Geo-Resilience 2023 Conference, Cardiff, Wales
D.G. Toll & M.G. Winter (Eds)
British Geotechnical Association, London. 2024
https://doi.org/10.53243/Geo-Resilience-2023-6-3

The Management, Licensing and Permitting of Groundwater Control for the Construction of a Box Culvert during a Four-day Railway Blockade at Littleborough, Rochdale

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Abstract

There have been several significant flooding events in Littleborough and Rochdale over the past 20 years, with the frequency of these events increasing as a result of climate change. To mitigate against the risk of flooding, the Environment Agency commissioned the construction of two large storage reservoirs in Gale, Littleborough, to collect and store river water during storm events. To divert the river water from Greenvale Brook, a tributary of the River Roch, to one of the storage reservoirs, a storm culvert was constructed beneath the adjacent Calder Valley Railway Line. The culvert construction required a four-day railway blockade during which the tracks were removed, the ground excavated, the foundation laid, the culvert constructed, and the railway line reinstated. Following the site investigation works, it was identified that groundwater posed a major risk to the temporary construction works, with the risk of groundwater flooding, ground destabilisation and heave, together with uplift failure, all identified as geohazards. To ensure that the ground at the site did not destabilise and liquefy during the excavation process, a robust and resilient groundwater control system was designed and constructed to maintain both the water table and artesian head in the underlying soil deposits to a level below the excavation formation elevation in advance of the blockade. The groundwater management required careful planning in the lead up to the railway blockade, which involved obtaining a groundwater abstraction licence and discharge permit from the EA, undertaking test pumping works and associated analysis, undertaking settlement calculations, and the implementation of a comprehensive groundwater and settlement monitoring plan. Despite the challenges posed by the groundwater at the site, the implementation of a robust groundwater control system helped lead to a successful project outcome where the culvert was constructed within the timescale of the four-day blockade, and the railway line was back operational within the planned schedule.

Keywords: Geohazard, Flood Risk Management, Ground Excavation, Groundwater Control System.

1. Introduction

In many parts of the world, flooding is expected to increase as a result of climate change. Disastrous flood events have threatened the vast majority of historical communities developed around rivers in the UK, with railway lines being crucial to connecting them (Dieco, Barbosa and Pregnolato, 2022). The flood risks, causes and consequences recently have regained public awareness, with Local Authorities and the Environmental Agencies often playing key roles in the governance arrangements for flood risk management (Garvey and Paavola, 2022).

Rochdale and Littleborough are communities in the Greater Manchester which are at risk of significant flooding events, with several such events occurring in the past 20 years (Environment Agency, 2009). As a consequence, the River Roch, Rochdale and Littleborough Flood Risk Management project has been set up in partnership between the Environment Agency (EA) and Rochdale Borough Council to improve infrastructure necessary to reduce the risk of flooding in the future. Part of the scheme involves the construction of two large attenuation reservoirs in Gale, Littleborough that collect and store river water from the River Roch and nearby tributaries during storm events. For river water to reach the attenuation lagoon on the west side of the railway line, the construction of a storm culvert was required beneath the Network Rail Calder Valley Railway Line.

The Calder Valley Railway Line is a busy line, with passenger and freight trains traveling between Manchester and Leeds, passing at least every 15 minutes. The culvert construction required a 4-day rail blockade during which the track was removed, ground excavated, culvert installed and the railway line reinstated. It appeared that due to the strict 4-day blockade for the completion of the main works, there was no time available for design modifications once the construction works commenced. Hence, a robust and resilient groundwater control system was required to ensure that the hydraulic head in underlying alluvium (clay, sand, gravel) and buried glacial channel (sand and gravel) was maintained below the excavation level in advance of and during the blockade works.

2. Project Overview

The flood overflow channel comprises a box culvert which is designed to connect two storage reservoirs located on either side of the railway line in Gale, Littleborough. The storage reservoirs are designed to store large volumes of river water in the event of a storm event, therefore reducing the large volumes of river water flowing downstream in a storm event and causing flooding.

Because the box culvert is required to pass beneath the railway line, Network Rail have responsibility for undertaking the construction works. Network Rail appointed its framework contractor J. Murphy & Sons and their designers Arcadis to design and build the flood overflow channel. The design included the construction of a 45m long precast concrete box culvert beneath the railway line.

