What lies beneath? - a decade of underground construction in Hong Kong

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Over the past decade Hong Kong has seen a rapid expansion in the use of underground space for Civil Engineering infrastructure projects (Fig 1). Forty-eight kilometres of rail tunnel has been or is in the process of being constructed with associated shafts (Fig. 2) for access and ventilation and mined caverns for stations (Fig. 3). The catalyst for this expansion may be due to the integration of the Hong Kong Special Administrative Region with China which commenced in 1997 (with the handing back of Hong Kong and the New Territories to China) and has accelerated over the last decade in line with the global aspirations of China. This integration has been the catalyst for: three new major road border crossing projects (Deep Bay Link, Hong Kong to Macau Bridge and, Liantang/Heung Yuen Wai crossing) and; connection into the mainland express rail link (Hong Kong High Speed Rail Project) (Fig. 1). The population has also risen over this period from c.6.9M in 2005 to c.7.3M in 2016 (tradingeconomics 2016) fuelling in part the expansion of mass transit rail systems: the Kowloon Southern Link (3 km – complete); the West Island Line (3km - complete); Shatin to Central Link (17km - under construction); the South Island Line East (7km - under construction); the Kwun Tong line extension (3km - under construction) and the Hong Kong Express Rail Link (26km - under construction) (Fig. 1). Pressure on valuable land resources has seen the emergence of the innovative use of underground space for: explosives magazines; sewage treatment systems, service reservoirs (Fig. 4); urban drainage and flood protection projects (Fig. 5) and, new road networks such as the Central - Wan Chai Bypass (Fig. 6).

This paper presents a photographic record of some of the major underground projects constructed between 2006 and 2016. This record has been collected during student field study tours run by the University of Portsmouth for both undergraduate and post graduate students of Engineering Geology and Geotechnics and Engineering Geology degrees respectively. A brief overview of the relevant facts regarding Hong Kong climate, topography and geology are presented. This is followed by a review of typical construction methods used to create underground space in Hong Kong. Pertinent geological context is given in the text or as supplementary data to the photographs presented.

Background

Hong Kong (Fig. 1) is a small (c. 1100km^2) ex-British colony on the southern coast of Mainland China. Its landmass consists Hong Kong Island, Kowloon and the New Territories plus a number of small to large islands. It has a subtropical climate with dry cool winters associated with a northerly monsoon (October to April) which brings dry cold air from northern China, and hot wet summers associated with a southerly monsoon (May to September) which brings moist warm air from the South China Sea. Average rainfall in the summer months is c.1200mm at sea level to c.3000mm at Tai Mo Shan which has an elevation of +960m above sea level (Chau, Sze, Fung, Wong, Fong, & Chan, 2004).). Most rain falls as intense events associated with typhoons which originate in the South China Sea.

The terrain is predominantly (c.70%) mountainous consisting of steep (c.25 - 36 degree) slopes often heavily vegetated. The urban areas are densely populated with the majority living in high rise apartment blocks which abut the steep terrain often cutting into the steep slopes to form building platforms (Fig. 7).

The geology of Hong Kong comprises a suite of Mesozoic acidic igneous rocks (Fig. 8), the majority of which (c. 70%) are fine to coarse grained vitric and lithic tuffs often exhibiting a compaction or eutaxitic fabric. The tuffs mantle cores of coarse to fine grained granites, diorites and quartz monzonite. Quartzitic rhyolite and basalt dykes intrude and cross-cut the tuff and granite. Major northwest - southeast and northeast - southwest faults dissect the solid geology and control to some extent the topographic relief and the joint orientations within the country rock (Sewell, Campbell, Fletcher, Lai and Kirk, 2000). Minor outcrops of Cretaceous to Tertiary and Devonian to Permian sedimentary rocks can be found in the northern parts on the New Territories (Fig. 8).

Intense chemical weathering transforms the extremely strong to strong igneous rocks when fresh to an engineering soil when completely decomposed. Weathering can be over 100m deep (especially when associated with faulting) and produces complex weathering profiles from the classic core stone models to weak and possibly sheared seams surrounded by strong fresh rock . The weathering profiles are notoriously difficult to predict and model and are associated with highly complex hydrogeological regimes. Weathering products are principally kaolinite and halloysite from feldspars which are often mobilised in the weathering profiles either in solution or as a colloid and redeposited at weathering fronts or disseminated through the weathered rock (material and mass).

Quaternary superficial deposits mapped as Debris Flow Deposits or Colluvium by the Hong Kong Geological Survey are commonly encountered overlying the weathered rock mantle and often form the focus for perched water tables and zones of enhanced groundwater flow. It is common to encounter internal erosion pipes at the interface between the saprolite and overlying colluvium. These pipes make the prediction of hydraulic conductivity difficult and can range in size from a 1-2mm to well over 1m in diameter. Other Quaternary onshore deposits are predominantly Alluvium associated with low lying areas and fluvial systems and can sometimes contain a high organic content. Offshore are significant thicknesses of Quaternary alluvium overlain by normally consolidated recent marine clay and silt (Fyfe, Shaw, Campbell, Lai and Kirk, 2000). The Anthropocene is represented by reclamation Fill which fringes the coastline particularly in Kowloon and the Central District of Hong Kong Island (Fig. 8). The reclamation materials range from non-engineered Victorian age heterogeneous Fill to fully engineered sand Fill which is placed on either a dredged or partly dredged foundation. Fill bodies are also present on land forming building platforms, fill slopes and behind retaining structures

It is the combination of steep terrain, intense rainfall events, urban encroachment, the complex underlying geology, and the chemical weathering which create significant ground engineering challenges for engineering geologists, geotechnical engineers and hydrogeologists working on construction projects in Hong Kong.

