THE APPLICATIONS OF SURVEYING TECHNIQUES IN KUALA LUMPUR SMART TUNNEL PROJECT

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ABSTRACT

Underground survey, a branch of Geomatic engineering, is done practically in underground environment. The important applications of underground survey are tunneling and mining surveys. Recently, a special tunnel called SMART (Stormwater Management and Road Tunnel) was successfully constructed in Kuala Lumpur, Malaysia. SMART is the first tunnel in the world which combines two systems, i.e. a motorway system to reduce traffic congestion in Kuala Lumpur and a stormwater system to reduce flash flood in the city centre. Underground survey is an integral part of SMART Tunnel Project. This study examines the applications of surveying techniques in SMART tunnel project in various construction stages (i.e. pre-construction, during construction and post-construction). The following surveying techniques were used: control survey via GPS, total station and precise leveling; detail survey with total station; underground survey using total station; monitoring survey with total station and leveling; and specialized technique for real time survey during the construction.

KEY WORDS: Surveying Technique, SMART Tunnel

1.0 INTRODUCTION

Stormwater Management And Road Tunnel (SMART) in Kuala Lumpur, Malaysia is a new extreme engineering project designed to alleviate the flood problems and provide traffic relief in the City Centre of Kuala Lumpur. This project was implemented through a joint venture pact between MMC Berhad and GAMUDA Berhad, with Department of Irrigation and Drainage (JPS) Malaysia and Malaysia Highway Authority as the executing government agencies (SMART, 2003). This project commenced in Dec 2003 and was completed in June 2007.

The unique feature of this project is the 3 km double deck motorway within the stormwater tunnel at the centre of tunnel (Figure 1). The length of the stormwater tunnel is 9.7 km (Figure 2). The operation of SMART system is based on the flood discharge at Sg. Klang or Sg. Ampang confluence and the operation status of the motorway.

The SMART operational modes are divided into Mode I, II and III (Figure 3). Mode I is normal condition, where no storm or floodwater will be diverted into the system. Mode II will be activated during moderate storm and floodwater is diverted into the bypass tunnel in the lower channel of the motorway. Up to this stage, the motorway section is still open to traffic. Mode III is activated during major storm and the motorway will be closed to traffic. Sufficient time will be allocated to allow the last vehicle to exit the motorway before the automated watertight gates are opened for floodwater to pass through. In this event, the full cross section of the tunnel is available for water storage and diversion. The motorway will be re-opened to traffic within 48 hours after the closure (SMART, 2003).

Surveyors play a vital role in an underground project work like tunneling or mining project to clarify setting out, alignment and breakthrough error analysis. Underground survey is an important element in tunnel construction. Today's technology has changed the method and technique of underground activities with the usage of more sophisticated equipments. This makes underground survey easier, faster and more accurate. SMART project at city centre of Kuala Lumpur did involve underground survey.

