Auckland; PH (+64) 27-376-4063; email: david.poh@pdp.co.nz
[3]Senior Project Manager, Firstgas, 42 Connett Road, New Plymouth, Taranaki, 4312; PH (+64) 27 958 4759; email: ramesh.satrasala@firstgas.co.nz

ABSTRACT
Intelligent "pipeline pigging" detected deflection of a 200mm high pressure gas pipeline and a 250mm petroleum products pipeline buried in the same trench, where they cross a complex landslide for a length of approximately 40m. The landslide, located in West Auckland, New Zealand, comprises two lobes and is situated within a larger relic landslide underlain by East Coast Bays Formation. Surface and subsurface geotechnical investigations, monitoring and related assessment were used to define the landslide model. Slope stability analysis and remediation optioneering had to consider the urgency of landslide stabilisation, pipelines and personnel safety during pipelines exposure (Pipeline Stress Release Trench), and stability of a nearby dwelling. Stability and health and safety risk concerns were identified for a temporary unsupported Pipeline Stress Release Trench, which required exposure of the landslide failure plane across essentially the full width of the landslide. Remedial works included installation of subsurface drainage (Stage 1) followed nine months later by exposure of the pipelines for stress relief and inspection works (Stage 2). Subsurface drainage comprised 164m of French drains, typically 2.5m deep. Inter-stage monitoring, including groundwater levels, surface changes and drain flows confirmed satisfactory drainage performance prior to Stage 2 works. Excavation and subsequent backfilling of the 3m wide by 48m long Pipeline Stress Release Trench was completed safely via a staged approach using trench shields.

Keywords: pipeline, landslide remediation, subsurface drainage, stress/strain release

1 INTRODUCTION AND BACKGOUND

The Perris Road landslide ("the site", "the landslide") is located in Henderson Valley, West Auckland, New Zealand (Figure 1B). The landslide comprises two lobes and is situated within a larger relic landslide ("relic landslide") underlain by East Coast Bays Formation (Figure 1A). Two transmission lines – a 200mm high pressure gas pipeline, and a 250mm petroleum products pipeline ("the pipelines") – are buried 2.5 – 3.1m deep in the same trench and cross the landslide for a length of approximately 40m. The high pressure gas pipeline is owned by Firstgas and supplies gas to Northland, and the Marsden Point to Auckland Pipeline (MPAP), owned by Channel Infrastructure NZ, is a 170km long pipeline which carries diesel, petrol and jet fuel in controlled batches to the Wiri fuel terminal in South Auckland.

Results from 2017/18 intelligent pigging surveys identified the landslide/strain features which were deemed to be a potential risk to the integrity of the pipelines. Intelligent pigging is an advanced robotic technique that propels a purpose-built pipeline integrity gauge (PIG) unit fitted with a variety of probes and sensors through a pipeline to detect and measure corrosion, metal loss, cracks, dents, deformations etc.

Following the identification of these features, Pattle Delamore Partners Ltd (PDP) were engaged to investigate and provide remedial options for the landslide. Investigative and remedial works were carried out over four phases, beginning with Detailed Site Investigations (DSI - Phase 1) and finishing with Remedial Works Construction and Site Reinstatement (Phase 4).

This paper presents an overview of the phases involved to successfully remediate the dual pipeline stress within the landslide through close collaboration with Firstgas, Channel Infrastructure NZ, Whitaker Civil and local landowners.