Underground Space

The creation of underground space in Hong Kong is in general relatively straight forward as the strength of unweathered rock is high and discontinuities are often tight and rough. Complications however do arise within the complex weathered zones within a rock mass which are difficult to model and predict or where the underground space intersects the Quaternary and Anthropocene. In a congested urban setting such as Hong Kong, this interaction can lead to significant engineering problems associated mainly with ground movements which can affect existing structures. The ground movements are caused by either loss of ground during construction, basement wall deformation and, fluctuations in the groundwater table during dewatering or drawdown. This has led to an increasing use of the observational approach utilising geotechnical monitoring instrumentation, both traditional surveying techniques and more advanced real time systems.

Underground space in Hong Kong may be considered in three broad categories based primarily on the method of construction as follows: tunnels and caverns; basements and station box; and vertical shafts.

Tunnels are typically constructed using drill and blast methods where the quality of rock is good (Fig. 9) or by tunnel boring machine (TBM) in mixed ground conditions or where the length of tunnel justifies the large capital cost associated with the design and construction of the TBM (Fig. 5). Alternatively where shallow they are constructed using the cut and cover method (Fig. 6). Cavern construction in Hong Kong started in the early 1980's, primarily for water supply and metro station construction (Malone, 1996). This practice has continued with cavern stations for deep metro lines being created using mining techniques. Three government cavern projects were completed in the 1990's to house sewage treatment plant, explosives depot and, a waste transfer system. In 2009 the Hong Kong Government published the Enhanced Use of Underground Space in Hong Kong Feasibility Study (Arup, 2011) which recommended that the Hong Kong SAR Government formulates a strategy to systematically relocate existing government facilities underground.

Basements and shallow station boxes are normally built bottom-up using pipe piles and steel struts as temporary support (Fig. 10). Recently diaphragm walls have become more popular as basement wall construction and hybrid forms of top down/bottom up construction have been used.

Shafts are normally mined using either temporary pipe pile wall as support (Fig. 2) or diaphragm walls (Fig. 11) for the deeper shafts with a high groundwater table through reclamation fill.

Metro station boxes are either caverns mined from deep tunnels (Fig. 3) or using bottom-up forms of construction where they are relatively shallow (Fig. 12). Where space permits station boxes are constructed in open cut but this is rare (Fig. 13).

Drill and blast tunnels and caverns

There are many kilometres of tunnel in Hong Kong constructed using the drill and blast method and therefore there is an extensive knowledge base for this method of construction. The draw in drill and blast tunnels in good quality rock can be up to 5.2m per blast with commonly two blast cycles in a 24hr period. Temporary tunnel support in good quality rock will normally be a combination of rock bolts with shotcrete, either mesh of fibre reinforced (Fig. 14), with cast in situ concrete permanent lining for transportation tunnels and commonly a shotcrete permanent lining for utility tunnels. At tunnel portals it is common to encounter circa 10's of meters of poor quality weathered rock which require special support. Pre-grouting followed by spile installation is often necessary to commence tunnelling in conjunction with steel arch and fibre reinforced shotcrete as temporary support (Fig. 15). Commonly advance rates at portals is of the order of circa 1m per day. Away from weathered zones and faults the rock mass quality is generally good with discontinuities being rough, tight and generally dry. Close to weathering fronts kaolin infills along discontinuities are common with associated affects on strength and can form the locii for kinematic failure in the roof or sidewalls of a tunnel. Systematic rock bolting in predetermined patters as primary temporary support is common in these conditions. An example of a typical rock tunnelling project are the running tunnels for the High Speed Rail Link. These are typically 13.5 diameter horse shoe tunnels 26km long and have a cast in situ reinforced waterproofed permanent lining (Fig.16). A dual boom jumbo rig was used to drill probe holes, drill the blast holes and, to install primary patterned rock bolt support (Fig. 9).

Over the past decade two new caverns have been constructed to house an explosives magazine at Mount Davis Road and a service reservoir at the University of Hong Kong (Fig. 1 and 4).

The service reservoir cavern at the University of Hong Kong was the first of its kind in Hong Kong and was an integral part of the new campus development at the University. The existing salt water reservoir was moved underground to free up space at ground level for university expansion. The reservoir is housed in two new 17m wide, 14m high, 40m long caverns constructed in the Kowloon Granite Formation and partly in coarse crystal ash tuff of the Mount Davis Formation. A single entrance tunnel (Fig. 17) connects the caverns which have their long axis orthogonal to each other. Cavern excavation was carried out in two lifts with top headings being approximately 17.6m wide and 7m high.

A cavern complex for the sewage treatment plant at Sha Tin is at the time of writing in the investigation and design phase. The current sewage treatment plant occupies approximately 26 hectares of land in Sha Tin (Fig. 1) which will be released for redevelopment once the plant is moved underground. The caverns will be constructed within the Kwai Chung Suite of coarse to fine grained acid intrusive rocks and primarily within the medium to fine grained Shui Chuen O Granite. Caverns will have up to 200m of rock overburden and be subject to high ground water pressures. The ground investigation for the cavern design incorporates: two horizontal directional core holes between 845 and 1000m long (Fig. 18); one un-steered horizontal core hole 600m long; 129 vertical and inclined boreholes and; both seismic and gravity geophysical surveys.

Engineering Geological mapping of cavern and tunnel walls and face are systematically carried out after each blast with Barton's Q (Barton, Lien, & Lunde, 1974) being the most popular method for rock mass characterisation for subsequent support design. The adoption of the Geological Strength Index (Marinos, Marinos, & Hoek, 2007) does not seem to have taken hold in Hong Kong. Probing ahead of cavern headings and the tunnel face is common with cement or chemical grouts being used where poor quality rock is encountered and/or high volumes of water are anticipated.

