Stabilisation of a soft fill slope by compacted rockfill – an example of good practice

Stabilisation des pentes de remplissage mou par enrochement compacté – un exemple de bonne pratique

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ABSTRACT

Remediation was designed for a marginally stable fill slope comprising up to 5 m loose cohesive fill in a residential area adjacent to a deep valley. Excessive ground settlements around a sewage pumping station (SPS) and a tension crack in the vicinity of residential houses in an area near Glasgow were linked to possible burst utilities and gradual washout of fines in the fill. Desk study and ground investigations were carried out to determine the site history and geological setting. Remedial options were considered. In light of confined site space and availability of materials, crushed compacted rock fill was considered the best option for replacement of the soft fill. Topsoil [150mm] was used to cover the rockfill and promote vegetation growth. The advantages of the rockfill over compacted cohesive fill include ease of construction, performance and suitability. Effective drainage including in-slope and contour channel drainage were designed to prevent build-up of pore water pressures in the slope beneath topsoil. Construction sequence including excavation and preparation of temporary cut, installation of drainage layer, deposition and compaction of rockfill material in layers, deposition and seeding of the topsoil layer, construction of permanent surface drainage system and maintenance access was also designed.

RÉSUMÉ

Une stratégie de restauration a été conçue pour des pentes marginalement stables comprenant 5m de remplissage cohésif dans une zone résidentielle adjacente à une vallée. Le tassement excessif du sol autour d'une station de traitement des eaux usées et des fissures de tension a proximité d'une zone résidentielle proche de Glasgow a conduit au possible éclatement et lessivage des fines particules du sol. Une étude de Bureau et des examens d'échantillons du sol ont été menés afin de comprendre l'histoire du site et l'état géologique du site. Des stratégies de restauration ont été examinées. En considérant la taille du domaine et la disponibilité locale des matériaux, le remplissage par roche concassée a été considéré comme la meilleure option au remplacement du remplissage mou. La terre [150mm] a été utilisée pour couvrir l'enrochement et promouvoir la croissance de la végétation. Les avantages de l'enrochement par rapport au remplissage par sol cohésif compacté sont sa facilité de construction, ses performance et aptitudes au service. Un drainage efficace comprenant des voies internes à la pente et sur les contours ont été conçues pour empêcher l'accumulation de la pression de pore dans la pente en profondeur. Les séquences de la construction, comprenant l'excavation et la préparation des parois temporaires, l'installation des couches de drainages, le dépôt et la compaction du matériau d'enrochement en couches, le dépôt et l'ensemencement de la couche de terre arable, la construction du système de drainage permanent et l'accès d'entretien ont aussi été développés.

Keywords: rockfill, slope stability, stabilisation, remediation, shear strength, drainage, eco-engineering.

1 INTRODUCTION

Background: In July 2007, Jacobs UK Ltd. [now Jacobs Engineering UK Ltd] were appointed by George Leslie Ltd. acting on behalf of the ultimate client Scottish Water, to design mitigation of the effects of excessive ground movement adjacent to a sewage pumping station located in the Glen Noble residential estate in Cleland, North Lanarkshire, (*Figure* 1).

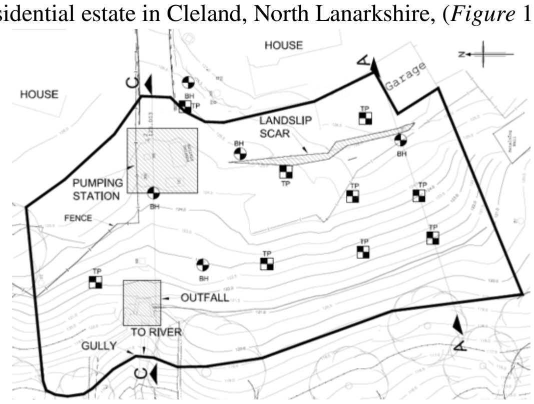

Figure 1. Site plan with marked areas of excessive settlement (shaded regions) and GI locations (BH-borehole, TP-trial pit)

The pumping station comprising a wet well, control chamber and valve chamber, is situated between two residential properties (F*igure 1*). The site boundary includes land owned by the local council, as well as land belonging to the individual owners of the two adjacent properties.

