Successful application of various anchor techniques against water pressure and under other particular conditions

Mise en œuvre performante de différentes techniques d'ancrage sous la pression de l'eau et sous autres conditions particulière

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ABSTRACT: Doha metro is an 85-km railway network in Qatar. There will be approx. 100 excavations built for the entire Metro Network, partially within the city centre of Doha. Various types of excavation support have been used; like Diaphragm walls, secant pile walls, contiguous piles and excavation with shotcrete or meshes as surface protection. A wide range of geotechnical challenges were encountered e.g. highly fractured ground conditions, high grout losses, water inflows which usually is zero to moderate leakages and occasionally enormous inflow within a range of few meters of drilling, application of various anchor techniques and standards, change of retaining wall and anchor design even during the execution.

For anchor works, various anchor systems from Europe and Asia have been used on client's requests, for challenging requirements such as 10 years life time for mainly removable anchors. During the anchor installation, various difficult and urgent issues such as cavities and high water inflow of up to 300l/s were successfully solved. Within these case studies interesting details, found obstacles and simple solutions from the execution of the geotechnical works will be given.

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. D'autres exemples présentant une valeur ajoutée particulière pour les travaux d'injection seront présentées en plus des projets de métro. Keller a effectué des travaux géotechniques pour la construction des stations de métro et des intersections pour trois différentes lignes à Doha. Un nombre significatif de défis géotechniques a été rencontré et résolu au cours de ces travaux : conditions de roche fracturée, sélection de paramètres d'injection selon les objectifs de dimensionnement, essais de perméabilité avant et après injection et choix de technologies d'injection les plus adaptées. Ceci a impliqué une application combinée d'injection à base de ciment et d'injection chimique. Dans la contribution proposée et sélectionnée, des exemples provenant de ces projets et des détails particulièrement intéressants seront présentés, mettant en évidence les défis et les solutions optimisées apportées à l'exécution des travaux géotechniques pour ces projets.

KEYWORDS: Anchoring, Excavation support, Qatar, Grouting, Dewatering, ELS

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 Keller has utilized in executing pre-stressed ground anchors.

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 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 GROUND ANCHORS

Ground anchors are typically required as an essential part of excavation's lateral support system. Keller was assigned the task for installing these anchors at 12 stations of two major metro lines. The given specifications from the clients required various types of anchors to be installed. Due to a very extensive and generally complicated material-approval system, the supplier for the anchor system had to be defined in a very early stage of the project. Various suppliers from around the world have been involved with the international joint ventures of design and build contractors from the beginning stages of the project.

3.1 *Types of Anchor Installed*

In addition to the standard requirements, international building codes have necessitated the use of the "semi-permanent" anchor for all projects. This particular requirement defined a minimum design life time of 10 years for all parts of the anchors. The background of this requirement was to cover a possible time for an open excavation of more than 2 years duration due to possible delay faced during execution later on.