Tunnel boring machines

TBM's often have to cope with mixed ground conditions along a tunnel bore. Mixed ground conditions can range from fresh good quality rock to saprolite with core stone profiles. If tunnels are shallow and close to the original coastline then they can also encounter a combination of alluvium, normally consolidated marine deposits and reclamation fill. With such a variation in ground conditions the selection and design of an appropriate TBM system is essential. In hard rock conditions a single or double shield TBM would be the normal choice in Hong Kong allowing for probing ahead, pre-grouting and inspection and mapping of rock quality by an Engineering Geologist. However, for the Lai Chi Kok drainage tunnel (Fig. 5) which was bored in predominantly good quality rock, an earth pressure balance (EPB) machine was utilised so that it could cope with a mixed ground, shallow tunnel and high pore pressure section at the end of the southern drive. This was a specially designed TBM which could deal with hard rock and soft ground conditions. In mixed conditions a slurry TBM is often used unless the overburden pressures are low (shallow tunnels) and the water pressures are high in permeable ground. In these scenarios EPB TBM's are utilised to ensure minimal face loss and to control the groundwater flows.

A current example of complex urban TBM tunnelling is the Admiralty tunnels being built for the new Shatin to Central Link (Fig. 1). The twin tunnel alignment is in places stacked due to space constraints imposed by existing underground utilities and as a consequence tunnel inverts are within 6m of the ground surface. Seventy six live piles are being removed and replaced as part of the advanced works to create space for the tunnels. Other constraints are: the risk of unexploded ordnance; tunnelling underneath exiting tunnels and; tunnelling within Victorian reclamation. To cope with these conditions the tunnels are being constructed using a slurry TBM and a hybrid slurry/EPB TBM both 7.44m in diameter (Fig. 19). Tunnel sections are scheduled to be complete by 2018.

Probing and grouting ahead of the TBM is often not carried out with an EPB machine but is common practice in Hong Kong where a slurry or open face machine is being used. Launch pits for the TBM's are commonly supported using diaphragm walls (Fig. 11). Where space is restricted, tunnel portals are mined and enlarged to enable the launching of a TBM from within the tunnel (Fig. 15).

Tunnel lining systems are either fully drained (allow groundwater to drain into the tunnel) or undrained (fully sealed against groundwater ingress). Drained systems are used where it is demostrated that groundwater drawdown will be minimal and that there are no settlement sensitive structures within the zone of influence of the tunnel drawdown. Drainage is provided behind the segmental lining by injecting a granular filter using compressed air. In this case the lining is only designed to carry the loading from the geology. Where drawdown is considered to be critical then an undrained segmental liner system is used with waterproof grout injected behind the lining as tunneling proceeds, In this case the lining is fitted with rubber gaskets and is designed to take the full hydrostatic pore pressures.

Cut and cover tunnels - station boxes - basements

Shallow road tunnels and some station boxes are constructed using the conventional cut and cover method of construction (Fig. 11). Lateral restraint during construction is provided by vertical reinforced concrete walls installed using the diaphragm wall technique (Fig. 6). In areas of reclamation the wall panels are normally socketed into Grade 3 rock for stability. The walls are normally supported using steel internal props (Fig. 6) rather than soil or rock anchors due to congestion below ground. Recent projects use a combination of clam shell hammer grab plus hydrofraise diaphragm wall machines (Fig. 20) to excavate through soft and hard ground respectively. Hydrofraise machines can be fitted with milling tools to produce sockets into rock with unconfined compressive strength of up to circa 50MPa (Fig. 21).

Alternative vertical lateral support can be provided by pipe-pile walls which comprise drilled in steel tubular piles up to circa 1m in diameter which form a contiguous wall (Fig. 18). The tubular piles are drilled into the ground using a hydraulic Odex percussion hammer system in front of the steel tube. These are normally socketed into Grade 3 rock or better. Water tight construction is provided by tube-a-manchette (TAM) grouting between each pile. The front face of the contiguous wall is often shotcreted to prevent soil loss from between the pipe piles or alternatively protection is provided by welding steel plates to the front of the piles (Fig.s 2 & 22). The hydraulic barrier provided by the grouting is demostrated by carrying out a pumping test from within the proposed excavation and measuring ground water response outside the excavation limits.

Basement construction uses similar support techniques to cut and cover tunnels and station boxes. With blasting normally prohibited in the urban environment of Hong Kong the estabilshment of a geological model which takes into account the amount of rock to be excavted is key to the success of a basement project. Strong rock is removed using mechanical breakers assisted by stitch drilling (Fig. 23).

A combination of bottom up and top down was used to construct the massive station box for the Express Rail Link terminus (Fig. 1). Due to the size of the excavation, berms were utilised as temporary support around the perimeter. A traditional bottom up construction was carried out in the center of the site (Fig. 24). However, a top down approach was used where the perimeter berms were being used (Fig. 24). Due to a layer of normally consolidated

Marine Clay outcroping in the berms it was decided to jet grout this layer to improve its strength and therefore the stability of the berms (Fig. 24).

Shafts

Shafts for tunnel ventilation, access, spoil removal, elevators into metro stations, access into deep sewage disposal tunnels and TBM launch voids have been a prominent feature of recent construction projects over the past decade. Circular shafts up to 110m deep were constructed for the Harbour Area Treatment Scheme Stage 2 project (Fig. 1) for temporary and permanent access and as pumping chambers and risers. Diaphragm wall panels have generally been used as lateral support for these large deep shafts through made ground, superficial deposits and saprolite (Fig. 21). Diaphragm wall panels are terminated once into good quality fresh or slightly weathered rock.

