Application to the Institute of Materials, Minerals and Mining (IOM3)

For

Chartered Engineer via the Technical Report Route

DESIGN AND CONSTRUCTION OF URGENT PERMEATION GROUTING DURING CROSSRAIL TUNNELLING OPERATIONS.

David Bradley

Membership No. 483330
1 Executive Summary

Whilst tunnelling for Crossrail at the new Tottenham Court Road Station, the main contractor was constructing an adit which unfortunately breached the London Clays and encountered the River Terrace Deposits, with the potential for uncontrollable water inflow and tunnel collapse. An emergency grouting solution was sought in order to mitigate delay to the Project.

I was the Contracts Manager of the Joint Venture subcontractor already on site carrying out compensation grouting works. The main contractor turned to us to develop and implement a solution to the problem.

Following an options review, and under my lead, we designed and constructed a permeation grouting solution from an existing compensation grouting shaft adjacent to the treatment area. Permeation grouting can be used to solidify granular soils, by infilling the voids between grains, in order to prevent water flow and / or allow easier excavation of material.

I proposed the Observational Method be utilised to design, measure and mitigate the works otherwise extremely pessimistic and costly design assumptions would have to be made. In addition validation measures would be essential to provide confidence prior to restarting tunnelling. The use of 3-D modelling assisted in positioning of the validation test holes and I developed a modified constant head permeability test to further validate the design and confirm the success of the works.
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2 Introduction

Permeation grouting can be used to solidify granular soils, by infilling the voids between grains, in order to prevent water flow and / or allow easier excavation of material. The River Terrace Deposits (RTD) contains the upper (perched) water table in the London geological formations, sitting above the impermeable London Clay. It is regularly subject to localised permeation grouting to allow excavation of basements and for civil engineering applications.

Whilst tunnelling for Crossrail at the new Tottenham Court Road Station, the tunnelling contractor (BAM – Ferrovial – Keir, known as BFK JV) was tunnelling within the London Clays. One adit (referred to as VWW) ran at an incline between the platform tunnel and the ticket hall, breaching the safe cover of clay from the RTD, potentially resulting in uncontrollable water inflow and tunnel collapse. They had not planned and designed a solution for this and only had limited time before they would have to suspend tunnelling operations.

I was the Contracts Manager leading a £40m JV subcontract (Keller – BAM Ritchies JV, known as KBR JV) to provide compensation grouting to BFK. As geotechnical specialists and an existing delivery partner for the construction of the station, BFK turned to us to develop and implement a solution.

Following an options review, and under my lead, we designed and constructed a permeation grouting solution from an existing compensation grouting shaft adjacent to the treatment area (figure 1).
3 Main body

3.1 Feasibility study

I conducted an initial feasibility study to understand the ground treatment options available to provide sufficient strength and reduction in permeability to allow tunnelling activities to recommence. The source of information was from my own knowledge and experience, internal JV sources, online papers and supplier conversations e.g. British Drilling and Freezing. The findings of this study are presented in the table below as a series of pros and cons.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| Jet grouting     | • High confidence of creating a homogenous treated soil mass of 5-15n/mm².  
                  | • Internal JV capability.                                            | • Ground heave risk affecting surface structures, utilities and pressure on ticket hall.  
                  |                                                                  | • Large volumes (200m² area) of water / grout flush to treat.       |
|                  |                                                                  | • Complex design and application of methodology including test columns. |
|                  |                                                                  | • Expensive                                                            |
| Ground freezing  | • High confidence of creating a homogenous treated soil mass.       | • Extended periods of time to freeze mass of ground (~30 days in these conditions) |
|                  | • Will freeze both terrace gravels and into the clay to prevent strata interface issues. | • Extensive monitoring requirements.                                   |
|                  | • Can be conducted from in-tunnel or surface.                       | • Ground heave/settlement risk affecting surface structures, utilities and pressure on ticket hall from freeze / thaw. |
|                  |                                                                  | • Large carbon impact                                                   |
Can replace multiple ground improvement techniques (for different soils) where required (not required here).

