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Case study of a dewatering and recharge system in weak chalk rock

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Case study of a dewatering and recharge system in weak chalk rock

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ABSTRACT

This case study describes the challenges involved in designing a dewatering and recharge system for a deep excavation in weak chalk rock supported by a diaphragm wall. The procedures used to assess the permeability profile which controls flows under a partial cut-off are considered in some detail. Back analysis of the installed scheme is used to review the accuracy of the design assumptions and suggestions are made for improving the design approach for future schemes.

Keywords: Groundwater, dewatering, recharge, settlement, permeability, case history

1 INTRODUCTION

The High Speed railway line connecting London to the Channel Tunnel passes beneath the River Thames to the east of London at West Thurrock, Essex. Twin tunnels were constructed using tunnel boring machines launched from a chamber located on the south side of the river at the end of the southern approach structure. The dewatering for the southern approach structure was impacted by a large-scale inhomogeneity in the chalk which has been described by Bevan et al [1].

This paper is concerned with the dewatering of the northern approach structure which was adjacent to an extensive petroleum products tank farm which had a potentially high sensitivity to settlement induced by groundwater lowering. Studies confirmed that in the absence of any mitigation measures the temporary works dewatering would result in appreciable lowering of the groundwater level below the tank farm. As a result, it was decided to implement a recharge system to maintain groundwater levels under the tank farm. A program of pumping/recharge tests and permeability testing was implemented to investigate the prevailing hydrogeological conditions. The results from this testing was used to provide input for a numerical model which formed the design basis for the dewatering/recharge scheme adopted. The plan layout of the northern approach structure and adjacent tank farm are shown in Figure 1.

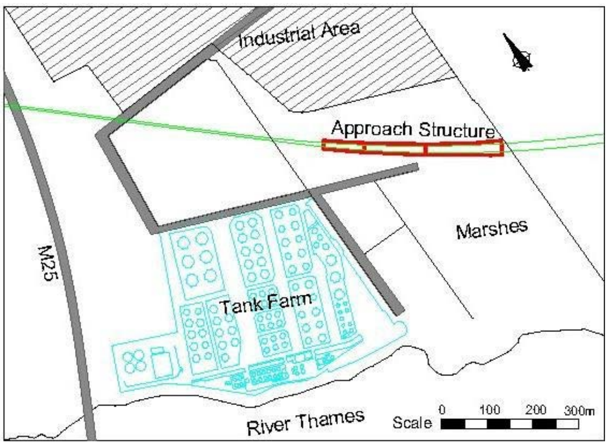

Figure 1. Layout of approach structure and tank farm.

A typical section along the structure is shown in Figure 2. This includes the design toe level of the propped diaphragm wall which provided side support for the excavation and acted as a barrier to groundwater flow.

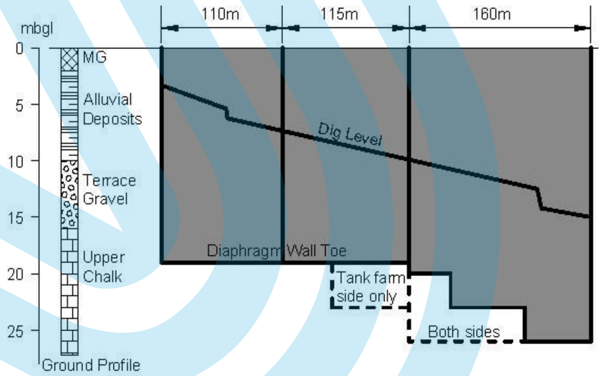

Figure 2. Long section showing dig level, diaphragm wall toe, end walls and cross cut-offs.

The dotted lines show the extensions made to the wall following the analysis of the test results described in sections 4, 5 and 6.

A cross section showing the conceptual model of the abstraction and recharge scheme is shown in Figure 3.

2 GROUND CONDITIONS

The site investigation borehole logs indicated the sequence of stratification given in Table 1.

Table 1. Sequence of stratification

Stratum	Top level
Made Ground	+ 1 mOD
Alluvial Deposits (peat and clay)	-2 mOD
Terrace Gravels (Sand and Gravel)	-10 mOD
Upper Chalk (weak limestone)	-16 mOD

The alluvium deposits comprise soft to very soft organic clays above and below a 4 to 5 m thick well- defined peat layer. The Terrace Gravels typically comprise medium dense to dense very sandy (medium to coarse) angular to rounded flint gravel with occasional cobbles and sand layers.