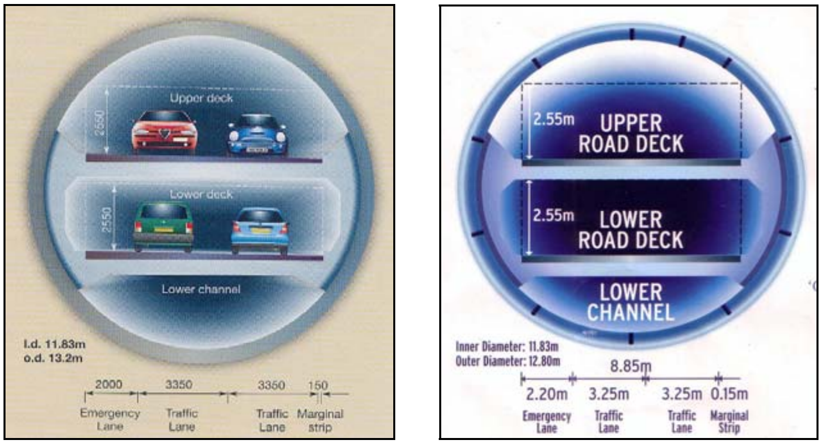

Figure 1: Special Features of SMART

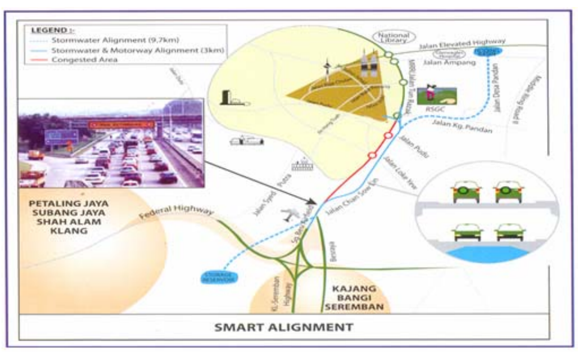

Figure 2: SMART Alignment

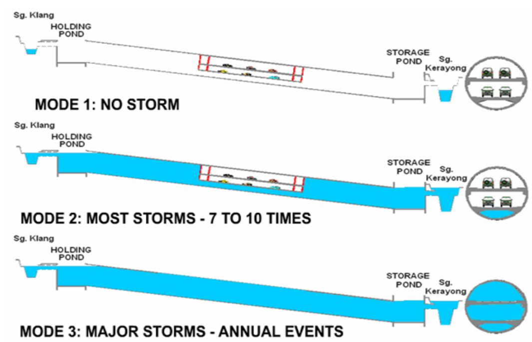

Figure 3: SMART operational modes

2.0 SURVEY METHODS

In SMART project, surveyor is responsible to perform the tunnel survey from beginning until the end of the project. Surveying applications are performed in various construction stages (i.e. pre, during and post construction) of SMART project.

2.1 PRE-CONSTRUCTION

Pre construction is the planning work before the SMART project is designed and constructed. The purposes of Pre Construction are to get the maximum physical data and economy aspect as this project is very costly. There were five parts in the pre construction phase (Figure 4): geological study, reconnaissance, detail survey, right of way (ROW) definition, and Tunnel Boring Machine (TBM) calibration.

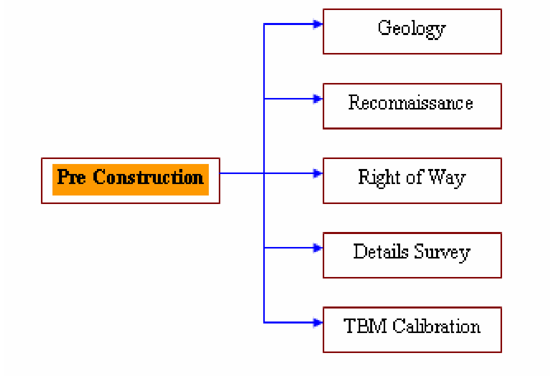

Figure 4: Five parts of Pre-Construction

Figure 5: Geological Condition of Kuala Lumpur

Kuala Lumpur city sits on karstic limestone geology with high ground water table. The special features of karstic limestone include cliffs, pinnacles, cavities, collapsed cavities and sinkholes (Figure 5). Overlaying this karstic limestone is loose alluvium (SMART, 2006). The geology data is important to estimate the mechanical reaction when the TBM (Tunnel Boring Machine) does the mining work.

Reconnaissance provides more information about the SMART area. It was done by MMC-GAMUDA Joint venture with JPS Malaysia, to investigate the tunnel, shaft location, position of the first point of mining process, ground condition, position of the machine (such as Crane and TBM) and others.

The detail survey was divided into two parts; survey of the natural features and the man made features. Jurukur Perintis was appointed as the licensed surveyor to carry out the detail survey. They applied the conventional survey method using total station to collect data in the SMART area. The data from conventional method are more accurate, complete and cheaper than aerial photography method.

Right of way (ROW) was prepared by JPS Malaysia. ROW describes the limit of work. ROW purposes are to determine the best tunnel alignment, to assure that this project is within the government land, and to avoid any obstruction that could interrupt SMART construction. Figure 6 shows the SMART alignment before the ROW. It proves that the tunnel is on the government land and does not cross the Kerayong River. JPS is responsible to solve the ROW to make a new alignment for SMART (Figure 7).

