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Approval & Reception Procedure

CA – Coordenação E Assessoria		
Quality Control of Topographic Surveying Activities of the Contractor in the NATM Tunnel (Ka-Hó)	Document No.	**ARP/CA/03**
	Rev. No.	**A**
	Date :	**2013-08-28**
	Page No.	**1 of 9**

Monitoring of tunnel behaviour during construction is an integral part of NATM (New Austrian Tunnelling Method). The NATM can be described as a "design as you monitor" approach based on monitored convergence and divergence and on mapping of prevailing rock conditions.

This monitoring activity should be carried out by the Contractor in accordance to design specifications that should prevail in case of any unresolved conflict.

This document specifies the activities that should be carried out by the Contractor regarding topographic monitoring, namely the:

1. construction of 3 topographic surveying pillars on each end of the tunnel
2. determination of the coordinates of the 6 above referred pillars
3. installation and the observation of monitoring points
4. LASER scanning activities
5. Reporting with interpretation of geological assessment

Reference system

Macau Cartographic System should be used including the Mean Sea Level for heights. At least 3 monumented Main Control Points (MCP) should be located near each end of the tunnel to define a unique Project Reference System (PRS). The Project Reference System (PRS) will be extended to the interior of the tunnel starting exclusively from the MCPs. No other point should be used after the MCPs coordinates have been computed.

Location and materialization of Main Control Points

The configuration and the design of the Main Control Points are intended to be used for both setting out and monitoring of the tunnel. Monitoring requires milimetric accuracy and should be carried out both during construction and during the operation of the tunnel, for many years although the frequency might vary.

The MCPs should have at least one levelling bench mark where the height (MSL) is determined. The pillar and the bench mark should have the names painted.

Location of Main Control Points (MCP) should be chosen by the Contractor following these rules:

1. in stable areas
2. not affecting or being affected by the construction works

Main Control Points should be built by the Contractor:

1. before any activity

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2. according to figure 1 a) and b) for pillars and figure 2 for the interface between pillar and different instruments or accessories

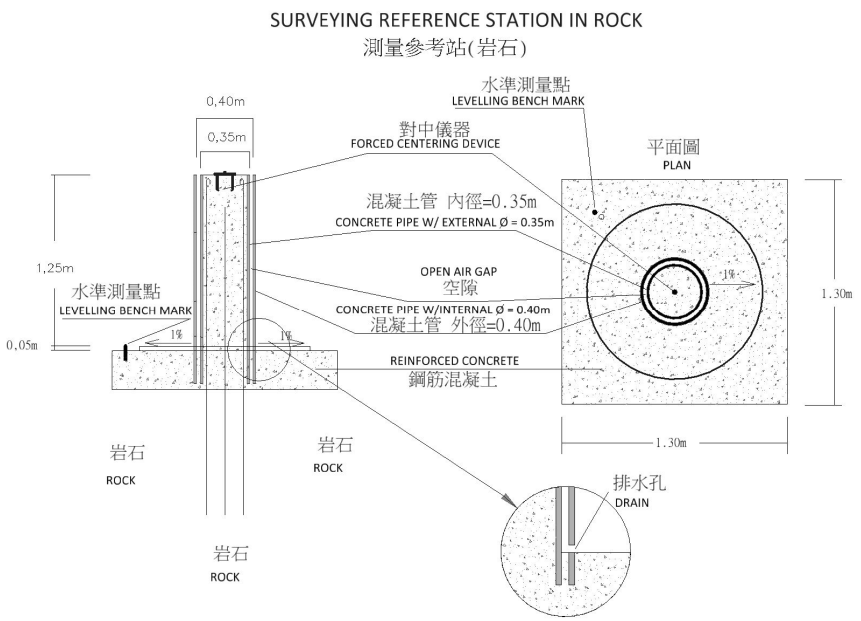

Fig. 1 a) – Materialization of Main Control Point in rock

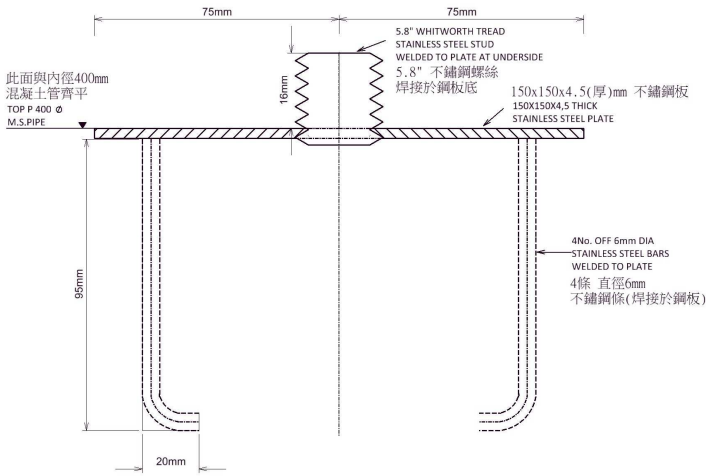

Fig. 2 – Universal interface between pillar materializing the reference point and instrument or accessories

