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Bloomfield Road Stormwater Storage Tanks Grouting Works, Blackpool, UK

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BLOOMFIELD ROAD STORMWATER STORAGE TANKS GROUTING WORKS, BLACKPOOL, UK

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ABSTRACT

Bloomfield Road Stormwater Storage Tanks, owned by United Utilities PLC, were constructed in 1999 in Blackpool UK to provide 60,000m^3 of storage to prevent overflow discharges during the summer bathing water season. The asset comprises two buried tanks (36m diameter and 40m deep) constructed as circular diaphragm walls. Significant groundwater inflows with minor fines content and turbidity up to 48l/s have been reported entering one of the tanks since 2001. From 2008 an increase of fines ingress has been observed indicating potential for progressive failure of the underlying formation strata.

The site stratigraphy comprises predominantly glacial superficial soils overlying an interlaminated Mudstone/Gypsum and Halite sequence. Groundwater inflows were likely to have initiated failure mechanisms in the formation strata including fines loss, dissolution of both gypsum and halite and potentially significant voiding.

An innovative event tree risk analysis tool was developed to identify and allow a focused remedial works design and a cost effective solution to be planned. The main works implemented comprised: sealing of the base slab joint by resin injection; contact grouting beneath the base; ground investigation works including cross hole tomography geophysics; and grouting within the Mudstone formation. This paper describes the implementation of the project which was completed ahead of programme ensuring continued compliance with coastal bathing waters standards.

INTRODUCTION

Bloomfield Road Stormwater Storage Tanks were constructed by United Utilities (UU) PLC in 1999 in Blackpool, UK to provide 60,000m^3 of storage to prevent unsatisfactory and untreated stormwater overflow discharges during each annual open water Bathing Water Season (May to September). The asset comprises two very large diameter (36m) and deep (40m) buried tanks constructed as circular diaphragm walls with an interconnecting tunnel and associated infrastructure. The site location is illustrated on Fig. 1. Figure 2 shows the tanks under construction in 1999.

The tanks are of major importance having a combined capacity representing two thirds of Blackpool's total storage and are amongst the largest of their type in the UK.

Since 2001 groundwater has been reported flowing into one of the tanks, Tank 2, around the joint between the base and a corbel ring beam which transfers groundwater uplift loads from the base to the diaphragm walls. Groundwater ingress with minor fines, dissolved mineral content and turbidity has increased since 2001. Inflows in 2010 were observed between 4l/s and 48l/s and averaging 18l/s. Between 2008 and 2010 an increase of fines ingress was also observed (Fig. 3).

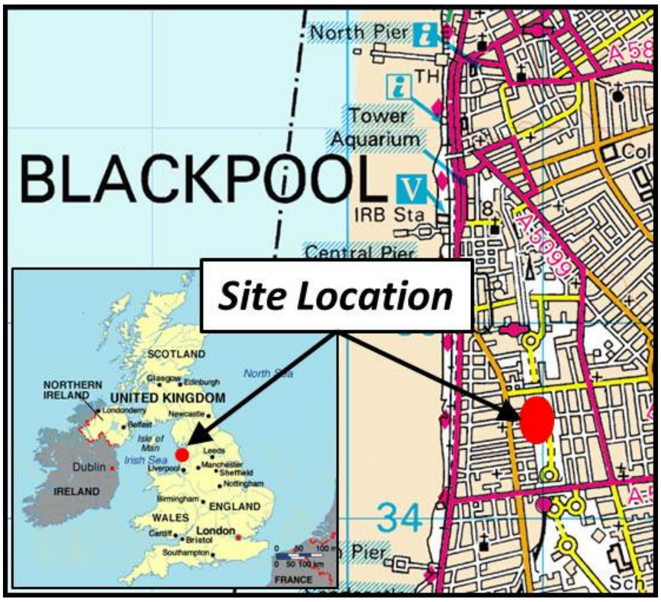

Fig. 1- Site Location Plan

Fig.2- Aerial photograph of tanks during construction, 1999

UU PLC, through in-house United Utilities Engineering and Engineering Service Provider MWH along with specialist geotechnical contractors Bachy Soletanche, developed a design to improve shaft water-tightness. This relied upon a clear phased definition allowing investigations to be carried out during the construction phase of the 2010 outage period when the tank could be kept empty between October 2010 and April 2011.