Rock mass assessment logging and discontinuity surveys are carried out once into good quality rock to provide design parameters for both the temporary and permanent support design. Temporary support in the rock shafts is generally provided by spot rock bolts and fibre reinforced shotcrete (Fig. 25). Where good quality rock is relatively shallow and the groundwater conditions permit, the initial part of the shafts can be sunk using cast in situ rings until rock is encountered. This was the case for the TBM launch shaft for the Lai Chi Kok surface water drainage tunnel (Fig. 26). Once into good quality rock the shaft was advanced using mechanical breaker.

The temporary support for the elevator shafts excavated for the access to the University Station for the new West Island Line metro were supported by a pipe pile wall method (Fig. 27). This was possible due to the groundwater table being below the top of good quality rock. Core stones in the saprolite were removed using mechanical breaker and hoist. Shafts constructed to intercept surface water from ephemeral streams as part of the Hong Kong

Island drainage tunnel were constructed using raised boring techniques. This was the first time that this technique had been used in Hong Kong and solved the mainly environmental concerns of constructing shafts through rock in built-up residential locations. Adits from the main TBM tunnel were first mined using drill and blast techniques (Fig. 28). A vertical pilot hole was then drilled from ground level to intercept the mined adit. A cutting head is connected to ground level via the pilot hole and a drive shaft to the drive head (Fig. 29). The cutting head is then pulled up to ground level excavating the shaft with the spoil being removed through the adits and main tunnel.

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Figure Captions:

Figure 1 - Simplified outline map of the Hong Kong SAR showing the location of the projects referred to in this paper.

Figure 2 – West Island Line Sheung Wan shaft being excavated using a pipe pile wall and ring beams for lateral support. Note the welded steel lagging used to protect the excavation from ground water and soil ingress. Excavation in good quality rock being made by hydraulic breaker in equigranular medium grained biotite rich Kowloon Granite. Date taken April 2011 by Koor, N.P.

Figure 3 – Mined cavern for the new Kwun Tong Station on the Shatin Central Link. Excavation in the Kowloon Granite which is equigranular medium grained and biotite rich. Date taken April 2015 by Koor, N.P.

Figure 4 – Completed cavern network for the relocation of a service water reservoir to free space for the expansion of University of Hong Kong campus. Cavern constructed in eutaxitic fine ash vitric tuff of the Ap Lie Chau Formation. Photograph curtesy of Gammon Construction.

Figure 5 - Lai Chi Kok Drainage Tunnel portal with full face earth pressure balance tunnel boring machine specifically designed to bore through good quality rock (Kowloon Granite) and mixed ground conditions with high pore pressures and low overburden cover (Reclamation Fill overlying soft Quaternary Marine Deposits and Alluvium). Date taken January 2010 by Koor, N.P.

Figure 6 – Central Wanchai Bypass cut and cover road tunnel being constructed within the Central Reclamation. Vertical diaphragm walls are supported by temporary steel struts prior to the permanent structure being built. Construction is within reclamation fill with partial removal of soft normally consolidated Quaternary Marine Deposits – diaphragm wall socketed into Kowloon Granite. Date taken January 2010 by Koor, N.P.

Figure 7 – View of Hong Kong Island – Central, Admiralty and Wanchai looking east taken from Victoria Peak (Figure 1). High rise structures are built adjacent to and cutting into the natural steep terrain. The tall building in the centre of the photograph is the Bank of China Building with the Hong Kong Convention Centre to the north protruding into Hong Kong Harbour. Date taken January 2009 by Koor, N.P.

Figure 8 - Simplified geological map of the Hong Kong SAR reproduced with permission of the Geotechnical Engineering Office of The Government of the Hong Kong SAR after Sewell, Campbell, Fletcher, Lai and Kirk (2000).

Figure 9 – Twin boom jumbo rig drilling charge holes for the Express Rail Link project drill and blast running tunnel. Temporary support of tunnel roof and side walls using patterned

rock bolts and fibre reinforced shotcrete. Rock is lapilli lithic bearing coarse ash crystal tuff of the Tai Mo Shan Formation. Date taken April 2012 by Gibson, A.D.

Figure 10 – Hennessey Centre deep basement in the dense urban setting of Causeway Bay utilising temporary pipe pile wall for vertical support for the excavation. Typical basement bottom up construction with heavy steel struts used as temporary support as excavation proceeds using mechanical breakers through strong Fan Lau Granite. Date taken January 2010 by Koor, N.P.

Figure 11 – Access and ventilation shaft at Diamond Hill for the Shatin to Central Line metro incorporating diaphragm walls as both temporary and permanent support for the shaft. Note crescent shaped tool marks from the milling cutter heads on some of the wall panels. Date taken April 2016 by Koor, N.P.

Figure 12 – Austin Road (Kowloon Southern Link) cut and cover station box construction utilising diaphragm walls for both temporary and permanent vertical support for the excavation. Typical bottom up construction used in Hong Kong with heavy steel struts used as temporary support during excavation to the underside of the bottom slab – these are then replaced by the permanent structure from the bottom up. Excavation primarily through reclamation fill with a high ground water table. Date taken June 2007 by Koor, N.P.

Figure 13 – Open cut excavation for the Kwun Tong Line Extension station. The reinforced concrete station box is on the left had side of the photograph. The concrete monoliths in the centre of the photograph and pad foundations for future residential and commercial structures. The excavation was 65m deep with the bottom 25m of the excavation being in strong equigranular medium grained biotite rich Kowloon Granite. Temporary support for the soil slopes was provided by soil nails with rock dowels used in the rock. Excavation in the rock was by drill and blast. Date taken April 2015 by Koor, N.P.

