

**GEO Technical Guidance Note No. 24 (TGN 24)
Site Investigation for Tunnel Works**

Issue No. 2	Revision: -	Date: 14.10.2009	Page 1 of 9
-------------	-------------	------------------	-------------

1. SCOPE

- 1.1 This Technical Guidance Note (TGN) provides guidance on site investigation (SI) for tunnel works in Hong Kong. It supplements guidance on site investigation given in Geoguide 2 (GEO, 1987) and Geoguide 4 (GEO, 1992). Any feedback on this TGN should be directed to the Chief Geotechnical Engineer/Mainland East.

2. TECHNICAL POLICY

- 2.1 The technical guidelines contained in this TGN were agreed by GEO's Geotechnical Control Conference (GCC) in December 2004.

3. RELATED DOCUMENTS

- 3.1 AGS (HK) (2004a). *Ground Investigation Guidelines 04.3 - Deep Excavations*. Association of Geotechnical and Geoenvironmental Specialists (Hong Kong).
- 3.2 AGS (HK) (2004b). *Ground Investigation Guidelines 04.4 - Rock Tunnels*. Association of Geotechnical and Geoenvironmental Specialists (Hong Kong).
- 3.3 AGS (HK) (2005). *Ground Investigation Guidelines 04.6 - Soft Ground Tunnelling*. Association of Geotechnical and Geoenvironmental Specialists (Hong Kong).
- 3.4 ETWB (2004). *Impossibility/Unforeseen Ground Conditions/Utility Interference (Environment, Transport and Works Bureau Technical Circular (Works) No. 17/2004)*. Environment, Transport and Works Bureau, Government Secretariat, Hong Kong.
- 3.5 GCO (1987). *Guide to Site Investigation, Geoguide 2*. Geotechnical Control Office, Hong Kong, 362p.
- 3.6 GEO (1992). *Guide to Cavern Engineering, Geoguide 4*. Geotechnical Engineering Office, Hong Kong, 156p.
- 3.7 GEO (2009a). *GEO Technical Guidance Note No. 5, Geoguide 2 - Guide to Site Investigation Updated Appendix B: Sources of Information*. Geotechnical Engineering Office, Hong Kong, 23p.
- 3.8 GEO (2009b). *Catalogue of Hong Kong Tunnels (up to December 2008)*. Geotechnical Engineering Office, Hong Kong.
(<http://www.cedd.gov.hk/eng/publications/reference/doc/HK%20Tunnel%20Cat.pdf>)
- 3.9 IMMM (2003). *Ground Investigation Working Party - Final Report*. Institute of Materials, Minerals and Mining, Hong Kong Branch, 46p.

**GEO Technical Guidance Note No. 24 (TGN 24)
Site Investigation for Tunnel Works**

Issue No. 2	Revision: -	Date: 14.10.2009	Page 2 of 9
-------------	-------------	------------------	-------------

- 3.10 ITA (2009). *General Report on Conventional Tunnelling Method*. International Tunnelling and Underground Space Association.
(<http://www.ita-aites.org/cms/ita-aites-home/latest-news-detail/datum/2009/05/13/ita-report-online-copie-1.html>)
- 3.11 Sewell, R.J., Campbell, S.D.G., Fletcher, C.J.N., Lai, K.W. & Kirk, P.A. (2000). *The Pre-Quaternary Geology of Hong Kong*. Geotechnical Engineering Office, Hong Kong, 181p.
- 3.12 USACE (1997). *Engineer Manual 1110-2-2901 Engineering and Design - Tunnels and Shafts in Rock*. US Army Corps of Engineers.
(<http://140.194.76.129/publications/eng-manuals/em1110-2-2901/toc.htm>)
- 3.13 USACE (2001). *Engineer Manual 1110-1-1804 Geotechnical Investigations*. US Army Corps of Engineers.
(<http://140.194.76.129/publications/eng-manuals/em1110-1-1804/toc.htm>)

4. DEFINITIONS

- 4.1 Tunnel works comprise tunnels, shafts, caverns and associated underground facilities, however constructed.