- Groundwater velocities affect performance.
- No internal JV capability or experience in main contractors design team.
- Expensive

**Permeation grouting**
- Reasonable confidence of creating a homogenous treated soil mass.
- Can be conducted from in-tunnel or surface or from an existing grout shaft.
- Extensive internal JV capability.
- Shaft drilling rig still exists from previous compensation grouting tube installation.
- Shaft drilling avoids utilities.
- Limited risk of ground heave and area already under settlement monitoring.
- Existing compensation grouting equipment can be utilised and fast lead-in time.
- Relatively cost effective.

- Geometry from existing shaft creates very difficult drilling conditions and radial drilling creates wide spaced injection tubes at the distal end.
- Observation method of construction required as radial grout flow paths are unlikely. Extensive validation required before tunnelling can commence.

**Restricted tunnelling advancements i.e. pocket excavation**
- Extremely cost effective in comparison to ground treatment.

- Risk of water ingress / tunnel collapse remains considerable.

<table>
<thead>
<tr>
<th>Table 1: Comparison of treatment options</th>
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</table>

On completion of the feasibility study I considered that permeation grouting stood out as the only option to carry forward to the initial design phase, on the primary basis of in-house capability, timeliness, existing site equipment and lowest risk to structures, utilities and ticket hall walls. This was presented to BFK and their temporary support designers, Donaldson Associates (DAL) who supported this decision.

### 3.2 Design of permeation grouting

Due to the natural variability of soil structure, the behaviour and flow paths of injected grout can only be modelled theoretically, generally using uniform radial flow. In practice it will flow along the path of least resistance which is rarely truly radial and can therefore leave masses that are untreated. Furthermore, in this project the injection tubes – Tube-a-machetes or ‘TAM’s’ – are installed sub-horizontally thus gravity has the effect of skewing the flow vertically downwards.
Taking these into consideration, I proposed the Observational Method (Peck, 1969\(^1\) and CIRIA, 1999\(^2\)) be utilised to design, measure and mitigate the works otherwise extremely pessimistic and costly design assumptions would have to be made. In addition validation measures would be essential to provide confidence prior to restarting tunnelling. The following stages comprise the Observation Method.

<table>
<thead>
<tr>
<th>Observation Method. Peck, 1969</th>
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<tbody>
<tr>
<td>a</td>
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<td>b</td>
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<tr>
<td>c</td>
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<tr>
<td>d</td>
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<tr>
<td>e</td>
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<tr>
<td>f</td>
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<tr>
<td>g</td>
</tr>
<tr>
<td>h</td>
</tr>
</tbody>
</table>

Table 2: Observational Method by Pick, 1969

The geometry of the design was complicated, so I modelled in 3-dimensions the structures, stratigraphy, TAM tubes, injection ports and grout volumes with the following conclusions:

- The available space in the concrete shaft wall allowed 12 boreholes to be drilled in one layer. At the distal end this created a lateral spacing of 1.2m.

- Grout quantities to therefore be calculated on a diameter of 1.4m to allow overlap of grout ‘bulbs.’ \(r=0.7\text{m}\)

- To achieve a grouted mass 2m deep (vertically) would require 2 layers of boreholes. Given the variability in deviation for horizontal boreholes and to provide design confidence I included a middle layer.

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\(^{2}\) CIRIA (1999). The Observational Method in ground engineering: principles and applications
To provide further design confidence the spacing of the ports along each TAM was 0.33m rather than a more standard 0.5m port spacing, which also allowed for some port failure or blockage to occur. [port spacing = 0.33m]

- A void ratio of 25% to calculate grout volumes, which is a conservative view based on the ground investigation previously carried out in the locality of the adit. [void ratio = 25%]

The theoretical grout bulbs were calculated on the following formula:

$$V = \pi \cdot r^2 \cdot \text{port spacing} \cdot \text{void ratio} = m^3$$

$$V = \pi \cdot 0.7^2 \cdot 0.33 \cdot 0.25 \cdot 1000 = 127 \text{ litres}$$

To ensure that the grout bulbs intersected sufficiently without any voids, I modelled this in 3D inverting the data to find gaps. The design drawings including 3D model are included in Appendix I.

3.3 Grout Design

There are three primary options for grout type’s dependant on the penetrability of the soil:

- Ordinary Portland cement grout. Suspension of cement that has grain size D95=70-80 microns.

- Microfine cement grouts. Suspension of cement that has grain size D95= 6-30 microns.
Chemical grouts. Solution grouts falling into polyurethanes, silicates and acrylcs, in order of penetrability.

