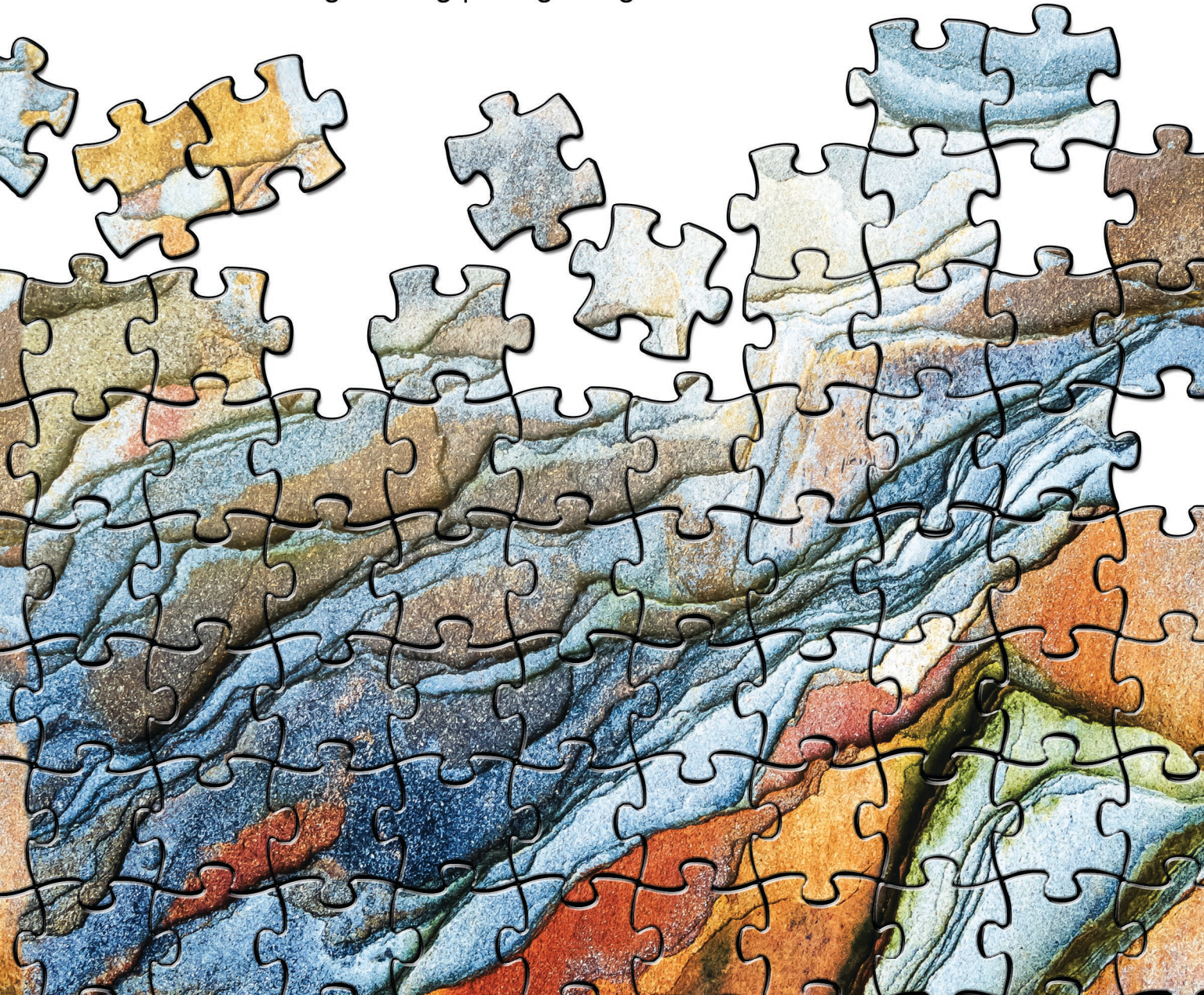


Geo-Innovation

Innovations and Technological Advances
in Geotechnical Engineering | Hong Kong

HK  E THE HONG KONG
INSTITUTION OF ENGINEERS
香港工程師學會

Geotechnical Division
岩土分部



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Foreword

Recent advances in geotechnical engineering have been both knowledge based (e.g. through technical development work and lessons learnt from investigations of failures) and technology driven (e.g. through digital, imaging, sensor and construction technology). Given that the geotechnical discipline continues to be fraught with uncertainties and can involve many empirical approaches, there is much scope for application of improved knowledge and technology to enhance practice.

Geotechnical engineers in Hong Kong have long been working together in partnership to foster innovations and embrace an innovative culture. The HKIE set up a Working Group on Application of Innovative Technology in Geotechnical Engineering more than ten years ago. To commemorate the 30th anniversary of the establishment of the HKIE Geotechnical Division, the Working Group have decided to compile this booklet to showcase a selection of geotechnical innovations and advances made in Hong Kong, which is not an exhaustive list, over the last decade.

The achievements made in various projects illustrate that we can add considerable value in addressing practical problems if we are willing to exercise lateral thinking and try out new ideas. It is hoped that this booklet will serve to stimulate more innovations and novel ideas by practitioners and researchers, with a view to further enhancing geotechnical engineering practice.

The Working Group wish to express their gratitude to the many parties who have contributed to the production of this booklet. Regrettably, space constraints mean that we are only able to present a limited number of innovative elements out of the many that were initially considered.



Ken Ho, JP
Chairman, Working Group on Application of Innovative Technology in Geotechnical Engineering
The HKIE Geotechnical Division
December 2017

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Foundations and Excavations

Multi-cell strut-free shafts for large excavations

As excavations become deeper and wider, the cost effectiveness and practicality of using traditional braced cut-and-cover techniques is reduced, and more creative and innovative solutions often become necessary.

Conventionally, large diameter strut-free circular shafts may be used to support deep excavations, taking advantage of the compressive strength of a concrete shaft to resist the radially applied pressure of the surrounding ground. However, this technique has the disadvantage that only a circular excavation is possible. This may result in an inefficient geometry for the excavation, or may be impractical due to physical constraints imposed by external structures.

These problems may be overcome by adopting a multi-cell shaft solution, where a series of interlocking circular cells are placed in a line to form an elongated open excavation, with struts necessary only at the intersection points of adjacent cells. This allows more flexibility in geometry, with the width of the excavation defined by the cell diameter and the length by the number of cells used.

This multi-cell technique has been put to effective use for the launching shafts for the two very large tunnel boring machines (TBM) used in the construction of the Tuen Mun-Chek Lap Kok Link Northern Connection project. These were built within a newly formed reclamation and required a wide strut free span for the erection and launch of these massive machines. The technique was also used to construct the TBM launching shaft for the Shatin to Central Link project at Wan Chai.