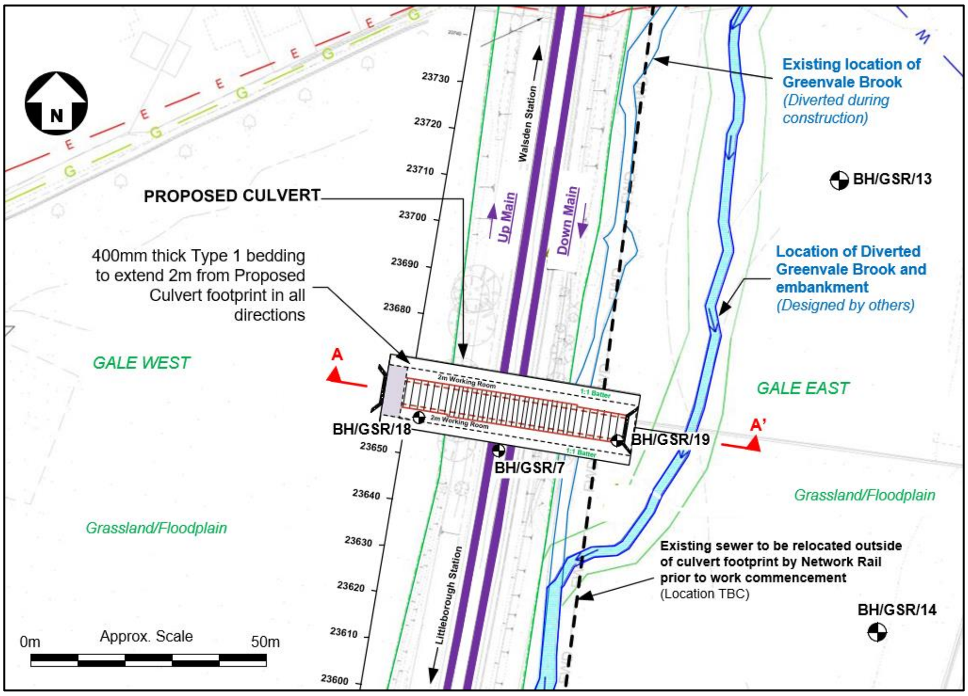

Figure 1: Site plan showing location of the box culvert in relation to the Network Rail Calder Valley Railway Line and Greenvale Brook.

3. Identification of Geohazards

The construction site lies within the centre of the upper Roch Valley, which was formed during the last ice age (Pearson *et al.*, 1985). The River Roch, together with a smaller tributary named Greenvale Brook, flow through the valley. Figure 1 depicts the location of the Greenvale Brook relative to the box culvert. The River Roch is located c. 100m west of the box culvert. The geology at the site has been heavily influenced by the past ice age, with a thick buried glacial channel encountered at a depth greater than 4.5m below ground level. Above this channel lies alluvium which was deposited by the meandering course of the River Roch, together with tributaries that previously flowed through the valley. The geology at the site is summarised as follows:

- **Made Ground/Topsoil:** On both sides of the railway embankment, topsoil is encountered in the upper half metre of soil.
- **Alluvium:** Present on both sides of the railway embankment, it consists of soft to firm silty **CLAY**, but also contains layers of silt, sand, gravel and peat. The alluvium varies between 4.0m and 4.5m thick across the area of the box culvert.
- **Buried Glacial Channel:** Beneath the alluvium is a buried glacial channel which consists of **SAND** and **GRAVEL** with occasional **CLAY** layers. The thickness of the sand and gravel is 19.3m in the closest borehole to the proposed culvert.
- **Bedrock:** Beneath the glacial channel lies the Lower Pennine Coal Measures Formation, which consists of **SANDSTONE** and **MUDSTONE.**

Groundwater monitoring took place during site investigation works in the lead up to the project. In the alluvial deposits, the phreatic surface (water table) was measured between 0m and 1m below ground level.

In the underlying buried glacial channel deposits, the groundwater level was measured as flowing artesian (natural piezometric head above ground level), with a head up to +0.3m above ground level. This high head in the confined underlying glacial channel deposits indicates a vertical upward groundwater flow direction.