Figure 14 – West Island Line drill and blast tunnel with fibre reinforced shotcrete and rock bolts as temporary support. Standard single track section is 5.8m from soffit to crown and 5.7m maximum width. Date taken March 2012 by Koor, N.P.

Figure 15 – Hong Kong West drainage tunnel eastern portal stabilisation using a combination of a spile canopy, steel arches, and fibre reinforced shotcrete. Due to space constraints the portal here is enlarged to enable the TBM to be assembled within the tunnel. Eastern tunnel TBM was a 7.21m diameter double shield with gripper system. Date taken January 2010 by Koor, N.P.

Figure 16 – Waterproof membrane being installed in one of the drill and blast running tunnels at Shek Yam for the Hong Kong Express Rail Link project. The permanent reinforced concrete liner is cast *in situ* using a prefabricated formwork gantry which can be seem advancing through the tunnel. Tunnel at this section is within the Needle Hill Granite which is commonly porphyritic and fine grained. Further north the tunnels are within lapilli lithic bearing coarse ash crystal tuff of the Tai Mo Shan Formation. Date taken May 2012 by Koor, N.P.

Figure 17. Hong Kong University salt water cavern reservoir tunnel access during construction. Tunnels and caverns excavated using drill and blast techniques with friction type expansion rock bolts and shotcrete as temporary support. Cavern void can be seen at the end of the tunnel - the excavator is starting the tunnel bifurcation for access to the second cavern. Date taken January 2008 by Koor, N.P.

Figure 18. Sha Tin Sewage Treatment Works cavern project – 38mm diameter core in fresh medium grained Shui Chuen O Granite 404.51m to 413.18m along directional drill hole CAV101. Date taken April 2016 by Koor, N.P.

Figure 19 – Shatin to Central Link Admiralty section slurry TBM in the launch excavation. The TBM is 7.44m in diameter and is one of two machines being used to drive this section of tunnelling. Date taken: April 2016 by Koor, N.P.

Figure 20. Hong Kong Express Rail Link approach tunnel construction using diaphragm walls for the tunnel walls – tunnels constructed using the cut and cover technique. Conventional clam and hammer grabs are used through reclamation fill, Marine Deposits, Alluvium and completely decomposed Kowloon Granite (tools in right hand corner of photograph). Walls advanced in less weathered rock using hydrofraise machines fitted with

milling tools. Reinforcement cage being lowered into a completed panel in centre of photograph. Date taken January 2011 by Koor, N.P.

Figure 21. Diaphragm wall hydrofraise used to construct a riser shaft for part of the Harbour Area Treatment Scheme Stage 2 project at Stone Cutters Island. The hydrofraise uses down the hole motors operating with reverse circulation. The cutter drums (at the base) are fitted with tungsten carbide cutters and rotate in opposite directions. These are used to excavate in variable ground conditions and can cut sockets into rock with unconfined compression strengths of up to 50MPa. Date taken January 2010 by Koor, N.P.

Figure 22. Jordan Road station box construction using cut and cover bottom up methodology. Temporary support using a contiguous wall constructed using c.1m diameter steel pipe piles socketed into Grade 3 Kowloon Granite. Water proofing provided by TAM grouting the gap between each pipe pile with shotcrete as a surface protection. Wall constructed through reclamation Fill, Quaternary Marine Clay and Alluvium and socketed into Kowloon Granite. Date taken June 2007 by Koor, N.P.

Figure 23. Hennessey Centre basement in Causeway Bay under construction. Typical bottom up construction with a pipe pile contiguous wall acting as the temporary vertical support with a heavy steel internal strut system being utilised. Excavation within partly weathered Kowloon Granite is by the use of stitch drilling and mechanical breaker. Date taken January 2010 by Koor, N.P.

Figure 24. Excavation in progress for the Hong Kong High Speed Rail Link terminus in Kolwoon. Conventional bottom up construction used in the centre of the excavation with a top down approach used through the perimeter berms. Basement excavated through reclamation Fill overlying Quaternary Marine Clay and Alluvium which in term overlies the Kowloon Granite pluton which is variably weathered. Marine Clay has been jet grouted to ensure stability of the perimeter berms – this can be seen as a ridge at mid-height in the berm in the centre of the photograph. Date taken April 2013 by Koor, N.P.

Figure 25. West Island Line shaft being excavated using a pipe pile wall for support though Fill and saprolite – once into good quality rock a combination of rock bolts and shotcrete is used to help support the rock faces. Excavation in good quality rock being made by hydraulic breaker in equigranular medium grained biotite rich Kowloon Granite. Date taken January 2011 by Koor, N.P.

Figure 26. TBM lunch shaft for the Lai Chi Kok Drainage Tunnel southern drive. Good quality rock is relatively close to ground surface allowing the initial support to be provided by cast *in situ* concrete rings – once into good quality Kowloon Granite the shaft is supported by rock bolts and shotcrete. Note TBM in the base of the shaft. Date taken April 2011 by Koor, N.P.

Figure 27. West Island Line Hong Kong University elevator shaft Entrance A during the initial stages of excavation. A contiguous pipe pile (610mm diameter) wall with ring beam provides vertical support in the completely decomposed Kowloon Granite. Steel struts being lowered into the excavation will be used to support a steel road deck allowing traffic to pass over the shaft during excavation. Photograph taken January 2011 by Koor, N.P.

Figure 28. Hong Kong West drainage tunnel with fresh Ap Lie Chau Formation fine ash vitric tuff exposed from behind the tunnel lining. Drilling is for the initial blast for horizontal adits from the tunnel which will connect to vertical interceptor shafts constructed using raised boring techniques. The shafts collect surface water which is directed into the main tunnel via the drill and blast adits. Date taken January 2010 by Koor, N.P.