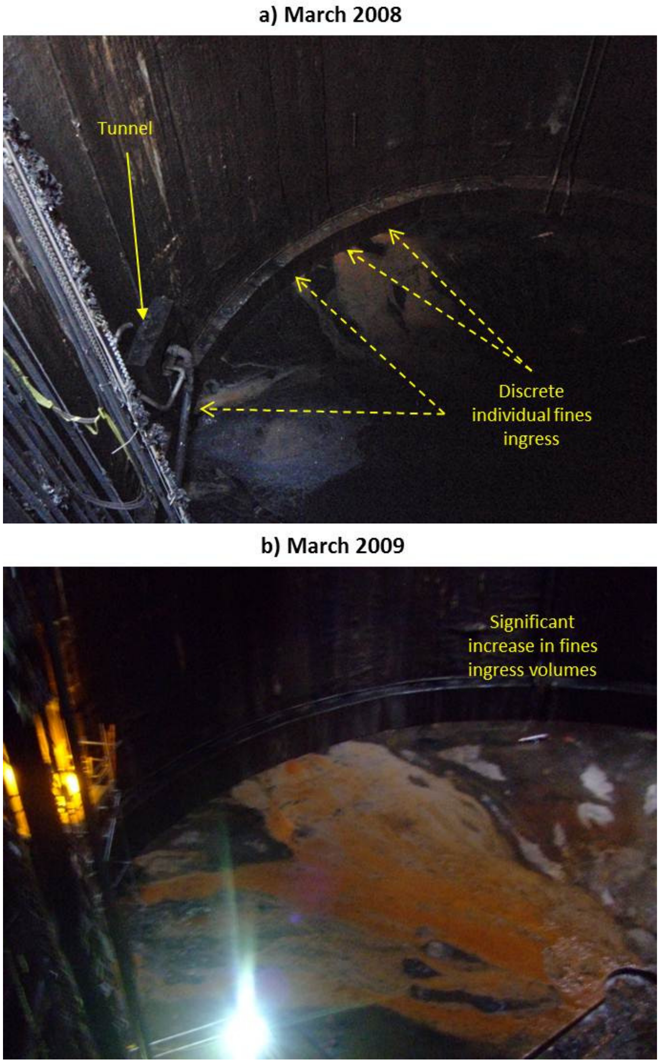

Fig. 3 – Notable increase in fines ingress volume between March 2008(a) and March 2009 (b)

This paper describes the implementation of the project which was completed ahead of programme. Post treatment inspections and monitoring demonstrated the successful stemming of observed groundwater ingress, recovery of external groundwater levels and achievement of the overall objectives.

SITE GEOLOGY

Historical Ground Investigation

Prior to construction of the tanks a ground investigation was undertaken by Norwest Holst comprising of seventeen boreholes constructed to depths between 15m and 98m below ground level (bgl). Boreholes were formed by a combination of standard cable percussion boring and rotary coring techniques. Piezometers were installed in each borehole to target various stratigraphic horizons to develop a full understanding of the local ground water regime.

Site Stratigraphy

The general site stratigraphy is illustrated in cross section within Fig. 4. The stratigraphy was indicated to comprise made ground, peat, alluvium, glacial soils of firm to stiff clay over medium dense to dense glacial gravel, Mudstone and Halite.

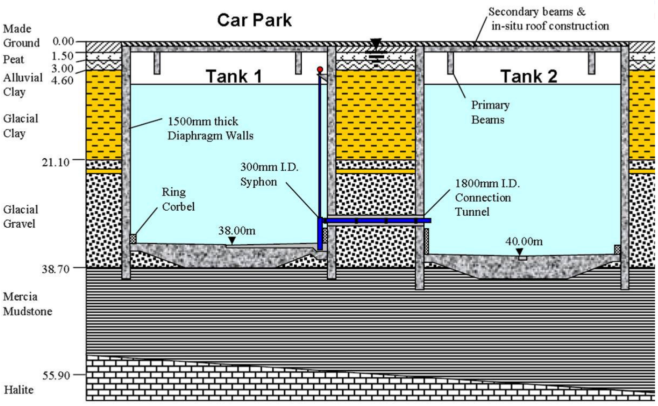

Fig. 4 – Generalised geological cross section and tank construction (after Wharmby et al, 2001)

Mudstone.

The Mudstone is identified as the Singleton Mudstone by the British Geological Survey [1972] and Wilson and Evans [1990]. Borehole records show the stratum comprises a very weak to moderately strong sub-horizontally bedded Mudstone with very closely to closely (40–130mm) spaced thin to thick (6-13mm) gypsum laminations.

Borehole records indicated the Mudstone to be completely to highly weathered to the upper 2m. It was also noted that the stratum became particularly 'gypsiferous' with increasing depth.

Halite.

The maximum thickness of the Halite stratum (designated as the Mythop Salt (BGS, [1972] and Wilson and Evans [1990]) was not proven. The historical Norwest Holst borehole records did however note distinct dissolution features and 'honey combing' within the upper surface of the stratum. Such natural dissolution is common with a natural flow of ground water at 'wet rockhead'.

Groundwater

Groundwater was encountered during historical ground investigation drilling at depths between 3 and 19.5mbgl within the glacial strata. Monitoring of piezometers installed within boreholes indicated a highest recorded groundwater level of approximately 2mbgl.

The site is located approximately 500m east of the Blackpool and Fylde coastline and the Irish Sea. The sea has a tidal range of up to 10m at a spring tide. Long term monitoring of site groundwater levels was undertaken in advance of construction to investigate possible tidal influences. This monitoring indicated that groundwater levels on site were not tidally influenced.

The tanks were designed to resist uplift groundwater pressures in excess of 400kPa (58psi).

PROJECT CONCEPT

Qualitative Risk Assessment

An innovative event tree risk analysis tool (Qualitative Risk Assessment) was developed to identify and subsequently target the most likely threats posed to the structure (Eddleston and Mason [2011]). This was developed from a similar approach used by UU associated with potential failure mechanisms of their reservoir embankment dams. Considering the available data the engineering team were able to quantify the probability of various threats and prescribe potential timescales. This allowed a refined view of the required scope, focused design and a cost effective solution to be developed. Figure 5 illustrates a typical event tree analysis output from the risk analysis workshop event undertaken by the engineering team.