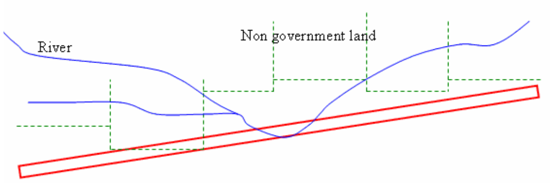

Figure 6: SMART Tunnel before ROW

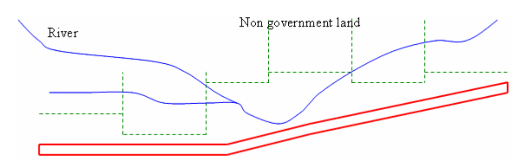

Figure 7: SMART Tunnel after ROW

The last part in Pre Construction is to perform the TBM calibration. TBM calibration is done before the TBM starts the mining process. The purposes of TBM calibration are to check the TBM installation and to guide the starting of TBM movement. Control points were established around the TBM cradle in North Ventilation shaft (NVS) at Padang JKR, Cheras (Figure 8). Leica™ TCA 1800 total station was used to observe the control points. All observations were processed using STARNET (least square adjustment) software to get the center bearing of the cradle. The TBM machine was laid down on the cradle (Figure 9). If the TBM was in a fixed position, they assumed that the TBM installation is correct and it is ready to do the mining process.

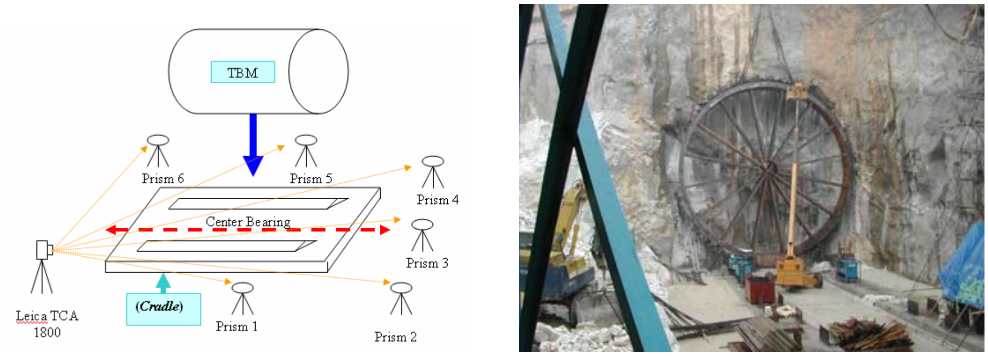

Figure 8: TBM Calibration

Figure 9: TBM Cradle

2.2 DURING CONSTRUCTION

Surveying aspect during construction involved some stages and operations. Figure 10 shows the stages during construction for SMART tunnel project.

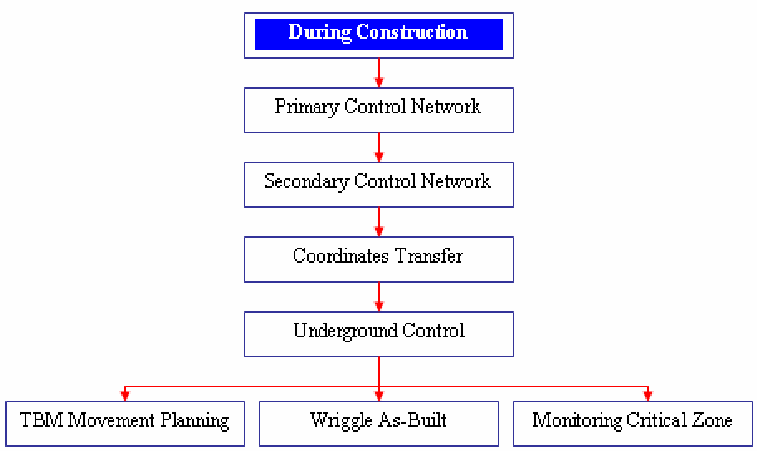

Figure 10: The Stages during Construction

Surface control network for SMART tunnel was established using three methods which are GPS (Global positioning system), leveling and traverse. The primary control network was established using the GPS for 2D positioning (X and Y axis) and Precise leveling to determine the height (Z axis). The secondary control network was established in the vicinity of SMART tunnel and near the tunnel portals and shafts using the traverse.