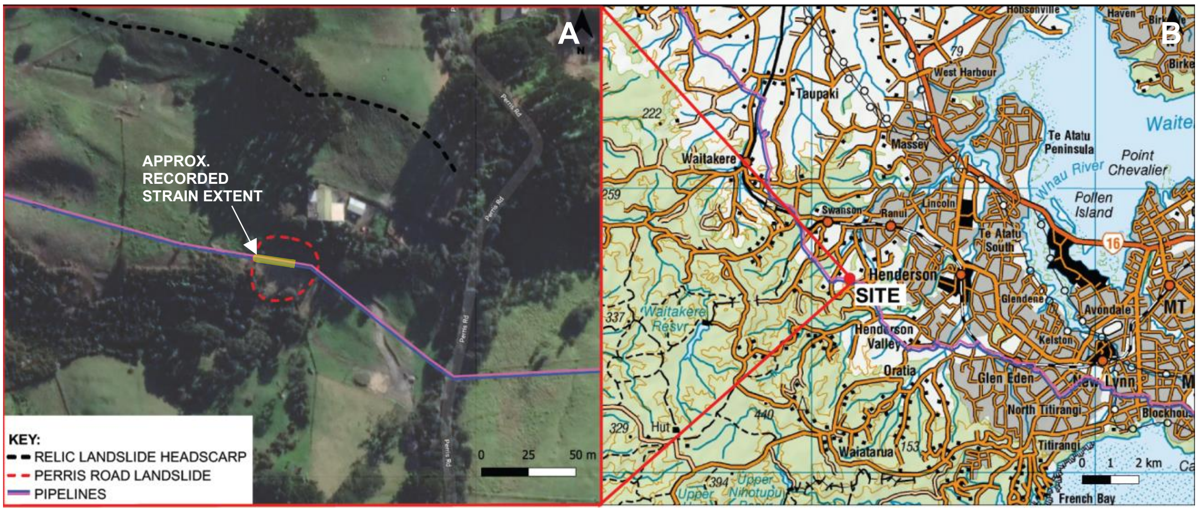

Figure 1: (A) Overview plan of the site and landslide features; (B) Site Location

2 PHASE 1 – DETAILED SITE INVESTIGATION (DSI)

2.1 Geology

The published geology (Hayward, 1983) indicates that the site is underlain by East Coast Bays Formation (ECBF, typically sands and muds with some volcanic content and grits) of the Waitemata Group. The closest structural information indicates bedding orientations have an approximately north-south strike with shallow (6° – 10°) dips to the west-southwest. Weathered Waitemata Group is susceptible to shallow flows, slumps, or creep, particularly when saturated and on slopes steeper than 20° (Hayward, 1983).

2.2 Field Investigations

DSI field investigations were carried out in June 2019 and comprised engineering geological walkover mapping, drilling of 10 hand augerholes up to 5.0m depth (with hand held shear vane tests in cohesive material), GPS topographic survey, abney lines for engineering geological cross-section development, depth and alignment survey of the pipelines, installation of three crack monitoring lines, and installation of three hand auger piezometers/rudimentary inclinometers with level loggers to monitor groundwater levels and ground movements.

The geology encountered during the DSI was generally consistent with the published geology and consisted of landslide debris underlain by relic, blocky landslide debris most likely derived from ECBF soils described in the published geology. The recorded strain was located within the inferred mapped landslide boundaries (Figure 1). No evidence of recent instability was identified during mapping of the relic landslide (Figure 1).

2.3 Conceptual Landslide Model

An inferred conceptual landslide model for the site instability was developed based on the DSI investigations. The landslide was inferred to compose of two landslide lobes: (1) the North Landslide Lobe (NLL); and (2) the South Landslide Lobe (SLL; Figures 2 and 3). The basal landslide failure plane was inferred to have a maximum depth of 4.2m below ground level (bgl) and be within landslide debris associated with the relic landslide features present on the upper slopes (Figure 1). The landslide failure direction was inferred to be approximately south (~194°), perpendicular to the pipelines.

The failure sequence and triggering mechanisms for the landslide was inferred to be movement of the SLL first, followed by movement of the NLL either: (1) very soon afterwards (essentially a single movement event for both lobes); or (2) at a later date (separate movement events). Movement of the SLL would have partially removed toe support for the upslope NLL allowing it to retrogressively fail. Site information indicated the SLL had moved since it was first triggered with fresh tension cracks and sharp scarps in the SLL indicating that the lobe had subsequently moved, likely within the past 5 years. In contrast, the instability features associated with the NLL indicated somewhat older movement. Initial and subsequent landslide movement was inferred to have been triggered principally by elevated groundwater levels due to a combination of heavy/prolonged rainfall events.