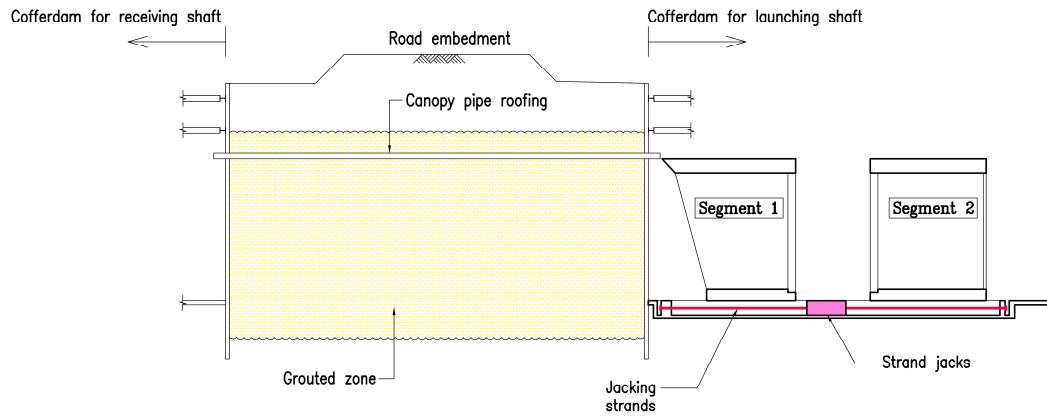
Triple-cell shaft for the Tuen Mun-Chek Lap Kok Link Northern Connection (courtesy of Dragages-Bouygues Joint Venture and Highways Department, HKSAR Government)

Excavation below sensitive structures using box-jacking

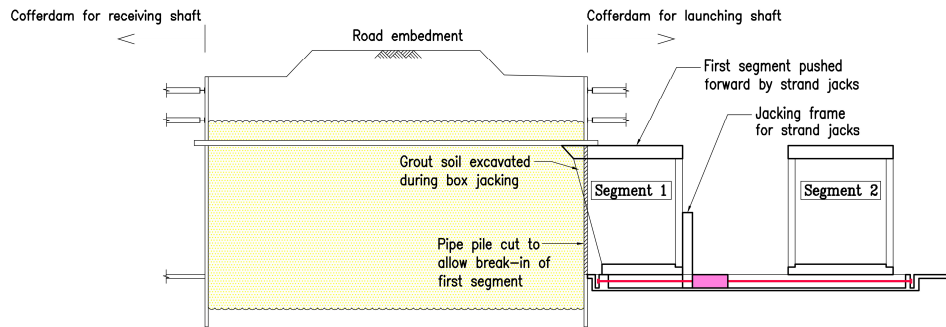
Box-jacking is a technique that is usually adopted in situations where excavation is required to be undertaken beneath critical infrastructure where there is no tolerance for the risk of collapse or for disruption caused by settlement, such as major transportation connections, or essential facilities which must remain operational at all times.

The technique typically involves the pushing of a series of precast concrete boxes (usually rectangular in section) through the ground beneath the affected infrastructure. The box structures are normally launched from a sliding pad in an area adjacent to the excavation, and may either be pushed horizontally using a high-capacity hydraulic jacking system or pulled into place using strand jacks, while excavation is undertaken from inside the box at the same rate as the jacked box advances.

This system has been used successfully in Hong Kong for several projects, most notably for the construction of passages beneath the Airport Express Link as part of the Hong Kong Link Road connecting the main Hong Kong-Zhuhai-Macao Bridge to the Hong Kong Boundary Crossing Facilities.

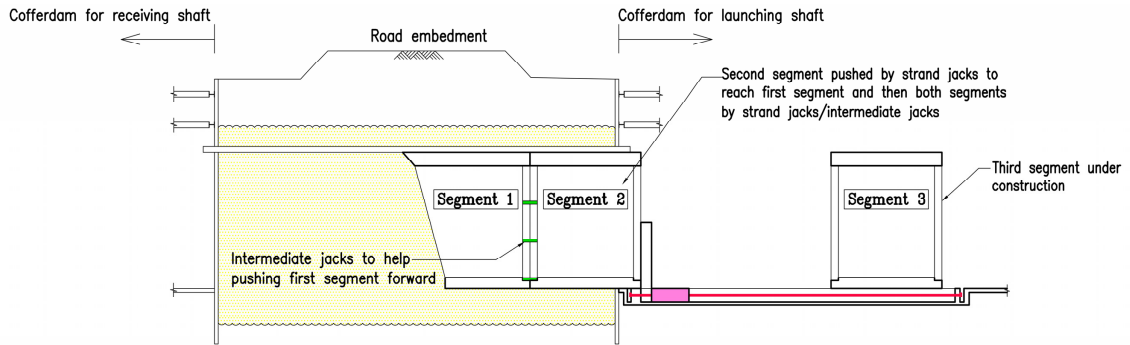


Stage 1: Concrete segments under construction within launching shaft

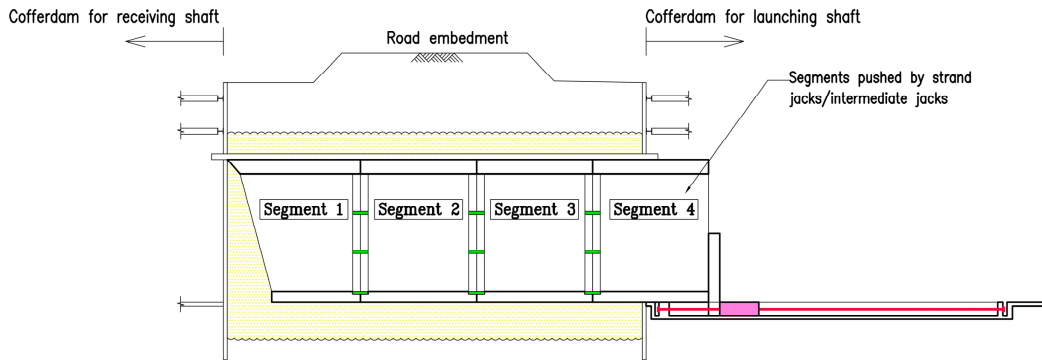


Stage 2: First concrete segment pushed forward by strand jacks

Box-jacking stage by stage (courtesy of Victor Li & Associates Ltd)



Stage 3: First and second concrete segment pushed forward by strand jacks/intermediate jacks



Stage 4: Procedures repeated for other segments

Box-jacking stage by stage (courtesy of Victor Li & Associates Ltd) (Continued)

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Suction foundations

Foundations for marine structures in Hong Kong are typically either tubular steel friction piles or large diameter bored piles. However, for the 66m tall meteorological mast installed in 2012 as part of a feasibility study for an offshore wind farm in the waters east of Sai Kung, neither type of foundation was expected to be effective. This was due to the particular geological conditions at the site (soft marine clays underlain by alluvial sand in 30m of water). Instead, a suction caisson foundation was proposed. Suction caisson foundations have been used in the offshore oil and gas sector for some time where ground conditions are suitable, but rarely in the offshore wind sector, and never before in Hong Kong.

