MICROTUNNELLING

A beautiful relationship

Dirk Derycke and Oliver Wiegner discuss a challenging large-diameter project in Casablanca, hailed as Morocco's first planned, curved microtunnel

ON MAY 23, 2011, the construction of a connector sewer to the future Sidi Bernoussi water treatment plant was awarded to the Denys Capep joint venture. Capep is a leading Moroccan construction company active in concrete construction, excavation and water infrastructure. Belgium-based Denys is a construction group specialising in gas, water, renovation and construction in Europe, Africa and the Middle East. Capep's know-how of Moroccan projects and the expertise of Denys' tunnelling division were combined to realise this important project.

The project comprises the construction of a 2,500mm id tunnel using microtunnelling over a length of 2,500m. Microtunnelling was chosen by the client (utility operator Lydec) and consultant Safège-C3E on account of the very permeable sandstone, the depth of the sewer below the ground water table, and the desire to minimise disruption to business activity at the surface. Next to the main sewer, two large connections will be constructed as an overflow to the Atlantic Ocean. Also required for the project are two starting shafts, two reception shafts and four intermediate shafts with depths of 10-18m.

To realise the shafts, numerous utilities had to be first located and then removed from this dense urban area, which has important harbour-related activities. Due to the presence of sand, clay and stones for the first 5-8m, the shafts were supported by a system of vertical beams (drilled into the ground) and horizontal sheeting. Subsequently, the excavation continued in fractured and permeable siltstone. Side-wall protection was fixed to prevent inflows of water, and rock anchors were installed in the shafts at frequent intervals to consolidate the rock.

The first shaft was ready around five months after the project started. By December 2011, the first equipment from Denys had started to arrive after a long and difficult journey, with all customs-related issues resolved.

HERRENKNECHT AVN 2500 TBM

Denys had purchased a new Herrenknecht AVN2500 microtunnelling machine equipped with a rock-cutting head and slurry-evacuation system; the integrated air-lock system would allow cutting-tools to be changed under compressed air. The geology that had to be crossed is rather homogeneous, very permeable and fractured siltstone and sandstone, with compressive strengths (UCI) ranging between 30MPa and 120MPa. Lowering of the tunnelling machine took place in the middle of January 2012 for the start of the first drive shortly after. The total drive length is 2,500m, split into three separate drives, of 940m, 800m and 810m respectively. The first drive of 940m – finished in the middle of May – was achieved using a two-shift system working 24/7.

Looking into the tunnel from the starting shaft

Project:	2,500/3,000mm microtunnelled sewer in East Casablanca
Client:	Lydec
Consultant:	Safège-C3E
Contractor:	Denys Capep joint venture

Technical information

Average advance:	8.47m/day
Max pressure main jacks:	270bar – 1131t
Telescope station pressure:	127bar
Max pressure interjack 2:	350bar – 974t
Max pressure interjack 4:	400bar – 1140t
Working hours:	2 shifts, 24/7
Accuracy of breakthrough:	V -2mm, H 10mm

The drives are designed with a low vertical slope (approximately 1mm/m) and horizontal curves having radii of around 900mm. This allowed the start and reception shafts to be positioned so as to minimise the effect on surface-activities.

To navigate these complex drives, Denys decided to use the SLS-Microtunnelling LT system from German navigation specialist VMT, with whom Denys has had a long and successful relationship.

A FIRST FOR MOROCCO

For the Casablanca project, Morocco's first planned curved microtunnel, Denys provided VMT with all necessary information relating to scheduling and completion of necessary survey works. Due to the complex alignment, intensive project preparation was necessary.

The project's total length was 2,500m; the first drive, P19-P16, had a length of 940m and a curve radius of 900m. The following two drives, both with grades of less than 1mm/m, were around 800m long and involved several 900m-radius curves.

VMT's preparation for the project included TBM measurement, take-over, checking and verification of the designed tunnel axis, installation of the navigation system, briefing the operators and accomplishment of the control measurements. The specified accuracies through the drive (including breakthrough) were +/-100mm horizontally and +/-20mm vertically. To achieve such accuracies required a laser total station system, for which the SLS-Microtunnelling LT system from VMT was chosen.