The below graph further illustrates the ground conditions where the various grout types are applicable.

![Grain size distribution from Dyckerhoff Mikrodur literature](image)

Where the soil Particle Size Distribution (PSD) curves show fine sands, with no or very little clay / silts then sodium silicate grouts prevail and are considered to be the least toxic. The River Terrace Deposits in London fit this profile as shown from the below summary of the GI conducted for Crossrail local to the VWW tunnel.

<table>
<thead>
<tr>
<th>Borehole ID</th>
<th>Clay / Silt</th>
<th>Sand</th>
<th>Gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4</td>
<td>1%</td>
<td>22%</td>
<td>77%</td>
</tr>
<tr>
<td>T4</td>
<td>0%</td>
<td>26%</td>
<td>69%</td>
</tr>
<tr>
<td>T18</td>
<td>6%</td>
<td>43%</td>
<td>51%</td>
</tr>
<tr>
<td>T18</td>
<td>0%</td>
<td>21%</td>
<td>78%</td>
</tr>
<tr>
<td>T18</td>
<td>0%</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>T19P</td>
<td>3%</td>
<td>47%</td>
<td>50%</td>
</tr>
<tr>
<td>T20</td>
<td>3%</td>
<td>31%</td>
<td>61%</td>
</tr>
<tr>
<td>T21R</td>
<td>2%</td>
<td>32%</td>
<td>66%</td>
</tr>
</tbody>
</table>

Table 3: Summary of GI PSD data in vicinity of VWW

Based on the manufacturers data sheet and the warm summer temperatures (sodium silicate grouts are extremely sensitive to heat) I developed the below grout mix and conducted a series of grout

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3 PQ Corporation, Industrial Chemicals Division, Bulletin 52-53
trials devised by me, and carried out by my Crossrail project team that validated the target 40-50 minute pot life.

<table>
<thead>
<tr>
<th>Permeation Grout Mix - material content:</th>
<th>Weight (kg)</th>
<th>Specific Gravity (g/cm³)</th>
<th>Volume (Litres)</th>
<th>Percentage of Mix Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Silicate</td>
<td>103.88</td>
<td>1.4</td>
<td>74.20</td>
<td>53</td>
</tr>
<tr>
<td>Hardener</td>
<td>7.63</td>
<td>1.09</td>
<td>7.00</td>
<td>5</td>
</tr>
<tr>
<td>Water</td>
<td>58.8</td>
<td>1.0</td>
<td>58.80</td>
<td>42</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>170.31</strong></td>
<td><strong>1.22</strong></td>
<td><strong>140.00</strong></td>
<td></td>
</tr>
</tbody>
</table>

3.4 Design Proposal
On completion of the above design work I programmed and priced the work and produced a fully costed proposal to BFK and DAL (Appendix II) which was accepted.

Commercial discussions ensued and due to the various technical, practical and risk-based reasons, I was not prepared for our JV to take on the design liability for these works and suggested that BFK’s existing design team, DAL, adopt the design. Ultimately we agreed this and that all three parties would work in in collaboration to progress the design and construction under the Observational Method.

DAL introduced a primary, secondary and tertiary grouting regime whereby every third port would be grouted first before a second and third pass on the other ports.

4 Construction
4.1 Drilling
Drilling progressed well and each TAM was surveyed with a non-magnetic deviation tool. It was found that deviation on the drill string was considerably greater than expected due to the variability of the stratigraphy. The upper layer deflected upwards above the target zone and the middle layer deflected downwards to converge with the lower layer. This effectively created a single very dense lower layer and an upper layer that was ‘too high.’ We also struck clay in several boreholes that
indicated clay was higher than expected closer to the shaft and then dropped into a bowl feature closer to the ticket hall. It was impossible to ‘steer’ bores into this bowl.