This upward groundwater flow direction can be observed at the southeast of the site, where groundwater is observed seeping upwards to the ground surface via a spring that flows into Greenvale Brook. As a result of this upwards groundwater flow direction, the site has always resulted in boggy ground adjacent to the railway line.

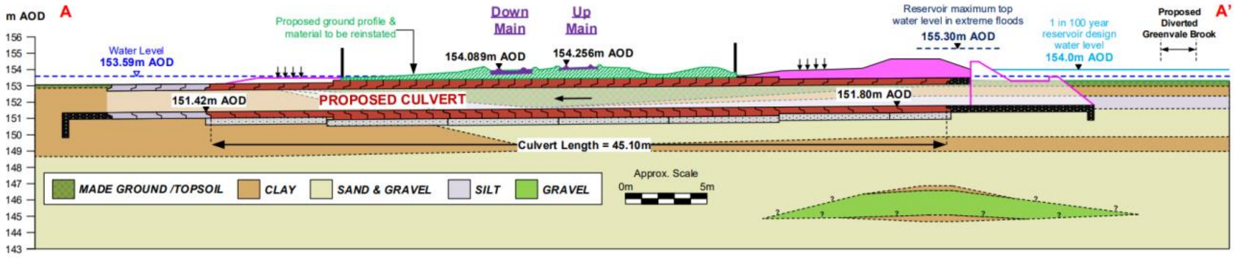

Figure 2: Conceptual model drawing showing the geology, groundwater level and culvert construction details.

The artesian groundwater conditions and highly permeable ground at the site combine to form clear geohazards that pose a significant risk to the safe implementation of the construction works. Three significant geohazards identified were (i) groundwater flooding caused by shallow perched groundwater in the alluvium (ii) soil destabilisation caused by high porewater pressure relative to the total stress, which results from the ingress of groundwater into the excavation from both below and from the sides of the excavation, and (iii) uplift failure of the clay layer at the base of the alluvium caused by the artesian groundwater pressure in the underlying buried glacial channel. The following sections detail how the above geohazards posed a risk to the construction works.

3.1 Groundwater Flooding

Groundwater flooding is caused by the ingress of groundwater into the excavation from the base and sides. It can occur in a variety of geological settings, including valleys in areas underlain by permeable rocks, and in river valleys with thick deposits of alluvium and river gravels.

In the context of this site, groundwater flooding becomes a risk when the groundwater level in the upper perched alluvium deposits is above the proposed excavation level. With the initial groundwater level measured between 0m and 1m below ground level, the groundwater level is well above the excavation formation level, which varies between 2m and 3m below ground level. If the ground was excavated to the excavation formation level without any dewatering measures in place, then the excavation would have become flooded from groundwater ingress, making the construction works impossible without groundwater removal.

3.2 Soil Destabilisation from High Porewater Pressure

When the porewater pressure within the pore space of a soil structure is greater than the total stress acting on the soil structure, the effective stress (total stress minus porewater pressure) becomes negative. Under such condition, a granular soil such as sand or gravel loses all strength, the soil destabilises, and failure occurs. Such failure is sometimes called Hydraulic Heave (British Standards Institution, 2004) and can be observed in many forms. This can be observed as "soil boiling", as the bubbling groundwater ingress within the formation looks like water is boiling up at the formation surface. Also observed can be the progressive failure of the soil slopes as groundwater seeping into the excavation through the battered sloping slides reduces the shear strength. Furthermore, even with the hydraulic head reduced to close to the excavation formation, vibration of the soil from moving, or even stationary mechanical plant, can be sufficient to liquefy the ground, with the plant sinking into the soil.

With the natural groundwater table and artesian head being above the formation level, this site is at risk from extreme soil destabilisation. To mitigate this risk, a robust groundwater control system was required.

3.3 Uplift Failure

As defined in Eurocode 7, failure by uplift (buoyancy) occurs when the pore-water pressure under a structure (including a low permeability ground layer) becomes larger than the mean overburden weight.