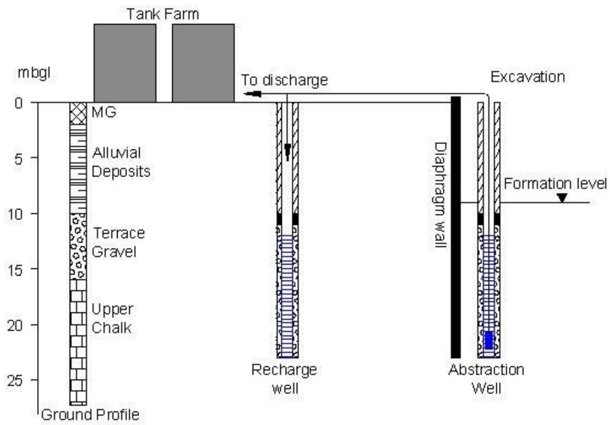

Figure 3. Conceptual model of abstraction and recharge.

Where the chalk is overlain by Terrace Gravels in the Thames Basin it is commonly weathered to significant depth. Using the CIRIA grading scheme, Lord et al [2], the top 1 or 2 m were found to be structureless Grade Dc chalk. Below this there was 3 to 5 m of Grade C5/3 blocky chalk which improved through Grade B3/2 to Grade A3/1 at about 10 m below the surface of the chalk (about - 25 mOD).

The standing groundwater level in the Terrace Gravel and Chalk was at 0 to -0.5 mOD although subject to tidal fluctuations of the order of 1 m typically within the range +0.5 to -1 mOD. These tidal fluctuations were derived from the Thames which is subject to a tidal range of approximately 4 to 5 m

3 THE PERMEABILITY PROFILE

It is well know that the bulk permeability of weak rocks, such as weathered chalk, is primarily controlled by the degree of fissuring. Al-though chalk has a high porosity (typically 30 to 40%) the inter-granular permeability of the rock matrix is low being of the order of 10-7 to 10-8 m/s. If the structureless Grade Dc chalk at the top of the stratum is too weak to sustain a fissure network then its permeability may be low and approach that of the rock matrix.

The blocky Grade C chalk and more competent Grade B chalk below can support an extensive fissure network and may be highly permeable. At greater depths in the Grade A chalk fissuring generally becomes less extensive with smaller apertures so that the permeability reduces. Super-imposed on this profile may be enlarged secondary fissures which can result in very high chalk transmissivity, see for example Bevan et al [1].

Figures 2 and 3 show that inflows to the excavation pass through the chalk under the diaphragm wall. As a result, the extent of dewatering to keep the works dry and the extent of recharge to maintain external groundwater levels was critically dependent on the diaphragm wall cut-off depth and the precise permeability profile in the Terrace Gravels and Chalk.

Furthermore, excessive recirculation occurs if the permeability profile is uniform with kv = kh. Thus, for a dewatering/recharge scheme to be viable there must be some reduction in permeability with depth and in order to design an effective scheme and optimize the cut-off depth it is important to quantify this reduction.
Sample descriptions and particle size grading curves can be used to provide some indication of the permeability of the Terrace Gravels. A more precise assessment of the permeability of the Terrace Gravels can generally be obtained from a pumping test.

For weak rock, such as chalk, even detailed descriptions of borehole samples and cores give little indication of permeability, and a pumping test will only provide the bulk horizontal transmissivity. It will give little information on the permeability profile. Packer testing during drilling can certainly be of value but can only be undertaken in relatively competent chalk rock (Grade A) and not in the critical upper putty (Grade Dc) or weak blocky (Grade C/B) chalk zones.

Falling and rising head tests undertaken in boreholes during drilling are notoriously unreliable being highly susceptible to conditions at the base of the bore. Falling and constant head tests are susceptible to plugging of the formation as are rising head tests to a degree giving rise to lower bound permeability values. Rising head tests are susceptible to loosening and blowing of the base of the bore potentially giving rise to up-per bound permeability values. In any case the discontinuity spacing for Grade C3/B2 chalk is in the range 60 to 600 mm which is likely to result in erratic hydraulic responses and corresponding permeability values in the base of a 150 mm site investigation borehole.