The foundation used was a tripod system with three steel caissons, each closed at the top and open at the bottom. The structure was installed by lowering it onto the seabed and then pumping out the seawater inside the caissons. This created a pressure differential which slowly pushed the caissons into the soft marine clay.

This technology is environmentally friendly, requiring no pile driving, dredging or similar disturbance to the seabed. The process is also reversible, as by pumping seawater back into the caissons, they will be pushed out of the seabed, allowing the removal of the structure at the end of its operational life. The technology is economical and the installation process is rapid, with no need for expensive offshore piling equipment, and a reduced dependence on weather conditions. The foundation has stood the test of time, having now experienced several major typhoons. This success now paves the way for the potential adoption of this foundation type for other marine structures in Hong Kong.



Installation of suction foundation structure (courtesy of Ove Arup & Partners Hong Kong Ltd)

Pile removal technologies

Extraction of the steel piles used in lateral support systems is common in Hong Kong. They are usually not installed to great depth and can frequently be removed using vibration techniques.

Removal of steel H-pile foundations happens less often, but is sometimes required where existing foundations obstruct new construction works. Their extraction is more challenging as the piles are driven to a greater depth.

Extraction by vibration involves clamping a vibrating hammer to the top of the pile, with the hammer suspended from a crawler crane. The vibrating action of the hammer will loosen the pile, and the crane is used to pull up the pile (with hammer attached).

Hydraulic jacking may also be used to extract H-piles. A short cylindrical 'helmet' is welded to the top of the pile, or a clamping device is used to grab the H-pile. A specially made jacking machine is placed on the ground below the helmet or clamping device, and by opening the hydraulic jacks, the H-pile is then pulled from the ground.

A more unconventional way of extracting H-piles is the rotation and wedge method. A wedge is placed inside a steel casing to restrain the H-pile. This wedge acts as a jamming and immobilising device between the H-pile and the steel casing, and when the casing is rotated, causes the pile to twist and break. The process is repeated until the entire length of the pile is removed from the ground.

Another method is to expose the H-pile inside the casing and then lower a diamond wire saw to cut the pile.

The introduction of these new techniques allows the flexibility to remove more old foundations in many redevelopment areas in Hong Kong.



Left: Pile removal by hydraulic jacking (courtesy of Victor Li & Associates Ltd). Right: Pile removal by rotation and wedge method (courtesy of Hsin Chong Construction Group Ltd)



Pile removal by diamond wire saw (courtesy of Victor Li & Associates Ltd)

Shaft grouted piles and barrettes

The loadings in Hong Kong's high-rise buildings have taken pile design to an extreme level. The drive for higher pile capacity while maintaining manageable pile lengths has resulted in the development of advanced techniques.

Shaft grouting is a technique that may be applied to drilled pile shafts and barrettes (rectangular panel foundations) to increase their capacity by reducing the softening of the surrounding soil caused during the excavation process.

Full-scale instrumented pile tests have demonstrated that the grouting process can increase the friction between the side of the pile and the surrounding ground by two to three times compared with similar piles without post-grouting, thus allowing the pile or barrette to support a larger load. This increase in load-bearing capacity often allows foundations to be designed with significantly shorter piles (with associated cost and time savings), particularly in places where the bedrock is too deep to be used to found the piles on.

The grouting is carried out by cracking the surface layer of concrete or cement grout of the cast pile, allowing pressurised grout to squeeze between the external surface of the pile and the surrounding soil. The cracking of the outer concrete layer of the pile is done by pre-installing a series of perforated tubes close to the surface of the pile, through which the grout is pumped after the pile has been cast. The grout injection process locally increases the lateral earth pressure acting on the pile, enhancing the friction between the pile and the ground along the shaft.

The technique has been widely used worldwide, primarily for bored piles. In Hong Kong, shaft-grouting was initially used in the 1990s on West Rail, and more recently on the barrettes of Hong Kong's tallest, 108-floor International Commerce Centre, as well as on pre-bored H-piles and mini-piles for tall building structures.



Installation of shaft grouted piles for the Hong Kong-Zhuhai-Macao Bridge (courtesy of Ove Arup & Partners Hong Kong Ltd and Highways Department, HKSAR Government)



Grout pipe attached to reinforcement cage



Soil
Cement grout at pile / soil interface
Pile

Left: Grout pipes attached to a reinforcement cage. Right: A core sample that shows the cement grout at pile/soil interface achieved through shaft grouting (both courtesy of Ove Arup & Partners Hong Kong Ltd)

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Landslide Risk Management

New framework for natural terrain hazard studies

There are many uncertainties associated with the evaluation of natural terrain landslide hazards. Previously there was no detailed guidance available, meaning that studies used to be done in a rather haphazard manner, and lacked a unified approach.

Following more than ten years of research effort to advance the understanding of rain-induced natural terrain landslides in Hong Kong, a new framework for natural terrain hazard studies has been developed as the best practice. This has recently been further refined and rationalised to take account of experience gained, and of the feedback provided by practitioners.

A risk-based framework is used to identify key landslide hazards and apply a Design Event approach. The systematic methodology incorporates the application of state-of-the-art engineering geological and engineering geomorphological mapping approaches, together with the latest landslide debris dating techniques, while taking account of the potential landslide hazards and the failure consequences.

Compared with the first-generation framework that was previously used in Hong Kong, the current framework places the hazard mitigation at a level that is more appropriate and practically achievable, providing a cost-effective and pragmatic approach to address natural terrain landslide hazards using the latest technology and geotechnical knowledge.



A new framework has been developed for natural terrain hazard studies to meet challenging natural terrain risk management in Hong Kong (courtesy of Geotechnical Engineering Office, HKSAR Government)

Improved debris mobility analyses

Conventional slope stability assessment is mainly concerned with the prediction and prevention of failure. Holistic landslide risk management, however, considers in addition the consequences of a landslide, including the behaviour after a slope failure, and in particular the dynamics of landslide debris motion.

