Grouting Works – A successful measure to optimize the construction of major infrastructure projects.

Travaux d'injection – Une mesure performante pour l'optimisation de la construction de projets d'infrastructure majeurs

Robert Thurner
Technical Director, Keller Grundbau, UAE, r.thurner@kellerme.com

Sami U. Raja
General Manager, Keller Qatar WLL., Qatar

Kulmer Reinhard
Head of Anchor & Grouting Technique, Keller Grundbau, Austria

ABSTRACT: Doha metro is an 85-km railway network in Qatar. There will be approx. 100 stations built for the entire Metro Network, partially within the city centre of Doha. In addition to the Metro projects, experience of other examples for value engineered grouting solutions will also be presented. Keller has executed geotechnical works for the construction of the Metro stations and cross passages for three different lines in Doha. A wide range of geotechnical challenges were encountered and resolved during the course of these works. This include fractured rock conditions, selection of grouting parameters based on the design targets, permeability testing pre & post grouting and effective grouting technologies. This includes a combined application of cement based and chemical grouting. In the proposed paper selected, case histories from these projects and some interesting details will be presented that throw a light on the multiple challenges and solutions from the execution of the geotechnical works for these optimized projects.

RÉSUMÉ: Le métro de Doha est un réseau de 85 km au Qatar. 100 stations sont prévues pour l'ensemble du réseau, en partie dans le centre de Doha. Différents types d'excavations ont été mis en œuvre, comme les parois moulées, parois de pieux sécants, pieux jointifs et excavations avec béton projeté ou treillis soudés en tant que protection en surface. Un nombre significatif de défis géotechniques a été rencontré, tels que des conditions de roche très fracturée, pertes importantes de coulis, pénétrations d'eau, inexistantes dans les cas usuels mais présentant ici des fuites modérées ou des flux très importants sur une longueur de plusieurs mètres de forage, mise en œuvre de techniques et directives d'ancrage variées, changement de type de paroi d'excavation et de dimensionnement d'ancrage, également en cours d'exécution. Pour les travaux d'ancrage, différents systèmes provenant d'Europe et d'Asie ont été utilisés à la demande du client, permettant de satisfaire des critères stricts tels que 10 ans de durée de vie pour des ancrages principalement amovibles. Au cours de l'installation des ancrages, des difficultés nécessitant des mesures urgentes comme des cavités et un flux d'eau important jusqu'à 300 l/s ont été résolues avec succès. Des détails particulièrement intéressants, des obstacles rencontrés et des solutions simples apportées pour l'exécution des travaux géotechniques seront présentés sur la base de ces exemples.

KEYWORDS: Grouting, infrastructure, excavation support, optimization.

1 INTRODUCTION

Qatar currently has a construction boom taking place, largely, as a result of infrastructure requirements for the upcoming world cup in 2022, Qatar vision 2030 and large private sector investments. This paper highlights the scope of work and techniques utilized in executing grouting and shoring works.

2 GENERAL OVERVIEW

2.1 *Doha Metro Qatar Integrated Rail Project*

The Doha metro is a 85-km railway network and a part of Qatar Integrated Rail Project (QIRP). QIRP will include the east coast link, high-speed link, freight link and a light rail system. The railway will serve the suburbs of Doha and developments such as Lusail, Education City, and West Bay. There will be approximately 37 stations & 60 further excavations built for the entire Doha Metro Network by 2020 (see Figure 1).

Figure 1. Overview about Doha Metro, Qatar Integrated Railways Project (QIRP)

2.2 *Underground Conditions*

The general underground conditions in Doha are shown in figure 2. There have been rare cases where open cut excavations in urban areas have had to utilize intensive dewatering schemes with wells, open trenches and local dewatering measures for this project.