4 PUMPING AND PERMEABILITY TESTS

The site investigations undertaken during the project design development stage included pumping tests two of which were undertaken in the Terrace Gravels. Steady state analysis of the distance drawdown data indicated a high permeability of the order of 2 x 10-3 m/s which is consistent with the Terrace Gravel description and particle size distribution data.

The three pumping tests that had been undertaken in the chalk were re-analysed. The tests included monitoring data for both the gravels and chalk and the re-analysis was undertaken by modelling the pumping tests using the USGS three-dimensional groundwater model ModFlow. The results of this exercise are summarized in Table 2. It can be seen that test N3 had a response zone in the more competent chalk below -26 mOD and had the lowest specific capacity implying a significant reduction in the permeability of this lower chalk. This level is approximately the same as the interface between the Grade B/A chalk and was taken as the level for a step change in permeability. Note that for all modelling and analysis work the chalk was assumed to be impermeable 50 m below the sur-face of the chalk (at -65 mOD).

Table 2. Reanalysis of design stage chalk pumping tests (all levels given in mOD)

	Test N1	Test N3	Test N7
Distance to portal	532 m	5 m	18 m
Gravel/Chalk interf	-15.4	-17.1	-16.8
Top response zone	-16.8	-26.0	-19.5
Base response zone	-22.8	-37.9	-38.4
Well drawdown	12.0 m	28.1 m	2.3 m
Discharge flow	30 l/s	8.5 l/s	25.1 l/s
Specific capacity	2.5 l/s/m	0.3 l/s/m	10.9 l/s/m
Best Fit Model results			
Well drawdown	7.4 m	21.8 m	5.0 m
Discharge flow	30.9 l/s	8.3 l/s	24.2 l/s
Gravel k m/s	$5.8x10^{-3}$	$5.8x10^{-3}$	$1.2x10^{-2}$
Chalk B/A interface	-26.0	-24.0	-26.0
Chalk B k m/s	$4.2x10^{-4}$	$4.2x10^{-4}$	$4.2x10^{-4}$
Chalk A k m/s	$2.3x10^{-5}$	$1.2x10^{-5}$	$2.3x10^{-5}$

The permeability profile of the chalk was further investigated by a program of constant outflow tests on piezometers installed expressly for this purpose. Each piezometer was 52 mm diameter and was installed with a 3 m response zone in a 150 mm borehole. The piezometers underwent a program of airlift development before testing commenced using a surface suction pump with data logger monitoring of flow and head.

A further borehole was drilled and used to under- take packer tests in the more competent chalk. The bore was cased to the top of the more competent chalk and then deepened by 3 m open hole. The bore was developed by bailing until clear water was returned to the surface. Following this a packer was installed to isolate the lower 3 m of the bore and a constant outflow was conducted in a similar manner as for the piezo-meters. A transducer was installed in the bore above the packer to confirm the integrity of the packer seal. Following each test the borehole was deepened by 3 m and the test repeated.

Note that the response zone of 3 m was chosen with care. A shorter response zone might have intercepted relatively few fissures leading to an erratic response and corresponding permeability profile. A longer response zone would have limited the resolution of the results with respect to depth. The results of this permeability testing program and the results of the re-analysis of the pumping test data are summarized in Figure 4.

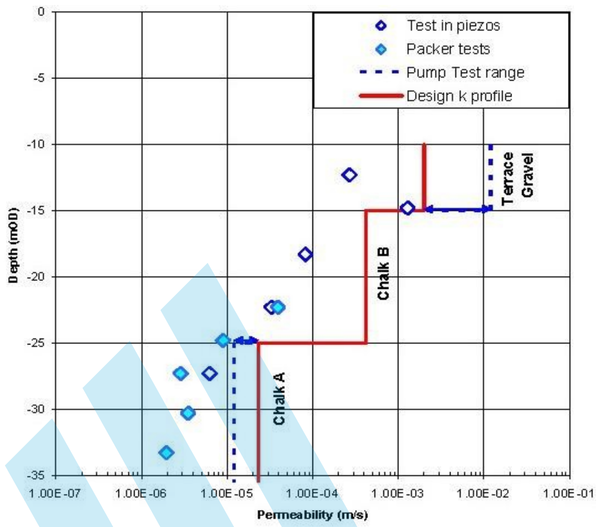

Figure 4. Summary of permeability test results.