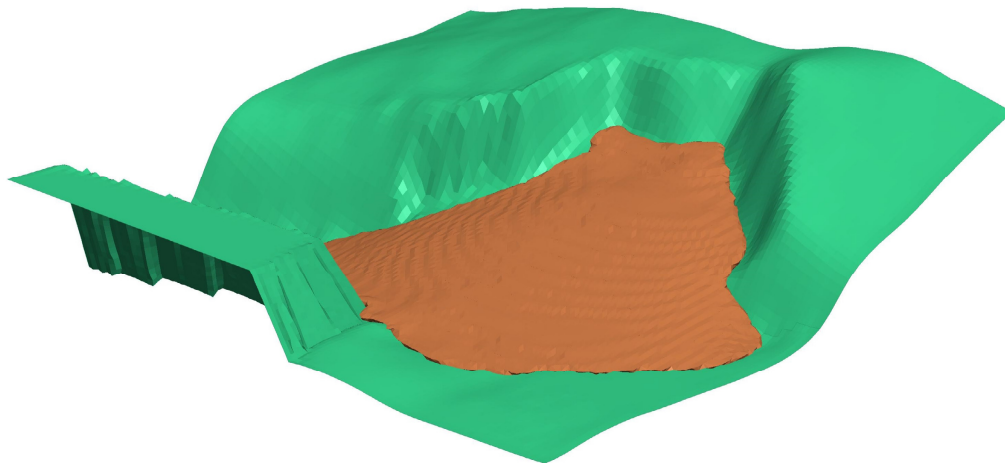
Two-dimensional landslide debris mobility analysis is now routinely carried out in Hong Kong as part of a natural terrain hazard study. For certain site settings, and for detailed assessment of landslides, three-dimensional landslide debris mobility modelling can be an important additional tool, with major advances made in Hong Kong over the past decade.

The latest approach for three-dimensional debris mobility modelling of landslides adopts an advanced numerical algorithm that couples Smoothed Particle Hydrodynamics (a numerical method for simulating the dynamics of debris flows) with spatial analysis and modelling tools. In parallel, landslide practitioners in Hong Kong have made significant advance in finite element modelling to couple the analysis of landslide debris mobility with the structural interaction between the landslide debris and the debris-resisting barrier on impact.

These advances have resulted in numerical models with an unprecedented analytical capability, streamlined the workflow for natural terrain hazard studies, and improved the visualisation of output. They have collectively led to more accurate results and improved efficiency in the study and mitigation of natural terrain landslide risk.



Three-dimensional debris mobility modelling of a debris flow (courtesy of Geotechnical Engineering Office, HKSAR Government)



Advanced finite element modelling of landslide mobility (courtesy of Geotechnical Engineering Office, HKSAR Government)

Rational design methodology for debris-resisting barriers

Debris-resisting barriers can be an effective solution to mitigate the risk of natural terrain landslides. However, there are no unified design standards for such barriers, with the design performed either empirically or using rudimentary methods which are unproven or poorly-substantiated.

Concerted research efforts have been made in Hong Kong over the last few years to improve our understanding of the performance of these barriers. Large-scale field and laboratory tests have been conducted to investigate the interaction of landslide debris impact and barrier performance. Advanced numerical modelling tools have also been developed and parametric studies carried out. The work has culminated in the formulation of rigorous and rational methodologies for the design of both rigid and flexible debris-resisting barriers, which consider debris impact as well as boulder impact.

With ongoing technical development work, there is scope for further refinement and optimisation of the rational design framework to achieve better cost effectiveness and improved robustness.



A rigid debris-resisting barrier comprising a reinforced concrete check dam together with gabion cushioning material and baffles (courtesy of Geotechnical Engineering Office, HKSAR Government)



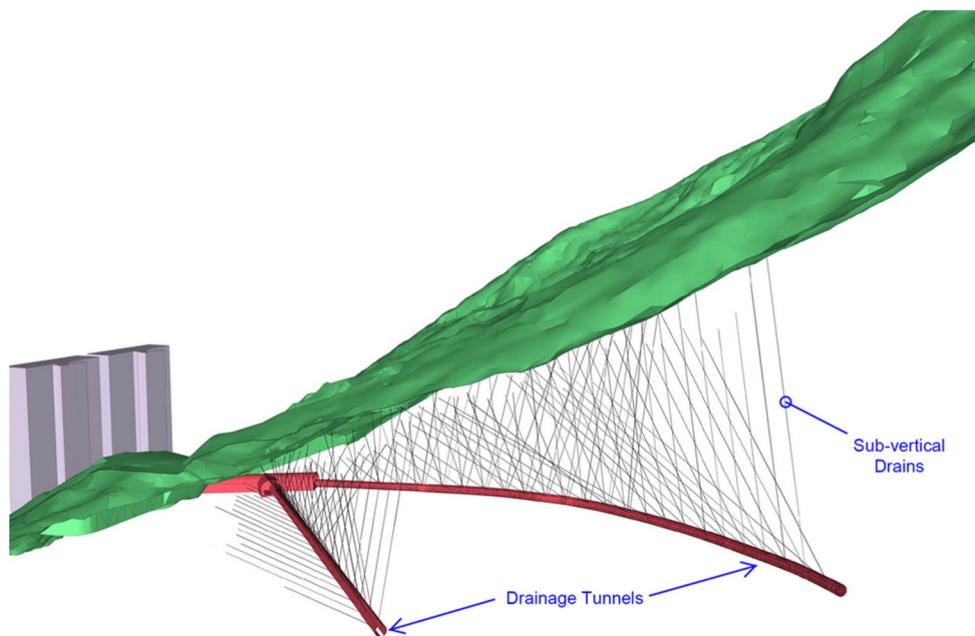
A flexible debris-resisting barrier (courtesy of Geotechnical Engineering Office, HKSAR Government)

Hillside stabilisation using drainage tunnels

The natural hillside at Po Shan comprises a thick body of ancient landslide debris that is susceptible to the development of high groundwater levels and at risk of large scale landslides under severe rainfall.

To improve the stability of the hillside and reduce the risk to the public, an innovative regional groundwater control system was implemented to regulate the groundwater levels within the natural hillside. This comprised two drainage tunnels with a network of 172 sub-vertical drains. The works were completed in 2009 and the drainage tunnel system has worked well since operation. The scheme has been demonstrated to be cost-effective and easy to maintain, with novel elements including:

- The use of a retractable tunnel boring machine to construct the two drainage tunnels, which avoided the need to build a separate receiving shaft and hence significantly minimised the environmental impact.
- The construction of more than 100m long sub-vertical drains by percussive drilling from within the drainage tunnels using an up-the-hole hammer (a world first).
- A pressure relief system using valves to regulate the groundwater levels within permissible limits to achieve sufficient safety margin against deep-seated landslides while avoiding excessive ground settlement caused by groundwater drawdown.
- An instrumentation system combining real-time continuous monitoring of water pressure in the sub-vertical drains with a warning system providing automatic alerts if the thresholds are exceeded.



Schematic diagram of the drainage tunnels and sub-vertical drains beneath the natural hillside at Po Shan (courtesy of Geotechnical Engineering Office, HKSAR Government)



Left: Entrance of the drainage tunnels. Right: Inside of the drainage tunnels (courtesy of Geotechnical Engineering Office, HKSAR Government)

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Tunnelling and Underground Space

Innovative use of rock caverns for infrastructure

Hong Kong has been using rock caverns and underground space for some time, and there have been some novel applications in the last decade, such as the Happy Valley Underground Stormwater Storage Tank, which demonstrated the successful use of underground space for flood prevention. Another notable example was the Po Shan drainage system, which used tunnels and sub-vertical drains to regulate regional groundwater levels in order to improve the stability of the hillside against large-scale landslides. A showcase project that adopted an underground solution to free up surface land was the Western Salt Water Service Reservoir, which was relocated to rock caverns constructed on an adjoining hillside as part of the development of the Centennial Campus of The University of Hong Kong.