Figure 29. Hong Kong West drainage tunnel raised boring surface installation consisting of the hydraulic power pack and drill in the centre of the photograph – drill rod extensions can be seen in the bottom left hand corner of the photograph. Date taken January 2011 by Koor, N.P.

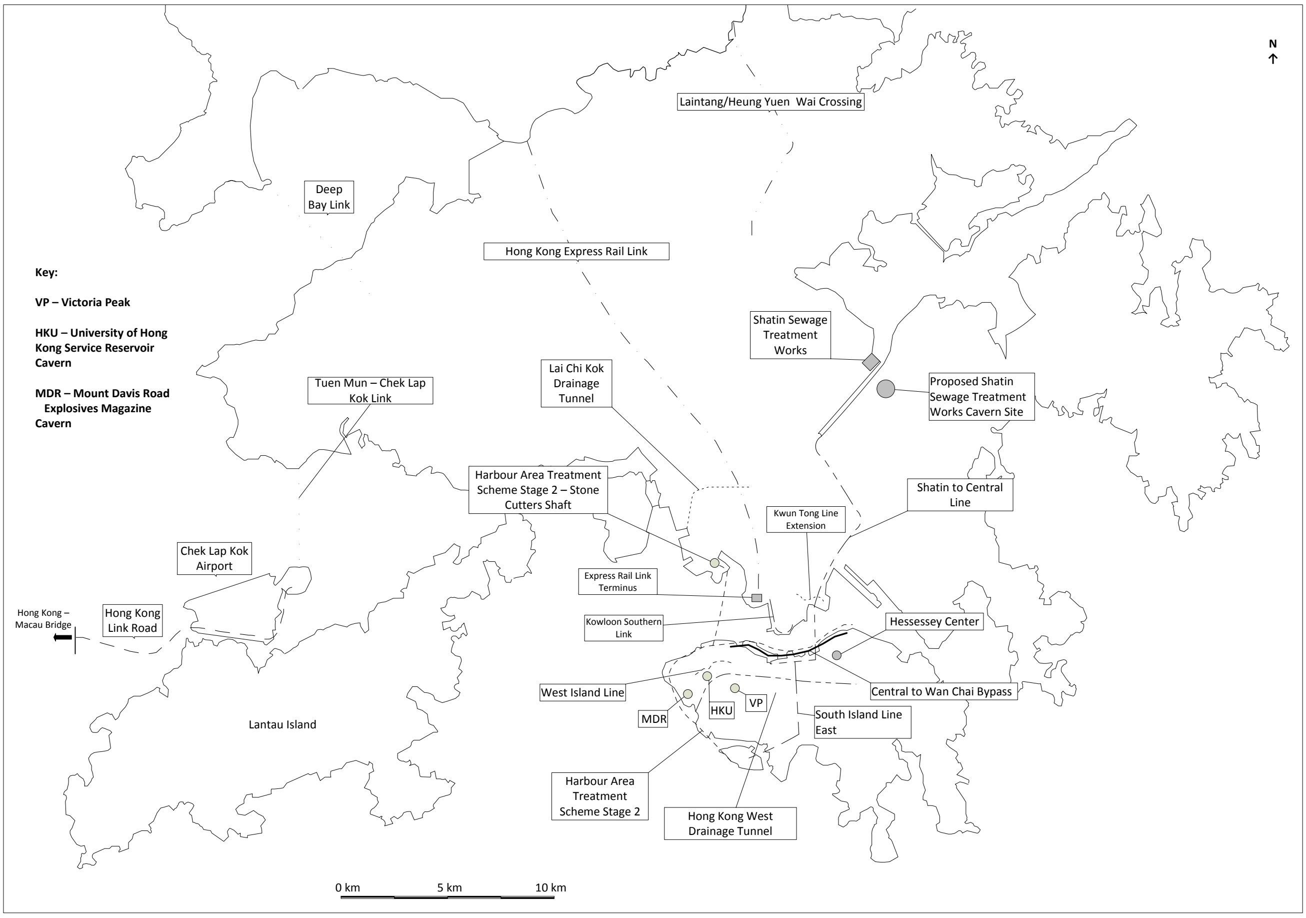

N
Laintang/Heung Yuen Wai Crossing
Deep
Bay Link
Hong Kong Express Rail Link
Key:
VP – Victoria Peak
HKU – University of Hong Kong Service Reservoir Cavern
MDR – Mount Davis Road Explosives Magazine Cavern
Shatin Sewage Treatment Works
Proposed Shatin Sewage Treatment Works Cavern Site
Lai Chi Kok Drainage Tunnel
Tuen Mun – Chek Lap Kok Link
Harbour Area Treatment Scheme Stage 2 – Stone Cutters Shaft
Shatin to Central Line
Kwun Tong Line Extension
Chek Lap Kok Airport
Express Rail Link Terminus
Hong Kong – Macau Bridge
Hong Kong Link Road
Kowloon Southern Link
Hessessey Center
West Island Line
Central to Wan Chai Bypass
MDR
HKU
VP
South Island Line East
Lantau Island
Harbour Area Treatment Scheme Stage 2
Hong Kong West Drainage Tunnel
0 km
5 km
10 km