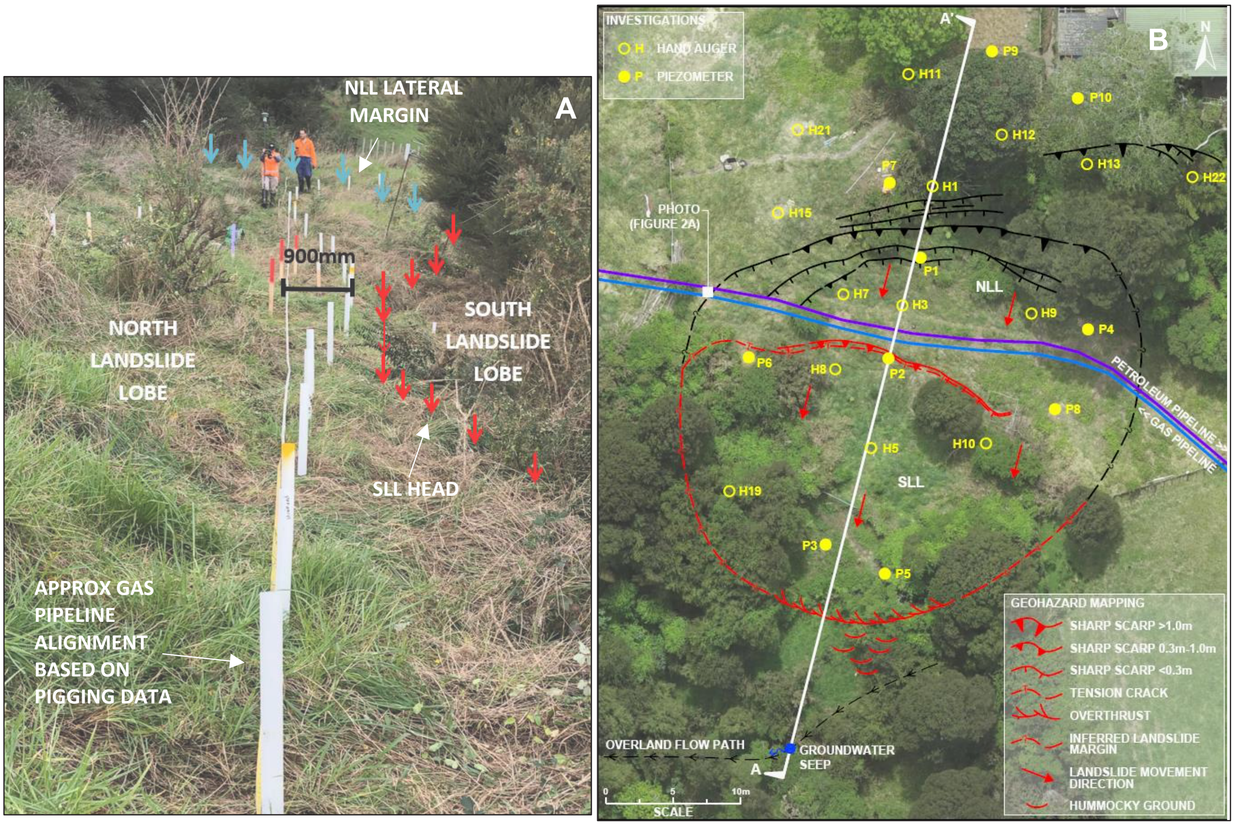

Figure 2: (A) Photo facing east across the landslide showing the inferred downslope deflection from assumed as-built alignment of the gas pipeline. (B) Simplified engineering geology sketch plan. Section A-A' shown on Figure 3.

2.4 Pipeline Risk

The pipelines are located within the inferred boundaries of the landslide for an approximate length of 40m (Figure 2). The inferred lateral margins of the landslide extended beyond the suspected deflection area. A suspected horizontal deflection of approximately 900mm from the assumed as-built alignment over a pipeline length of approximately 26m was inferred based on field observations (Figure 2). Based on the inferred landslide movement direction, some vertical deflection of the pipelines was also interpreted to be likely within the landslide. This is consistent with there being a vertical component of pigging strain at the site.

It was inferred that further movement of the landslide – i.e. movement of the SLL followed by re-activation of the NLL, or movement of both lobes in a single event – was possible following heavy and/or prolonged rainfall events. Potential implications for the pipelines of further movement were increased deflection and related additional strain/stress, potentially affecting the integrity of the pipelines.

3 PHASE 2 – CONCEPT DESIGN

Based on the results of the DSI, initial Conceptual Design (CD) options to stabilise the landslide and to reduce the likelihood of further land movement impacting the pipelines included: (1) Infill open tension cracks and continue to monitor the area with special site surveillance; (2) Head unload the NLL and SLL; and (3) Installation of subsurface drainage in the landslide area.

Option 1 was completed during a subsequent landslide monitoring round. The key reason for not adopting head unloading of the NLL and SLL (Option 2) was the inferred instability risk upslope of the NLL where a residential dwelling is located (Figure 1). Therefore, installation of subsurface drainage (Option 3) was the preferred remedial option to progress to Detailed Design (DD).