For sustainable city development, the strategic use of rock caverns is a viable solution that can create space for a variety of land uses. To promote the systematic utilisation of rock caverns, Hong Kong has recently developed a Cavern Master Plan providing strategic planning and technical guidance for the territory-wide application of rock caverns. The Cavern Master Plan marks a new milestone in subterranean land use planning, bringing a paradigm shift of managing land mass from a three-dimensional perspective, optimising the use of 'hidden' land resources and providing new opportunities for planning and development in Hong Kong.



View of the Centennial Campus of The University of Hong Kong and natural hillside containing the rock caverns (courtesy of Geotechnical Engineering Office, HKSAR Government)



Construction below live railway tunnels

Underpinning is a technique of supporting an existing structure from below while the foundations or rock that it rests on are removed.

The process of underpinning and excavation beneath the operating Island Line tunnels to bring the new South Island Line into Admiralty Station was one of the major engineering challenges of the South Island Line project. The underpinning works spanned 58m and were up to 19m wide and 26m deep, and involved supporting the operational Island Line running tunnels and passenger platforms with incrementally extendable steel support columns while the underlying rock was removed to a depth of more than 20m to create the new station extension.

Access for the underpinning was through temporary openings in the top-down excavation for the new station extension. Once the excavation reached the first formation level, headings were advanced to allow the underpinning supports to be installed. After the completion of each heading excavation, extendable steel columns fitted with hydraulic jacking assemblies were installed. Steel beams were installed across the tops of the support columns to support the existing structure using the jacks. Once the load of the existing structure was taken up, further excavation of the adjacent headings would commence. On reaching the new formation level, the support columns would be extended to support the existing structure, and excavation of the previous heading would commence down to the next formation level. This technique of alternating between two different sets of extendable support columns allowed the underpinning works to proceed systematically down to the final formation level. On completion of the excavation, half of the 28 temporary support columns were removed, and the remaining temporary support columns were encased in concrete to become part of the final structure.

During the underpinning and excavation process, seven separate monitoring systems including automatic deformation monitoring systems, three-dimensional vibrating wire strain sensors, load cells and stroke sensors were used to automatically monitor movements and the loads on the temporary works in real time and to check that any movement of the existing railway structures remained within the 3mm allowable tolerances.



Underpinning structures at Admiralty Station (courtesy of MTR Corporation Ltd)



Progressive excavation between temporary supports for underpinning of the Island Line (courtesy of MTR Corporation Ltd)

Raise-bored shafts

Raise-boring is a technique originally developed in the USA in the early 1960s for the construction of vertical, inclined or sub-horizontal shafts for the mining industry. A small pilot hole is drilled down into an underground excavation or tunnel, and then the hole is enlarged by pulling a reamer upwards through the pilot hole. The technique offers several advantages over traditional shaft excavation methods, including much shorter excavation durations and enhanced safety.

Today, the technology has the capability to reach depths of up to 2km and diameters of up to 8m. While it is still mainly used in the mining industry, the technology is gaining momentum for civil engineering applications.

The Hong Kong West Drainage Tunnel, completed in 2012, was the first civil project in Hong Kong to make systematic use of raise boring for shaft construction and is an excellent demonstration of the benefits that this excavation method can offer in metropolitan areas. An 11km long drainage tunnel with 34 intake dropshafts was constructed through granite and volcanic tuff between Tai Hang and Cyberport to divert stormwater and protect northern Hong Kong Island from flooding.

Most of the intakes, which varied in depth between 40m and 166m and had diameters of either 2.4m or 3.2m, were constructed by raise boring. Raise boring was adopted as it minimises the environmental nuisance and disturbance to the public. Disposal of spoil during construction was carried out underground through the main tunnel minimising the need for the use of heavy trucks within the congested urban areas above the tunnel. The raise boring equipment was relatively compact and adaptable, allowing mobilisation in extremely tight areas and the use of the same equipment to construct the different diameter shafts, with much higher production rates compared to conventional methods.

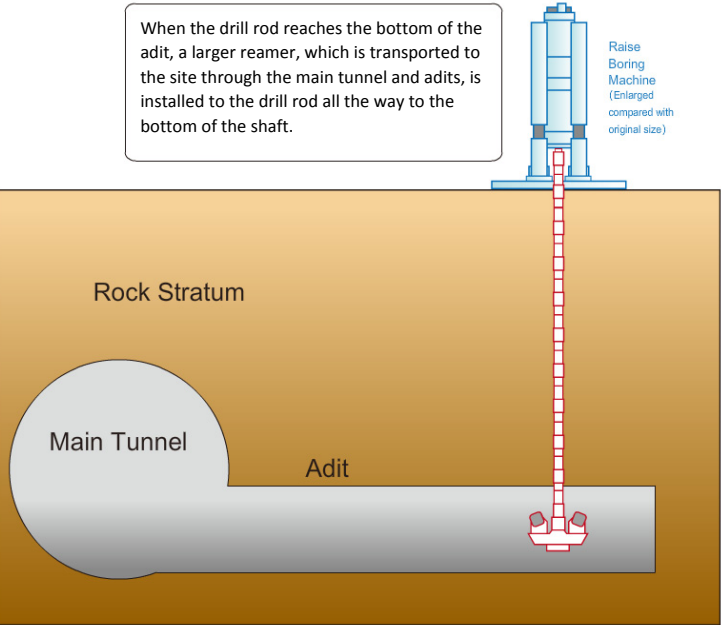
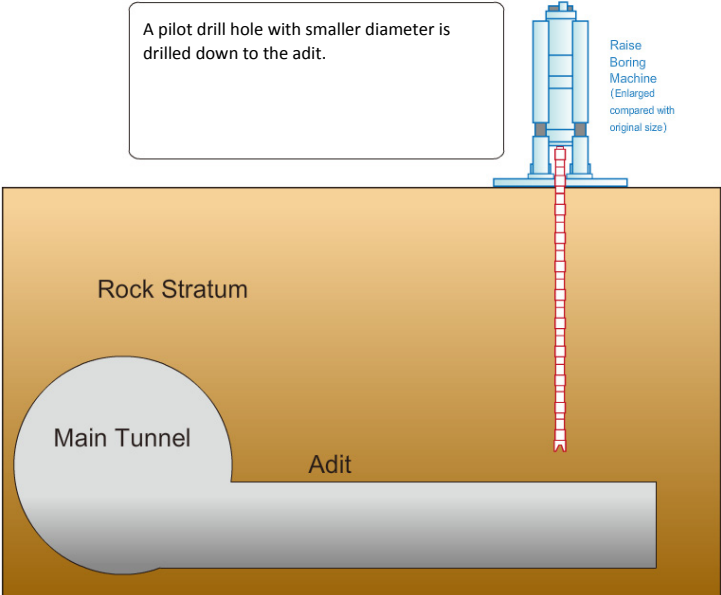