In this case, the risk of uplift failure is due to high artesian groundwater pressures acting on the underside of low permeability clay layers at the base of the alluvium deposits. When the soil is excavated, the reduced overburden decreases the total stress acting downward on the clay layer. This results in the downward stabilising total stress becoming smaller than the upward pore water pressure, so enabling the pore water pressure to lift and shear the clay layer causing failure of the underlying clay layer and further destabilisation of the excavation formation.

To mitigate the risk of groundwater flooding, ground destabilisation and uplift failure, a groundwater control dewatering system is required, that must be designed to sufficiently lower the groundwater artesian head from the underlying buried glacial channel, (see section 4.3).

4. Mitigation of Geohazards during the Temporary Works

To mitigate against the risk of the geohazards identified in the previous section, OGI was commissioned by JMS to develop a plan of works for the groundwater management in the lead up to the railway blockage. Due to the pre-planned 4-day railway blockage that was scheduled for the end of October 2021, the mitigation measures had to be robust and resilient to ensure that not only the design was complete and approved by JMS and Network Rail, but also all licences and permits were in place.

The groundwater management plan of works included the following wide range of activities (i) test pumping design, testing and analysis (ii) EA permitting to obtain an abstraction licence and discharge permit (ii) dewatering system design, settlement calculations, and (iv) groundwater monitoring during the construction works. The above sequence of works is summarised in the following sub-sections.

4.1 Test Pumping Works

Undertaking test pumping is critical to understanding the hydrogeological properties of the aquifers beneath the site, and for discussions with the Environment Agency when applying for a groundwater Abstraction Licence.

For a known water table/artesian head drawdown, it is the aquifer transmissivity that is the most important parameter to establish, as this enables the calculation of the total abstraction rate from the dewatering system.

Five separate tests were undertaken over four days, with a daily groundwater abstraction of less than 20m^3. A total of 12 No. test pumping wells were drilled, including 7 No wells to 8m bgl (W1 to W7), 3 monitoring wells to 4m bgl (named M1 to M3) and 2 No. recharge wells to 8m bgl (R1 & R2).

Test pumping was undertaken from wells on both sides of the railway line because the ground conditions vary across the site (see Figure 2). The results from the test pumping demonstrate highly transmissive soil deposits that would indicate required abstraction rates within the range of 20 to 40 Lit/s during the dewatering works.

Figure 3 presents the groundwater drawdown vs distance Jacob analysis for the test undertaken in W6. The results from the test pumping were critical to OGI's work that followed, including discussions with the EA and the detailed groundwater control system design.

4.2 Environment Agency Permitting

Groundwater abstraction for temporary dewatering became a licensable activity in 2018. Construction sites that plan to abstract more than 20m^3/day of groundwater over a period of more than 6 months, must have an abstraction licence from the Environment Agency in place. In addition, if the abstracted groundwater is to be discharged to a surface water feature such as a river or stream, then a discharge permit must also be in place.

As the ground beneath the site comprise a sand and gravel aquifer, it was clear from the start of the project that an abstraction licence and discharge permit would be required from the EA to legally allow dewatering to be implemented on the project. OGI liaised with the EA throughout the project on behalf of JMS.

This responsibility involved submitting a pre-application advice request at the beginning of the project, followed by preparation of the abstraction licence and discharge permit applications. Using the results from the test pumping, then preparing both a conceptual and mathematical model of the site, OGI calculated the likely abstraction and discharge rates for the dewatering system and used this to specify a maximum abstraction and discharge rate for the dewatering works. OGI prepared all the forms and supporting information and submitted these to the EA on behalf of JMS. Following the submission of the applications, OGI continued to liaise with the

EA throughout the determination period until the abstraction licence and discharge permit were issued well in advance of the blockade.