VMT'S PROJECT PREPARATIONS

TBM measurement

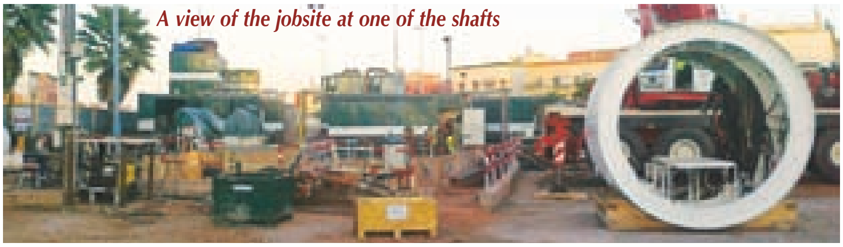
The electronic laser target (ELS) is an important element of the guidance system since it guides the advance. The target represents the movements of the TBM as exactly as possible. In order to guarantee this, it is important to determine the position of the ELS relative to the TBM axis.

The TBM measurement produces data on the position of the ELS in a machine co-ordinate system, defined by the circle centres. The installation co-ordinates of the ELS relative to the TBM axis and its roll and pitch angles can be derived from these. This guarantees the TBM driver that the machine moves in accordance with the guidance system. Another use of the measurement results is that the circularity or deformation of the shield skin may be determined. This ensures that the shield diameter is larger at the cutting wheel than at the rear of the shield. If this is not the case, the TBM would get stuck at the next curve along the alignment.

Survey network

The goal of VMT's network measurement is to establish a precise geodetic network to guarantee a successful breakthrough at the end of the TBM's drive. VMT elected to carry out network measurement on December 14, 2010, due to the very stable temperatures at that time of year, minimising the risk of refraction.

A major challenge of the survey network was the traffic situation. The measurement had to be undertaken along a highly trafficked, four-lane



A view of the jobsite at one of the shafts

arterial highway. Analysing the measurements was achieved using Tangens+ software. The survey points were placed around the start and target shafts, as well as along the tunnel alignment. These were marked with nails and serve as benchmarks for forthcoming measurements. VMT marked up at least 16 fixed points. The measurement was first calculated as free adjustment and thereafter transformed to the jobsite co-ordinate system, based on the survey points handed over by the jobsite surveyor.

Calculating designed tunnel axis

Normally, the alignment is handed over by the contractor. However, due to the survey network measurement, VMT checked the local geometry of this by measuring and marking up the start and reception shafts. As a result, the alignment had to be adjusted twice because the position of the target shaft had been changed several times by the local planning office. The alignment used in the VMT system refers to the co-ordinates determined during the network measurement.

NAVIGATION SYSTEM

The SLS Microtunnelling LT system is designed for the guidance of long-distance and curved-pipe jacking applications for pipe diameters above DN1200. The main component of the system is a servo-motorised laser total station, which is mounted inside the tunnel on a special bracket and moves along with the pipeline. The position of the laser total station is continuously calculated with help from the known (as-built) position of the already installed pipes.

The advantages of using the laser total station guidance system are:

- highest system accuracy;
- minimal effort for control measurements;
- no advance interrupts at system measurements;
- long drive intervals of up to 100m between control measurements;
- independence of refraction;
- independence of drift;
- robust hardware;
- optimal control by continuous monitoring of machine movements;
- fast action possible as deviations are quickly recognised;
- high advance output power;
- modularly expandable with further sensor and navigation systems;
- installing JC Pipe for real-time calculation of maximum allowed advance force;
- identifying problems along the alignment, and
- quality assurance due to real-time acquisition, analysis and notification.

In addition to the guidance system, VMT supplied an experienced engineer to oversee the guidance of the machine, which completed drive 1, over a length of 940m, in four months, including a curve of 900m radius for a length of 446m, to complete this complex project.

VMT NAVIGATION SYSTEM

Phase 1

A guided VMT SLS-Microtunnelling LT system was used from the moment the TBM commenced drilling on January 18, 2012. The laser station (a standard Leica TCA 1203 motorised total station, →

Denys-VMT teamwork

VMT guidance systems have helped achieve successful alignments with a wide range of tunnelling machines on projects globally.

Since 1998, VMT has supplied Denys with navigation systems and tunnel guidance know-how. Very complex and challenging projects in a wide range of different diameters (800-2500mm id) have been completed successfully thanks to the close co-operation between the companies.

A specialist in survey technology, VMT was founded in 1994 to supply tailor-made solutions, services and surveying systems to the tunnelling industry. Its main product development drive has been in the guidance of TBMs for segmentally lined and pipe-jacked tunnels. To date, VMT is present on six continents, with subsidiaries in Australia, China, Russia and the US.