The part of residential development where the Glen Noble SPS is located was completed in 2000, when the SPS was presumably installed. Available records showed that the SPS was fully functional until noticeable ground settlement around the pumping station became evident in February 2005. On the basis of the available records and photographs, the subsidence around the SPS in 2005 is estimated to have ranged between 0.10 m and 0.60 m. The ground settlement around the SPS appeared to have increased in magnitude to 0.6 m – 0.8 m by the end of 2007, when the works described in this study began (*Figure 2a*).

In addition to this, during the same inspection in 2005 a tension crack (landslip backscar) became evident around 10 m to the south of the pumping station, in the garden of one of the properties adjacent to the pumping station (*Figure 2b*). This scar, visible over a 10.0 m length of the slope crest, ran from north to south, approximately 7.0m from and parallel to the western wall of one of the residential properties. The settlement

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at the scar increased from 0.1 m- 0.2 m in 2005 to 0.4 m – 0.6 m in 2007.

Figure 2. Magnitude of settlement around the pumping station and in the garden of the adjacent house .

George Leslie Ltd were employed by Scottish Water to help with reinstatement of the subsided pumping station in July 2007. During these works, a displaced pipe joint and a burst pipe connecting the sewage network to the SPS was reported and measures were taken to mitigate the damage arising from this fault. These measures included re-direction of the sewage water to another pumping station and reinstatement of the atmospheric waste water collection and disposal system bypassing the pumping station. At the time the investigative works on the site begun, the pumping station was functioning only for the domestic sewage water collected from the adjacent two properties.

Before any mitigation strategy could be devised for the site, an investigation of the site history and background in pursuit of a possible cause of the extensive settlements together with ground investigations were carried out.

Site setting: Initial survey showed that the site is located on a relatively level ground at approximately 121.0 m aOD (Figure 1). Approximately 10 m west of the wet well, the terrain slopes westwards towards the Tillan Burn river at approximately 30º. An outfall structure discharging the overflow from the pumping station was recorded on the survey. The soil around and underneath the outfall was heavily eroded, possibly as a consequence of washout and soil erosion due to underground and overland flow, and the stability of the outflow structure was compromised. The water discharging from the outfall had incised an approximately 2.0 m deep and 10.0 m wide gully into the slope. The slope was vegetated with dominant mature and senescent trees (*Fraxinus Spp, Betula Spp.*) and understory vegetation in form of grasses and coppice. No surface water drainage in form of gullies or channels was present on the site.

Site history: Available historical OS maps indicated that the site was developed only recently (2000). Formerly, the site was part of the Knownoble estate with the Knownoble House located around 200 m south-west of the site until 1960. Cleland and Morningside mineral railway-line is shown to pass approximately 250 m north-east of the site, suggesting possible mining activities took place in the area at the time. Mining pits and abandoned shafts marked on the historical maps confirm that the area has been extensively mined.

No records of previous topographic or geotechnical surveys could be identified with the original residential site developer (no longer active), Scottish Water, or the North Lanarkshire Council Planning Department.

2 GROUND INVESTIGATIONS

In absence of any historical GI records and to obtain information relevant for the design of the remedial works, a topographic survey and intrusive ground investigations comprising 5 terrier boreholes and 9 trial pits were carried out on the site *(Figure 1*).

The GI revealed the site to be underlain by very soft and soft and loose silty and clayey fill, with an enhanced liquefaction potential. The fill thickness increased westwards towards the burn from 1.90 m adjacent to one of the houses to 4.60 m close to the outfall structure. Standard Penetration Testing undertaken in this stratum showed values of N_{SPT} ranging from 2 to 13 with a typical value of 4.

