SLOPE SAFETY TECHNICAL REVIEW BOARD

REPORT NO. 28

to

Director of Civil Engineering and Development
The Government of the Hong Kong Special Administrative Region

Hong Kong
30 November 2018

EXECUTIVE SUMMARY

During 2018, GEO made good progress in the management of slope safety in Hong Kong. SSTRB confirms that GEO discharges its responsibilities effectively. Conclusions from the 2018 review include:

- It has been ten years since the last landslide fatality in Hong Kong (a record) and 24 years since the last multiple fatality event, a remarkable achievement. There is the need to recognise that the continued low level of losses from landslides is a combination of the ongoing highly successful programme and the run of years without wide-scale, extreme rainfall events. Hong Kong should avoid a sense of complacency. It is essential to maintain the current level of investment in slope safety.
- GEO faces an important challenge with the need for increasing innovation in slope safety management. This challenge links directly to the Chief Executive's commitment to make Hong Kong an international Innovation and Technology (I&T) hub and a smart city. SSTRB believes that the spirit of innovation that GEO is building within its organisation is essential for improving the safety of slopes, especially against future climate change related events.

SSTRB endorses the work done to date. SSTRB has 28 recommendations. Key recommendations include (Recommendation No. in parenthesis):

- In view of the need to promote innovation in building and construction practice, SSTRB recommends that GEO considers assuming an even more active liaison role between research (universities) and practice within geotechnical innovation (4).
- SSTRB recommends that GEO prepares a plan that describes the short and long term development of their competence within I&T. A champion should be identified for each technology. SSTRB further recommends that GEO prepares plans for vocational training of GEO professionals in assessing new technologies (5).
- SSTRB recommends that GEO investigates the characteristics of previous tropical cyclones that have delivered large amounts of rainfall (for example Typhoon Rose in 1971) to get an appreciation of the characteristics of tropical cyclones that have caused substantial landslide impacts (1).
- SSTRB recommends that GEO engages with appropriate agencies to explore the mounting of a large-scale permanent public exhibition about disaster risk in Hong Kong, including the threats posed by landslides (12).
- SSTRB recommends that GEO provides a detailed plan and timeline for barrier work and quantifies the technical achievement level of each development against this plan, for both rigid and flexible barriers (20 and 21).
- SSTRB recommends that GEO devises a strategy for the development of public engagement in the potential Kowloon Park underground space project and that GEO continues to explore whether there may be innovative processes that allow the development of the Kowloon Park project without large scale excavations (26).

TABLE OF CONTENTS

1. INTRODUCTION

The 28th meeting of the Slope Safety Technical Review Board (SSTRB) was convened in Hong Kong between 24 and 30 November 2018. This was the first meeting of the 7th SSTRB. The members of the 7th SSTRB are Dr Suzanne Lacasse, Professor David Petley and Professor Kenichi Soga. The activities of SSTRB followed the programme prepared by the Geotechnical Engineering Office (GEO), which is enclosed in Appendix A.

On 24 November, the three SSTRB members participated in an induction programme on the slope safety system of Hong Kong, notable past landslides, the Landslip Prevention and Mitigation Programme (LPMitP), geotechnical control, emergency system and landslip warning system, public education and communication and the major stakeholders for slope safety.

On 25 November, SSTRB visited the Fan Kam Road site where clusters of landslides occurred in August 2018. SSTRB was also apprised of the use of a new handheld laser scanning device. SSTRB also visited HKUST's Kadoorie debris flow testing flume. Comments on the demonstrated technologies are given in the report.

SSTRB met with Director of Civil Engineering and Development (DCED), Mr R.C.K. Lau, on 26 November 2018, and with Permanent Secretary for Development (Works) (PS(W)), Mr S-H Lam, on 29 November 2018. A meeting with local professional bodies was held in the evening of 28 November 2018. Debriefing with the GEO Management Committee (ManCom) took place on 30 November 2018.

On 27 November 2018, Professor Kenichi Soga presented a Joint CEDD-GEO, HKIE(GD) and HKGES Technical Seminar on "Trends in large deformation analysis of landslide mass movements with particular emphasis on the material point method".

This report presents SSTRB's recommendations after its review of GEO's work in 2018. SSTRB expresses its appreciation to all, both within and outside of GEO, for the highly professional organisation of the review and stimulating discussions during the SSTRB week. Mr Frankie Lo acted as Secretary for SSTRB, and provided attentive and effective support.