5. TECHNICAL RECOMMENDATIONS

5.1 GENERAL GUIDANCE

- 5.1.1 Pre-tender SI should be as comprehensive as possible to provide adequate information for the design of tunnel works and contract preparation. In addition to the geological and hydrogeological conditions, the SI should identify utilities and buried installations to ascertain whether they will interfere with or be affected by the tunnel works (see ETWB TC(W) No. 17/2004 for government projects)
- 5.1.2 There are inherent uncertainties in the subsurface geology and hydrogeology, regardless of the extent of SI. Also, physical constraints, e.g. existing buildings and subsurface installations could limit the pre-tender SI for particular sections of tunnel works. Therefore, it is essential to make provision for additional ground investigation (GI) in the works contract to check and monitor continuously the actual conditions against those assumed, and to take measures to deal with conditions not anticipated but having significant impact on the design, construction, or on life and property.
- 5.1.3 The US Army Corps of Engineers Manual (USACE, 1997) includes a practical guide to the relative cost of SI as a proportion of the estimated construction cost. Based on this guide, the typical cost of SI for a deep tunnel located in difficult ground conditions and in a dense urban area is about 3-4% of the estimated construction cost. Notwithstanding, the cost of SI for a particular project depends greatly on the quality, suitability and adequacy of available information, and the data needed for the design and risk management of the types of tunnel works involved. The client should include adequate funding for SI in the project cost estimate.

**GEO Technical Guidance Note No. 24 (TGN 24)
Site Investigation for Tunnel Works**

Issue No. 2	Revision: -	Date: 14.10.2009	Page 3 of 9
-------------	-------------	------------------	-------------

5.2 SITE INVESTIGATION STRATEGIES

5.2.1 General

5.2.1.1 SI for projects involving tunnel works should be phased. This approach is necessary as different phases of the project have different requirements. Also, the tunnel alignment and design requirements can change during route planning or design.

5.2.1.2 Using the data obtained at each phase, the impact of the proposed excavation method on the sensitive receivers identified and the geotechnical risks at each tunnel section should be assessed. The risk assessment should be reviewed when the tunnel alignment is fixed and as more information becomes available.

5.2.1.3 Some simple guidelines on SI for tunnelling are given in ITA (2009). An outline of the engineering considerations and SI techniques for rock tunnels, based on IMMM (2003), is given in Annex TGN 24A1. Supplementary information on ground investigation techniques is given in Annex TGN 24A2.

5.2.2 Planning Stage

5.2.2.1 In the project planning stage, alternative tunnel routes and potential shaft locations are typically considered. It is sufficient to have only a general picture of the subsurface geology and hydrogeology, to define the preferred route corridor and to estimate the order of project cost. The SI should largely comprise desk studies and site reconnaissance, and include only limited GI, if any is needed. Reference should be made to information available from nearby tunnel projects (see, for example, the references given in GEO (2009b))

5.2.3 Preliminary Design Stage

5.2.3.1 In the preliminary design stage, recommendations are made on a preferred tunnel alignment and the scope of works, including risk mitigation measures based on assumed methods of excavation. GI with a geophysical survey could be undertaken to refine the geological model, to gain additional information on significant geological features, identify sensitive receivers and to establish baseline conditions.

5.2.3.2 Boreholes should extend well below the anticipated depth of the tunnel and shafts to allow for any subsequent changes in the vertical alignment of the tunnel in the detailed design stage.

5.2.3.3 Soil permeability tests and Lugeon tests at close spacings should be undertaken in the boreholes to assess the soil mass and rock mass permeability, respectively. It is important not to overlook areas of apparently strong bedrock, as the mass permeability of these areas may be high and may affect significantly construction of the tunnel works. The test results should be used for development of the hydrogeological model, defining the hydraulic boundary conditions for the design and for assessing the need to control groundwater inflow/drawdown during construction.

**GEO Technical Guidance Note No. 24 (TGN 24)
Site Investigation for Tunnel Works**

Issue No. 2	Revision: -	Date: 14.10.2009	Page 4 of 9
-------------	-------------	------------------	-------------