This stratum is underlain by a firm becoming stiff glacial clay with bands of fine to coarse sand with measured SPTN values increasing with depth from 5 to 43. These findings confirmed published geological information indicating glacial till (boulder clay) of up to 5 m in thickness.

Sandstone bedrock, inferred from the recovered gravel sized fragments, was presumed to underlie the glacial clay at depths ranging from 2.5 to 3.5 m below ground at the east of the site, dipping at an unknown angle towards the burn and visible as an outcrop above the river level. This compares well with published geology shown to comprise a cyclical sequence of sandstones, siltstones, mudstones and seatrocks, with several economic coal seams and locally worked seams of ironstone (Middle Coal Measures of Carboniferous age).

The installed standpipe piezometers did not indicate any presence of groundwater during the monitoring period of 1 month. However, it was considered prudent to include ground water levels 0.5m above bedrock in the stability analysis to allow for seasonal fluctuations, water presence due to burst utilities, flooding or overflowing runoff from upslope caused by blocked surface or road drainage.

Existing slope stability: Based on the in-situ (SPT) and laboratory (PSD, Atterberg limits, shear, triaxial) tests on soil samples from the site, the stability of the existing slope was assessed using the soil model and parameters shown in Table 1.

Table 1. Soil model and adopted design soil properties.

Stratum	Description	N_{SPT}	c_u [kPa]	c' [kPa]	ϕ'[°]	γ [kN/m^3]
Made ground (fill)	Very soft and soft sandy CLAY	2-13 (4)	20	0	28	18
Glacial clay	Firm becoming stiff CLAY with bands of sand	5 – 43 (20)	50	0	32	19
Bedrock	Sandstone	50+	-	-	40	22

Limit equilibrium Methods (LEM) were used for slope stability analysis. Bishop and Morgenstern-Price methods for assessment of minimum slope factor of safety (FS) were used to satisfy both force and moment equilibrium. Critical slope cross-sections through the pumping station and perpendicular to the landslip scar (*Figure 2*) had minimum factors of safety of 0.97 and 1.08, respectively, when analysed using the Bishop method and, thus, the existing slope was considered to be only marginally stable.

3 DESIGN

To improve the slope stability and to prevent future disturbances to the residents and Pumping station, several design options were considered. Since any form of retention structure was discarded due to inaccessible terrain and site boundaries, and in-situ reinforcement was not considered suitable in soft loose fill, excavation of the fill and replacement with engineered fill was considered necessary. Taking into account the experience of the client with similar projects, as well as the availability of material locally, it was decided that crushed rock fill should be used as a replacement material.

Options concerning the amount of existing fill to leave in place and residual risk were discussed with the ultimate client. It was recommended by Jacobs and agreed that the maximum possible excavation depth to remove all the existing fill should be the final design in order to minimise the possibility of future stability problems and claims from the adjacent residential properties. The surface area of the slope to be remediated was approximately 450 m^2.

Special care was taken during the design process to allow for effective in-slope drainage in order to minimise the build-up of pore water pressures in the slope and possibly cause future instability. To this effect, 0.5 m thick granular filter layer appropriate for this grading of the rockfill (Class 6A material, grading 20-50 mm) underlining the engineered fill was designed (*Figure 3*). This filter layer both drained any high or perched water from the natural in-situ Glacial Till deposits and any surface seepage passing through the rockfill.

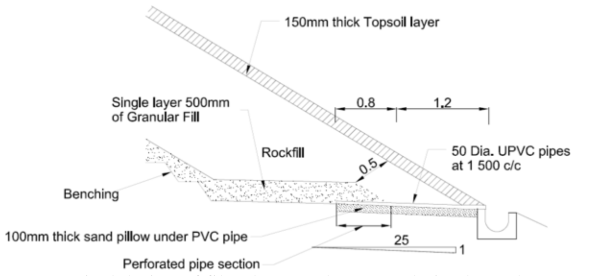

Figure 3. Typical design of filter layer and contour drain channel.