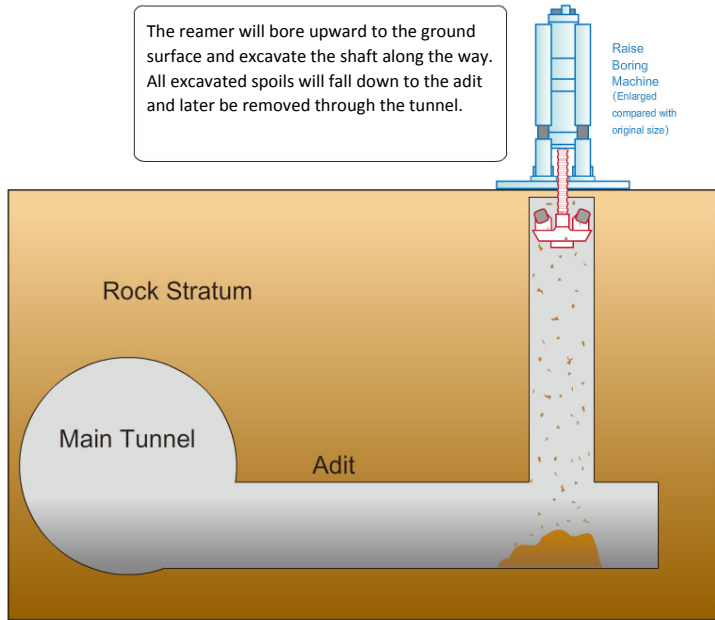
The reamer in position below the pilot hole (courtesy of Dragages Hong Kong Ltd)



A close-up view of the reamer cutter head (courtesy of Dragages Hong Kong Ltd)

Construction of a raised-bored shaft stage by stage (courtesy of Ove Arup & Partners Hong Kong Ltd)





Construction of a raised-bored shaft stage by stage (courtesy of Ove Arup & Partners Hong Kong Ltd) (Continued)

TBM innovations

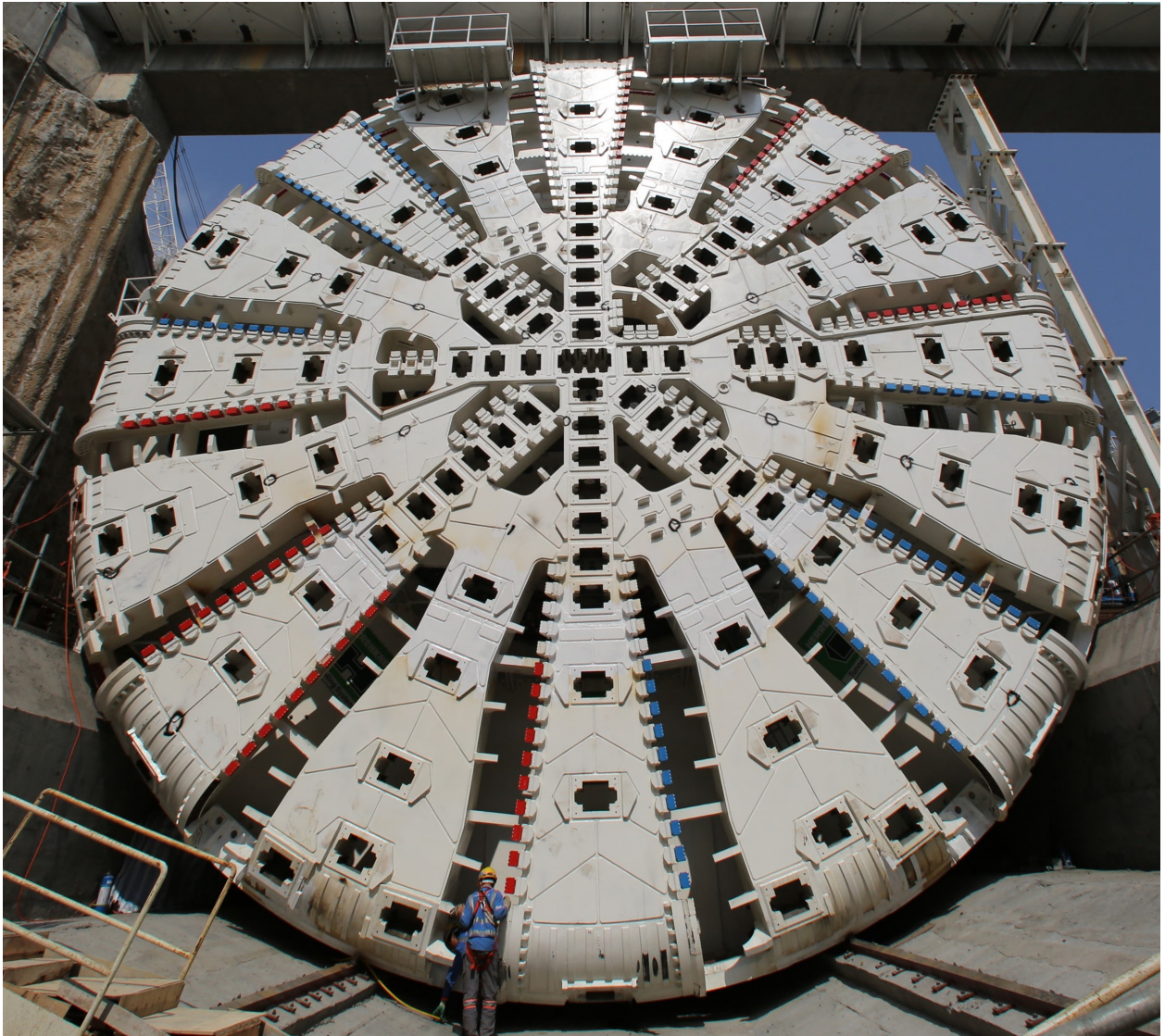
In the past, tunnelling through variable geologies often demanded time consuming modifications or even changes to the tunnelling equipment.

Recent developments in multi-mode and variable-density Tunnel Boring Machines (TBMs) allow a single TBM to transition between different modes of operation and face support.

Multi-mode TBMs can switch between at least two different operation modes, for example between slurry mode and earth pressure balance mode, or between open mode and slurry mode.

Variable-density TBMs allow a continuous transition of support from a low-density slurry, through a high-density slurry up to full earth pressure balance mode. They utilise a screw or belt conveyor to extract excavated material from the tunnel face into a slurryfier box, where it is mixed with bentonite to create a slurry of the correct density needed to support the current excavation. This slurry is then pumped back into the excavation chamber to support the tunnel face.