A pipeline strain/stress analysis, which was performed by Firstgas in parallel with the CD process, indicated the need to relieve the strain/stress in the affected section of the pipelines. This involved a Pipeline Stress Release Trench (PSRT), comprising a staged excavation to expose the pipelines to allow rebound of the deflected section of the pipelines.

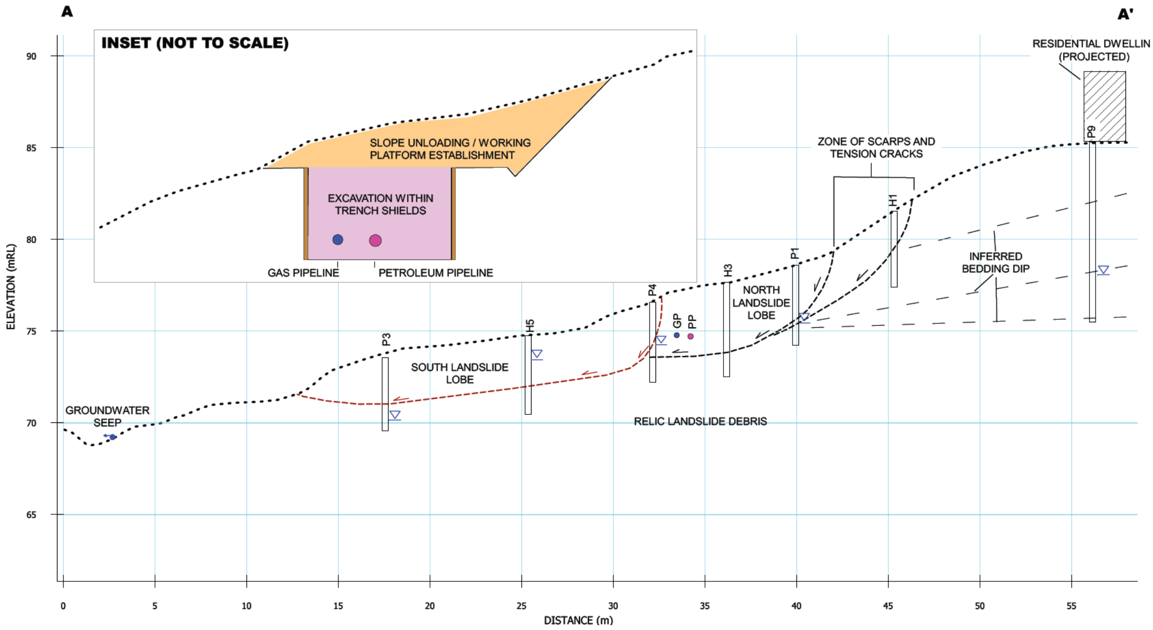

Figure 3: Engineering geological cross-section. Refer Figure 2B for section location. Inset: Simplified schematic of PSRT excavation methodology.

4 PHASE 3 – DETAILED DESIGN

4.1 Detailed Design Geotechnical Investigation

A detailed design geotechnical investigation (DDGI) was carried out to refine and update the geological ground model for DD analysis and modelling associated with the Pipeline Stress Release Trench (PSRT). The DDGI focussed mostly on the area upslope of the pipelines to provide additional ground information inputs for the stability assessment related to the PSRT excavation as well as consideration of the upslope residential dwelling. The DDGI included detailed engineering geological mapping, 13 hand augerholes to a maximum depth of 6.1m bgl (including installation of five 32mm hand auger piezometers/rudimentary inclinometers), two PQ (83mm diameter) machine drilled boreholes to a maximum depth of 10.2m bgl with piezometer installations, photogrammetry, and collection of Light Detection and Ranging (LiDAR) data to provide a detailed topographical model of the site.
Key findings from the DDGI included identification of additional NLL instability upslope of the pipelines and inferred downslope dipping bedding in the ECBF in the area upslope the landslide. Figure 3 shows an engineering geological cross-section of the updated conceptual landslide model following the DDGI works.

4.2 Slope Stability

Slope stability analysis using SLOPE/W (GeoStudio 2020) was carried out to analyse the current Factor of Safety (FoS – back analysis) of the landslide and to determine the FoS with the provision of the subsurface drainage system for groundwater control. Slope stability analyses were carried out for the long term/permanent condition i.e., on completion of the subsurface drainage system under both static and seismic conditions. The results indicated that: (1) the stability of the landslide is dependent on the groundwater levels and instability can be triggered by an increase in groundwater levels across the landslide; and (2) an acceptable FoS was met under normal (static) conditions and seismic SLS and ULS scenarios.