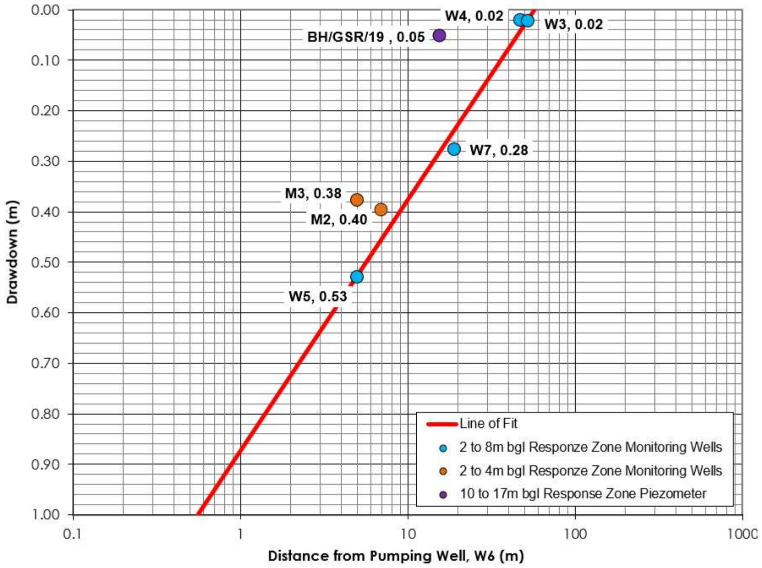

Figure 3: Drawdown vs distance Jacob analysis for the pumping test undertaken in W6.

4.3 Dewatering System Design

Following the test pumping works, OGI designed a groundwater control system with the objective of lowering the groundwater level and artesian pressure to enable construction of the box culvert in dry and stable ground conditions, thereby minimising the risk of the geohazards identified in Section 3.

With groundwater head at/above ground surface, the groundwater control dewatering system had to meet the following primary objectives,

- Lower the groundwater level in the upper 4.0m of ground i.e., the alluvium deposits, to minimise groundwater inflows entering the excavation during construction of the box culvert and causing groundwater flooding.
- Lower the artesian pore water pressure in the deeper buried glacial channel to prevent hydraulic heave failure during excavation and construction of the box culvert.
- To lower the groundwater level and artesian groundwater pressures in the two weeks prior to the 4-day railway blockade whilst the railway line remained active to traffic.

To achieve these primary objectives, the groundwater control system design comprised the following items:

- Active suction dewatering system with 59 No. drilled suction wells located around the perimeter of the excavation and outside the Network Railway boundary fence.
- 7 No. monitoring wells to assess both the performance of the system and the groundwater levels beneath the live railway line by measuring the groundwater drawdown across the site.
- 2 No. recharge wells to enable discharge to ground to satisfy the EA abstraction licence conditions.
- Filtered sump pumping to control any residual perched water ingress and rainfall.
- An Inspection, Testing and Monitoring (ITM) Plan to be implemented during the dewatering works.

Figure 4 depicts the locations of the dewatering wells, monitoring wells and recharge wells at the site, together with the dewatering system set up including suction pumps and header pipe. Dewatering suction wells were strategically placed along the sides of the excavation batters and parallel to the railway line to ensure sufficient drawdown at the centre of the railway line where wells could not be placed.

4.4 Calculation of Ground Settlement along the railway embankment

The alluvium deposits at the site consist of a mix of soil types, including clays, silts, peats, sands and gravels. The site investigation works identified clay and silt soils within the top 4m of ground that had low strength, and which were highly compressible. As a result, the soils were identified at risk of ground settlement when the groundwater level was reduced as a consequence of the increased effective stress caused by the reduction of porewater pressure, which was the very purpose of groundwater control dewatering. This risk of potential ground settlement was raised with Network Rail, and as a result, this risk needed to be thoroughly investigated by undertaking calculations of settlement prior to the implementation of the dewatering works on site.

