WTC 2013
Switzerland - Geneva

World Tunnel Congress 2013 Geneva
Underground – the way to the future!
G. Anagnostou & H. Ehrbar (eds)

ISBN 978-1-138-00094-0

Ground conditioning: STEP Abu Dhabi sewer project

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ABSTRACT: The paper presents a general overview of the Strategic Tunnel Enhancement Programme (STEP), 40-kilometer long wastewater tunnel, which will upgrade the Emirate's previously strained sewage network in Abu Dhabi, UAE. The whole project includes 3 contracts: T-01, T-02 and T-03. The contracts T-02 and T-03 were assigned to the Italian Company IMPREGILO, that is excavating with TBM-EPBs manufactured by Herrenknecht. In particular, the T-02 covers 14.5 km of tunnel from West/Southwest of the Khor al Maqta to the Mafraq Pump Station, excavated from winter of 2011 to spring of 2012.The 3 TBM working for the T-02 excavated in a ground consisted mainly of mudstone and gypsum, where presence of underground water was expected. Prior to the EPB launches, the UTT (Underground Technology Team) of MAPEI carried out a series of laboratory tests with samples of soil coming from the job-site, with the aim to characterize the soil and find out an estimation about products and parameters for ground conditioning. These laboratory tests were later controlled directly on site during the TBM advance and optimized according to the local conditions. In particular, the optimization of the ground conditioning parameters allowed to complete successfully the T-02 contract in approximately one year of production.

1 Introduction

The government of Abu Dhabi has developed an important hydraulic project, the "STEP", Strategic Tunnel Enhancement Programme, which has the aim of satisfying the growing demand of management of used water, coming from the current and future development foreseen of the city of Abu Dhabi.

The project consists in the construction of a deep tunnel to link the city center with the future treatment plant in order to collect all the used waters coming from the city and suburbs of Abu Dhabi. The whole tunnel will reach the length of 40 km, with a constant slope in order to bring waters by gravity to the treatment plant. Being a gravity tunnel the depth of shafts increases from the city center to the suburb where the last one reaches the depth of 100m

For the realization of the project the whole tunnel length has been divided in 3 parts named T-01, T-02 and T-03. In the chart below the main characteristics are shown:

Table 1. STEP project sections

	Sections		
	T-01	**T-02**	**T-03**
Total length	16 km	14.5 km	10.5 km
Number of shaft	3	3	2
Number of TBMs	3	3	2

Since the total length of aprox. 15 km of the T-02 Contract has been already completed by Impregilo, the ground conditioning parameters and correlated productivity results are described in this paper.

STEP T02 contract includes 3 Herrencknecht TBM. On April 2011 the first TBM was launched in a 16 m diameter and a 50 m depth shaft, emerging on April 1st, 2012 (figure 2). The second TBM was launched on the end of June 2011 concluding on May 1st, 2012. The third TBM from the T-02 contract started to excavate at the end of July 2011 and emerged at the end of May 2012).

The new STEP tunnels are a challenging underground construction taking into consideration the high depths (WS 5-50 m deep and 16 m diameter) of overburden present.

In the table 2 are the main parts involved in the STEP project:

Table 2. STEP project main parts

Client	Abu Dhabi Sewerage Services Company (ADSSC)
Consultant	CM2MHILL
Contractor	IMPREGILO S.p.A