![Figure 4: Shaft drill rig mounted on swivel and scissor legs](image)

As part of the Observational Approach we evaluated the completed drilling pattern in 3D, figure 4, and concluded that 5 additional boreholes were required and could be squeezed into the shaft wall which was now extremely congested, figure 6. Two validation holes were also drilled that would not be grouted through until the final pass to assess changes in the injection pressures to make an assessment on the change in permeability due to the treatment.
Figure 5: As-built paths of boreholes

TCR1 Permeation Grouting - Hole layout

Figure 6: Shaft wall - borehole layout
4.2 Grouting
Grouting commenced utilising our computer controlled multi-pump ‘grout modules’ which provide real-time and data-logged pressure and flow data for each injection. We carried out grout batch testing to ensure the gel time stayed within the 40-50 minute target and to ensure each batch ‘hardened.’

5 Validation
Validation of the works was to be conducted through a number of ways:

1. Comparison of injection pressures between the primary, secondary and tertiary grout passes. It is expected that a higher pressure is required to maintain the same flow rate as the passes progress and the ground becomes less permeable.

2. Grouting of ‘virgin’ validation TAM’s on completion of the tertiary grout pass. Similar to method 1, pressure data is compared to the primary pass.

3. Probing through the crown of the VWW tunnel into the clay and grouted mass of granular material to assess the rate of groundwater flow that may still pass.

The primary method was to be the comparison of the three passes. Figures 8 and 9 show the injection pressures in Primary and Tertiary passes respectively. Comparing individual TAM’s between the graphs generally show’s a considerable increase in pressure indicating a decrease in
permeability. However, it was not convincing across the grouted mass, for example TAM 34 and 25 (both on the Eastern side of the treated mass) do not show an increase.

**Figure 8: Pressure required to inject on the primary grout pass in individual TAM's**

**Figure 9: Pressure required to inject on the tertiary grout pass in individual TAM's**
As the results were not conclusive from this comparison across the entirety of the mass, we required to prove the reduction in permeability numerically which would require permeability testing of the grouted mass compared to virgin ground. As the grout mass is ‘remote’ from the shaft and conventional boreholes cannot be drilled vertically from surface for conventional permeability testing I devised a method that could be undertaken.

Constant head permeability tests to BS EN ISO 22282 2012 require a constant head pressure and known length and diameter of “Test Section.” I mobilised a small drilling rig to drill out the end of the steel TAM pipe caps into the grouted mass by a set distance to create the test section.

![Image: Small drill rig for drilling through TAM tube end caps and forming test section.](image)

A header tank was connected via hose to an inflated packer at the distal end of the TAM pipe, see figure 12 for general arrangement. We could now perform a variation on the standard constant head tests within the grouted mass. Where the setup is considerably different from the British Standard, I assessed that the engineering principles had not changed and the same calculation could be used.
Figure 11: Permeability testing header tank with volumes marked

Figure 12: General arrangement of permeability testing apparatus
The formula for constant head test method is

\[ k = \frac{Q}{F \cdot h} \]

where
- \( Q \) is the steady state water flow rate;
- \( F \) is the shape factor according to ISO 22282-1;
- \( h \) is the hydraulic head of the test.

The chart in figure 13 shows the flow rate vs time achieved in the five boreholes tested.

![Flow Rate vs. Time](chart)

*Figure 13: Flow rate recorded within each TAM for permeability testing*

I then calculated the permeability of each test section using the formula above with results shown in table 4.

<table>
<thead>
<tr>
<th>TAM 31</th>
<th>TAM 34</th>
<th>TAM 28</th>
</tr>
</thead>
<tbody>
<tr>
<td>k (lower)</td>
<td>k (upper)</td>
<td>k (lower)</td>
</tr>
<tr>
<td>Permeability</td>
<td>1.39E-06</td>
<td>1.45E-06</td>
</tr>
</tbody>
</table>

*Table 4: Permeability test results within each TAM*
The probe hole from within the VWW tunnel was also completed and showed that there was no water flow from the gravels into the probe hole. With this combination of validation measures, DAL were satisfied that tunnelling may resume.

6 Discussion
The observational method allowed the design to be developed to have a satisfactorily high chance of success, however with a project as technically and geometrically challenging as this there would always be a requirement to review the information available and make engineering judgement to overcome problems encountered. I have not detailed all of the problems encountered, but there were considerably more issues that required myself and the rest of the design team to solve on a day to day basis.

7 Conclusion
The cost of failure in this project is life threatening in a large scale and we were unable to satisfy ourselves that the grouting had worked on a comparison basis with virgin ground. I then had to develop an innovative way of validating the works numerically.