The coverage area for the GPS surveying works is within the vicinity of SMART project (from the South reception shaft (which is located in the locality of Taman Abadi Indah, Kuala Lumpur) and to the North reception shaft (which is located off Jalan Ampang, Kuala Lumpur)). The survey was executed on 9th March 2004 using 4 Geotracer GPS receivers (Figure 11) which were setup on specified station to observe data simultaneously at a predefined time (session) as planned. The whole GPS network that consist a total of thirteen stations was planned to be observed in a total of thirteen sessions. Duration of one-hour-thirty minutes (1:30) was allocates for every session occupying four stations at the same time to ensure that sufficient data are being gathered. There were 13 sessions with 13 control stations. Table 1 shows the site description for 13 GPS control stations for SMART project (Figure 12). Trimble Total control (TTC) software was used for data processing, network adjustment and network transformation from WGS 84 coordinates to RSO coordinates.

Station	Description
GM3	Cheras Batu, at SMART project area : Nail on Concrete
GM45B	Taman Ikan Emas, Nail on concrete
NJB1A	Taman Maluri, at SMART project area: Nail on concrete
SVS305	Taman Ikan Emas, at SMART project area: Metal Base plate mounted on concrete
JV1	Taman Keramat; Mounted on a GI pipe cast on concrete
JV2	Kuala Ampang; Nail on concrete
JV3	Taman Uthant, Persiaran Ampang Helir; Nail on concrete
JV4	Kampung Pandan Luar, Jalan Kanan 1 ; Mounted on a GI pipe cast on concrete
JV5	Taman Ikhsan, Round about; Mounted on a GI pipe cast on concrete
JV6	Bandar Sri Permaisuri; Nail on concrete
JV7	Taman Abadi Indah, Andan: Mounted on a GI pipe cast on concrete
JV8	Taman Abadi Indah, at SMART Project area; Nail on concrete
KP20A	Taman Maluri, Jalan Perkasa; Mounted on a GI pipe cast on concrete

Table 1: Site description for 13 GPS control station

Figure 11: Geotracer 3220 L1/L2 and Geotracer 3104 L1 GPS

Figure 12: GM3 station setup during the survey

The precise leveling network was observed with Leica™ NA3003 digital level (Figure 13). Starting and closing point of this method was referred from the JUPEM bench mark. The observation were done using back sight fore sight technique (Figure 14) and the level data were recorded in REC Module. Control bench marks were established close to the SMART tunnel shaft. The leveling data was processed using Microsoft Excel software. The tolerance for precise leveling is ± 0.25mm.

Figure 13: Leica NA 3003

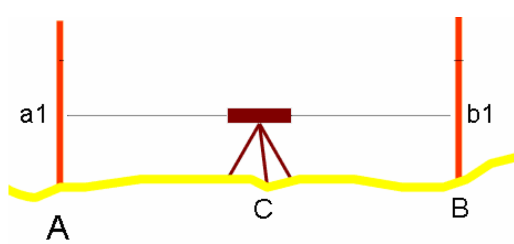

Figure 14: Back Sight Fore Sight Technique

The traverse survey (using robotic total station) was performed on the shaft area on SMART tunnel at North Junction Box (NJB) at Cochrane, North Ventilation Shaft (NVS) at JKR Field (Cheras), South Ventilation Shaft (SVS) near the Jalan Tun Razak, and South Junction Box (SJB) near TUDM airfield (Figure 15). This stage is very important to make sure that no error may affect the tunnel alignment when control is transferred to underground environment.

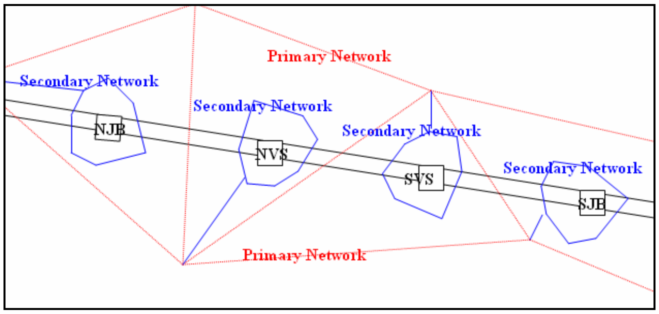

Figure 15: The conventional traverse around the tunnel shaft

Leica™ TCA 1800 total station was used to transfer coordinates X and Y from surface to the tunnel (Figure 16). This method is suitable for SMART project because the width of SMART tunnel shaft is around 40m x 80 m square. The observation was done frequently and the adjustment was done using the Starnet software. The Leica™ NA 3003 digital level were used to transfer the height from surface to the tunnel. Steel tape and digital staff were used together with Leica™ NA 3003 (Figure 17). The length of the steel tape is 30 meters. The accuracy of SMART level transferring is ± 2 mm.