In 2015, Hong Kong saw the world's largest TBM used to excavate the 4.2km long dual subsea tunnels of the Tuen Mun-Chek Lap Kok Northern Link at depths of up to 50m below sea level. The 17.6m diameter variable-density TBM worked under compressed air at pressures as high as five atmospheres due to the high water pressures encountered. To reduce manual operations and increase safety, innovative tools were developed to monitor cutter wear and map the rock-face geology in real time, to remotely clean and inspect the TBM heads, and to remotely replace the TBM cutters.



The cutter head of the 17.6m diameter Tuen Mun-Chek Lap Kok TBM (courtesy of Dragages Hong Kong Ltd)

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Geospatial Data Acquisition and Sensing Technology

Enhanced remote sensing techniques

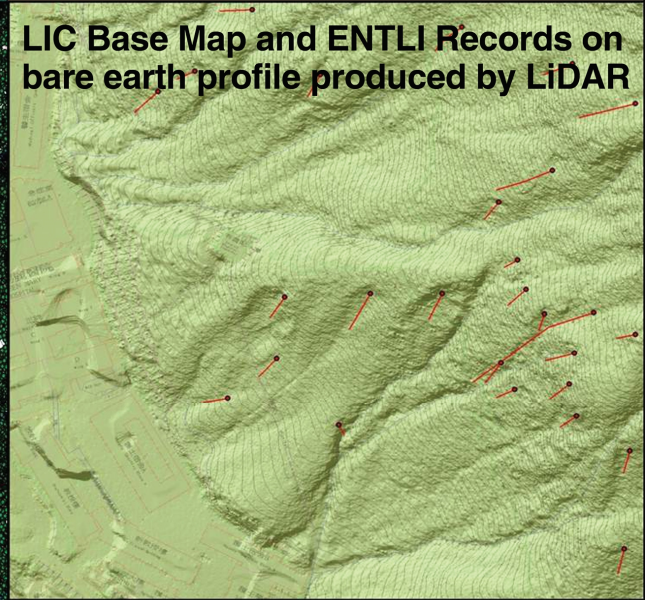
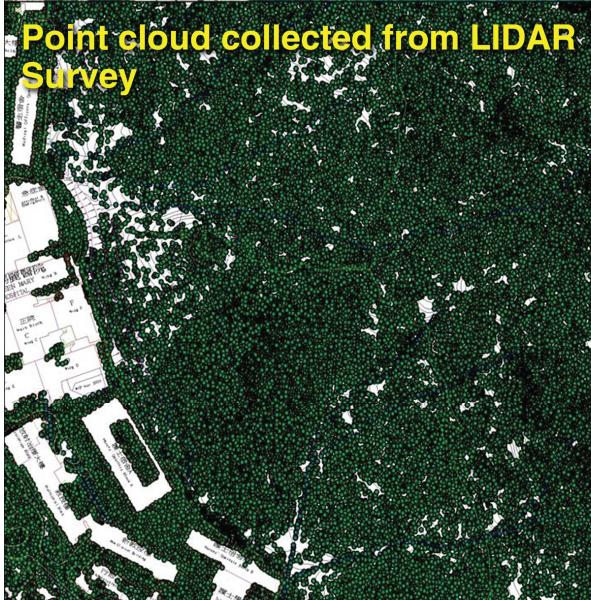
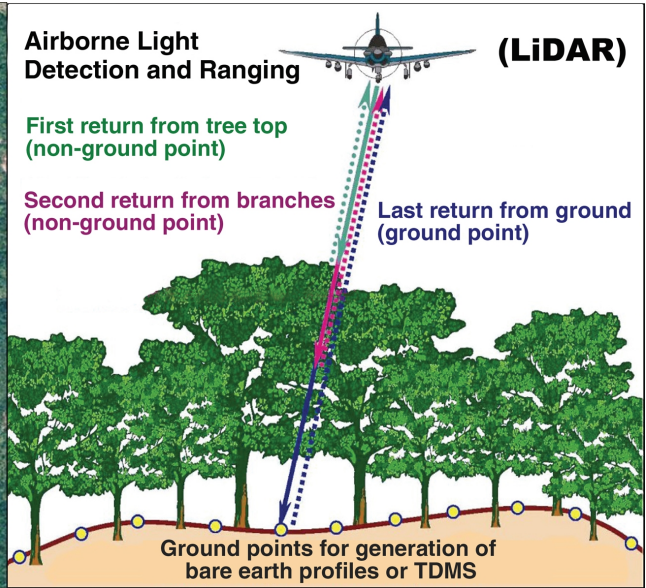
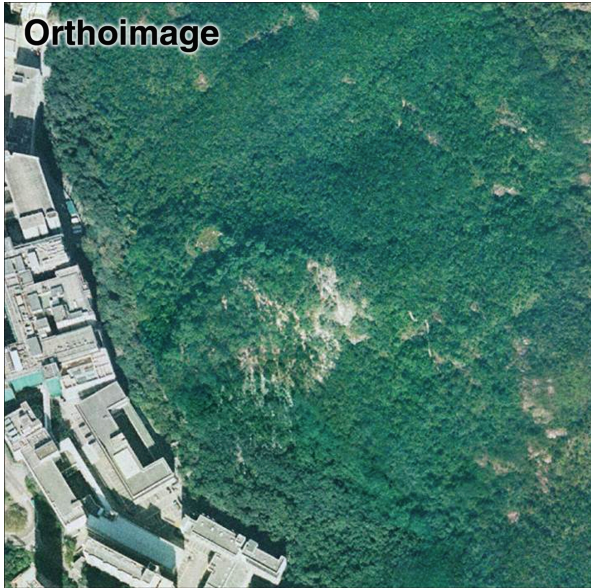
Traditionally, most geotechnical observation and monitoring has been carried out using single point measurements, with the area and density of measurement locations constrained by cost, time and practicality.

However, the ability to take a wide scale view can assist in the understanding of many geotechnical processes. Recent developments and cost reductions in various remote sensing techniques have made additional tools routinely available for investigating such processes as settlement due to groundwater extraction or mining, or landslide behaviour and failure mechanisms.

Techniques available include stereo photography, interferometric synthetic-aperture radar (InSAR), and laser scanning (known as light detection and ranging, or LiDAR). The various techniques have their own advantages and disadvantages, but the data obtained is a collection of points in three-dimensional space (“point cloud”), which can be used to generate a model of the surface of the area of concern (digital elevation model, or DEM). This may be directly input into computer aided design or modelling software and used to help with feature identification, mapping, hazard prediction, and monitoring.

Depending on the application and the size of the area to be covered, data may be acquired from satellites, fixed-wing aircraft, helicopters, or from a location on the ground adjacent to the area of interest.

In 2011, a territory-wide airborne LiDAR survey was performed for the HKSAR Government. The ability of a LiDAR system with multi-return capability to penetrate vegetation (“virtual deforestation”) to map the underlying ground surface, has revolutionised Hong Kong’s approach to natural terrain hazard study, and allowed the identification and study of previously hidden landslide scars, terrain morphology and historical man-made features.