5.2.4 Detailed Design Stage

- 5.2.4.1 In the detailed design stage, when the tunnel alignment has been fixed, the main aim of the GI should be to obtain information for the reference design or detailed design of the tunnel works and the associated temporary works. The GI should also identify conditions at likely problematic areas along the chosen alignment. The GI data should be adequate for preparing the design of the ground support, ground treatment, groundwater control works and the risk mitigation measures. It should also be adequate for planning the inspection, testing and monitoring works during construction.
- 5.2.4.2 Where existing boreholes are found close to or intercepting the tunnel, the risk of these boreholes not properly grouted should be assessed and mitigation measures, where necessary, should be carried out to ensure that these boreholes would not form preferential flow paths that could jeopardize the tunnel construction.
- 5.2.4.3 New boreholes along the chosen tunnel alignment and shaft locations should generally extend to a sufficient depth below the invert of the tunnel/shafts to obtain information for the assessment of possible failure mechanisms/limit states, and/or construction of the tunnel/shafts. For tunnels in rock, this should be a least 2.5 times the tunnel diameter (or the crown to invert dimension) below the invert.
- 5.2.4.4 Directional coring along the tunnel alignment should be considered. If this is to be carried out, it should preferably be done immediately on commencement of the detailed design stage, in order to yield early data to maximise its benefit for the design. Despite the cost, the directional coring together with pumped down packer tests could provide useful information on the geology and hydrogeology along the tunnel alignment which could not be obtained from vertical or inclined boreholes. The information along the tunnel alignment would help to enhance the management of ground risks in tunnel excavation.
- 5.2.4.5 For GI to support the design of shafts, particular attention should be given to identifying poor ground conditions, which could lead to collapse, excessive ground deformation/vibration or excessive groundwater inflow/drawdown. For deep shafts with a significant length in rock, the GI should assess the hydrogeology and inflow into the unlined sections of the rock mass, and the need for ground treatment and groundwater control works to prevent excessive drawdown of piezometric pressures in the rock and the soil overburden.
- 5.2.4.6 For significant temporary works to be designed by the contractor, e.g. major ground treatment, groundwater control and ground support works, the pre-tender SI should provide sufficient geological and hydrogeological data for the pre-tender reference designs of such works, which should be carried out to adequately define the scope of the works required to meet the safety standards and the performance criteria specified.

5.2.5 Construction Stage

- 5.2.5.1 In the construction stage, further SI should be undertaken to obtain information to support the design review of the tunnels, caverns and shafts, in order to ensure that there is adequate safety margin and performance.

**GEO Technical Guidance Note No. 24 (TGN 24)
Site Investigation for Tunnel Works**

Issue No. 2	Revision: -	Date: 14.10.2009	Page 5 of 9
-------------	-------------	------------------	-------------

- 5.2.5.2 For the exposed faces in tunnel works, the SI should include geological and engineering geological mapping, and an assessment of the tunnel sections/shafts using a soil/rock mass classification scheme on which the design may be based. A proforma for recording the rock mass mapping and classification data in rock tunnels is available from the Hong Kong Slope Safety Website under the downloading area at <http://hkss.cedd.gov.hk>.
- 5.2.5.3 Depending on the tunnel excavation method and the risk assessment, probing ahead of the tunnel excavation may be carried out. The penetration rate, the quantity of water inflows, and the colour and nature of cuttings and flushing water returns should be recorded. This information should be used to assess the ground conditions ahead, in particular the soil/rock interfaces and sections with potentially high water inflow, and the need for implementation of robust mitigation measures before further tunnel excavation. In addition to probing, use of non-invasive techniques and coring during construction may be considered where cost effectiveness can be demonstrated. For TBM works, further GI may be necessary prior to or during the TBM drive to confirm the locations of permeable soils and soil/rock interfaces and the variations in groundwater pressures for design.
- 5.2.5.4 Sufficient time should be allowed in the construction programme for the results of additional GI and site inspection and monitoring to be fed back into the design and risk management processes, in order that modifications to the design can be implemented or other contingency measures undertaken in a timely manner.

5.3 SOURCES OF INFORMATION AND EXPERTISE

- 5.3.1 Reference should be made to Geoguide 2 (GCO, 1987), GEO Technical Guidance Note No. 5 (GEO, 2009a) and GEO (2009b) for general guidance on, and sources of information for SI and tunnels in Hong Kong. Reference should also be made to Geoguide 4 (GEO, 1992), which contains guidance on SI for cavern schemes, much of which is also applicable to tunnels and shaft construction.
- 5.3.2 Information on the pre-Quaternary geology of Hong Kong is given in Sewell et al (2000). The Hong Kong Geological Survey (HKGS) section of GEO/CEDD has the most detailed information on the geology of Hong Kong and offers an advisory service. HKGS should be consulted, especially at the planning stage of new projects involving tunnel works, in the formulation of geological models, anticipation of difficult areas, and the verification of significant geological features (faults, dykes, contact zones between geological units, etc.). This consultation process in actual projects also allows feedback of important geological information from the project to existing geological archives maintained by HKGS.

5.4 DOCUMENTATION

- 5.4.1 Factual engineering geological and hydrogeological data relating to the project should be fully documented including any field data obtained from the excavation faces or inferred from the equipment/processes adopted for the tunnel works.
- 5.4.2 Survey and monitoring reports should include factual data, details of the survey and monitoring methods, and equipment/system calibration.