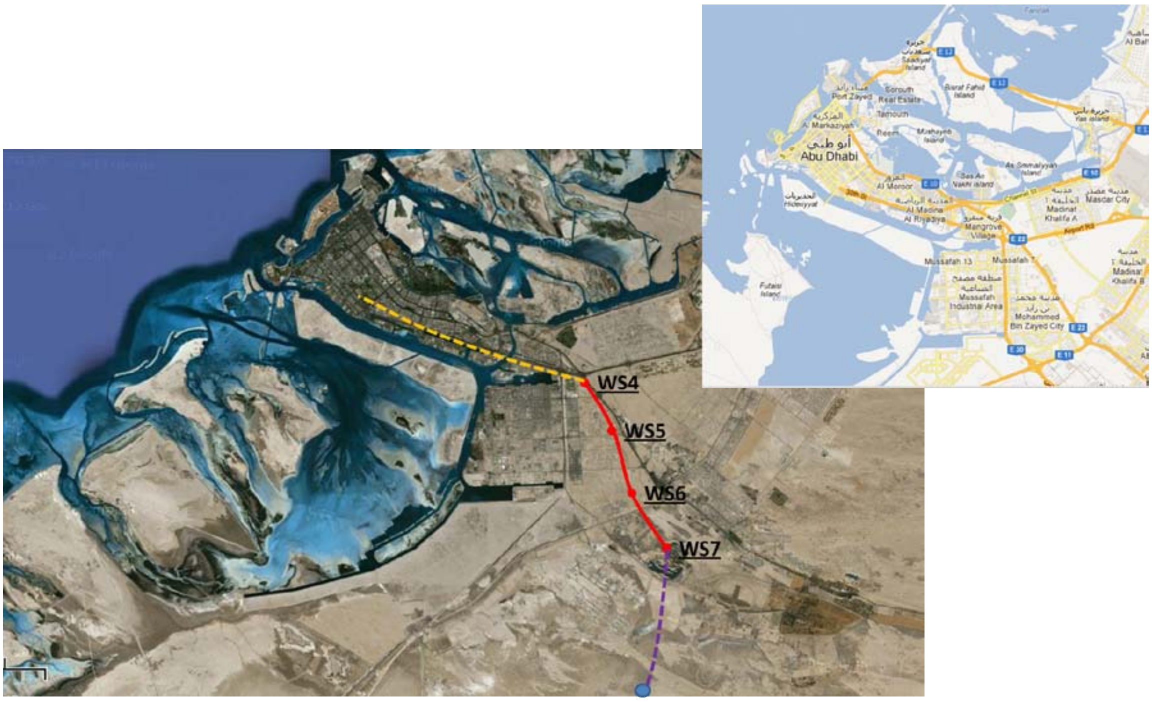

Figure 1. Abu Dhabi "STEP" project location. Source: ADSSC

Figure 2. Positioning of the Herrechnecht TBM shield on the bottom of the shaft 7

Table 3. T02 contract STEP project characteristics

T02 contract Tunnel length	Approx. 15 km	**WS5**-5251 m	**WS6**-5159 m	**WS7**-4809 m
T02 Contract- Tunnel Boring Machines Characteristics				
Machine type	Earth pressure balance shield			
Bore diameter	6.340 mm			
Length TBM + Back-Up	Aprox.106 m			
Power	3 x 315 kW			
Cutter head speed	0-4.5 rotation/min			
Max. working pressure	6.0 bars			
Lining type	Pre-casted segments			
Intern ring diameter	5500 mm			
Segment length	1400 mm			
Number of segments for ring	5 plus crown			

Figure 3. Shield of the Herrenchnecht EPB used for the Hydraulic tunnel "STEP"

2 Geology of the T02 Contract

The project area geology consists in a liner coastline dissected by ancient channels and creeks made by marine sands and silts, which in addition of wind erosion, capillary action and evaporation has led to hypersaline Sabkha deposits. These deposits overlay alternating beds of carbonate rocks which are predominantly dolomite and they consist of mudstone, claystone, siltstone, calcarenite, carbonate sandstone, gypsum and cemented sands. The subsurface are considered to be in a karst terrain with carbonate based rocks susceptible of dissolution.

The T02 contract shafts penetrate the superficial deposits into saturated silty sands followed by a sequence of mudstone and gypsum.