BLOOMFIELD ROAD STORAGE TANKS - EVENTS AFFECTED BY GROUNDWATER PRESSURE								
EVENT DESCRIPTION					PROBABILITY OF FAILURE WITH NO GROUNDWATER PRESSURE		PROBABILITY OF FAILURE WITH FULL GROUNDWATER PRESSURE	
Source of Inflow	Flowpath to Tank	Effect on Stratum	Part of Infrastructure Affected (incl. secondary failure)	Timeframe Considered	Event ID	1 in X	Event ID	1 in X
Mudstone	Through Mudstone Plug & Drainage Layer to Base Joint	Fines Loss	Base only.	Immediate (next 2 years)	26	113	30	11268
Mudstone	Through Mudstone Plug & Drainage Layer to Base Joint	Gypsum Dissolution	Base only.	Immediate (next 2 years)	42	2247	47	22469
Mudstone	Through Mudstone Plug & Drainage Layer to Base Joint	Gypsum Dissolution	Base only.	Long (next 50 years)	45	1	50	1
Mudstone	Through Mudstone Plug & Drainage Layer to Base Joint	Gypsum Dissolution	Base and Tunnel Collapse (fines loss).	Long (next 50 years)	46	204410	51	204410
Halite	From SI Boreholes to Wet Rockhead. Across & Up through Mudstone Plug & Drainage Layer to Base Joint.	Halite Dissolution	Base only.	Immediate (next 2 years)	66	5404	68	54038
Halite	From SI Boreholes to Wet Rockhead. Across & Up through Mudstone Plug & Drainage Layer to Base Joint.	Halite Dissolution	Base only.	Medium (next 10 years)	70	473	72	4728

Fig. 5 – Event tree risk analysis output, failure events affected by groundwater pressure

The highest risk was identified as base failure associated with potential void migration and subsequent structural instability.

Mineral Dissolution Estimates

Data Collection.

Early desk study works into dissolution of the evaporites included useful engagement with the British Geological Survey (Cooper [2008]). Investigations by Klimchouk *et al* [1997] suggest that gypsum solubility increases by up to four times with exposure to sodium chloride saturated water in comparison to unsaturated water. Understanding that gypsum dissolution increased significantly with increasing sodium chloride (dissolved halite) concentrations within the groundwater allowed estimation of the timescales to complete dissolution of the gypsum within the footprint of the structure. That time period was identified as 3-5 years and underlined the importance of the works.

Archive records from inspection works undertaken in 2004 were located and provided a single groundwater inflow rate (Table 1) established by undertaking a timed water level rising test within the tank sump (sump rise test).

Planned routine tank maintenance entries in 2008 and 2009 allowed the engineering team to record, monitor and sample groundwater inflows in to the tank. During internal tank inspections groundwater inflow rates were established by means of sump rise tests (Table 1). This established periodic spot point inflow rates over very limited time periods.

Automated dataloggers were installed to remotely record tank water levels from the tank ultrasonic sensors. Analysis of this data allowed a full understanding of the rate of groundwater inflows whilst the asset was in service and without need to enter the tank.

Collected groundwater samples were submitted for chemical testing within the laboratory to establish concentrations of dissolved determinant constituents of both Gypsum ($CaSO_4$) and Halite ($NaCl$) (see Table 2).

Groundwater Inflow Rate.

Table 1 presents a summary of the recorded groundwater inflow rates in to the tank. Review of the data indicated that groundwater inflow rate was progressively increasing with time. This might be expected as flow paths within the formation strata are gradually enlarged leading to progressive formation strata degradation.

Table 1. Groundwater Inflow Rates

Date	Inflow Rate (l/s)	
	Range	Average
March 2004	-	6.7
March 2008	-	9
October 2008	-	17
March 2009	12.2 - 14	13
April 2009 to March 2010 (tank ultrasonics)	4 - 48	18

Mineral Dissolution.

Potential halite and gypsum dissolution volumes were calculated based on determinant chemical analysis of groundwater samples collected, assumed average annual groundwater inflow rates from recorded data and established likely trend with time and typical Halite and Gypsum densities of 2.3Mg/m^3 and 2.8Mg/m^3 respectively.

The dissolved mass of individual determinant elements of Halite and Gypsum (sodium, chloride, calcium and sulphate) per litre of water was measured through laboratory testing. Summation of individual constituent masses allowed engineers to establish Halite and Gypsum mineral masses suspended within ingress groundwater. With knowledge of groundwater inflow rates in turn allowed determination of likely volumes of mineral loss from the formation strata. Table 2 summarises measured individual elemental masses from laboratory testing and subsequent halite and gypsum concentrations.

Table 2. Groundwater mineral content

Test Determinant	Range (mg/1)	Resultant dissolved mineral (mg/l)
Sodium (Na)	239-20,900	Halite 585-47,100
Chloride (Cl)	346-26,200	
Calcium (Ca)	134-210	Gypsum 304-1217
Sulphate (SO_4)	170-1010	

Prevailing estimated total Gypsum and Halite dissolution volumes since initiation of the observed groundwater ingress were estimated to be 500m^3 and 12,000m^3 respectively. The engineering team considered that dissolution of Gypsum would be confined to a zone within the approximate footprint of the structure, however two hypotheses required consideration for the Halite:

1. Dissolution localised to the structure footprint.
2. Widespread dissolution along wet rockhead leaking as saline water into the structure.