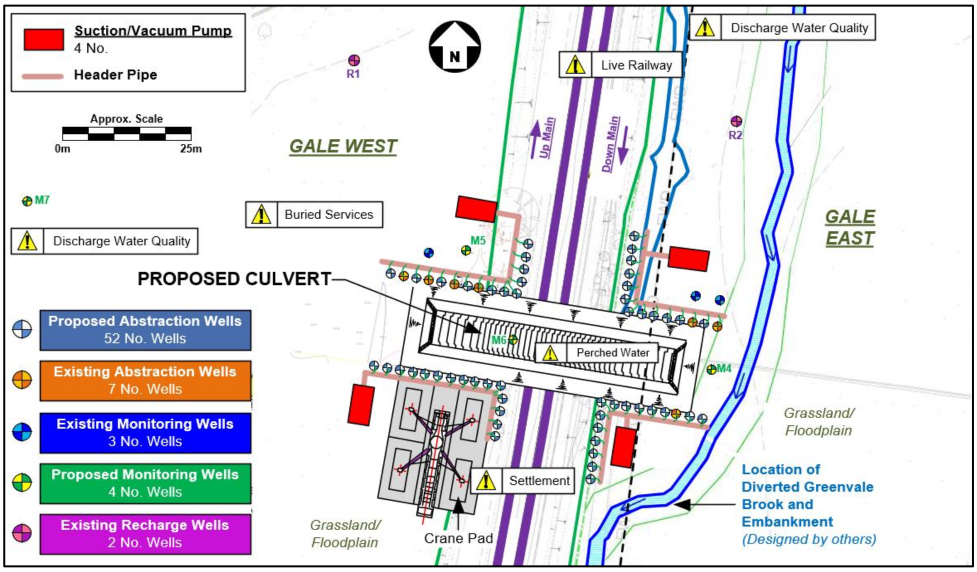

Figure 4: Site plan showing well locations and dewatering system pumping set up at the site.

OGI undertook modelling of the groundwater control system to simulate the predicted groundwater level beneath the railway embankment during dewatering (see Figure 5). This groundwater profile was then used as an input to the settlement calculations.

OGI undertook settlement calculations for a range of vertical ground compressibility values based on the results of laboratory oedometer tests, together with a range of modelled groundwater drawdown levels below possible historic low groundwater levels. The historic low groundwater level is the lowest groundwater level that has occurred in the soil in the past, and is therefore the point at which the soil begins to compress along the virgin consolidation line as effective stress increases. Because the historic low groundwater level is unknown, a sensitivity analysis of soil compressibility and drawdown below historic low groundwater level was undertaken. The results of this sensitivity analysis indicated possible ground settlements up to 30mm for the most compressible soils, and up to 6mm for the least compressible soils. This is demonstrated in Figure 6.

As a result of the findings, JMS implemented a thorough track monitoring plan that would monitor any movement in the railway embankment during the dewatering operation. A traffic light system was implemented, whereby the dewatering works would be halted if the railway embankment settled beyond the trigger levels.

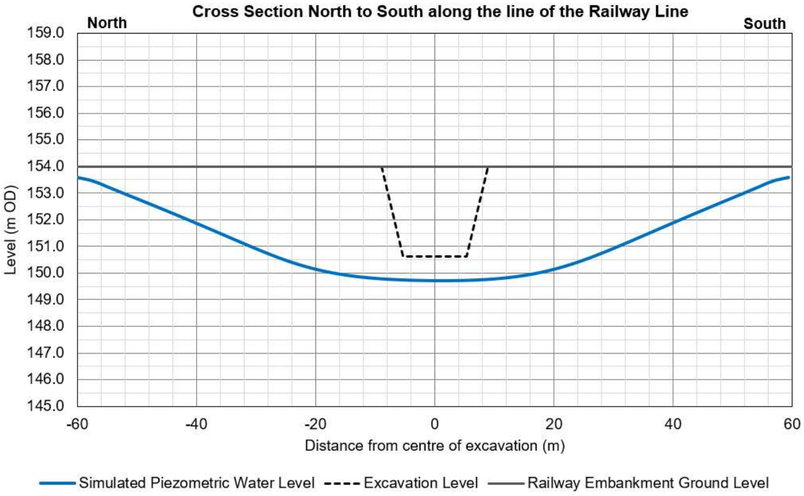

Figure 5: Cross section north to south along the line of the railway embankment showing the modelled piezometric groundwater head during the dewatering works.