The geological sequence of Doha are Quaternary and Tertiary. The residual soil has sand, gravel or clay as its predominant component and can be described as light brown, sandy, silty, gravelly, clayey, fine to coarse SAND/CLAY/GRAVEL with gravels that are fine to coarse sub-angular to sub rounded fragments of limestone. Residual soils are generally derived from physical and chemical breakdown of the underlying limestone bedrock. These materials are directly overlying the Simsima Member of the Eocene (upper Dammam Sub-Formation), Midra Shale, and Rus Formation.

Dissolution cavities can be occasionally encountered. Other small voids and fissures are also encountered in the limestone strata. When in proximity to the shore, these can be connected with the sea also greatly influence the local strata permeability.

Simsima Limestone can generally be described as unweathered to destructured (completely weathered). It is frequently fractured, crystalline dolomitic limestone with pockets of calcareous siltstone/silt. The upper layers of the formation are typically destructured which generally tend to be less competent in terms of cementation, strength, fractures and weathering with depth (RQD values vary from 0% to greater than 50%). The limestone has highly variable intact strength (UCS values vary from 5 MPa to 30 MPa and RMR vary from 11 to 55). It is also frequently intermixed, or contains pockets of very poorly to well cemented siltstone.

The Midra Shale Member consists two different facies including the Midra Shale/Siltstone and Midra Limestone. These layers can easily be identified in figure. These two facies are interbedded and sometimes there may be up to three layers of siltstone with interbedded limestone. The thickness varies from 0 - 4m. The top and bottom of the unit are generally defined by the presence of the siltstone layers. This unit is highly variable in terms of intact strength (UCS values vary from 1 - 20MPa and RMR vary from 45 - 56).

The Rus Formation consists of very weak to weak, off white to dull, porous, fossiliferous, fine-grained limestone in the upper part of the formation, followed Lower part of it is Rus Formation Gypsum which is weak to strong, light to greyish brown, Gypsum interbedded with limestone and claystone. This unit is highly variable in terms of intact strength (UCS values vary from 1 - 30MPa and RMR vary from 43 - 69).

3 GROUTING WORKS

Due to the rocky strata of the Qatar Peninsula, permeation grouting was considered by some designers as the primary solution for water control at Doha metro project. Keller executed permeation grouting work at both the Gold Line and Red Line south projects. The purpose of these measures have been to reduce the water inflow. Therefore, the entire water management system typically consisted of active dewatering using deep wells both outside and inside the excavations. This system decreased permeability by executing the permeation grouting and French drains for the collection of the water inside the excavation (Figure 3).

The grouting technique employed was bottom up grouting using the installed Tubes a Manchettes (TAMs) to stabilize the borehole. Borehole plans were divided into primary, secondary & tertiary boreholes. Each of the vertical boreholes was sub-divided in depth into different stages of 3 to 5m typically. Each stage was sub-divided into steps depending on the grout intake.