➔ which includes an integrated diode laser mounted parallel with the visual axis and a sensor system allowing automatic targeting of prisms) was initially (in Phase 1) mounted between the push rams on a purpose-built measurement pillar. For reference measurement, a further pillar with a survey prism was installed outside the shaft.

The first 100m are measured from the fixed laser station, where the laser beam is continuously on the ELS target and follows the TBM during the advance. The calculated position values are displayed on the system's PC screen and saved in a database.

The system normally remains in Phase 1 until the laser can no longer activate the target unit, due to either distance or line of sight limitations. On this project, this condition was reached after 100m. At this point, it was already 50m into the curve and was approaching the position where the laser would no longer activate the target.

Phase 2

On January 31, 2012, VMT decided to move to Phase 2, where a bracket for the laser station with automatic tripod and inclinometer is mounted in the tunnel in such a way that the sight to the target unit is guaranteed at all times. Two extra brackets for the reference prisms were mounted a short distance in front of the laser station.

A prism mounted on the measuring pillar in the shaft is now used as the back sight reference. As the laser station advances with the progress of the pipe, its position is known from the previously stored reference points, which are indexed via the chainage.

The laser station is constantly updated with the

A view of the reference prisms used in Phase 2 of the project

information supplied by the distance measurement system in the start shaft. When a measurement cycle is activated – either automatically, after a pre-set distance or time interval, or by pressing a key – the laser station receives the signal to refer to the rear back sight target. The automatic positioning system of the total station is aimed precisely at the prism and the distance is measured. This data is transmitted to the PC. The 3-D co-ordinates of the axis point in the ELS target unit plane are now saved as the current course of the TBM.

Because of the fixed back sight target, the second phase allows the chainage of the laser position to be ascertained independently of the inter-jack stations, and thus more precise co-ordination of the reference points with respect to the longitudinal measurement.

In addition, a first measurement of each tunnel pipe was undertaken to get an impression of the stability/accuracy of the tunnel advance, and to allow time to adjust the system.

Phase3

As the distance between the laser and back sight target increases, eventually no measurement will be possible because of the effects of refraction, air turbulence or the curvature of the alignment. When this situation is reached, Phase 2 is completed. Therefore, on February 14, 2012, Phase 3 was installed.

The back sight target now had to be installed in a pipe at the longest practical distance from the laser station, taking into account the alignment of the tunnel for the remainder of the drive. This bracket is also equipped with an inclinometer to allow the roll of the pipes to be included in the computation.

With Phase 3, the SLS-Microtunnelling LT reaches its final arrangement inside the tunnel and is able to operate independently from the start shaft for about 80-100m without intermediate control measurements.

With each control measurement, the actual reference line of the tunnel is measured. The reference line tool is used to import the new line in the system database. Further advance is then undertaken in relation to the new reference line.

To recalibrate the guidance system, a control measurement has to be taken, normally every 80-100m. The guidance system in Morocco had been adapted in such an effective way that the distance between the control measurements could be increased up to 150m. The number of control measurements could be decreased to six.

CONCLUSION

On May 15 2012, the TBM broke through into the receiving shaft, and was recovered a few days later to be prepared for drive 2 – P14-P16. The breakthrough accuracy was 10mm in the horizontal axis and -2mm in the vertical. This completed a very successful first curved drive in North Africa. The combination of a precise and reliable automatic navigation system and proper survey measurements guaranteed that from start to finish the specified tolerances would be achieved.

Another important guarantor of success was the manpower available. This included the very dedicated preparation and jobsite management of Denys engineers, including Geert Heytens, Dirk Derycke, Mathieu Griselain, Thomas Geerts, Steve de Corte and Yassine El Fakire; the handling of the sensitive jobsite by professional and longstanding operators, such as Mario de Muynck, Michelè Ameye and their crews (Denys); and last but not least, the highly thorough management of navigation system and tunnel control measurements by system engineer Oliver Wiegner (VMT).

Control measurements

Measurement	Date (2012)	Chainage	Difference horizontal	Difference vertical
Phase 2	Jan 31	99.14m	9mm	-11mm
Phase 3	Feb 14	193.36m	25mm	8mm
KV 1	Mar 1	316.29m	20mm	-4mm
KV 2	Mar 20	428.37m	5mm	-1mm
KV 3	Apr 2	568.33m	-14mm	-5mm
KV 4	Apr 18	680.45m	21mm	1mm
KV 5	Apr 27	790.08m	-15mm	-8mm
KV 6	May 9	864.02m	-11mm	6mm

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