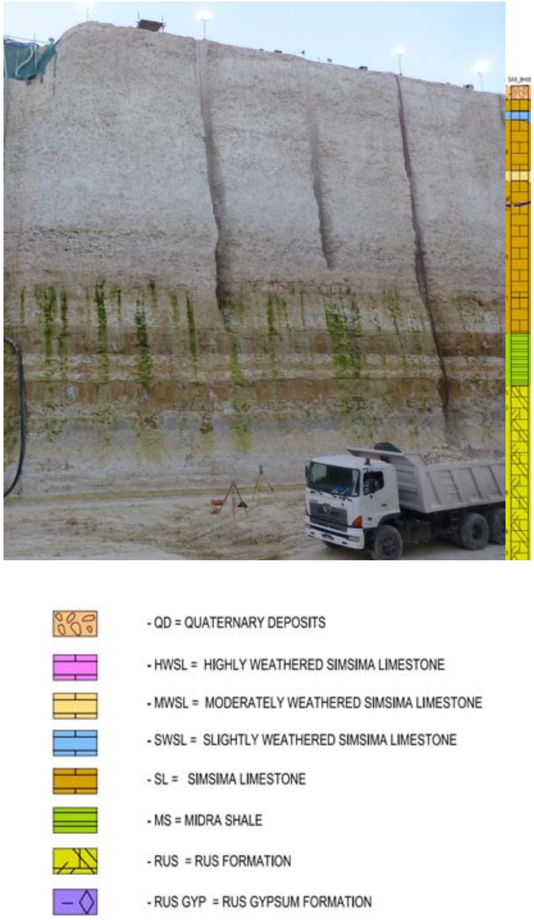


Figure 2. Ground condition excluding overlaying sand layer in Doha City

Since the majority of the excavations were located in inner city areas, the property owners or authorities of the adjacent plots often required removable anchors for their properties. Therefore, most of the installed anchors needed to have the capability of being removed after reaching a certain point in the construction phase of the permanent structure.

At one metro line, anchors installed by Keller were mainly from DYWIDAG System International (DSI), though other brands such as MK4 and Dextra GFRP anchors have also been installed. For DSI and MK4, semi-permanent and removable or non-removable anchors have been installed (Figure 3.I-IV).

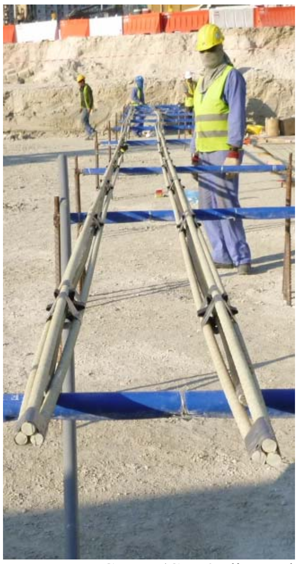
At a different metro line, all anchors installed have been from SAMWOO, and have a totally different load transfer mechanism for the removable and non-removable anchors. The non-removable anchor has been very similar to a permanent anchor from this manufacturer, except the head details. For permanent anchors, head details include a trumpet also for corrosion protection which was not present in anchors installed at this project hence called as semi-permanent anchor.

There are various differences detailed for several aspects of the anchors including the design of the individual parts of the anchor, details for corrosion protection, removal system for the anchors, details in the stressing procedures and the installation process itself. For removable anchors, three different systems have been utilized which are cut wire, thermally weakened section and withdrawal by rotating. An experienced team of operators and engineers was required to ensure proper functioning of all anchors. In particular since during the execution of a trial program before starting the execution of main works at one project, 16 out of 24 anchors executed from another geotechnical subcontractor failed. Therefore the entire success of this project was depending on the proper execution of those anchors, even if the handling is very peculiar for geotechnical site conditions. Figure 3 I-IV shows the physical appearance of different kinds of anchoring strands used in this project.

I - SAMWOO (PTF, RCD)

II- MK4 (Removable)

III - DSI (Semi-Permanent)



IV- Dextra GFRP (Cut & disposable)

Figure 3. I-IV Some Anchor Types

3.2 *Red Line North Underground*

Red Line North is one of the two parts of the red line of the QIRP Project. Keller has been assigned as the specialist geotechnical contractor by the design & build joint venture for execution of anchoring works. The work were completed at West Bay station, Doha Exhibition & Convention Center Station, Katara Station and at Exit Box near the Lagtifia Golf Course. In addition, co-ordination and support in the detailed preparation for the execution of the excavation and a high flexibility in the anchor installation process has been provided for the project since the sequence for execution changed several times. For a typical cross section from the design reports please see Figure 4.