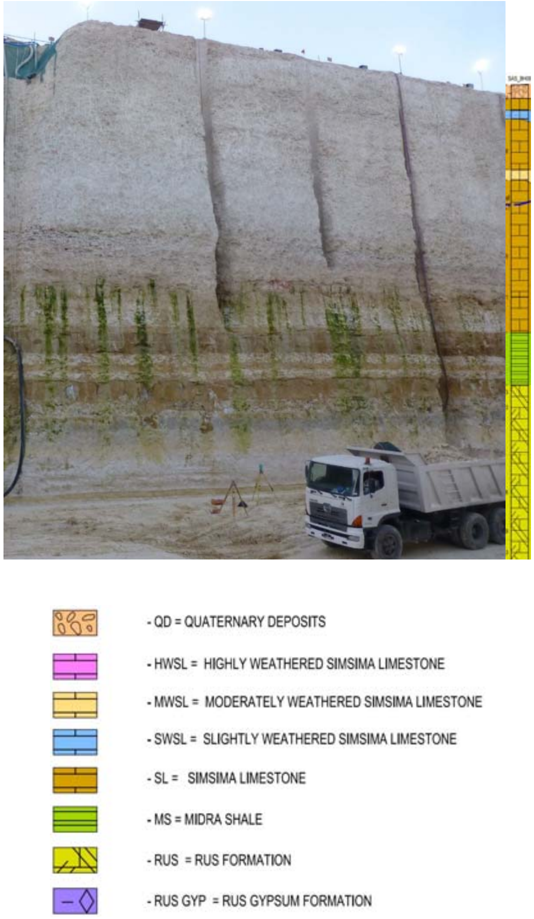

Figure 2. Ground condition excluding overlaying sand layer in Doha City

Grout volumes and pressures were monitored and recorded to an entire overview for the individual locations. Such grout consumptions were depicted in longitudinal sections. Zones of high consumption were indicative of high fracture zones and additional grouting works have been executed in these areas. The continuous evaluation of grouting data assisted in treating the ground with the right grout mixes and quantities. The design concept of grouting curtain is shown in figure 3.

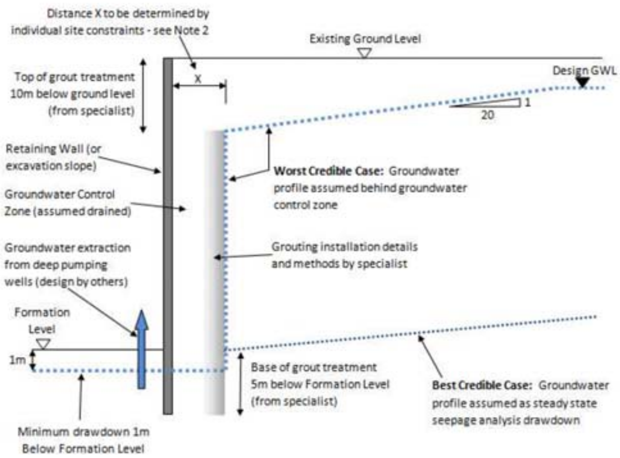

Figure 3. Design model with grout curtain for reduction of water pressure (from ELS design report)

The term "grout curtain" is used in the below sections for the executed grouting to reduce the permeability until a certain extent, not really stopping the water inflow in general.

3.1 *Standard grouting works at Gold Line*

For metro stations up to 40m x 800m size (Figure 4) permeation grouting using TAMs have been executed from the surface. The TAM with bottom-up grouting stages had been preferred to avoid extensive drillings works which would be required for the top-down approach.

The grouting itself has been executed using standard technologies like single and double packers, colloidal mixers and piston pumps installed in a grouting container. Typically, three different mixes have been used. For the grouting process, clear pressure and volume criteria have been defined depending on the overburden, water levels and in-situ rock conditions.

The pressure was limited depending on the depth of the individual stage. In most cases a maximum effective pressure of 2 to 10 bar has been applied. Regarding the volume criteria a total quantity of 2.4m^3 for the first two mixes have been allowed, whereas for mix no 3 (the thickest one) the grout has been pumped until the pressure criteria has been reached. Drilling logs & grout consumption in primary boreholes reveals the efficiency of selected pressure and volume criteria.

Three metro stations were grouted with a grout curtain design of preliminary distance between the boreholes of 10m and one metro station grouting works was carried out to mitigate excessive water ingress into the excavation box.

Figure 4. Open cut excavation with grout curtain

Project Summary is :

- Commenced in August 2014 and finished in April 2015
- Drilling and TAM installation of more than 30,000m for maximum depth 30m
- More than 4,000m^3 of grout
- Standard spacing between primary boreholes was 10m; secondary and tertiary boreholes were completed after evaluation of the drilling and grouting data.

Due to high temperatures of up to 55°C during in the summer, the grouting works were mainly executed during the night shift (Figure 5). Otherwise, permeation of grout into fissures/fractures would have been restricted and ultimately would have reduced grouting efficiency. Figure 6 shows how some fractures above the excavation level were filled with grout.

It has to be mentioned that during the entire grouting works dewatering works using deep wells has been ongoing nearby the grouting application, Logically this lead to an reduced effectivity of the grouting, but has been required from the main client to enable the parallel ongoing excavation and shoring works. As foreseen the executed grouting works reduced the ground water intake by a factor of three to four as per the evaluation from the main designer.