Impact of Reduced Groundwater Levels

It was identified that continued groundwater ingress since 2001 had potentially led to a reduced external groundwater level due to local drawdown effects. The leaking tank would effectively be acting as a very large pressure relief well. During early risk assessment and development of project objectives there were no groundwater monitoring standpipes available to determine current groundwater levels close to the structure.

Reduction in groundwater levels local to the structure will in turn result in a reduction in uplift groundwater pressures acting on the structure. Whilst this acts as a beneficial action when considering flotation risks, a reduced uplift groundwater pressure might result in a net positive downward bearing pressure on the formation of the tank when the tank was filled.

Formation voiding and degradation had been identified as key risks within the Qualitative Risk Assessment. Dependant on the scale of any potential drawdown of external groundwater levels, there was a risk that the base of the tank could suffer from settlement resultant from any positive net bearing load. The base slab of the tank was not rigidly fixed to the diaphragm wall and was therefore free to displace if able. The design of the base slab was reliant on an external uplift groundwater pressure exceeding pressures exerted during internal water loading during a storm event.

It was recommended that future investigative phases of work included the early installation of groundwater monitoring piezometers. This would allow early assessment of current groundwater levels and assessment of the risks and impacts associated with any observed reduction in groundwater levels.

Concept and Objectives

The concept and objective for the project required consideration of the above problems to determine the potential impacts to the structure and the community of any proposed solution. Did the benefits from addressing the water ingress dissolution provide value for money, reduced risk and demonstrate tangible improvements? The benefits were identified as:

- Maximised storm water storage capacity without requiring new structures;
- Maintain full storage capacity during bathing water season;
- Reduce the likelihood and thus cumulative volume of any permitted discharge;
- Have an overall positive impact on the quality of bathing waters to the benefit of the community;
- Provide greatly enhanced assurance as to the longevity of the benefits of the above, assisting in regulatory compliance and reduced impact on the community.

To achieve these objectives it was evident that a multi-disciplined engineering and multi company approach was required. A major focus of this concept was the required geo bias necessary for success; geotechnical engineers, geophysicists, ground investigation contractors and ground engineering specialists were all needed for delivery of this important project.

DESIGN AND PLANNING

Project Challenges

The project presented some very specific challenges; the works inside the tank had to be undertaken during the period October to April, outside of the open water bathing season when full storage had to be available. The tanks represent a confined space environment with the added constraint of limited tank access opening sizes located within a public car park.

A number of threats to structural stability had been identified but the final scope of work required to address these could not be established at pre-contract stage. Estimates of possible dissolution volumes were used to scope and estimate costs in advance of the works.

Early Contractor Involvement

A contract to reduce water ingress and dissolution was let on the basis of completing a first phase of works followed by an investigation phase to define the extent of further works to be undertaken under the same contract. The design and planning for the project was undertaken by Geotechnical and Civil Engineers from UU Engineering and MWH. The Main Contractor appointed to the project was UU Partnering Contractor Kier Murphy Interserve (KMI) who sub-contracted specialist geotechnical investigation and grouting works to Bachy Soletanche.

Advance Ground Investigation

An advance phase of ground investigation works comprising the drilling of three boreholes (BH101 to 103, Fig. 6) to depths between 50m and 62.3m bgl were undertaken by Bachy Soletanche. Value engineering discussions identified that specialist sonic drilling techniques would provide the most efficient technique and provide continuous sampling, particularly within the deep glacial gravel stratum. The objectives of this investigation were as follows:

- to establish current groundwater levels.
- to investigate any loss of relative density and potential change in grading (resultant from potential loss of fines) within the Glacial Gravel supporting the interconnecting tunnel.
- undertake preliminary grouting trials within formation mudstone stratum to investigate the extent of potential Gypsum laminae dissolution.

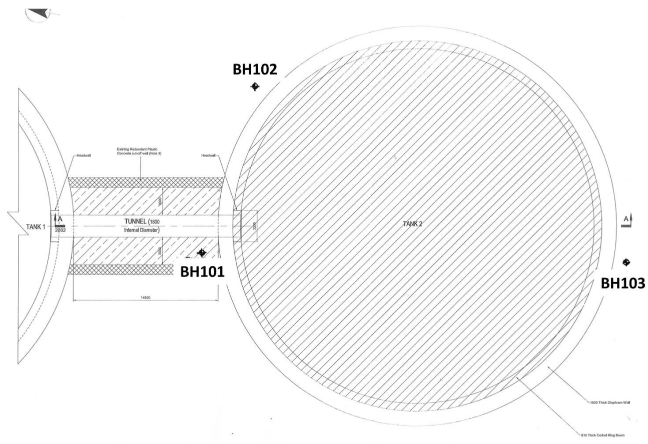

Fig. 6 – Advance Ground Investigation Borehole Location Plan

Figure 6 illustrates the location of the three boreholes. Borehole BH101 was located to investigate potential change in ground conditions close to the interconnecting tunnel. Boreholes BH101 and 102 were located where highest volumes of groundwater inflows had been observed within the tank. Borehole BH103 was targeted in an area of no observed internal groundwater ingress to act a control during subsequent interpretation of results.