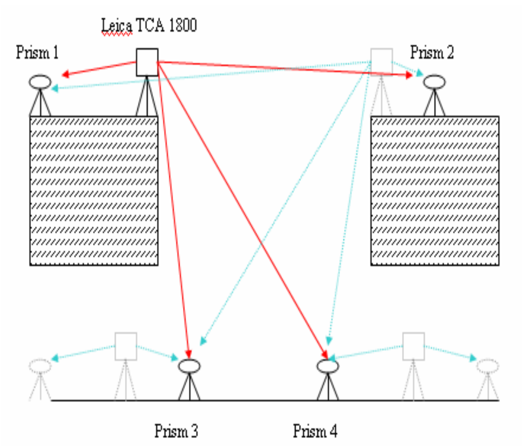

Figure 16: Coordinates transfer

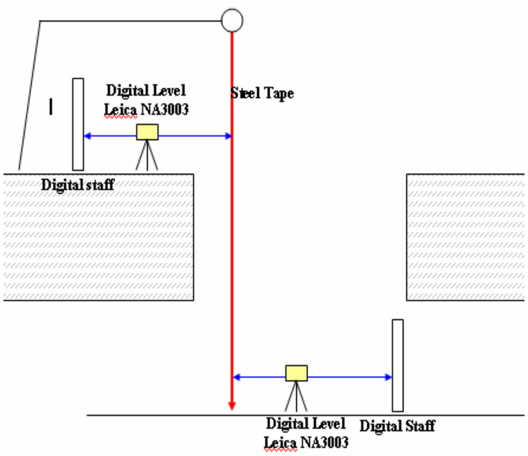

Figure 17: Level transfer

The development in technology and equipment nowadays mean that tunnel control survey (Figure 18) is now carried out using different method. Leica™ TCA 1800 total station was placed on a specially made tunnel bracket mounted on the tunnel lining for every 50 meter interval (Figure 19). They used the Zig Zag traverse to establish the underground network control in SMART tunnel. Tolerance for underground control of SMART is about ± 10 mm. The main leveling survey from shaft bench mark to another bench mark was executed using the Leica™ NA3003 (Figure 20). The tolerance of leveling in the tunnel is around ±0.25 mm.

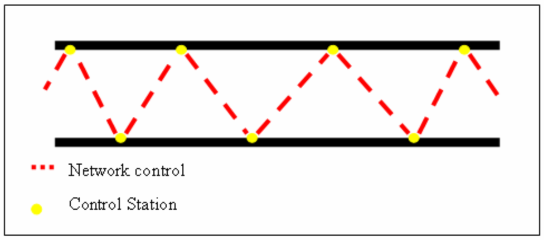

Figure 18: Underground control

Figure 19: control station bracket

Figure 20: Underground Leveling

A borehole was sunk to check the coordinates of the tunnel control station. A plumb line was dropped into the SMART tunnel passed through the borehole (Figure 21). The observations at the surface and the tunnel were done simultaneously, and the comparison between control station of surface network and tunnel network done (Patrick, 2007). Three boreholes were sunk at the north area (before Jalan Ampang, at Jalan Ampang and at Jalan Ampang Hilir) around 200 meter interval.