In some particular sections additional cement grouting with accelerators has been used to totally stop the ground water inflow to allow dry preparation works for the reinforced concrete.

Figure 5. Grouting at night shift

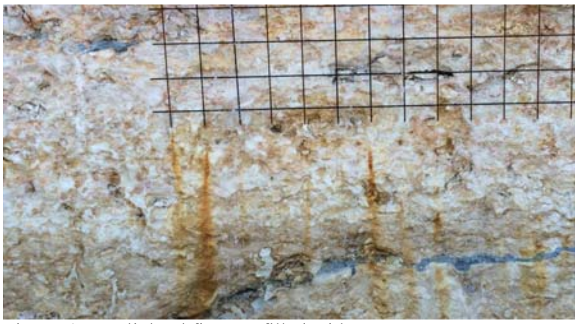

Figure 6. Day lighted fissures filled with grout

3.2 *Remediation Works – Flooded Station*

Keller was engaged in this project for mitigation of a flooded excavation pit of approx. 27 * 180m. The original design was open cut with active de-watering using deep wells. Huge discharges of water could not be dealt with as the excavation proceeded below 10m excavation depth out of a total excavation of 22m. The dewatering amount went up to 2,000m^3/hr, from a design value of 700m3/hr, even at only 10m excavation level.

Figure 7. Excavation works pre and post grouting excavation box.

Cement grouting techniques with TAMs has been used to create a grouting “curtain” to reduce the water inflow into the excavation. The grouting work has been concentrated in the Simsima limestone which had a high permeability / fractured. The cement grouting has been the preferred option since in comparison to chemical grouting and the given size of the excavation pit the cost for the unknown quantity of material has a lower influence. This has to be seen in particular with the running dewatering of 2,000m^3/hr even during the application of grouting. To avoid any damage of dewatering pumps due to grouting works nearby a close cooperation between the grouting and dewatering teams had to be ensured on a shift base. Each pump has been switched off nearby grouting works and reactivated including air-flushing afterwards. This process had to be done for the individual pumps several times during the execution period for grouting of approx. one month.

This resulted in the required reduction of approximately 30% of water inflow therefore enabling the client to excavate down to the design depth (Figure 7).

Project Summary is:

- Commenced in Jan. 2015 and finished in Feb. 2015
- Drilling and TAM-installation of more than 7,500m
- More than 400m3 of grout volume was pumped
- Standard spacing between primary boreholes was 3m
- Secondary boreholes were completed after the evaluation of the drilling and grouting data

4 QUALITY CONTROL AND HSE

The grouting process for the project required a very strict quality control and assurance plans. This quality assurance involved material quality e.g. viscosity of grout, material type, free water determination, strength of grout, etc. For drilling, a detailed checklist had to be followed which included drilling logs, logging of loss of air/drop of tool and geometrical parameters. Regular calibrations, certification of the plant, equipment and personnel ensured the quality of the process. A detailed risk assessment including mitigation measures were also in place.

Keller executed all projects as per Keller´s and the client's strict HSE policies. All hazards related to drilling and grouting activities were identified and mitigated. Risk assessments were prepared for each activity ranging from drilling to the handling and lifting of rods, casings and materials, grouting works, pressure hoses, equipment handling, material handling, pre-stressing, etc. All hazard ratings were reduced to acceptable values. Training for workers, operators, supervisors and on-site management staff were conducted regularly. Environmental and personnel health and safety concerns were fully monitored and corrected when necessary.