2. RESPONSE TO SSTRB's PREVIOUS RECOMMENDATIONS

The role of SSTRB is to advise GEO and the HKSAR Government on technical aspects of slope safety and to measure this effort against international practice and research on slope safety and related areas.

During the SSTRB week, GEO presented to SSTRB a description of the work done in 2018. Several of the SSTRB's review topics in 2018 pertain to innovation and new technology to manage landslide risk. GEO also provided a response to the 42 recommendations made by SSTRB in Report No. 27 (2017). A summary of the responses by GEO is included in Appendix C. GEO followed up each of SSTRB's recommendations very satisfactorily. SSTRB is pleased with the attention GEO gives to its recommendations. The responses of GEO were documented in technical notes and briefs sent to SSTRB prior to the meeting in Hong Kong and in the presentations and discussions during the SSTRB week in Hong Kong.

3. REVIEW TOPICS

3.1 Rainfall in 2018

In common with previous years, GEO briefed SSTRB on the patterns of rainfall to date in 2018. The single reference rain gauge at the Hong Kong Observatory (HKO) indicates that total rainfall was about 11.2% below the mean level (2077 mm recorded to the end of October). On the other hand, when rain gauges providing spatial coverage of all of Hong Kong are considered, the total was about 6% above the mean (2229 mm to the end of October), reflecting slightly higher than average rainfall totals in the northern part of Hong Kong. In general, the pattern was a dry start to the year followed by a reasonably average wet season. The occurrence of very intense rainfall events was comparatively low.

The pattern of rainfall led to the issuing of 27 amber and four red rainstorm warnings. No black rainstorm warnings have been issued in 2018 to date.

To date, 231 landslides have been recorded, of which eight have been classified as major landslides, a figure that is close to the long term background rate. Three landslip warnings were issued:-

- On 7 June 2018, as a result of Typhoon Ewiniar. In total 12 landslides were recorded;
- On 29 August 2018, as a result of heavy rainfall. In total 44 landslides were recorded, of which five were major (see below);
- On 16 September 2018, as a result of Super Typhoon Mangkhut. In total, 28 landslides were recorded, of which one was considered to be major.

In general the landslip warning system appears to have operated effectively. SSTRB notes that the landslide-generating rainfall in the New Territories on 29 August 2018 was not associated with a black rainfall warning.

Overall, once again Hong Kong has experienced a year without a very high magnitude rainfall event in a densely populated area, and so has avoided high consequence landslide events. In part this is a recognition of the extraordinary success of GEO, but it also reflects the comparatively benign rainfall conditions, in particular with respect to extreme events in hilly urban areas. Even the passage of Super Typhoon Mangkhut, which caused substantial wind and flood/storm surge damage and over 60,000 treefalls, did not trigger extensive landslides. This may have been associated with a comparatively high track speed, which meant that the rain bands tracked through quickly, reducing rainfall totals. Thus, this super typhoon event differs from some previous typhoons.

Recommendation No.1:
SSTRB recommends that GEO investigates the characteristics of previous tropical cyclones that have delivered large amounts of rainfall (for example Typhoon Rose in 1971) in terms of, for example, typhoon magnitude, size, wind speed, track speed, eyewall size at landfall, track direction and track location. The aim is to get an appreciation of the characteristics of tropical cyclones that have caused substantial landslide impacts.

3.2 Landslides in 2018 and selected landslide investigation studies

GEO presented to SSTRB the statistics on landslides triggered to date in 2018. Of the 231 recorded incidents, 178 occurred on man-made slopes and 53 occurred on hillsides. The majority of the landslides on man-made slopes occurred on cut slopes, with only a few incidents affecting fill slopes and retaining walls. The annual failure rate for registered engineered slopes remains at 0.05%, much lower than for non-engineered slopes, and significantly better than the target success rate in preventing major landslides. Thus, the statistics continue to demonstrate that the risk-based approach to slope management is proving to be effective.

GEO presented some examples of incidents in 2018, including rockfalls and washouts. Two incidents are particularly notable. In one incident, at Pai Tau village in Shatin, a 1.5 m^3 landslide on a cut slope impacted upon a squatter shelter, resulting in permanent evacuation of the building. In the other, the most significant event in 2018, a cluster of landslides occurred on 29 August at Fan Kam Road in Fanling. This landslide cluster, which SSTRB visited on 25 November 2018, was triggered by a severe rainfall event, which had resulted in a landslip warning being issued. The cluster of landslides can be split into three parts – two channelized debris flows, each with multiple small landslide sources, and a cluster of open hillslope failures. Debris from the landslides, and/or from outwash from the toe, reached Fan Kam Road, which became blocked. Some vehicles and abandoned structures were affected.