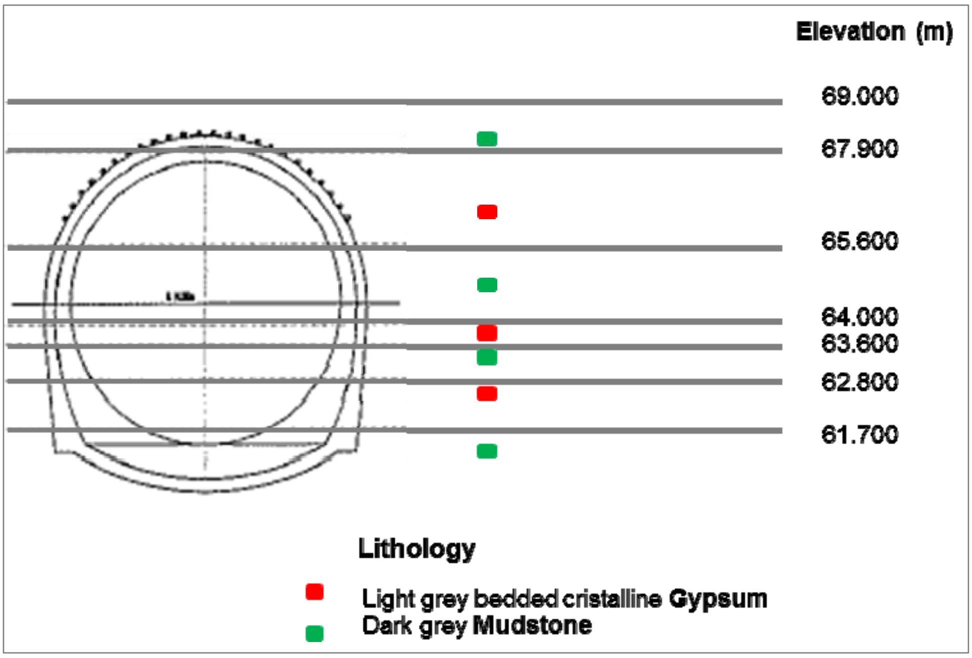

Figure 4. Working Shaft 5 Geological profile, "STEP" project

The geological profile from Working Shaft 5 (figure 5) shows difficult conditions which could develop problems for the ground conditioning as:

- The heterogeneous ground, can generate problems to correctly choose the ground conditioning parameters that should be continuously adapted during the TBM advancement according to the local lithology.
- The fine particles of clay, present in the mudstone and inside some cracks in gypsum, are particularly sticky when wetted. The accumulation of material "glued" onto the metallic parts of the TBM (on the cutting wheel and inside the excavation chamber) create many problems in the EPB operations. Therefore, the stickiness effect must be minimized in order to avoid slowdowns in TBM production.
- The mineral gypsum ($CaSO4$ when anhydrate or $CaSO4 . 2H2O$ when hydrated), at high temperature (present at the TBM face and inside the excavation chamber), tends to swell and to get very high adhesive properties, thus creating the same problems described above.

During the excavation of the Working Shaft 5 (WS5) several samples of ground were collected.

The samples show the main composition of the ground area:

- light grey gypsum with some cracks.
- light grey to dark grey mudstone intercalated with gypsum.

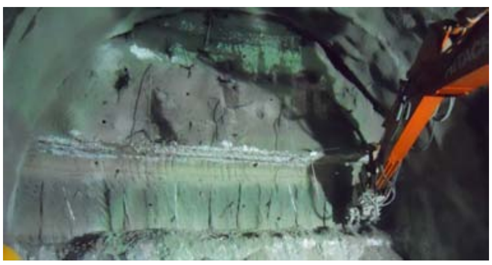

Figure 5. Mudstone and gypsum strata present on the WS5 at the TBM depth

Figure 6. Ground excavated in the WS5 at the TBM depth

Figure 7. Samples of ground from the TBM depth

As a first laboratory test, a sample of ground, constituted approximately by 50% of gypsum and 50% of mudstone, was wetted in a bucket. The stickiness effect that was produced by the addition of pure water is shown in the figure 8. Figure 8 shows the adhesion of the soil to the tool metal surface, which increase the abrasive wear of the cutting tools on the TBM while excavation.

Figure 8. Addition of pure water to the ground and thixotropic properties of the wetted material

3 Laboratory ground conditioning tests

The geology described previously demonstrates that the ground conditioning is very important in order to achieve a successful TBM advancement.

Laboratory tests are necessary in order to choose the correct product or products for this material and to obtain a first idea of the ground conditioning parameters to set up in the TBM.

For this reason, ground samples were taken from WS5 and sent to the “Technical University” of Turin (Italy), that started a cooperation with MAPEI several years ago with the creation of a laboratory fully dedicated to ground conditioning tests is present.

According to the sample of ground, the product POLYFOAMER FP has been chosen for the tests. The POLYFOAMER FP is a high performance liquid foaming agent based on biodegradable anionic surfactants combined with a lubricating polymer, specially formulated for preparing stable foams.

For the tests, the foaming generator was set at a concentration of 2.0%, that represents a medium value for the use of POLYFOAMER FP.

A medium value of **FER** was chosen, which is useful to obtain a foam wet enough in order to superficially lubricate the material and at the same time with an acceptable half-life time.

Different **FIR** were tested until a suitable value was achieved, able to wet and lubricate properly all the ground.

Table 4. Parameters used for ground conditioning at laboratory test

Test	Cf [%]	FER	FIR [%]
1	2.0	12	50

Figure 9. Slump test

The slump test at the figure 9 shows the consistency of the conditioned ground with the POLYFOAMER FP. The ground is now plastic enough to be excavated and to transmit the EPB pressures over the tunnel face and its stickiness effect is minimized. The new ground consistency is suitable for EPB operations.