Piezometers were installed to 40m bgl within each borehole. Groundwater monitoring dataloggers were installed in boreholes BH101 and 103 to provide continuous data following completion of the site works (Fig. 7). Subsequent monitoring indicated lowest recorded groundwater levels of 9.47m and 7.39m bgl within boreholes BH101 and 103 respectively. During the period 6th August to 7th September it is believed that groundwater levels fell below 10m bgl although as the datalogger was suspended above groundwater this was not recorded.

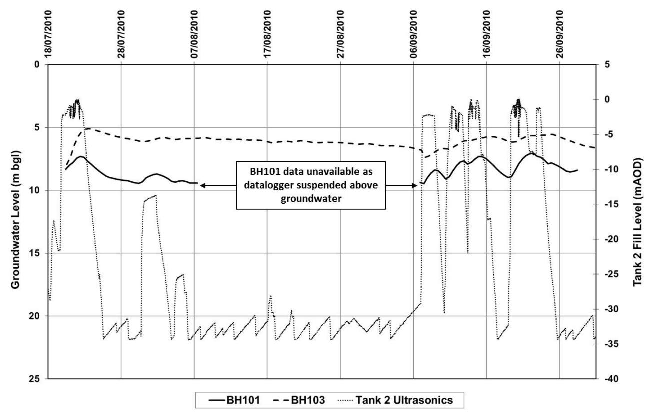

Fig. 7 – Groundwater Monitoring within Boreholes BH101 and BH102

Groundwater monitoring indicated a lower level to that previously recorded during pre-construction investigations. It was also established that groundwater levels increased rapidly during storm events (indicated in Fig. 7 by the rapid increase in tank fill levels). There was a discernible difference in the rate of groundwater level reduction between the two boreholes following storm events; groundwater levels falling more rapidly in BH101 compared to BH103. BH101 was constructed close to the greatest point of observed ingress and as such it was considered that the increased rate of groundwater level reduction was attributable to inflows within the tank.

In situ Standard Penetration Testing (SPT) was undertaken in borehole BH101 as the borehole was advanced through depths adjacent to the interconnecting tunnel. Testing returned SPT 'N' values of 14, 38 and 50. Pre-construction SPT 'N' values were consistently greater than 50 thus indicated a potential loss in relative density of the Glacial Gravel supporting the interconnecting tunnel. Particle Size Distribution (PSD) laboratory testing however did not indicate any discernible difference in grading to that indicated by equivalent pre-construction ground investigation testing.

Advance grouting trials were undertaken over 4m stage lengths in the Mudstone stratum within each borehole. Results from the grouting trials are summarised in Table 3. The grouting trials indicated significantly higher grout takes and lugeon test results in boreholes BH101 and 102 when compared to BH103. This confirmed that the Mudstone stratum in BH101 and 102 was heavily fractured whilst being significantly less fractured in BH103 and generally confirmed the potential for significant fissure voiding within the Mudstone due to Gypsum dissolution.

Table 3. Advance Grouting Trials summary data

Borehole	Stage No.	Grout Vol. (litres)	Lugeon Result
BH101	1	306	25.0
	2	572	24.9
BH102	1	1030	26.7
	2	849	18.1
	3	1642	16.8
BH103	1	397	0.9
	2	155	1.0
	3	141	0.2

Scope of Works

Early involvement of the specialist geotechnical contractor to work with the design team was essential to ensure delivery of effective fit for purpose solutions within challenging programme constraints. A close working relationship was developed at an early phase allowing value engineering along with continuous constructability inputs throughout the planning stage.

Design and planning developed the following scope of works:

- Investigations to inform additional works to be identified and determined.
- Sealing of joint between corbel ring beam and base slab by specialist chemical resin grout injection techniques to form a primary seal to the observed groundwater ingress.
- Contact grouting beneath the base to stabilise any localised voiding.
- Descending stage fissure grouting of the mudstone to deliver staged improvement of stability. Grouting to be terminated within the mudstone above the halite.

Investigation works were designed to consider:

- The relative density of the ground supporting the interconnecting tunnel to investigate any potential deterioration or loss of support in glacial gravel strata above rock.
- The mudstone/halite interface beneath Tank 2 and interconnecting tunnel.
- The possible presence of voiding within the Halite beneath Tank 2 and the interconnecting tunnel.

Value engineering determined that the most effective and lowest risk investigation of the mudstone/halite interface and possible voiding in the halite could be achieved by electrical resistivity cross hole tomography (CHT) geophysical techniques. This had the following added benefits:

- It required only a limited number of boreholes to penetrate the halite thus minimising the risk of possible future flow path development.
- Presence of high salinity flow paths through the mudstone could be identified to aid planning of grouting in the mudstone.
- The survey could be repeated to allow post treatment validation of any subsequent halite stabilisation, if found to be required following interpretation of results.