Project Summary is:

- Started in November 2014 and finished in May 2015
- 1,250 anchors were installed with over 20,000m of drilling
- Walls: Diaphragm walls, bored pile walls, secant pile walls
- Anchor working loads varied from 500kN to 1,500kN
- Length of anchors varied from 12m to 27m

Table 1. Anchor Types with their characteristics

Type of Anchor	*Material*	*Strand Area (mm^2)*	*Yield Load (kN)*	*Failure Load (kN)*	*Function in case removable*
DSI	Steel	150	246	279	Cut wire & thermally weakened
SAMWOO	Steel	140	234	260	With drawl by rotation
MK4	Steel	150	246	220	Thermally weakened
DEXTRA	GFRP	127	130	250	Disposable

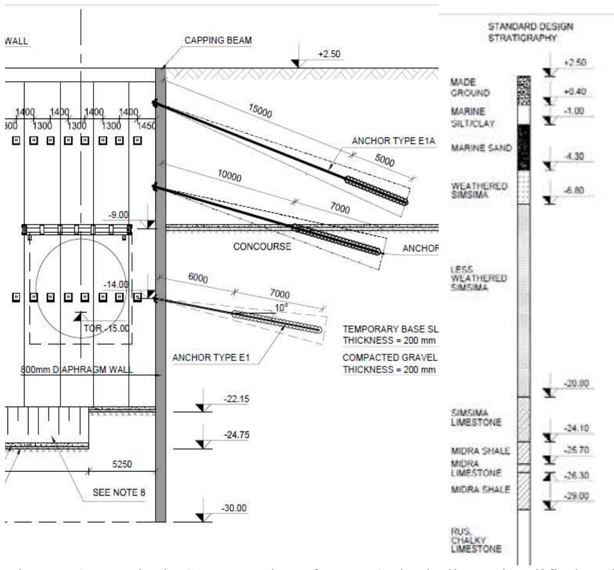


Figure 4. Typical Cross-section for ELS including simplified soil profile

The construction sites were congested because of its proximity to city center and highway along the coast as shown Figure 5. Some locations near the shore line lead to some serious issues due to high water ingress during and after drilling works which was a major challenge successfully tackled by applying accelerated grouting techniques to plug the high water ingress.

3.3 *Gold Line North Underground*

The Gold line metro is running from the airport through the city centre towards south of Doha. Keller was assigned as the specialist geotechnical contractor by ALYSJ joint venture for design and installation of ground anchors for nine different metro stations.

Project Summary is:

- Started in October 2014; finished by September 2015
- 1,500 anchors were installed with over 30,000m of drilling
- Tied Diaphragm walls, bored pile walls, tangent pile walls, contiguous pile walls
- Anchor working loads varied from 200kN to 2,000kN
- Anchor lengths varied from 12m to 45m

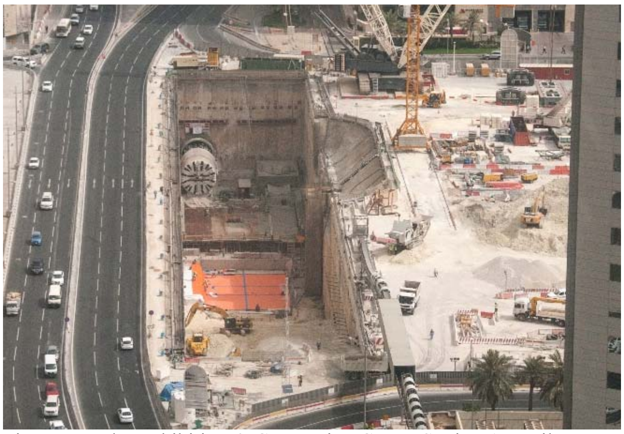


Figure 5. Doha Exhibition & Convention Centre Station As Built

3.4 *Anchor Design and Testing*

The detailed anchor design has been carried out in according to EN1997. General anchor requirements (working and test loads, number of layers, spacing etc.) were determined from Excavation and Lateral Support (ELS) design of the station. The typical design value for the bond strength and length within the various layers of rock has been 300kN/m2. This value has been verified during the various numbers of tests executed (see table 2).