A second test was carried out in order to analyze the wearing property of the ground. With the abrasion test it is possible to measure the wearing that the ground to be excavated produces on a standard material and to make comparisons among different ground conditioning products and/or parameters.

The abrasion test consists of a disk, connected with an apparatus that rotates inside a bucket filled with approx. 20 kg of ground.

A constant pressure on the top of the tank for a period of 10 minutes and a constant speed of 320 rpm are applied, in order to simulate what happens during the excavation with the EPB. The weight of the disk is measured before and after the test. The difference in weight gives an idea about the abrasion of the soil and the produced wearing on the rotating tools.

Comparing the results between the natural and the conditioned ground, it is possible to see the effects of the addition of the POLYFOAMER FP to the ground.

The Table 5 shows the abrasion on the rotating disk in percentage for the natural ground from WS5.

Table 5. Soil abrasion of the natural ground test results

Weight of the disk before the test [g]	Weight of the disk after the test [g]	Loss of weight [g]	Abrasion on the disk [%]
150.00	112.50	37.5	25

The test shows that the natural ground has a high wearing property on the rotating disk.

Table 6. Soil abrasion of the ground conditioned test results

Weight of the disk before the test [g]	Weight of the disk after the test [g]	Loss of weight [g]	Abrasion on the disk [%]
150.00	144.00	6.00	4.0

It is possible to confirm that the addition of the current quantity of foam help reduce significantly the wearing (table 6) on the cutting tools.

4 Job site trials

Ground conditioning parameters determined from the laboratory must be tested at the job site, optimizing them according to the TBM behavior and the local geology through the alignment.

Impregilo and UTT Mapei worked together in order to find the optimal ground conditioning parameters during the T02 excavation.

The average ground conditioning parameters used at the job site are comparable with the values found after the laboratory tests at the Technical University in Turin. This confirms the utility of making laboratory test before the TBM launch.

The results demonstrated the correct choice of the POLYFOAMER FP as the foaming agent to condition the T-02 Contract ground. The lubrication effect and the reduction of the stickiness of the material on the cutter tools of the TBM were due the lubricant polymer effect created by the POLYFOAMER FP.

The optimization of the ground conditioning parameters made possible to achieve average records on productivity of 14.0 rings per day (20 m per day). Working Shaft WS5 and WS7 had 12.2 and 12.9 rings per day record, respectively. Advances rates hit 218 m per week and 777 m per month max (table 7). Lubricating water was pumped into the excavation chamber and at the face by means of additional 2 lines or by using a foam line. This further lubrication (10-20 m^3) of water was required when no ground water was present, in order to further facilitate the soil mucking out in particular high speed.

Table 7. T02 TBM performance statistics

IMPREGILO	WS5		WS6		WS7		T02 Contract (WS5+6+7)	
TBM starting date	12-Apr-11		30-Jun-11		22-Jul-11		12-Apr-11	
Total Rings Build	3751		3685		3435		10871	
Calendar days	357		311		315			
Daily average*	12.2		**14.0**		12.9		39.2	
Best shift	**18**	7-Mar-12	15	23/11	14	var		
Best day	**33**	7-Mar-12	30	23/11	25	22/11	75	7-Mar-12
Best week	**156**	wk 07/12	147	wk 06/12	145	wk 51/11	406	WK 07/12
Best month	**555**	Feb2012	510	Mar-12	512	Feb 2012	1559	Feb2012
B'through	1-Apr-12		1-May-12		28-May-12			

The ground conditioned with the **POLYFOAMER FP** with the following parameters at the Working shaft 5:

The TBM was set with the parameters as in table 8.

Table 8. Parameters use for foam generation at TBM trial

Trial	Cf [%]	FER	FIR [%]
1	1.8	10	50

5 Conclusion

Firstly the paper gives a general description of the project "STEP" in Abu Dhabi and then goes more in details about the ground conditioning system that was used during the excavation of the Contract T02.

Some preliminary laboratory tests were carried out, that allowed the choice of the most suitable product according to the geology to be excavated. The parameters were later optimized during the TBM advance and the final results showed a good correlation with what achieved previously in the laboratory.

The proper use of the ground conditioning system helped the Contractor achieve great results in terms of TBM advance speed and productivity, as described in the table above.

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