CONSTRUCTION

Ground Investigation works

The interconnecting tunnel ground investigation boreholes were constructed to 75m depth within 1.5m on plan from the tunnel lining (boreholes G01 to G05 and T08 Fig. 8). Prevention of damage to the tunnel during investigation drilling was a key risk. The drilling procedure included a hold point above the tunnel to check borehole verticality ensuring tunnel encroachment was within acceptable limits. Sonic drilling techniques were again adopted through superficial strata following success during initial investigation works. Conventional rotary techniques were used in rock with brine flush in the Halite stratum. On completion, four boreholes (G02 to 05 Fig. 8) were prepared for grouting works and two for CHT (boreholes G01 and T08 Fig. 8); this re-use of boreholes for treatment maximised efficiency and minimised waste.

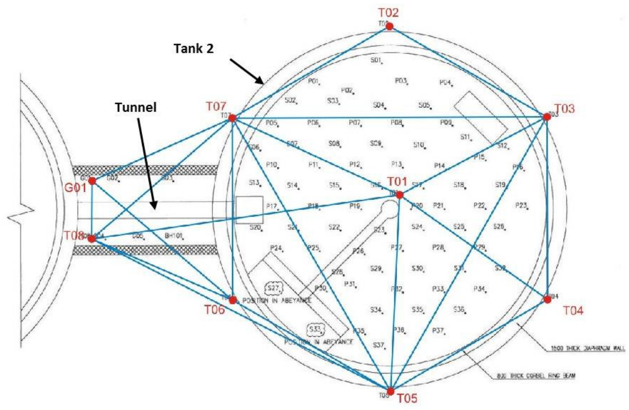

Fig. 8 – CHT borehole location and survey lines

Investigations to establish the mudstone/halite interface included six boreholes (T02 to T07 Fig. 8) to 75m depth around the perimeter of Tank 2 and one borehole (T01 Fig. 8) to 38m deep within the centre of the tank. The central borehole was drilled from the base of the tank at approximately 40m below ground level. The boreholes were fitted for subsequent CHT surveys to investigate potential voiding.

CHT surveys were undertaken by Europeenne De Geophysique (EDG), specialists in advanced geophysical techniques based in Paris, France. A pseudo 3D image (Fig. 9) of the investigation zone was prepared on post processing of the CHT data achieved between borehole pairs (Fig. 8).

Results from the CHT survey indicated high chloride groundwater flow through the mudstone. It was concluded that significant halite voiding was not present (Fig. 9).

CHT and physical borehole data was interpreted to map the Mudstone Halite interface within the footprint of the tank (Fig. 10). In turn this data was used to schedule final depths for grouting boreholes within the Mudstone and avoid unnecessary penetration of the Halite.

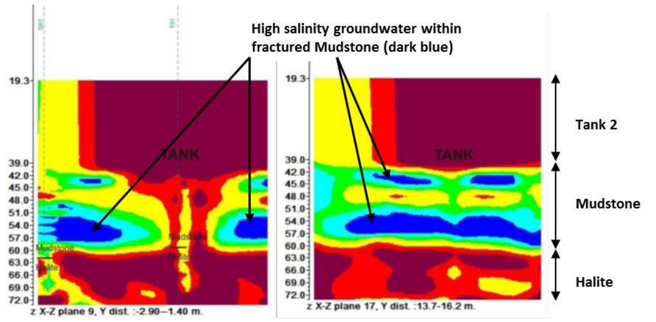

Fig.9 - Example of CHT interpretation indicating high salinity flows through fractured/fissured Mudstone

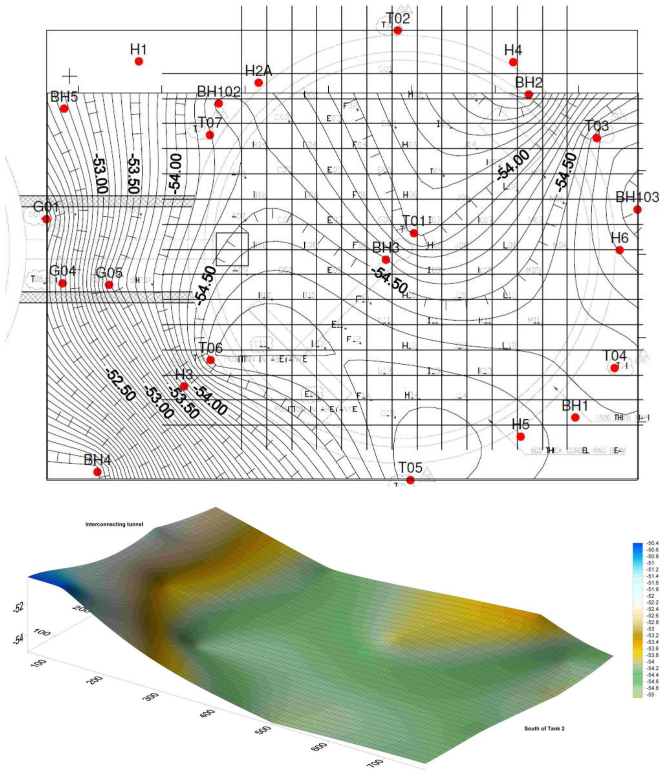

Fig. 10 – Mapped Mudstone Halite interface (above, contour plot to mAOD; below 3D visualisation)

Investment in advance techniques gave the project confidence in the final works and reassurance as to the absence of significant halite voiding resulting in significant savings over drilling and treatment.

Grouting Operations

Base Joint Sealing.