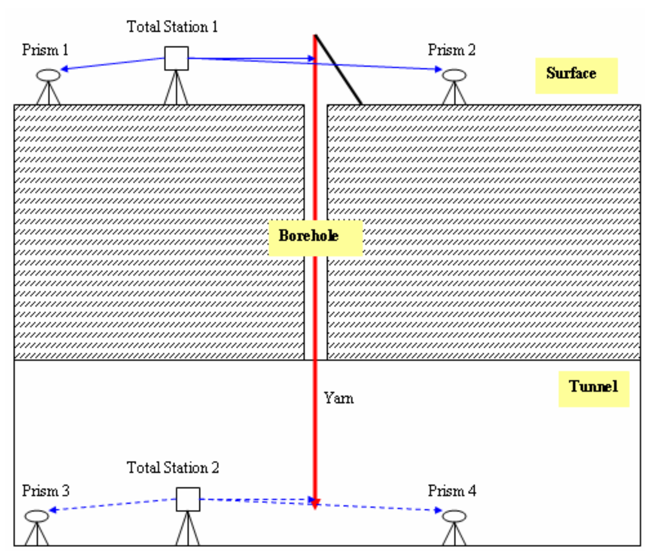

Figure 21: Borehole

Control of the guiding systems for TBM is an extension of the SMART underground control network (Figure 22). Leica™ TCA1100 total station (Figure 23 and 24) was placed on a bracket attached to the roof of the tunnel (lining). This bracket had been coordinated from the underground control. The guidance system (Figure 25) had to be moved forward frequently to keep up with the TBM. All of the observations were done in real time and the data was displayed in VMT screen at the TBM control room (Figure 26). In this manner, TBM driver can refer to the VMT screen (Figure 27) to guide the direction of TBM movement for SMART.

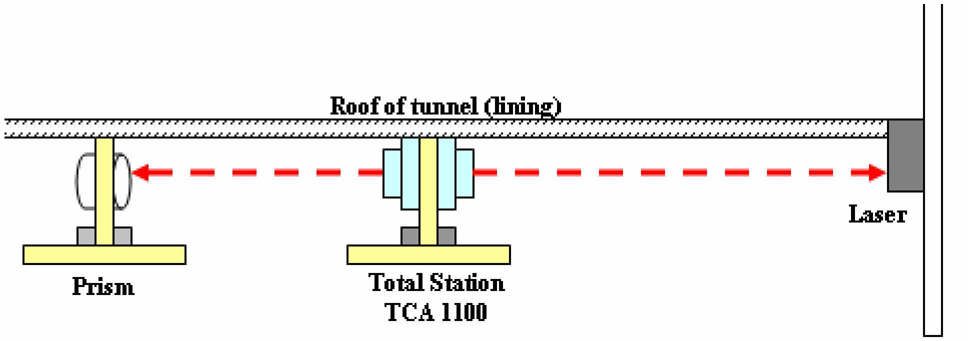

Figure 22: Laser Guiding System for TBM

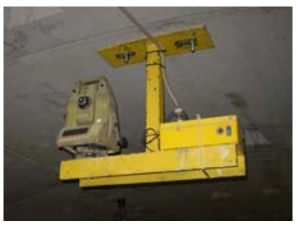

Figure 23: Leica TCA 1100 total station

Figure 24: Prism

Figure 25: Laser Guiding System

Figure 26: TBM Control room

Figure 27: VMT Display

As-built is one of the survey methods to collect detailed data during the construction. In SMART project, wriggle as-build survey was done to check the lining installation (Figure 28). Leica™ TCRA 1103 total station (reflector less) was used (Figure 29) to observe every wriggle point and all the data was processed in "NG Survey System" software (Figure 30).