Based on the ongoing groundwater monitoring it was noted that the groundwater levels were highly sensitive to rainfall events and surface water recharge. Therefore, it was determined that the subsurface drainage network was required to be in place to control the groundwater levels for stability prior to the PSRT excavation.

A stability assessment for the PSRT excavation, based on a typical open cut slope excavation with subsurface drainage installed (i.e., modelled groundwater levels), yielded unsatisfactory results for temporary conditions. Subsequent discussions with Firstgas and Channel Infrastructure around safety of personnel and the pipelines, and the potential impact to the residential dwelling upslope of the work area, concluded that an open cut slope excavation approach for the PSRT was deemed high risk and therefore unacceptable. Therefore, an alternative staged excavation approach using trench shields was introduced and the stability of the method assessed. The stability assessment achieved an acceptable FoS for the temporary conditions (i.e., during the PSRT excavation).

4.3 Subsurface Drainage

As described above, the required groundwater drawdown for the subsurface drainage system was established through a series of slope stability modelling with different groundwater levels to achieve the required FoS. Subsurface drainage coverage and layout was modelled using FEEFLOW, a computer program for simulating groundwater flow using parameters determined from the DSI and DDGI. Several configurations of the drainage layout were analysed to determine the effectiveness of the drainage systems. The modelling of the finalised layout confirmed that the subsurface drainage network would provide sufficient coverage across the landslide area for adequate groundwater drawdown.

4.4 Safety in Design and Risk Assessment

As part of the detailed design process, Firstgas/Channel Infrastructure, PDP, and Whitaker carried out a joint safety in design review process, including review of the design and the risk and hazard assessment for safe construction of the remediation works around the pipelines. For this project, the excavation was across the full width of the landslide and in places, to below the interpreted failure plane (i.e. >3m deep). The potential risks to personnel working in the trench and the integrity of the pipelines (supplying gas and petroleum products to Northland and Auckland, respectively) were of paramount importance when undertaking the safety in design review and risk assessment.

5 PHASE 4 – REMEDIAL WORKS CONSTRUCTION

The preferred remedial option (landslide drainage and PSRT) was divided into two work stages: Stage 1: Installation of landslide subsurface drainage, including a pipeline trench cut off drain east of the landslide; and Stage 2: PSRT – Excavation and exposure of the pipelines to relieve land movement related stress/strain, pipeline integrity checking, coating repair works, backfilling and reinstatement. Figure 4A shows the layout of the subsurface drainage network and the extent of the PSRT.

5.1 Stage 1: Subsurface Drainage

Subsurface drainage construction works were completed from April–May 2021 and comprised installation of 164m of 1.5–3m deep subsurface French drains, a pipeline trench cut-off drain east of the landslide, 25m of buried carrier pipes carrying the drainage discharge to three culvert drainage outlets, 13 buried drainage inlet risers at the head of subsurface drain stems, and two drain flow monitoring points. Subsurface drain pipeline crossings were installed during Stage 2 following excavation of the pipeline stress relief trench (PSRT).