GEO and the Landslide Investigation Consultant have found that the cluster of landslide broadly reflects the area of highest measured rainfall in the storm, which was the most severe short duration rainfall event recorded to date at this location. The two-hour and four-hour rainfall return periods were c.1000 and c.600 years respectively. Initial investigations suggest that the rainfall triggered shallow slope failures close to the ridge line or to significant breaks of slope. In this case, the mobility of the landslides was quite low.

GEO successfully used a variety of technologies to gain a rapid understanding of this landslide cluster. The day after the event a UAV was deployed to examine and photograph the source zones of the landslides, and in the initial investigation a handheld laser scanner was used to document the site. SSTRB commends GEO for this sensible use of appropriate technologies, and notes that they helped to facilitate rapid assessment of the residual risk.

The causes for this tight cluster of landslides are fraught with uncertainties. Adjacent catchments appear to share characteristics with the catchments impacted by these events, without suffering a similar cluster of landslides. SSTRB was presented with a number of potential plausible explanations, which investigations continue.

Recommendation No. 2:
SSTRB recommends that GEO investigates the causes of the clustering of landslides at Fan Kam Road. GEO may like to construct a series of hypotheses around potential causes, and then to seek to test each hypothesis rigorously in order to ascertain the most likely explanation (see also section 3.8).

3.3 Overview of Landslip Prevention and Mitigation Programme (LPMitP)

The rolling Landslip Prevention and Mitigation Programme (LPMitP) is a mature programme operating at its full expected level. In 2015, SSTRB recommended that GEO maintains its landslip prevention and mitigation works at the current level. The performance of the programme in 2018 was as follows (Table 1):

Table 1: The performance of LPMitP in 2018.

Activity	Pledged output	Forecast output 2018
Upgrade government man-made slopes	150	152
Conduct safety screening for private man-made slopes	100	100
Implement risk mitigation works for natural terrain catchments	30	33

GEO must be praised for reaching its LPMitP targets year after year, and for the accolades received in 2018 for the LPMit Programme.

SSTRB acknowledges the efforts made by GEO to facilitate delivery of the consultancy liaison initiatives with the consultants and new engineering contracts (NEC) implemented from 2018. The reported safety performance index of 0.15 reportable accidents per 100,000 man-hours worked is well below the DEVB limit.

SSTRB supports the integration of BIM technology as part of the LPMit design and project management process.

Recommendation No.3:
In view of the discussions with the professional bodies of Hong Kong, SSTRB recommends that GEO considers whether it is appropriate at this time to include an incentive for more innovative solutions in the award criteria of landslip prevention and mitigation works.

3.4 Innovation and Technology for slope safety management, including sensing technologies

GEO presented their new developments in the area of Innovation and Technology (I&T), which directly links to the Chief Executive's commitment to make Hong Kong an international I&T hub and a smart city. I&T is one of the top strategic priorities within GEO to transform their geotechnical engineering practice. SSTRB is impressed with the breadth and depth of the developments that GEO has made in this area in the past few years. SSTRB also recognizes that GEO is one of the front runners in the area of I&T within CEDD. SSTRB believes that this spirit of innovation that GEO is building within its organization is essential for improving the safety of slopes, especially against future climate change related events, as well as for demonstrating their leadership to influence other departments in the I&T area.

Recommendation No. 4:
In view of the discussion with PS(W), and the need to promote innovation in building and construction practice, SSTRB recommends that GEO considers assuming an even more active liaison role, not unlike a revolving door, between research (universities) and practice within geotechnical innovation.

SSTRB notes that GEO is embracing I&T from multiple angles. An internal steering committee has been established to develop I&T strategies and to oversee their implementations by actors outside of GEO. SSTRB fully endorses the four I&T pillars that this committee has developed. These include (i) development of multidisciplinary teams within GEO, (ii) cross-disciplinary collaboration across different stakeholders, (iii) technology identification and development, and (iv) engineering implementation.

3.4.1 Development of multidisciplinary teams within GEO

SSTRB observes enthusiasms in the I&T activities at all levels within GEO. In particular, young professionals feel inclusive in the developments, which is essential in nurturing future leaders of the GEO community. SSTRB notes active engagements of several early career GEO professionals with Hong Kong academics in the development of technologies for slope safety management. These include wireless sensor network-based landslide detection system with the Chinese University of Hong Kong, artificial intelligence-based landslide detection with The Hong Kong Polytechnic University and virtual reality simulation tools with The Hong Kong Jockey Club (HKJC) Disaster Preparedness and Response Institute (DPRI). SSTRB welcomes these activities because successful leadership development in I&T will create an innovation culture within GEO and the industry.