“Virtual deforestation” capability of multi-return airborne LiDAR survey, compared to landslide records in the Enhanced Natural Terrain Landslide Inventory (ENTLI) (courtesy of Geotechnical Engineering Office, HKSAR Government)

UAV remote sensing

In the past few years, the number of small pilotless aircraft, known as Unmanned Aerial Vehicles (UAVs) or drones, suitable for professional use has continued to increase. Functionality and ease of use are improving and the cost continues to decrease.

Subject to local licensing and regulatory requirements, these devices fill the gap between terrestrial survey and conventional remote-sensing, and have opened up the possibility to safely, quickly and cost-effectively carry out small-scale, close-range airborne survey and sensing operations that are not practical by other means.

It is expected that the use of UAVs will further increase, as manufacturers continue to develop conventional airborne survey tools such as LiDAR into packages small enough to be operated from a UAV.

UAVs are currently used in Hong Kong for several engineering applications, including the use of visible and infra-red photography for mapping and inspection of landslides and structures, as well as photogrammetry for generation of digital elevation models and earthwork volume assessments.



Close-up photos taken by UAV following a landslide above Sai Wan Road in 2016 (courtesy of Geotechnical Engineering Office, HKSAR Government)



Left: UAV images of the landslide. Right: DEM generated by photogrammetry from the UAV images, which was used to assess the landslide source volume by comparison with the pre-landslide LiDAR survey data (courtesy of Geotechnical Engineering Office, HKSAR Government)

Real-time remote monitoring

Geotechnical monitoring has been used for many years to provide information to reduce the technical and commercial risks associated with geotechnical structures such as slopes, excavations, tunnels and reclamations, from the design stage, through construction, and eventually during the service life of the structure. It forms an integral part of the observational method for geotechnical design.

Traditionally, most geotechnical monitoring has been performed by taking manual readings. This is slow, labour intensive, and error-prone, with delays in making the data available due to the time required to prepare monitoring reports. There may also be access restrictions that interfere with the monitoring process, for example if instrumentation is installed inside an operating railway tunnel.

Automating the process not only overcomes these issues, but offers additional benefits, including the ability to monitor many sites from one location and to acquire additional information by monitoring more frequently than is practical or cost-effective with manual monitoring.

The Government was an early adopter of real-time monitoring in Hong Kong, setting up an Automatic Rain gauge System in 1984 to measure rainfall at various locations and regularly send the data to a central system. The system, which has had several technology upgrades over the years, is still used to help determine the need to issue the Landslip Warning.

Although cost and technology issues initially hindered the wide adoption of automated monitoring, recent advances in intelligent, networked sensors with Internet connectivity which allow users to control the function of the device and analyse the readings (the “Internet of Things”) as well as Hong Kong’s excellent telecommunications infrastructure mean that it is now commonplace to use real-time remote monitoring systems to monitor geotechnical processes as they are occurring. Websites are routinely used to manage large volumes of monitoring information and make it instantly available to all stakeholders, and immediately issue warnings or alarms when monitored parameters exceed predefined limits.

Similarly, the use of dedicated mobile apps allows site-based supervisory staff to efficiently capture and transmit key quality control information, for example during soil nailing works, or to allow engineers to record and report details of landslide incidents.

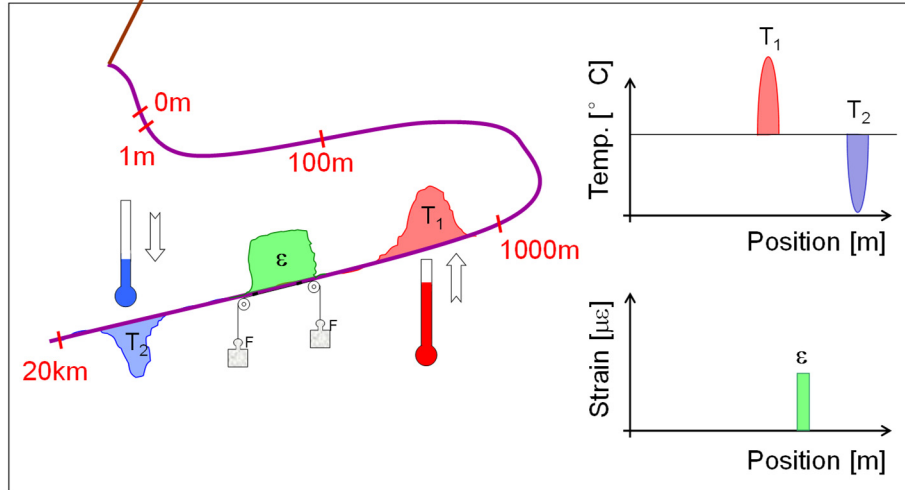
Information and communications technology will continue to advance, and provide new opportunities for the application of real-time information in the geotechnical field, possibly using big data analytics and artificial intelligence to examine patterns and correlations to help engineers make better-informed decisions.

Optical fibre sensing

Geotechnical instrumentation has been routinely used for more than 70 years, initially with simple mechanical and hydraulic sensors, and later with electrical sensors. Most instrumentation today remains very similar, with limited technological development. Conventional geotechnical sensors have several inherent limitations including susceptibility to electromagnetic interference, the need to install many cables when monitoring at multiple locations, and signal deterioration when long cables are used.

Optical fibre sensing technologies can help to overcome these issues. There are two main optical fibre sensing technologies in common use today. The first requires microscopic diffraction gratings to be etched into the fibre (Fibre Bragg Gratings) at regular intervals along the fibre, which allow different frequencies of light to pass as the fibre is stretched. These become the sensing elements, and may be used to measure parameters including strain, acceleration and pressure. The second technology uses the interaction between laser light and imperfections in the fibre (Brillouin Scattering) to measure strain and temperature. Although measurements using Brillouin Scattering are slower and less precise than those using Fibre Bragg Gratings, standard optical cable may be used as the sensor, and sensing is continuous along the length of the cable. Both technologies are immune to electromagnetic interference, and may be used for sensing over distances greater than 10km.

Since the first optical fibre sensors were fabricated in the late 1970s, significant progress has been made on their development and commercialisation. Although the cost of the data loggers used for optical fibre sensors are reducing, they remain many times more expensive than data loggers for conventional geotechnical sensors. However, for measurements involving many measurement points and long distances, for example along a pipeline or embankment, the total system cost (sensors, cabling and data loggers) can be significantly less than that of a solution using conventional sensors, because there is no need to install telemetry equipment, individual sensors, cables to each measurement point and multiple data loggers. In some cases, the optical fibre sensors can be used for measurements that are not possible using conventional sensors, such as being woven into a geotextile to measure strain and temperature.



The use of Brillouin scattering for the distributed measurement of strain and temperature along a sensing fibre (courtesy of The Hong Kong Polytechnic University)

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