	Totals (ltrs)	No.	Average (ltrs)																
0 to 5 m	32,680	252 No.	130	25	65	20	110	25	65	124	58	19	27	20	29	38	10	20	[illegible]
5 to 10m	254,138	256 No.	993	732	193	295	46	157	1452	618	2475	353	349	96	1955	324	261	448	[illegible]
10 to 15 m	347,653	258 No.	1,347	217	296	171	2141	292	2176	899	2540	395	2573	1519	1596	1743	1292	1631	[illegible]
15 to 20 m	396,797	258 No.	1,538	229	258	2465	1815	351	1021	1644	2852	1513	2463	1963	279	538	2876	2477	[illegible]
20 to 26 m	404,585	258 No.	1,568	657	1396	2490	1802	2882	2640	1517	2467	392	1654	1412	2642	1082	2586	2472	[illegible]
25 to 31 m	67,359	76 No.	886																
Sum	**1,503,212**	**1,358 No.**		**1860**	**2208**	**5441**	**5914**	**3707**	**7354**	**4802**	**10392**	**2672**	**7066**	**5010**	**6501**	**3725**	**7025**	**7048**	[illegible]
			Hole Depth (m)	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	[illegible]

Plan, Showing the Total Volume for Each Borehole

	Totals (ltrs)	No.	Average (ltrs)																
Primary P1	436,570	73 No.	5,980		2208				7354				7066				7025		
Secondary (exc. PB)	626,456	112 No.	5,593	1860		5441		3707		4802		2672		5010		3725		7048	
Primary P2	440,186	73 No.	6,030				5914				10392				6501				[illegible]
Sum	**1,503,212**	**258 No.**																	

Figure 8. Grouting data in longitudinal section and in plan view

Furthermore, the gathered data had to be evaluated directly on site to ensure a high quality grouting process. Therefore, simple tools have been developed to enable the geotechnical lead engineers to make quick, sound decisions about potential additional grouting works in certain locations. Some examples of the evaluated data and submitted sheets are shown in figures 8 and 9.

The various red colours shown in the above figure 8 indicate the amount of grout consumption per stage and borehole. A combined evaluation of the collected data from drilling (see figure 9) and grouting has been the base to decide if additional grouting works have to be done.

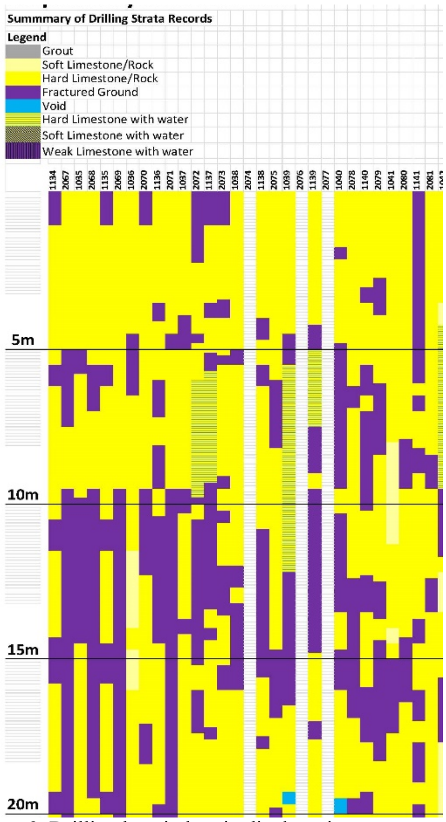

Figure 9. Drilling logs in longitudinal section

4 CONCLUSIONS

Making the use of well-established grouting solution to deep excavation pits in Doha has led to following conclusions:

- Grouting techniques are a value engineered alternate to typical water tight retaining structures as secant pile walls or diaphragm walls and in favorable conditions it can even allow open cut excavations.
- Flexibility of this technique allows mitigating negative effects of high water ingress, flooded excavation boxes and reducing water discharge from dewatering wells.
- Water discharges can be reduced to 1/3rd than the unimproved discharge values even executing the grouting during ongoing dewatering works close by
- Pressure grouting through TaMs in up-stage grouting method is quick and can attain better grout control throughout depths, ultimately saving costs in comparison to the top-down method.
- A sound combination of experience, innovative thinking, available resources, optimized design and high QHSE standards during execution project team to minimize the time, risks and costs for the owner.

5 ACKNOWLEDGEMENT

Keller would like thank all participant on the presented projects for their successful cooperation and team spirit.