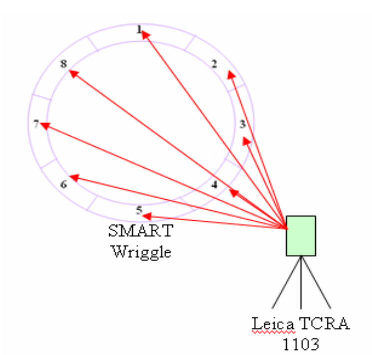

Figure 28: Wriggle As-build method

Figure 29: Leica TCRA 1103

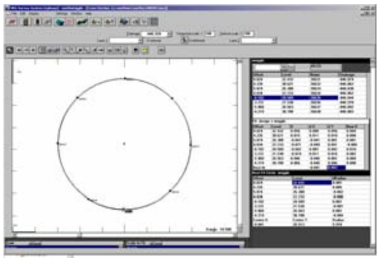

Figure 30: NG Survey System software

In SMART project, many factors are suspected to cause ground movement before, during and after the operation of TBM. Consequently, constant monitoring survey was done at critical area such as COMUTER rail lines in Sungai Besi, STAR LRT Chan Sow Lin station, and TNB Transmission Towers in Kampung Berembang. MMC-GAMUDA JV appointed Geocrete Laboratory Sdn. Bhd. to do the monitoring survey during construction of SMART. There are two monitoring techniques, i.e. automatic monitoring (Figure 31) and manual monitoring (Figure 32). For automatic monitoring, normally they used a total station connected to a remote PC. The total station was programmed to take readings to the prism in sequence at a specified time interval. The readings are recorded and processed using software on the remote PC. Any movement detection can be graded in terms of severity and alerts automatically sent to other systems and individuals concerned. For manual monitoring, a digital level is used to measure their height precision. Any changes in height can thus be identified as tunneling activities progress beneath (Mason, 2004).

Figure 31: Automatic monitoring

Figure 32: Manual Monitoring

2.3 POST CONSTRUCTION

For the post construction of SMART, a surveyor must monitor the SMART at the surface and the tunnel part during SMART operation for about 1 month and after major storms in mode III operation (full cross section on the tunnel is available for water storage and diversion). This work depends on request from the JPS Malaysia to decide whether the monitoring process is needed or not. The maintenance and operational of SMART is supervised by SMART Control Office at Kampung Berembang (Figure 33).

Figure 33: SMART Control Office

3.0 SURVEY RESULTS

Figure 34, Table 2, and Table 3 show the GPS primary control network configuration, network precision, and the tunnel breakthrough results respectively. The maximum magnitudes of semi-major axis and semi-minor axis were 2.7 mm and 3.1 mm respectively, at 95% confidence level.

Table 2: Adjusted Points Error Ellipses

Point	Semi major Axis	Semi minor Axis	Angle	95% Confidence Radius
GM3	2.0 mm	1.8 mm	-83.7º	4.6 mm
GM45B	2.5 mm	2.2 mm	-74.4 º	5.8 mm
JV1	1.9 mm	1.6 mm	89.4 º	4.3 mm
JV2	2.2 mm	1.7 mm	-79.6 º	4.9 mm
JV3	1.7 mm	1.4 mm	-89.3 º	3.8 mm
JV4	1.5 mm	1.2 mm	-83.1 º	3.3 mm
JV5	2.5 mm	2.2 mm	-80.4 º	5.8 mm
JV6	3.0 mm	2.7 mm	-80.9 º	6.9 mm
JV7	2.9 mm	2.5 mm	-77.5 º	6.6 mm
JV8	3.1 mm	2.7 mm	-83.0 º	7.1 mm
KP104	1.7 mm	1.6 mm	-69.9 º	3.9 mm
KP105	2.1 mm	1.8 mm	-77.7 º	4.8 mm
KP20A	1.7 mm	1.4 mm	-87.5 º	3.9 mm
KP500	2.2 mm	1.8 mm	88.3 º	4.9 mm
NJB1A	1.9 mm	1.6 mm	-81.3 º	4.3 mm
SVS302	2.3 mm	2.0 mm	-88.5 º	5.3 mm
WF501	2.2 mm	1.9 mm	-82.9 º	5.0 mm
WF502	2.6 mm	2.2 mm	-74.7 º	5.9 mm
WF503	2.5 mm	2.2 mm	82.7 º	5.9 mm
WF504	2.6 mm	2.2 mm	-87.9 º	5.9 mm
WF505	2.8 mm	2.3 mm	87.7 º	6.3 mm