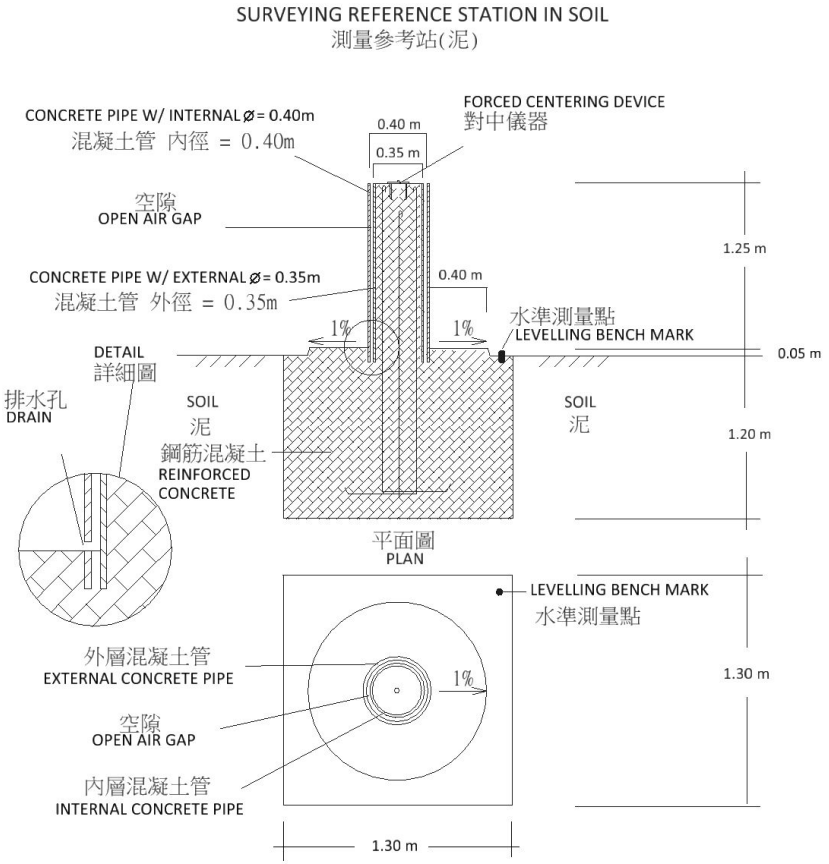

Fig. 1 b) – Materialization of Main Control Point in soil

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	Rev. No.	**A**
	Date :	**2013-08-28**
	Page No.	**4 of 9**

The determination of M, P and N coordinates for the MCPs should be made by the Contractor in 3 phases:

1. **Phase I** - **GNSS observations for M and P**:
    a. Using DSCC MosRef system with reference stations listed in Table I
    b. One session of one hour in the morning and one session of one hour in the afternoon
    c. Three base lines should be used for computations, no rejection of base line is allowed
2. **Phase II** - **High accuracy terrestrial observations for M and P**:
    a. Total station with accuracy of 5” and 1mm+1ppm
    b. Connecting all the MCPs including connecting MCPs on both sides of the tunnel
    c. Computations: fixing the M and P coordinates provided by Phase I (GNSS) of the two most distant MCPs and considering the remaining MCPs as new points.
3. **Phase III - Spirit levelling for N**
    a. To determine heights of bench marks on the pillar shoe
    b. Instrument with 0.3mm/Km accuracy on double run and invar rods
    c. Invar rods
    d. Double run
    e. Connecting the pillars on both ends of the tunnel

This system, as materialized and computed by the Contractor for this specific project will be named Project Reference System and the coordinate components will be named XYZ. No other point should be used after the MCPs coordinates have been computed.

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	Rev. No.	**A**
	Date :	**2013-08-28**
	Page No.	**5 of 9**

TABLE I – GNSS REFERENCE STATIONS OF MosRef system (DSCC)

	FOMO	COAL	DSMG
Type of Satellite	GPS,GLONASS	GPS,GLONASS	GPS,GLONASS
Receiver Type	Leica GRX1200+ GNSS	Leica GRX1200+ GNSS	Leica GPS GRX1200 GG Pro
Antenna Type	Leica AR25 R3	Leica AR25 R3	Leica AT504 GG
Data Format	RINEX	RINEX	RINEX

Extension of the project reference system

This reference system will be extended by the contractor to the inside of the tunnel according to the progression of the construction by temporary control points. However, as soon as the tunnel sections have been definitely coated some new and definitive control points materialized by the Contractor as in figure 3 should be setup for:

1. accurate transmission of the reference system for the work front that will become far away from the MCPs outside the tunnel
2. Structural safety monitoring
3. Fast setting up of the laser scanner
4. All setting out and monitoring activities related to the construction

These definitive control points will be named Tunnel Control Points (TCP) and should have their name clearly painted on the platform or wall.