Primary base joint sealing works were undertaken to seal the joint between the base slab, diaphragm wall and corbel ring beam to stem the observed groundwater inflows. These works commenced with the drilling of inclined small diameter

(30mm) injection boreholes at 500mm spacing around the internal tank perimeter. The boreholes were drilled through the base slab to target the open joint against the diaphragm wall. Each borehole position was installed with a non-return packer valve and injected with a slow set chemical resin grout.

During these drilling operations an initial rapid reduction in external groundwater levels was observed (Fig. 11) due to the resultant temporary increase in inflow in to the tank. The injected resin grout resulted in an effective temporary seal against groundwater inflow. On completion of these sealing operations, combined with initial contact grouting beneath the base slab (see below), a rapid recovery of external groundwater levels was observed (Fig. 11).

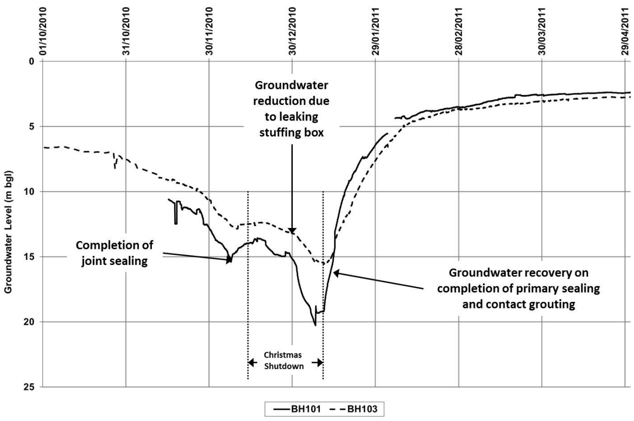

Fig.11 – Rapid External Groundwater Recovery on Completion of Primary Sealing

Formation Strata Grouting.

Grouting operations within the tank were planned through 37 primary and secondary holes at approximately 3m centres (Fig. 8). Initial preparation required installation of a 'stuffing box' (Fig. 12) over each borehole position to allow drilling under the challenging anticipated 3 to 4bar groundwater pressures.

Initial drilling extended 500mm below the tank base slab to allow primary contact grouting between the base slab and formation mudstone. During these works high groundwater pressures were only experienced close to the observed groundwater ingress locations; limited pressure was encountered elsewhere. Voids up to 700mm depth were encountered directly below the base slab in locations around the sump where the predominant groundwater and fines ingress was observed. This validated assumptions associated with assessment of this being the primary threat to the structure. Grouting operations demonstrated extensive connectivity between borehole positions with a number of connections being identified across the tank. Figure 13 illustrates typical drilling and grouting operations within the tank.

Fig. 12 – 'Stuffing box' installation

Descending stage drilling and grouting commenced in the primary positions. Drilling and grouting was completed in advance of the next stage to ensure progressive improvement to stability (Fig. 14). Interpretation of ground investigation works undertaken concurrently allowed final treatment borehole depths to be scheduled to ensure penetration into the underlying Halite was avoided (see above and Fig. 10).

Grouting adopted the Grouting Intensity Number 'GIN method' (Lombardi *et al* [1993]) to restrict the risk of rock hydro-fracturing as grout volumes increased. Grouting was terminated when a maximum specified pressure (500kPa/73psi) or a minimum specified flow rate was achieved. The maximum specified pressure was based on a structural assessment of the existing base slab and it's working limits such that it's continued integrity was not compromised. Connectivity between primary grouting locations at 6m centres was observed confirming the early design model that suggested mudstone had suffered significant degradation. The success of the primary grouting meant that secondary grouting positions were not required for grouting and were utilised to validate the effectiveness of the overall treatment.

Limits of vertical displacement of 40mm and 5mm to both the base slab and corbel ring beam respectively were imposed before the onset of grouting operations. These elements of the structure were continuously monitored throughout operations within the tank. The limits of displacement imposed were based on conservative initial estimates of the possible relative position of the base slab assuming that it had hogged during initial construction as per the original design. During grouting operations surface concrete cracking was observed around the sump (Fig. 15) within the limits of imposed displacement. On observing this cracking grouting works were temporarily suspended pending review. The engineering team concluded that the observed distress, to a relatively inflexible area of the base slab, had been induced as a result of the observed rapid recovery of external groundwater uplift pressures. It was suspected that the base slab had never realised full uplift pressures that might have contributed to the distress observed. With continued grouting operations monitoring indicated no further progression of the observed distress confirming adequate initial base slab design. Concrete repairs were undertaken to make good the slab.