Figure 1

Figure 2

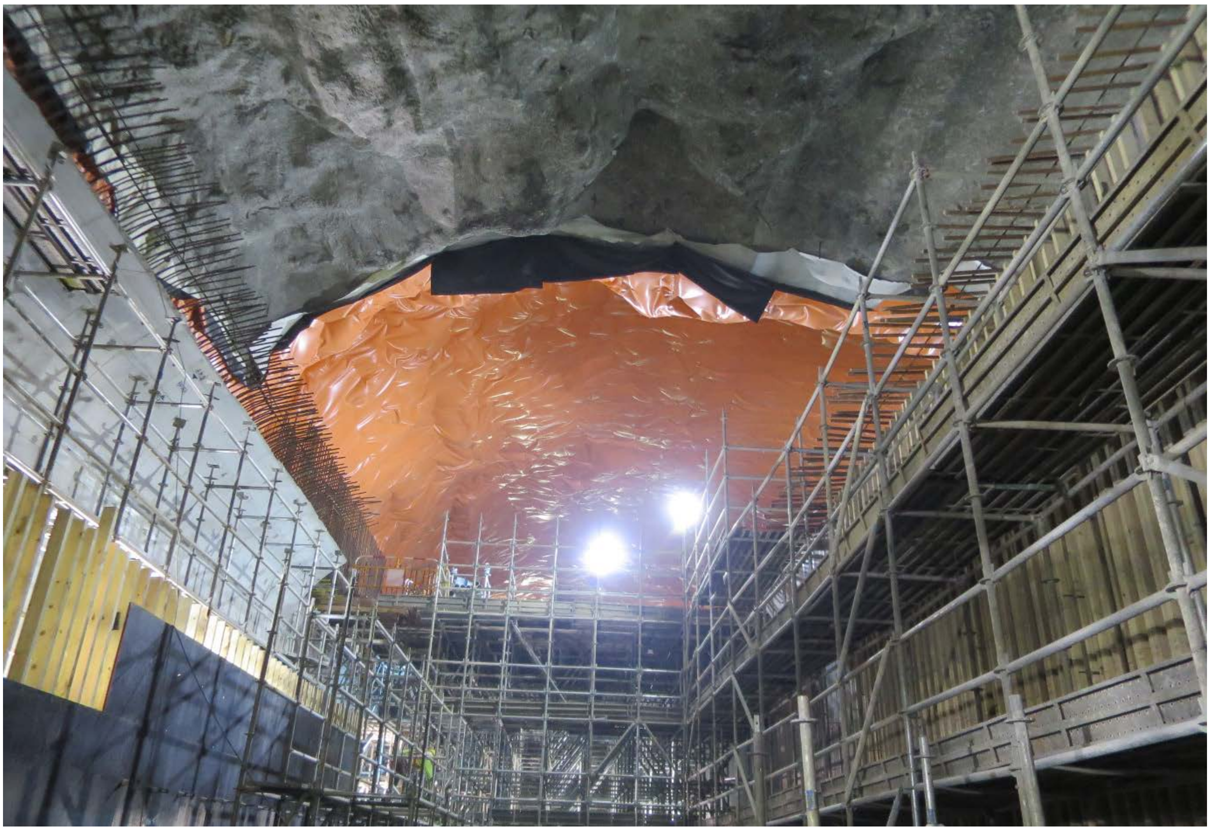


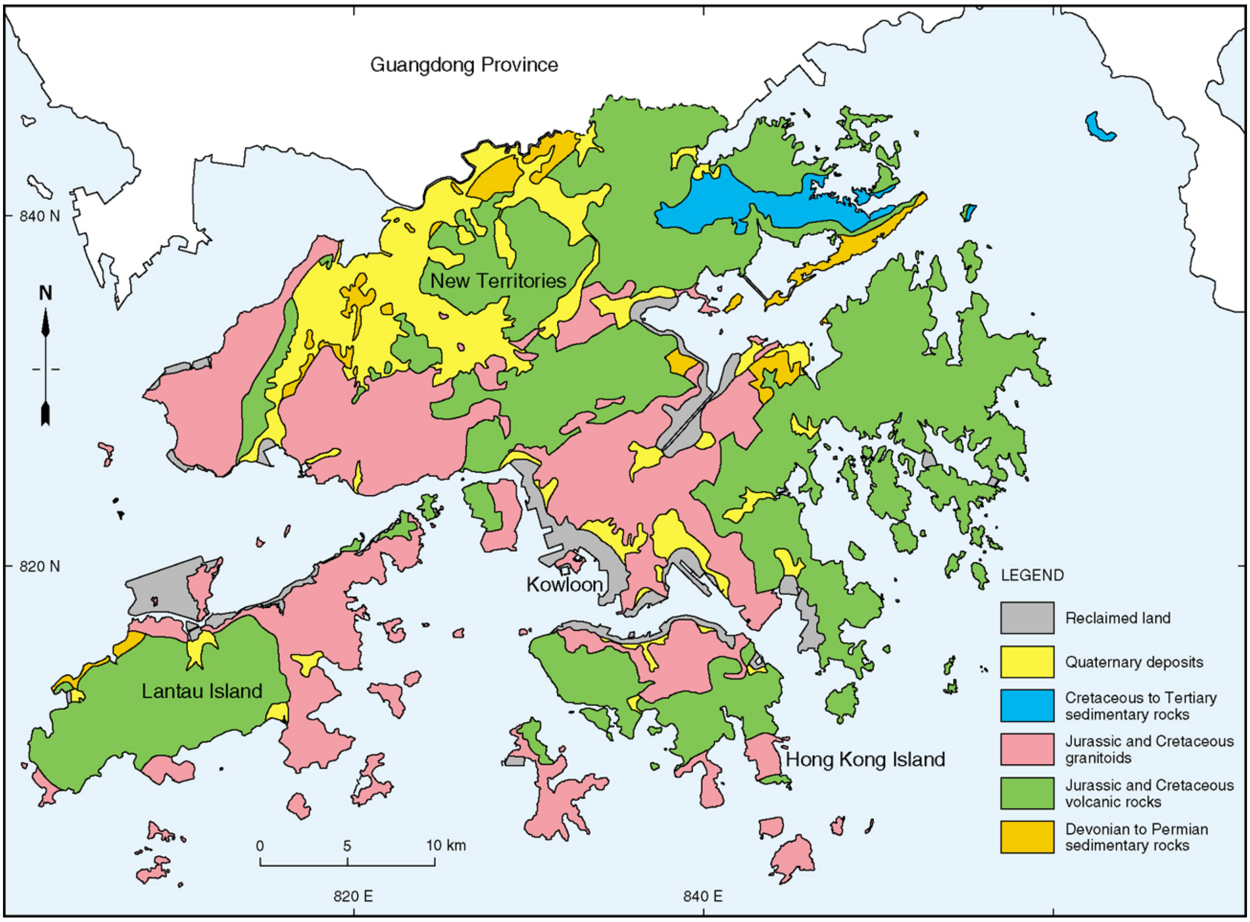
Figure 3.