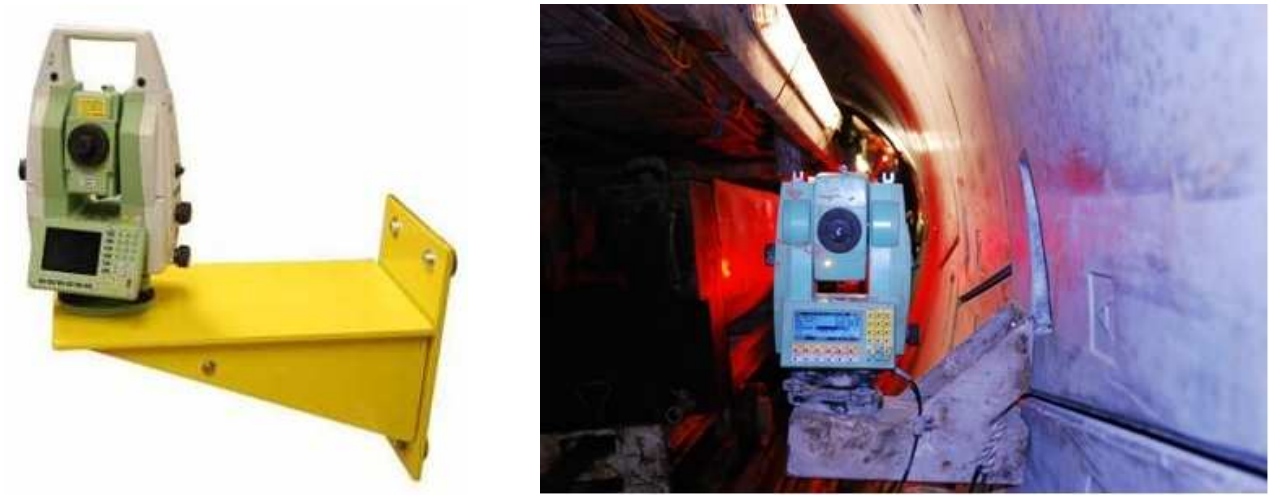

Fig.3 – Two types of steel wall plate

The MCPs and TCPs should be rechecked every 3 month with terrestrial observations. This rechecking should use only the MCPs and the TCPs. The bench marks should be rechecked also every three month. Unless some abnormal situation is detected there is no need to recheck the connections between North and South end of the tunnel.

The determination of coordinates of MCPs, TCPs and their rechecking should be documented by a narrative.

Monitoring points

Monitoring points should be located according to the design. The monitoring points should be:

1. Embedded on the rock with a rod
    a. that should surface the final lining OR
    b. the rod has to be replaced after each coating layer, thus losing the point history
2. The targets should be

a. Accepted by the Owner or Owner's consultant

b. observed from both sides

c. observed by laser scanner and total stations

d. removable from the rod

The Monitoring points should be observed for the first time with total station. Other epochs of measurement can be done by laser scanning.

Both laser scanner and total station should use the platforms of TCPs whenever these are available.

Monitoring frequency and reporting

The monitoring frequency is established on the design documents. Monitoring the materialized monitoring points can be carried out by total station or laser scanner.

Deliveries

The results provided by the Contractor should be:

1. Per cross section
2. time related (to an initial measurement as long as the monitoring point has not been intentionally moved or changed)
3. both showing the displacement history of several epochs of observation, the last displacement as compared to the previous measurement and the accumulated total displacement (from the initial measurement)

and include:

1. the 3 components of the displacement vector on numerical form for every monitoring point and TCP or MCP

2. the 3 components of the displacement vector on graphical form for every monitoring point and TCP or MCP
3. values of convergence in numerical form
4. Convergence in graphic form.

Laser scanning

The Contractor should give to the Owner and prior to the commencement of the works, the 3D model of the design of the tunnel with the geometry of the tunnel surfaces in a CAD platform, extension DXF, DWG or DGN and a mesh extension OBJ or STL.

Laser scanner shall be used by the Contractor for:

1. Reporting of over excavation and under excavation
2. pin point monitoring (with less accuracy than the total station)
3. monitoring surface deformation on the tunnel
4. Geological or geotechnical mapping and assessment.
5. Leakage mapping
6. Shotcrete or any other type of lining thickness evaluation
7. General modelling after tunnel completion (road surface, facilities, etc.)

Point density and voids

The average point density should be more than one point per cubic centimetre. The voids should be less than 10% of the scanned area.

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	Date :	**2013-08-28**
	Page No.	**9 of 9**

Deliveries

The Contractor shall provide the following deliveries as the tunnel excavation progresses:

1. Graphic and numeric report on over excavation and under excavation after mechanic or blast excavation
2. Shotcrete thickness or of any other type of lining
3. Distance between rock bolts
4. Geotechnical analysis of the excavated surface before any treatment of the surface
5. Leakage mapping based on intensity map of reflected LASER
6. Time related convergence curve after excavation
7. Inverse analysis of ground stress
8. Analysis of potential wedge
9. Components of displacement vectors in monitoring points
10. Map of deformations
11. Comparison of the final geometry of all major surfaces with design