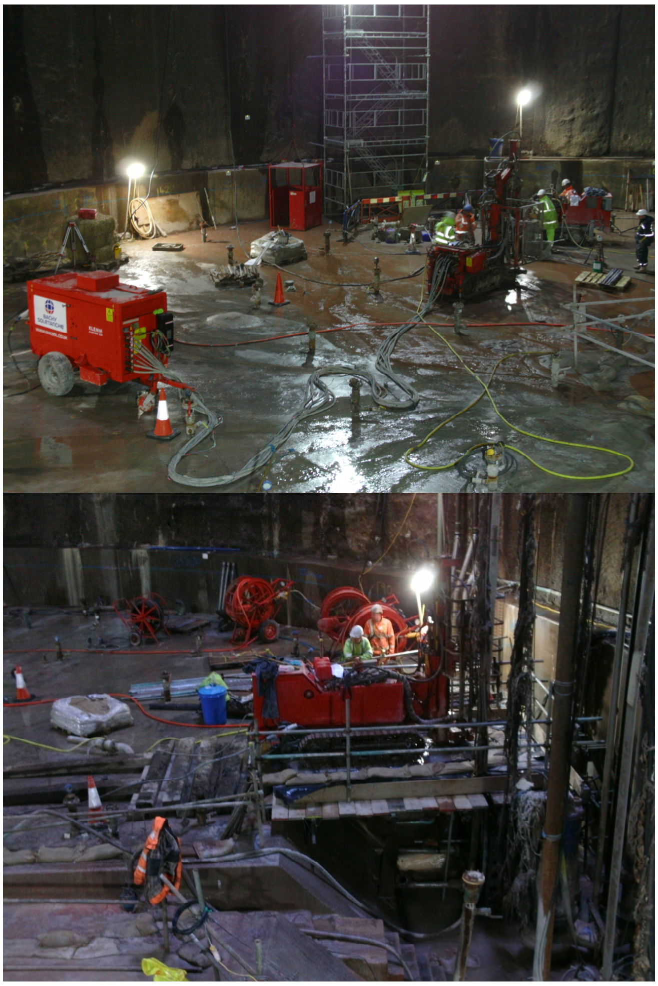

Fig. 13 – Site operations within the tank.

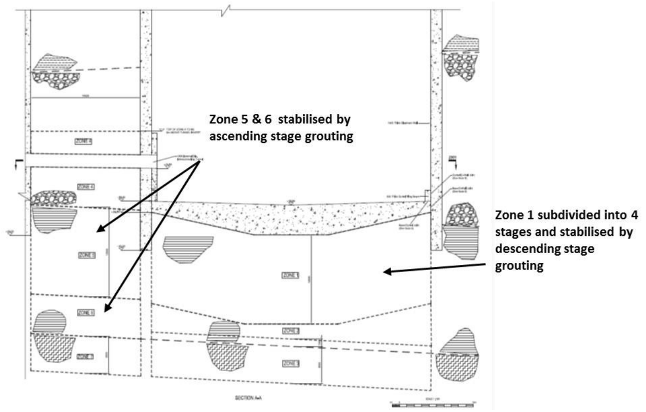

Fig. 14 – Investigation and treatment zone delineation drawing.

Fig. 15 – Cracking to tank base slab in vicinity of the sump.

Site construction works were completed ahead of schedule and the asset was returned to operation for the 2011 open bathing waters season.

Inspections and Monitoring

Post treatment external groundwater monitoring continued throughout the summer (May to September 2011) within boreholes BH101 to 103. Internal tank inspections and monitoring were programmed within November 2011.

Continued groundwater monitoring following completion of site works indicated continued recovery to levels comparable with those demonstrated during pre-construction investigations (Fig. 16).

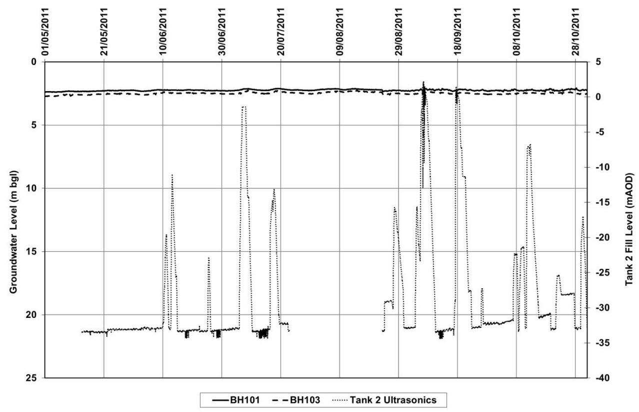

Fig. 16 – Post Construction Groundwater monitoring

Post treatment internal inspections demonstrated the successful stemming of observed groundwater ingress. Also, no further progression or deterioration of concrete cracks to the base slab was recorded.

It was considered that the various works had achieved the overall concept objectives.

CONCLUSIONS

During construction the following observations were made that verified earlier design assumptions:

- High groundwater pressures were initially limited to the primary observed ingress points.
- Initial base slab coring works identified voiding of up to 700mm immediately below the base close to the main groundwater ingress.
- Geophysics suggested high chloride groundwater flow through the mudstone strata and established that significant voids were not present within the Halite.
- Grouting in the mudstone demonstrated an extensive and complex network of voids/flow paths.
- The injected volume of grout within the Mudstone was within a few per cent of the design and pre-contract estimated volume of dissolved gypsum validating the initial design model.

A phased approach to the investigation and remedial works allowed the following:

- Detailed project scope to be defined early.
- Limitation of works to specific strata horizons where required.
- Remedial grouting works to be achieved within a single outage avoiding two phases of construction works with additional expense.
- Completion of required works within tight programme constraints.

The project was considered an overall success and the tanks were operational for the start of the 2011 bathing season. The works undertaken form part of a multimillion pound investment by UU to ensure compliance with prevailing standards to improve the quality of coastal bathing waters. The solution provides assurance of significantly increased longevity for storage for the community in the long term.

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