5 ABSTRACTION RECHARGE TRIAL

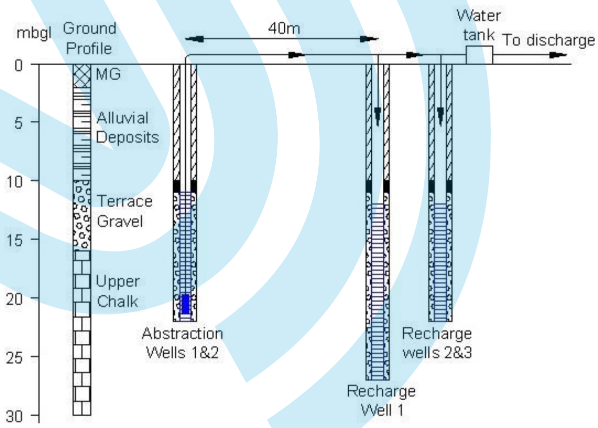

Figure 5. Abstraction/recharge test well response zones.

An abstraction/recharge trial was carried out using two abstraction wells and three recharge wells. A schematic section showing the response zone of the trial wells is shown in Figure 5.

Individual well capacities were established during an initial equipment test. Abstraction flows were 20 and 32 l/s and recharge flows were in the range 12.5 to 9 l/s with the highest flows for RW1 which had a deeper and longer screened zone. Some of the trial data is shown in Figure 6. The tidal influence on water levels in the Terrace Gravels is clearly evident.

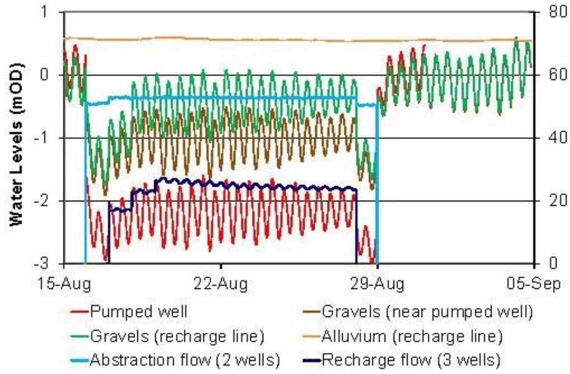

Figure 6. Pumping abstraction and recharge trial data.

6 NUMERICAL MODELLING

Numerical modelling of the dewatering and recharge system for the north portal was carried out in three dimensions using the Groundwater Vistas MODFLOW finite difference software package.

The model results showed that in the absence of mitigation measures drawdown below the adjacent Tank Farm was likely to be unacceptably high at up to 4 m. Implementation of a recharge system between the excavation and the tank farm would reduce drawdown to less than 1 m, see Figure 7.

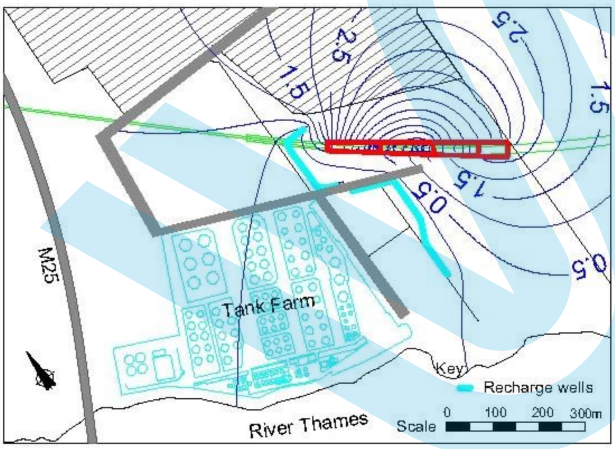

Figure 7. Model contours with recharge system in place.

However, the model results also showed that a recharge scheme increases the hydraulic gradient leading to a 90% increase in abstraction flow, from 390 l/s to 740 l/s. The permeability profile shown in Figure 4 was used for the model. Further model runs showed that extending the diaphragm wall to
-26 mOD around the deeper end of the structure greatly curtailed the abstraction flow. Studies were also carried out on the sensitivity of the results to variations in the Chalk B/A interface level and as a result the diaphragm wall was also extended to -23 mOD for a 70 m section at the shallower end on the Tank Farm side only, see Figure 2. The final design flow for the dewatering scheme was 375 l/s abstraction with 80% recharge (300 l/s).