To further control infiltration into the slope, 150 mm thick topsoil layer was adopted in the design. A smooth interface between the rockfill and topsoil was avoided by mixing the top 100 mm of rockfill with the topsoil and adding 3% cement in the mix. It was considered that this proportion of cement will not impede root growth and provide extra topsoil stability until the plants have propagated. The cement stabilised topsoil strengthens the soil and helps to prevent local micro-slips within the topsoil layer.

(a)

(b)

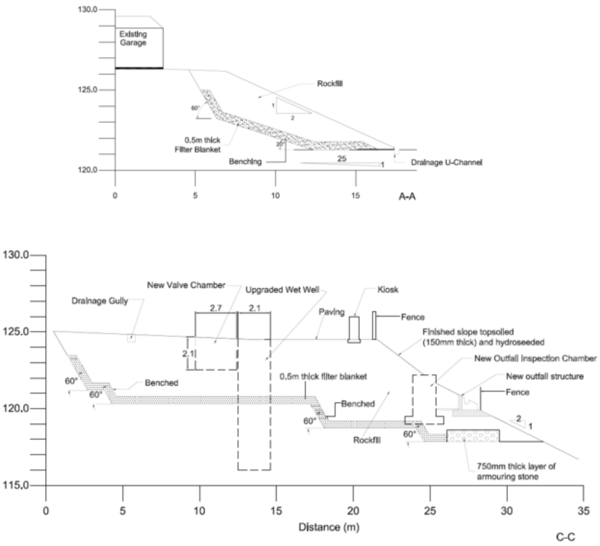

Figure 4. Magnitude of excavation and design of rockfill slope below the landslip scar (a) and around the SPS (b).

Using the Slope Decision Support System (Mickovski and van Beek 2006), eco-engineering techniques including hydroseeding and planting of native species were designed to complement the engineering works. The combination of hydroseeding and planting was designed to protect the slope against erosion and washout of topsoil as well as to provide extra structural toe support. Hydroseeding with grass mix comprising fescue (*Festuca rubra rubra, Festuca longifolia*) ryegrass (*Lolium perenne*), bentgrass (*Agrostis capillaries*), and clover (*Trifolium repens*) was designed to provide protection to the topsoil layer against washout and erosion. Planting of young cuttings of ash and birch on the sides of the incised gully and below the remediated portion of the slope was designed to provide support to the gully slopes in terms of soil arching around the stems, similar to the one observed with the mature trees present on the portion of the slope unaffected by failures, and to decrease the soil moisture and thus the build-up of pore pressures in the intact portion of the slope.

From eco-engineering practice reported in the literature (Norris et al. 2008), it can be considered that upon establishment of vegetation cover, at least 50% of the rainwater becomes runoff. Additionally, roots penetrating the topsoil and permeating rockfill will act as anchors for the topsoil layer against erosion and slips (Norris et al. 2008). In light of the above, it was considered unnecessary to produce method specification for topsoil compaction.

Slope stability was assessed for the designed rockfill slope using strength parameters for the rockfill of c'=0 kPa and ϕ'=40° which are on the lower bound of the typical ranges reported (Barton 1981, GEO 1984) for this type of material (grading 100-150mm, γ=20 kN/m^3). LEM analysis showed that the FS for the rockfill slope ranged between 1.43 (section through the existing landslip scar, A-A on *Figure 1*) and 1.49 (section through the PS, C-C on *Figure 1*).

4 CONSTRUCTION

The works entailed excavation of the soft fill, placing of a filter layer, and compaction of the rock in layers, in accordance with the standard Specification for Highway Works (The Highways Agency, 2009) and Geotechnical Manual for Slopes (GEO, 1984). The site was divided into three adjacent sectors running parallel to the slope and each sector, starting with the southernmost, was filled before the next one was excavated.