As per ELS design, 100% of the anchors were tested for acceptance test as per EN1537. 2-3% of the anchors were tested for suitability tests and a few anchors on each station were designated as investigation test anchors. As per investigation load tests, the following skin friction values were observed in each type of strata. For design skin friction, a factor of safety of 2.0-2.5 was used.

Table 2. Anchor Types with their characteristics

Type of Strata	*Drill dia. (mm)*	*Bond Length (m)*	*Test Load (kN)*	*Skin Friction (kN/m²)*	*Des.Skin Friction (kN/m²)*
Simsima Limestone	150	3.0	1500	1028	300
Weathered Limestone	178	5.0	1114	778	300
Rusformation	178	4.0	2000	894	300

Loads for acceptance tests were defined at 125% of the design load. All anchors were tested first and then locked-off at the designated forces (Figure 6). A carbon fibre reinforced polymer (CFRP) jack was used for pre-stressing with maximum loading capacity of 2,700kN. These pre-stress loads were also monitored by installation of load cells at few anchor locations on each station. On some sites walling beams were also installed to distribute loads uniformly over a group of piles. For different anchor types, different pre-stressing protocols were developed.

3.5 *Installation of Anchors*

The standard execution process as per EN1537 was followed for ground anchors. Anchors were drilled with a diameter of approximately 150mm. Due to the highly fractured rock zones, the drilling need to be completely cased. Down to hole (DTH) powered with air drilling technique was used because of rocky formations. Finally the anchors were then installed, primary and secondary grouting were then carried out. This technique has been the key to the highly successful installation of anchors.

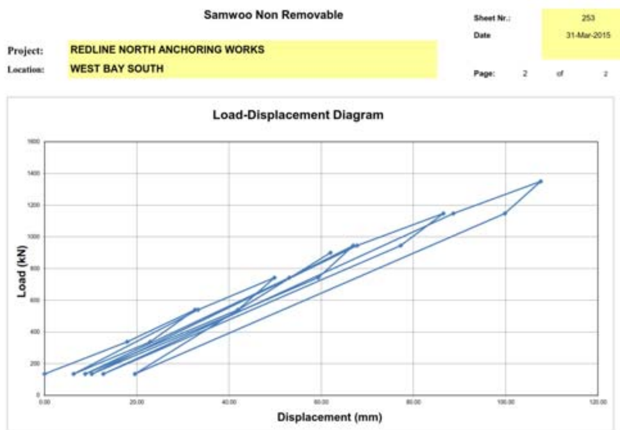


Figure 6 Suitability Test Graph as per EN 1537

In all cases dewatering measures (deep wells around and inside the excavation) were in place during the execution of the anchors. Due to the nature of the highly fractured ground, some cases of water ingress of up to 300 litres/second was recorded. Even though such numbers are exceptional, in many locations "normal" water inflow of 10-30 l/sec from an individual bore hole had to be managed. To stop such water ingress, pre-assembled anchors were fitted with multiple packers and injection tubes and that would seal the borehole. Pressure grouting was done in later stages to ensure proper grout in the bonded length. A detailed pressure and volume criteria was devised for quality control. During the initial phase of anchor installation, a detailed plan of the active dewatering system was developed to minimize the possibility of a negative effect of the water flow on the final capacity of the anchors. Figure 7 is showing some situations to be dealt with on site.

Figure 7. Some particular situation to be dealt to ensure capacity of anchor

4 CONCLUSIONS

Extensive experience with various anchor types at multiple support systems lead to following conclusions:

- Allowable ground bond resistance value in Doha region varies from 300-500kPa thus allowing designers to optimize their proposals.
- Successful installation of anchor systems below ground water table in combination with ongoing dewatering has been proven to be successful even the execution is giving challenges due to the fractured nature of the ground.
- The simpler the individual removable systems are, the more reliable is their installation and greater are the chances of removing the anchors at a very high percentage.

5 ACKNOWLEDGEMENT

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