When tunnelling recommenced we found that the silicate grout had not only penetrated the terrace gravels but had also found fissures into the clay as shown in figure 14.

![Image of London clay with Sodium Silicate grout](Figure 14: London clay with Sodium Silicate grout (white))
I certify that this Technical Report is all my own work.

Signed

I certify that I have read the Technical Report of David Bradley and confirm, to the best of my knowledge, it is their own work.

Signed
8  Appendix I – Design drawings.
Section A

1.2 x 0.33 x 1 grid spacing with injection volume to equal a radius of 0.7m, 25% void ratio.

\[
\text{Volume per sleeve} = \pi \times 0.7^2 \times 0.33 \times 25\% = 127
\]

Bulk volume = 168m^3 * 35\% = 59m^3

OUTLINE PROPOSAL SUBJECT TO BFK VALIDATION
Notes:
1. Showing permeation grouting block and theoretical grout spreads.
2. Injections treat entire grout zone except grey areas at extents.
3. Validation notes
4. V1 validates through grouting zone to ticket hall and side of treatment area.
5. V2 validates through grouting zone to ticket hall and directly over crown.
OUTLINE PROPOSAL SUBJECT TO DETAILED DESIGN

Notes:-
1. Base of permeation grouting zone 0.5m below Thames Gravels / London Clay interface.
2. TaM sleeve spacing at 330mm within target zone. Plain pipe out with target zone with the exception of 3 pipes which will remain ported over their full length for settlement mitigation and select top layer TaM's.
3. Steel TaM pipe in 1m lengths with rubber sleeves as per C300/410 compensation grouting works.
4. Drilling by cased water flush method. Drill hole planned depth = 200mm offset from D-Wall.
5. TaM sleeve grouted prior to casing withdrawal to maintain bore stability in RTD.
6. Sodium silicate grout injected at up to 8 bar with a flow rate at least 3 l/min.
7. All level and geotechnical data taken from "TCR VWW Predictive Model 190514" provided by BFK.
8. Temporary works for shaft segment and drilling platform (design and construction) by BFK.
This budget quotation is for an outline design and methodology to provide permeation grouting above TCR VWW excavation from TCR1 grout shaft using standard industry methods and experience. It has been agreed that this is subject to review upon acceptance of the treatment method and detailed design conducted.

**Design Proposal Brief**

To provide a permeation grouting block for approximately 10m along the axis of VWW tunnel from the Western Ticket Hall, targeting a volume of around 14m wide (double tunnel diameter) and 2m height, extending 0.5m below the advised River Terrace Deposits / London Clay interface. All works have to be conducted from the existing TCR1 grout shaft and surface compound.

Appendix 1 contains the “TCR VWW Predictive Ground Model” supplied by BFK to produce this outline design.

<table>
<thead>
<tr>
<th>Treatment Volume Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (along tunnel axis)</td>
</tr>
<tr>
<td>Width</td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td>Idealised Ground Volume</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Levels (as advised by BFK)</th>
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<tbody>
<tr>
<td>Water table</td>
</tr>
<tr>
<td>Top of London Clay</td>
</tr>
<tr>
<td>Top of excavation</td>
</tr>
<tr>
<td>Base of permeation grouting zone</td>
</tr>
</tbody>
</table>

The above levels and geometry provides 3 metres from the tunnel crown to top of treatment zone.

The number of holes passing through each shaft segment is not to be considered during this stage of design development and any additional temporary works including temporary works design to structurally support the shaft will be conducted by BFK.

**Design Proposal**

Although KC20 has been considered this proposal does not necessarily meet with that specification.

Due to the advised granular make-up of the River Terrace Deposits (as described in borehole log appendix 1 as Terrace Gravels) a chemical grout (sodium silicate) and hardener shall be used to increase penetrability and allow reasonable pumping rates while minimising heave. Please note that we would need to be provided with particle size distribution curves of the material encountered, so as to consider if the % silt content would negate our proposals.

A theoretical void ratio of 30% is taken to produce a theoretical total grout injection volume of 42m³.