7 MONITORING RESULTS

A study had concluded that the alluvium could sustain a change of effective stress of 5 kPa (equivalent to 0.5 m drawdown) over a 60-week period (the anticipated duration of the dewater- ing) without measurable change in ground sur-face level. The aim of the recharge scheme was therefore to limit drawdown to 0.5 m below the ambient tidal cyclic groundwater levels. Based on long term monitoring records the ambient groundwater level was taken as -0.5 mOD and amber and red trigger levels were set at -0.75 and
-1.25 mOD respectively.

Trigger levels were also set for settlement monitoring but it was recognised that groundwater levels, being a lead indicator, were key to controlling ground movement. One complication was the extent of tidal influence on groundwater levels which meant that amber trigger levels were apparently breached on almost every low tide. This was overcome by de-fining the trigger levels on the basis of 7-day average readings which eliminated tidal fluctuations. All data for piezometers was collected hourly using transducers, loggers and GSM data communication. Data access off site, processing and alarm triggers were all fully automated.

Breach of trigger levels resulted in a pre-agreed response;

- Amber: Data verification, trend analysis, implementation of measures to reverse trend.

- Red: Immediate cessation of all work within 50 m of approach structure.

A sample of the monitoring data is shown in Figure
10. This shows hourly and 7-day average data from one of the gravel piezometers on the Tank Farm site. It can be seen that an amber trigger level was breached on one occasion at the end of September. The breach was due to insufficient attention being paid to recharge well bio-fouling cleaning following a change of site staff. A program of comprehensive well redevelopment was implemented which recovered re-charge well capacity and reversed a long-term trend of declining recharge flow and falling groundwater levels.

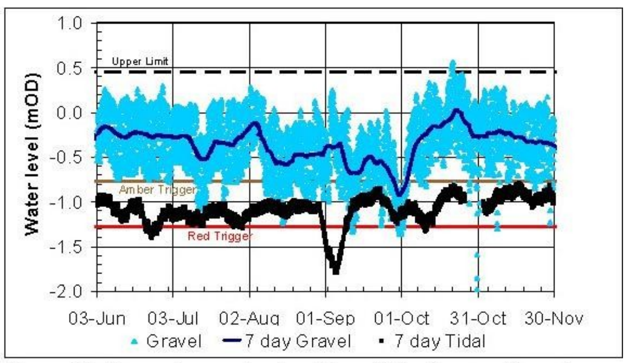

Figure 10. Example monitoring data within Terrace Gravels

The pumping requirement for the full dewatering scheme was 110 to 140 l/s with the majority of the flow derived from the shallow end of the excavation with recharge flows in the range 60 to 140 l/s. Back analysis was undertaken using the numerical model which suggested that the permeability of Chalk A was probably of the order of 1 x 10-4 m/s which is more consistent with the borehole permeability test data shown in Figure 4.

8 CONCLUSIONS

When an excavation is surrounded by a partial cut- off, the dewatering flow and head loss are critically dependent on the permeability profile which cannot be determined from a conventional single well pumping test.

For this project, a program of piezometer /packer tests provided useful information on the permeability profile. Such an approach carries risks because the tests are very local and because experience shows that results can be unreliable. The abstraction/recharge trial provided important information on abstraction and recharge well yields. With hindsight, the following modifications to the trial specification could have greatly improved the value of the data collected:

- Recharge wells screened in the Terrace Gravels only.
- Confirm Terrace Gravel permeability with an abstraction test on one recharge well.
- Install piezometers with separate response zones on the Terrace Gravels and Chalk.
- Install two abstraction wells, one with a response zone in the chalk only across the depth of the diaphragm wall, and a second with a response zone from the toe of the diaphragm wall down 6 to 7 m.
- Undertake a conventional single well pumping test on each chalk well.

The application of a 3D numerical groundwater flow model to analyse the data from such an abstraction/recharge trial is essential to extract the full value from the data in the context of the design of any associated cut-off wall arrangement.

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