Figure 4

Figure 5

Figure 6

Figure 7



Guangdong Province
840 N
820 N
N
New Territories
Kowloon
Lantau Island
Hong Kong Island
0
5
10 km
820 E
840 E
LEGEND
Reclaimed land
Quaternary deposits
Cretaceous to Tertiary sedimentary rocks
Jurassic and Cretaceous granitoids
Jurassic and Cretaceous volcanic rocks
Devonian to Permian sedimentary rocks

Figure 8

Figure 9


埋碼吊運要安全
必須要有訊號員
個人防護裝備你要知
打鑿工序要有 PPE
緊急出口
行人通道
Passage
移動機械需圍封
2米轉動距離
要緊守！

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17.


HDC – CAV101
DEPTH: FROM (405.51m) TO (413.18m)
BOX NO. 68 OF
DATE 6/4/2016 TO 7/4/2016
407.31m
410.20m
412.84m

Figure 18.

Figure 19

Figure 20.

Figure 21

Figure 22.

Figure 23.

Figure 24.

Figure 25.

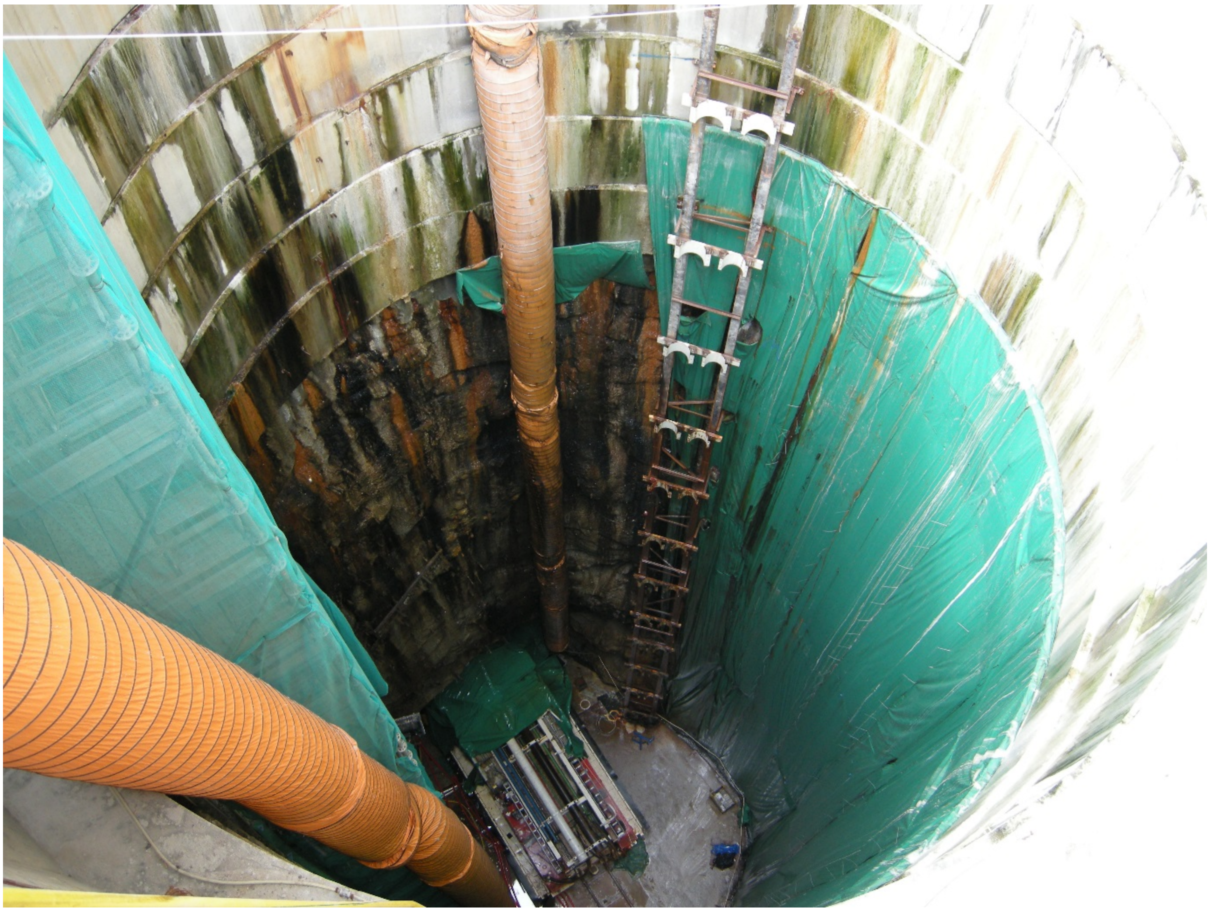


Figure 26.

Figure 27.

Figure 28.


No 19908
2170 8638
THIS PROTECTIVE EQUIPMENT
MUST BE WORN
IN THIS AREA

Figure 29.