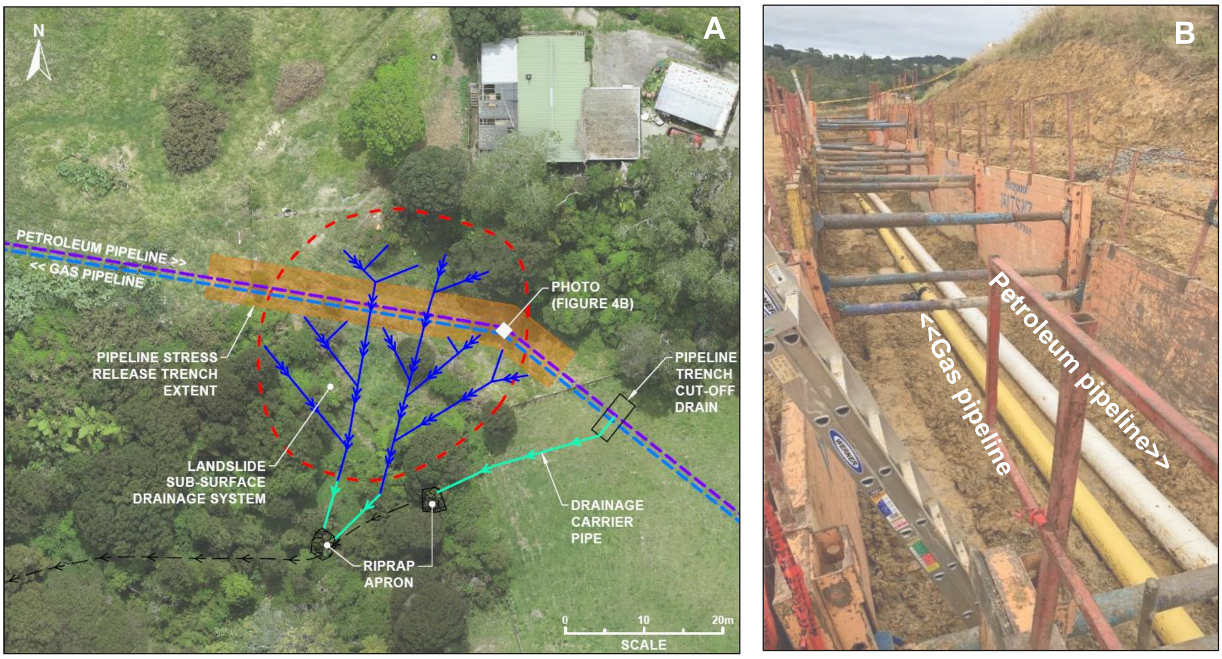

Figure 4: (A) Remedial works overview plan. (B) PSRT during Phase 4 (Stage 2) works. Photo facing west.

Monitoring of groundwater levels at 8 locations within the drainage network area of influence and drain flow measurements in the period between Stage 1 and Stage 2 works indicated effective performance. of the drainage network. Stage 2 construction works were carried out over January-March 2022. A summary of the works is provided below.

5.2 Stage 2: Pipeline Exposure and Reinstatement

The pipelines were potholed to complete a pre-excavation baseline survey. Approximately 1-2m of soil was removed from the slope in the PSRT area to form a level working platform and provide a slope unloading function (Figure 3 inset). Pipeline cover was removed to within 0.5m of the crown of the pipelines using an excavator and trench shields. The remaining 0.5m of soil overlying the pipelines was removed via hand excavation to expose the pipelines (Figure 4B). During pipeline exposure and destressing works, the pipelines moved back towards the approximate original straight-line pipeline alignment. Pipeline defects were repaired and permanent crossings underneath the pipelines were retrofitted to complete the subsurface drainage network. Trench shields were then removed, the PSRT was backfilled, and the site was reinstated.

Following the completion of the PSRT works, rock riprap aprons were placed at the base of the drainage outlets. Piezometers and groundwater monitoring equipment that was damaged or removed during the remedial works was reinstalled. In addition, a post works monitoring site visit was carried out by PDP in May 2022 to provide the landslide monitoring network baseline measurements. A monitoring plan was developed for the site going forward with the plan including rainfall trigger thresholds for monitoring site visits.

6 CONCLUSION

This project demonstrates a comprehensive phased approach for remediating pipeline stress/strain caused by landslide movement. A network of subsurface drainage installed 10 months prior to pipeline stress relief prevented the landslide from moving between the two remediation stages.

Strain assessment showed the need to relieve pipeline stress using an open excavation across the landslide. Multiple landslide lobes and potential upslope instability that could have affected a residential dwelling, together with trench safety requirements, required an alternative design for the open excavation. This design comprised trench shields for support and safe excavation of the pipelines.

Important takeaways from the project are:

- It is essential to investigate and understand site ground conditions and the landslide mechanism and its impact on key infrastructure. It is fundamental to “get the geology right” and establish a representative ground model for slope stability analysis and design of the remedial works.
- Effective and clear communication between the consultant, clients, landowners, and the contractor is essential for ensuring that the project runs smoothly. In this case, clear intention and communication between PDP, Firstgas/Channel Infrastructure and landowners were imperative in the early investigative stages of the work. In addition, close collaboration during the construction phase ensured key technical and construction issues were resolved quickly to allow smooth progress of the construction.
- The use of French drains (with associated carrier pipes and drainage outlets) is a practical and successful method for stabilising shallow landslides.
- The joint safety in design review process ensured a robust review of the design and the risk and hazard assessment for the safe construction of the remediation works around a critical lifeline infrastructure.

The remedial works effectively restored the integrity and longevity of both pipelines. This, together with the post works monitoring and maintenance plan, will prolong their operational life.

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