A standard maximum TàM pipe spacing of 1.2m in plan and 1m in section, coupled with injection sleeves at 330mm centres provides sufficient port density to achieve an approximately homogenous treated volume. To achieve this spacing approximately 28 TàM pipes should be installed in 3 levels. As the treatment area is below the ground water level in the River Terrace Deposits, drilling is advised to be conducted above the water table from the shaft with the bores angled downwards into the treatment area – this prevents ground water flowing back into the shaft during and on completion of the drilling. This general arrangement can be seen on the drawing in Appendix 3.
**Construction Proposal**

A temporary works solution is required (designed and installed by others) to allow us to drill at this elevation. Drilling will be conducted by a shaft rig or tracked rig using fully cased water flush system. The steel T&N tube will be installed and sleeve grouted prior to removal of the casing to maintain bore stability and minimise settlement during the drilling and installation process. Should settlement occur during the drilling and installation phase that requires priority jacking, this can be conducted using a (non-instrumented) grout mixer with a maximum pressure of 10 bars. All holes will be surveyed along their length for deviation.

During the permeation grouting phase, each T&N sleeve will be isolated by a double packer and chemical grout injected at a target volume of 100 litres with maximum pressure of 8 bar measured at the pump — and a limiting flow rate of 3 litres/minute. These parameters are set to combine the necessity to get a reasonable flow of grout into the voids without generating heave, however it is essential that ground levels are monitored during this process (by BFK and their specialist monitoring subcontractor) and that information fed back to the grouting team. Should heave be generated a review of the pressure and flow parameters will be undertaken. Grouting shall be carried out using the state of the art grout module as is being used in the contract for compensation grouting. To allow pore water pressures to dissipate and minimise heave, grouting will be conducted on an 11/5 shift pattern, but this may be able to increase to 24/7 for part of the works.

**Programme**

Design and installation of temporary works by BFK has not been included. There will be one week required to clear out the shaft base to allow it to be used as the drilling water circulation sump. A further one week to clear the shaft of sodium silicate grout washout by vacuum excavator will be required on completion. A mobilisation and demobilisation period of 1 week each is anticipated.

An estimated drilling and installation production rate of one T&N pipe installed and grouted per shift on a 24/7 shift pattern produces a drilling and installation phase of 2 weeks plus a few days.

An estimated average permeation grouting production rate of 2.8m³ per shift on an 11/5 working week produces a grouting phase of 3 weeks. If ground conditions allow, the work may be completed 22/5 or 22/7 in 1.5 to 2 weeks.

Including mobilisation and demobilisation of equipment, the works are estimated to last for 9 weeks.

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>5</th>
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<tbody>
<tr>
<td>Mobilisation</td>
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<tr>
<td>Drilling and Installation Phase (including rig out)</td>
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<tr>
<td>Permeation Grouting Phase</td>
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<tr>
<td>Tunnelling commence (dependant on ground)</td>
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<td></td>
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<tr>
<td>Demobilisation</td>
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<tr>
<td>Vacuum Excavator to Clear Shaft</td>
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**Qualifications**

Please note the following items have not been included for or is the responsibility of BFK:-

1. This is an outline design and methodology that shall be subject to a detailed design by BFK to ensure this meets the performance requirements.
2. A further quotation is required to be produced should this technique be accepted and detailed design complete. No guarantees are made that the works will be successful.
3. KBR will not be held responsible for the performance of these works in relation to the tunnelling thereafter.
4. The programme period is indicative. Permeation grouting is results driven, the grouting durations may exceed that shown due to low flow requirements or greater than anticipated volumes required.
5. KBR will not be responsible for any delay to the Contractors works that arise from the requirement for this work or the works themselves.
6. Temporary Works and rig modifications have not been included in the budget quotation. All temporary works design and construction shall be carried out by BFK.

7. The number of holes penetrating each shaft segment and their spacing has not been considered. Given the number of TâM’s and the limitation on levels this is expected to far exceed that of the current shaft design. BFK are wholly responsible for the design check and any additional shaft support measures required.

8. No re-drills have been included in this budget quotation and will be subject to inclusion in revised quotation or as a subsequent Compensation Event.

9. Although KC20 has been considered this proposal does not necessarily meet with that specification.

10. Pre or post grouting permeability and core testing have not been included for and will be the responsibility of BFK should they be required.

The above list is not exhaustive and generally any works (including programme increases) not included for in the attached quotation shall be subject to future Compensation Event under the Subcontract or included for in a revised quotation to PMI166.