The construction sequence included:

- Site clearance,
- Initial survey and setting out of the slope,
- Setting out of temporary slope profile,
- Excavation and preparation of the temporary cut including benching and removal of soft spots,
- Delivering the rockfill and deposition of excavated material off site,
- Installation of perforated polyethylene pipe on a blinding layer,
- Deposition and compaction of the granular filter material on the benched excavated surface,
- Deposition and compaction of the rockfill material in layers,
- Construction of permanent surface drainage system and maintenance access,
- Deposit topsoil layer,
- Hydroseeding and planting.

During construction, special attention was paid on the correct excavation angles for the back- and the side-cut, to ensure maximum excavated soft material at safe back-cut angles (*Figure 4*). All excavated slopes were benched as recommended by the Highways Agency (2007) and GEO (1984). The total excavated volume was approximately 1800 m^3.

After excavation to the base line, a 100 mm thick sand layer was laid and the perforated PVC pipes were laid on top of the sand (*Figure 5*). The purpose of this layer was to prevent migration of fines from the clay base and potentially blocking the drainage pipes. Granular filter layer was then laid and lightly compacted above and around the pipes, before placement of the layers of rockfill and compaction (*Figure 6*) in accordance with Specification for Highway Works (The Highways Agency 2009).

Due to the variability of the fill thickness, depth to in-situ till and/or depth to bedrock throughout the site, the thickness of compacted rockfill ranged from 2.0 m to 5.5 m, and was greatest in the area adjacent to the PS (*Figure 4*).

Figure 5. Laying out of the perforated drainage pipes and the filter layer.

Figure 6. Compaction of the rockfill in layers.

On-slope drainage was provided via a contour U-channel drain made of 1.0m long concrete sections running along the toe of the remediated slope and discharging into the new outfall structure (*Figure 3; Figure 7*). Permanent surface drainage in form of a new gully channel drain was installed on crest and above SPS to prevent surface water from entering the slope.

Figure 7. Completed vegetated slope with contour channel drain at the toe.

In the process, the valve chamber, the inspection chamber, the outfall structure, the pipe network, and the pumping station installations were replaced with new ones complying with the current standards. The wet well was not replaced as it was considered to be founded at or just above bedrock and I had specifications that comply with the standards.

5 DISCUSSION

Two possible causes of the excessive settlement around the SPS were identified during the investigation. Site geology and historical records suggested mining as a possible cause. An investigation of the available mining records obtained from The Coal Authority showed mining activity adjacent to the site. However, this mining was at depth and would have resulted in different form of settlements. A more plausible explanation for the settlement was leakage of the water pipes and seepage through the fill materials, softening and reducing shear strength, washing out fine particles and promoting settlement. This was corroborated by the Contractor's reports of displaced and broken pipes at approximately 4.0 m bgl adjacent to the PS several months prior to the commencement of the restoration works.

A decisive factor in opting for granular fill for the failed slope, apart form the advantages in draining and adaptability to any future minor differential settlements, was the experience of the Contractor with this type of earthworks. As rockfill slopes are not common in Scotland, close on-site supervision had to be provided during the works. Cohesive fill would have required a greater level of in situ testing and re-use suitability determina- tion, and would have resulted in a longer construction period as well as site stockpiling, segregation, and protection difficulties.

Two major construction problems were the lack of stockpiling areas and the sourcing of sufficient acceptable rockfill material. Due to limited space and accessibility on site, it was important to ensure constant supply of fill material in the same time with organised disposal of the excavated soft material off-site.

6 CONCLUSIONS

Compacted rockfill was used to stabilise a failed fill slope around and adjacent to a pumping station in a residential area south of Glasgow, Scotland. It was considered that the cause for the failed slope was connected to washout due to burst utilities. The rockfill provided advantages over the option of re-use of the existing cohesive fill such as faster, easier and safer construction. The filter layers and drainage pipes were designed remove any water entering the slope. Hydroseeding and planting has proved very successful as shown on *Figure 7*.

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