**GEO Technical Guidance Note No. 24 (TGN 24)
Site Investigation for Tunnel Works**

Issue No. 2	Revision: -	Date: 14.10.2009	Page 6 of 9
-------------	-------------	------------------	-------------

5.4.3 Interpretative engineering geological and inspection and monitoring reports should be prepared using the data obtained during the various phases of the SI and from construction records. These reports should update any previous relevant interpretative reports and be presented in a form that will meet the needs of the professional users. They should incorporate information on the cavern/tunnel/shaft excavation method and working sequence, trends of key performance indicators and records of actual impacts observed during construction.

6 ANNEXES

Annex TGN 24A1 Outline of Engineering Considerations and SI Techniques for Rock Tunnels
Annex TGN 24A2 Supplementary Information on Ground Investigation Techniques

(R K S Chan)
Head, Geotechnical Engineering Office

Table 1: Outline of Engineering Considerations and SI Techniques for Rock Tunnels (based on IMMM, 2003)

MAJOR ENGINEERING CONSIDERATIONS	KEY POINTS FOR SI	APPROACH TO INVESTIGATION	TESTING	SURVEY / MONITORING		
<p>Blasting design</p> <p>Machineability (suitability for TBM)</p> <p>Soil and rock mass excavation and support design (possibility of presence of mixed face conditions, fractured ground, and weak, compressible and/or permeable zones)</p> <p>Water pressures acting on lining /retaining structures for their design</p> <p>Potential water inflow into the shafts and along the tunnels.</p> <p>Assessment of tunnels/shafts drainage and pumping requirements</p> <p>Effects of the tunnel works on land stability, e.g. ground collapse/landslide due to inadequate support, hydraulic failure, blow-out failure, etc.</p> <p>Ground settlement, heave and lateral movement and distortion of sensitive receivers as a result of construction-induced ground loss, ground deformation/vibration and groundwater inflow/drawdown</p> <p>Design of tunnel portal slopes</p> <p>Lining/retaining structure durability design</p> <p>Effects of blasting on surface/subsurface facilities and slopes</p>	<p>Nature of soil and/or rock at tunnel level (invert and crown) and around the tunnels, and around/within the shafts</p> <p>Rock mass weathering (including presence of corestones and mixed ground) and strength</p> <p>Distribution, orientation and characteristics of discontinuities</p> <p>Rock mass permeability</p> <p>Insitu stress</p> <p>Presence of fault zones, dykes, contact zones between geological units, etc.</p> <p>Hydrogeology, including permanent groundwater table, perched water tables, permeable zones feeding water to the tunnels, etc.</p> <p>Potential recharge in response to rainfall and the sea, and hydraulic boundary conditions</p> <p>Dewatering effects of the tunnels, and the tunnel works damming subsurface groundwater flow</p> <p>Nature of surface materials, in particular, strength, permeability, compressibility and consolidation and creep characteristics</p> <p>As-built records and site history, in particular, effects of past and on-going construction activities that could affect the tunnels/shafts and the sensitive receivers</p> <p>Ground and groundwater chemistry</p>	Investigation Methods	Insitu Testing	Instrument Types		
		Geological mapping of surface rock exposures	Aerial photograph interpretation to identify photolineaments	Geophysical surveys to identify anomalies and low seismic velocity zones	Boreholes – vertical holes needed for sampling and downhole tests. Unless surface materials need to be characterised for assessment of effects of the tunnel works, boreholes can be wash-bored down to the zone of interest	Sub-horizontal/inclined holes from the tunnel portal and/or shaft locations to examine variations of ground conditions along the tunnel drive
		Inclined holes to intercept faults, dykes and contact zones at tunnel level	Probing ahead during tunnelling operation	Directional coring (for deep tunnels)	Laboratory Testing/Analysis	Survey / Monitoring
		Sampling	Rock coring through proposed tunnel levels (including all alternative alignments) and covering sufficient ground above crown and below invert	Undisturbed soil samples for near-surface materials, potentially affected by the tunnel and shaft construction	Unconfined Compressive Strength Young’s Modulus Poisson’s Ratio Point Load Strength Rock joint characteristics Abrasiveity Hardness Geological thin sections	Location survey of physical constraints and sensitive receivers
			Classification and consolidation creep tests for settlement-susceptible near-surface materials	Complete annual cycle needs to be monitored to indicate groundwater pressure response to rainfall and seasonal fluctuation, and to recharge from the sea		
			Salinity testing to assess the effects of groundwater on tunnelling equipment and lining	Baseline ground movement and vibration survey and condition survey of sensitive receivers (e.g. cracks on existing structures) over a sufficiently long period to establish trends		

NB: Reference should also be made to the ground investigation guidelines for deep excavations and rock tunnels produced by AGS (HK) (2004a & b; 2005).