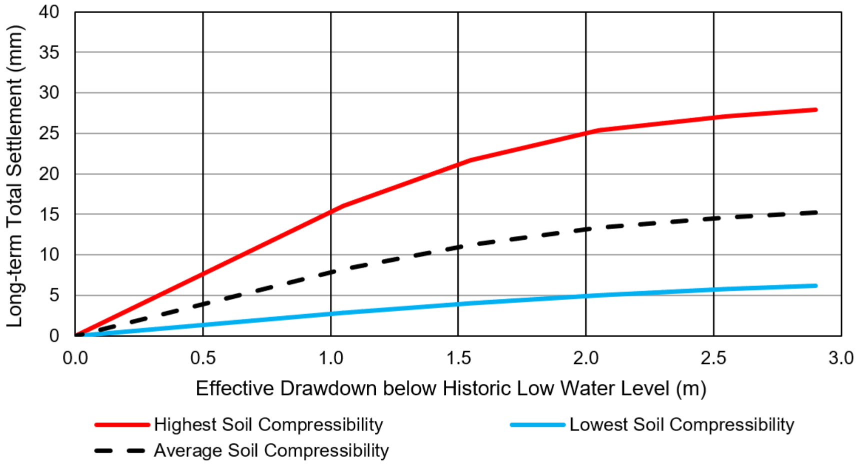

Figure 6: Calculated total settlement vs effective drawdown below historic groundwater level.

5. Implementation of Dewatering System on Site

In the four weeks leading up to the railway blockade, the wells for the dewatering system were drilled and installed by the specialist dewatering contractor. Prior to switching on the dewatering system, a phased approach to turning the system on was agreed between OGI and JMS to minimise differential settlement.

Wells on the south side of the railway were switched on first, with a one-hour period of groundwater monitoring undertaken prior to the northern group of wells being turning on. The groundwater level was reduced to 1.0m below the excavation level within two to three days of the pumps turned on. During this time, settlement monitoring of the railway embankment measured maximum settlements of 7mm. This was below the trigger levels set by the track monitoring plan, meaning the dewatering system could continue pumping.

Once the dewatering system had been operational for several days, a large trial pit was excavated to check the ground conditions. The ground was shown to be dry, which demonstrated that the groundwater dewatering system was working effectively, and the design objectives were being achieved. During the blockade, the dewatering system continued to work effectively, resulting in a dry and stable excavation environment for the construction works to proceed to the original schedule (Figure 7a). The box culvert was installed within the excavation, the ground backfilled (Figure 7b), and the railway was back operational as planned at the end of the four-day blockade (Figure 7c).

Figure 7: Photos of the construction works from left to right: (a) excavation in dry ground, (b) laying the foundation, and (c) the box culvert after the reinstatement of the railway line.

This operation demonstrates how detailed planning of the groundwater control during the project, combined with the clear identification of the geohazards caused by groundwater, led to the successful implementation of a robust and resilient groundwater control dewatering system, and a time critical construction project completed within the strict railway blockade period.

Two weeks after the railway blockade, the criticality of the groundwater control operation became observable when the dewatering system was switched off. Within only 24-hours, the water table rebounded to close to the original water level and all parties were able to see first-hand the importance of the groundwater control system in enabling the successful completion of the project. The flooded and saturated ground after the groundwater rebounded is depicted in Figure 8.

Figure 8: Photos of the box culvert after the dewatering system was turned off, from left to right: (a) Gale East (b) Gale West .

6. Conclusions

The construction of the box culvert in Littleborough was required to reduce the risk of flooding in Littleborough and Rochdale in Greater Manchester. The culvert construction required a railway blockade during which the track was removed, ground excavated, culvert installed, and the railway line reinstated within a four-day period. Following the site investigation works, the impact of groundwater on the temporary works was identified as a clear geohazard. Groundwater flooding and saturated soil destabilisation were identified as the most significant risks to the works. To mitigate against these risks, OGI developed a groundwater management plan which included undertaking test pumping design and analysis, dewatering system design, EA permitting, settlement calculations and the monitoring of the groundwater levels during the works. The robust and resilient approach to the groundwater management led to the implementation of a groundwater control dewatering system, with the construction of the box culvert successfully completed during the 4-day railway blockade.

Acknowledgements

The authors would like to thank the project team from the main works contractor J. Murphy & Sons Ltd, who worked collaboratively with OGI to help deliver the successful implementation of the groundwater management strategy during the project. We would also like to thank Alba Dewatering Services Ltd, who were the specialist dewatering contractor, for successfully implementing the dewatering system designed by OGI. Finally, we would like to acknowledge the various offices from the Environment Agency, who worked closely with OGI to advise and guide all parties through a complex water management operation. This enabled the required abstraction licence and discharge permit to be obtained within the time-critical programme

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