Figure 34 :GPS Control Network

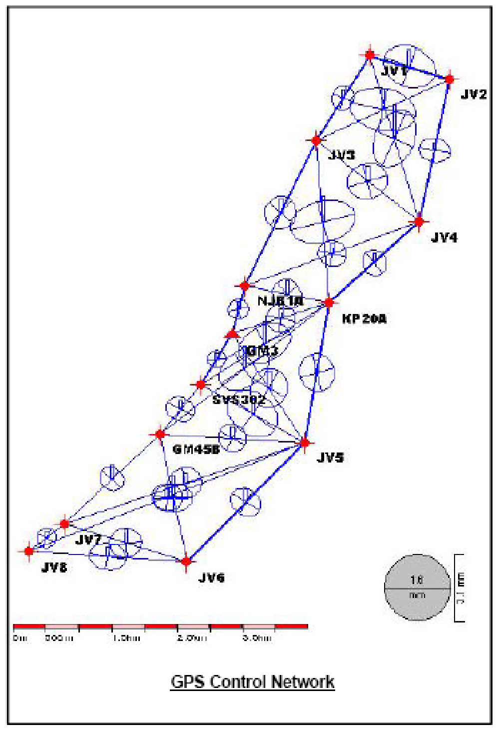

Table 3: Tunnel Breakthrough Results

TBM	Length (km)	Breakthrough Tolerance	Error in SMART
Gemilang	4.1	±100 mm arc	12 mm arc
Tuah	5.2	± 100mm arc	2 mm arc

4.0 ANALYSIS

The analysis in this study is on the surveying aspect in SMART project construction is divided into 3 parts.

The first analysis is about the detail survey of SMART. Most engineering projects used aerial photographic method to collect data for the detail plan. For example, the TESLA tunnel project in Germany also used the aerial photographic method to produce detail plan. In SMART project, surveyors used the conventional method using the total station to collect the detail data. This method took longer time compared to aerial photograph but it provides more information (spot height, contour and hazards) and also low cost budget.

The second analysis is about the method of TBM (Tunnel Boring Machine) operation for SMART project. TBM operation for SMART project was different compared to other tunnels construction like Channel Tunnel and Euro Tunnel. Usually in tunnel construction, there have two situations occurred. The first case is where a tunnel is driven in one direction only and breakthrough occurs at the predetermined location. The second case arises where a tunnel is driven from opposite ends, with breakthrough at some point in between (Fowler, 2006). For this method, if one TBM was hindered, the second TBM can be replaced to continue the mining process for tunnel construction.

For SMART project, both TBM Tuah and TBM Gemilang started from the JKR field area in Jalan Chan Sow Lin. The first machine, TBM Tuah, headed north under Jalan Tun Razak and Jalan Taman Desa Pandan before terminated at the pond in Ampang behind Gleneagles Hospital (Kampung Berembang pond).TBM Gemilang, the second machine, headed south under Jalan Chan Sow Lin and the KL-Seremban Highway next to Sg. Besi airfield before terminated at the existing pond in Taman Desa. That means, two Slurry Shield TBMs started the mining process in the same area (Figure 36) and breakthrough at different places. This approach was adopted because KL area is very crowded and does not have enough spacious area.

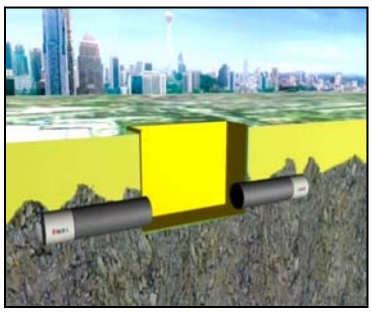

Figure 35: TBM Operational for SMART Project

The last analysis is about the strength of SMART tunnel from any vibration. SMART tunnel will not be affected by earthquakes or tremors because, the tunnel was built underground and it was in a circular shape that able to withstand forces from any direction (The Star, 2007). The tolerance of SMART tunnel resilience is around ± 5 mm (Patrick, 2006).

5.0 DISCUSSION

In conclusion, SMART (Stormwater Management and Road Tunnel) with approximate 3 km of motorway system and 9.3 km of stormwater system is a challenging survey project. The surveying method in SMART project starts from pre, during and post construction.

There are five parts of pre construction including the geology, reconnaissance, detail survey, right of way and TBM calibration. The pre construction focus on project planning before the construction is done.

For during construction, there are five stages starting from surface control network which include Primary network (GPS method and precise leveling) and Secondary network (conventional traverse). The next stage is coordinates transfer from surface to the tunnel using the local coordinate system (RSO coordinates) and underground control. The final stages involved TBM movement planning, as-built and monitoring the critical zone, where those processes were done simultaneously.

In Post construction, the research explained about the maintenance of SMART and the survey requirement after SMART project is completed. This necessity depends on request from Department of Irrigation and Drainage Malaysia.

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