**GEO Technical Guidance Note No. 24 (TGN 24)
Site Investigation for Tunnel Works**

Issue No. 2	Revision: -	Date: 14.10.2009	Page 8 of 9
-------------	-------------	------------------	-------------

SUPPLEMENTARY INFORMATION ON GROUND INVESTIGATION TECHNIQUES

1. GEOPHYSICS

- 1.1 Non-invasive surveying methods using geophysics techniques are comparatively inexpensive compared with invasive GI. Furthermore, they can often be completed within a short time, without major conflict over land use, and can cover large areas.
- 1.2 Magnetic surveys to identify faults have been successful in offshore areas in Hong Kong (Sewell et al., 2000 and references therein). Confirmatory boreholes and insitu testing should be carried out to verify the interpretation obtained from the survey.
- 1.3 Geophysical surveys do not provide direct measurement of engineering properties such as strength and permeability. They may not detect small-scale geological features. The interpretation and translation of the survey data into engineering geological information requires expertise and professional judgement.

2. VERTICAL AND INCLINED BOREHOLES

- 2.1 Although vertical boreholes are the most commonly used method of GI, the samples and logging obtained may only indicate very localised characteristics of the ground along a tunnel alignment.
- 2.2 Inclined boreholes may give comparatively more information along the tunnel alignment than vertical boreholes. Where the orientation of suspected subvertical fault zones or other significant geological features is known, targeting an inclined borehole in a direction roughly perpendicular to the feature may give a useful indication of the location, overall thickness and engineering properties of the feature.
- 2.3 The relative inclinations of the borehole and the feature being investigated govern the success of the inclined borehole. Faults in Hong Kong are commonly discontinuous and typically have variable dip, dip direction, width and weathering characteristics. These factors may affect the effectiveness of inclined boreholes.

3. HORIZONTAL BOREHOLES

- 3.1 Drilling of horizontal boreholes can be carried out either from the excavation face, an intermediate shaft or from the other end of the tunnel to investigate the ground conditions, in particular to check whether suspected features of poor ground are present and if so their nature and extent.
- 3.2 There are limitations to the maximum length that the horizontal borehole can be driven, depending on the ground conditions, the size of the hole and the power of the drilling rig. 'N' and 'H' size cores have been obtained from an 800 m long hole in Hong Kong.
- 3.3 Drilling of a horizontal borehole during the planning and design stage is often not feasible due to lack of access to the tunnel level; usually, for deep tunnels, the construction of vertical access shafts will not have commenced at this stage.

**GEO Technical Guidance Note No. 24 (TGN 24)
Site Investigation for Tunnel Works**

Issue No. 2	Revision: -	Date: 14.10.2009	Page 9 of 9
-------------	-------------	------------------	-------------

3.4 During the construction stage, drilling of horizontal boreholes from the tunnel face can affect the rate of progress of the excavation; hence alternative access points should be investigated and the cost-effectiveness of the operation needs to be carefully assessed in the light of the adequacy of ground data for the design and risk management.

4. DIRECTIONAL CORING TECHNIQUES

4.1 Directional coring techniques are now available to drill from ground level to great depth and then along a horizontal alignment. This method does not require provision of working space at the tunnel level and can be very useful for investigating deep tunnels.

4.2 These techniques could provide continuous information of the geological conditions along the alignment of a tunnel. Insitu tests could also be carried out for assessing the actual conditions of the ground to be excavated. The information along the alignment would minimize uncertainty of the tunnel works and enhance the management of risks for the project.

4.3 There may be limitations as to the maximum depth and length that a directional corehole can reach as well as the type of core samples that can be taken and the type of geotechnical tests that can be performed. These matters, as well as drilling location accuracy, cost, mobilisation considerations and drilling rate should be examined as early as possible in a tunnel project.

5. OTHER ASPECTS

5.1 To avoid creating preferential flow paths and obstructions in the ground that could pose hazards to the tunnel excavation, for boreholes that are close to or intercept the tunnel, the person supervising the GI should ensure that all metal casings are removed and the boreholes are properly grouted after completion of sampling and testing.

5.2 For long boreholes, probe holes and core holes, the position of which could impact on the design and construction, the specification should require the orientation (dip and dip direction) and the position of the holes to be checked regularly as drilling progresses to ensure that they follow the intended alignment.