The Information and Communications Technology sector is rapidly growing. SSTRB welcomes the strategy of GEO to continuously assess various technologies for potential application in geotechnical engineering. Such assessment requires vocational training of GEO professionals in new areas so that they can become critical appraisers, rather than relying on outside support. For example, many AI tools are written in Python language and training on Python can be useful in testing new data analysis and interpretation methods by GEO professional themselves rather than relying on external support.

Recommendation No. 5:
SSTRB recommends that GEO prepares a plan that describes the short and long term development of their competence within I&T. The plan can be linked to various ongoing and future I&T activities. A champion (preferably from early career professionals) should be identified for each technology. SSTRB further recommends that GEO presents to SSTRB its plans for vocational training of GEO professionals in new technologies. The plan can be a dynamic document that is updated every year.

3.4.2 Cross-disciplinary collaboration across different stakeholders

GEO is making excellent progress in adopting new technologies in their engineering practice and building up confidence in their use for slope safety management. Several case studies were presented to SSTRB and the outcomes are very impressive.

The adaptation of the Cloud-based Geotechnical Information Infrastructure (GInfo) in GEO engineering practice has shown promise in transforming the GEO processes to be efficient and at the same time disseminating data more effectively to the industry. GEO is considering to release data on LiDAR and ground investigation data into public domain. Several mobile applications have been developed based on this platform for internal use.

GEO is also planning to apply BIM in their geotechnical practice. GEO's ground investigation data will be available in their BIM software to create ground models. BIM Models of GEO-related structure such as barriers and soil nails have been created and shared to the industry partners.

The Enhanced Integrated Landslide Information System (EILIS) is linked to the Common Operational Picture (COP) platform for sharing emergency information among government departments. GEO's initiative on COP is strongly supported by SSTRB (Section 3.6).

3.4.3 Technology identification and development

In 2017, SSTRB recommended that GEO explores machine learning, big data and artificial intelligence in the management of slope hazards and the opportunities these approaches may present within the slope system. GEO has teamed up with Professor Shi of The Hong Kong Polytechnic University to test the feasibility of deep learning in identifying new natural terrain landslides and rock outcrop from aerial photographs. At present, the natural terrain landslide inventory database is updated every year by reviewing about 10,000 aerial photographs by humans. This aerial photograph interpretation (API) operation takes time due to skill dependency. If such artificial intelligence techniques are proven to be effective, the time and cost savings can be significant. At the meeting, Professor Shi presented the results of the two pilot studies (Tai O and Sharp Peak) and both showed the promise of the applicability of deep learning techniques. A prototype of the Landslide Inventory Mapping program utilizing GPU was also presented.

In 2019, GEO plans to have 0.25m resolution airborne LiDAR survey and to conduct a trial of hyperspectral imaging. These new datasets will be valuable to improve the artificial intelligent based landslide extraction method.

Recommendation No. 6:
SSTRB recommends that GEO continues to test the feasibility of deep learning technology and different image analysis methods to realize artificial intelligent-based landslide extraction. Considering the current API operational process, the target values for precision and recalled accuracy should be set and they should be compared to the outcomes of the feasibility studies.

GEO presented the recent application of UAV-based photogrammetry and remote sensing technologies such as handheld LiDAR and air-borne LiDAR for post-landslide response. GEO is building their confidence in using these technologies for landslide dimension measurement and volume estimation. This includes both equipment deployment at the site as well as data interpretation. The level of confidence is approaching to the level that they can replace the conventional landslide geometry evaluation.

Recommendation No. 7:
SSTRB recommends that GEO evaluates the value (e.g. time saved) of LiDAR technologies when compared to the conventional method for landslide geometry evaluation. A road map including the timeline to bring these technologies into routine practice should be developed. Furthermore, having residual risk management of post-landslide in mind, other potential

useful dataset that can be obtained by photogrammetry coupled with LiDAR should be identified.

Satellite based monitoring technologies such as InSAR are gaining attraction for land subsidence and infrastructure monitoring. SSTRB considers that the data can be beneficial for GEO's operations. For GEO an important application of satellite remote sensing may be in assessing landslide impacts in the aftermath of an extreme rainfall event. In this case GEO should be able to access satellite imagery from a wide range of providers via triggering of the International Charter: Space and Major Disasters. The Disaster Charter is activated at the request of "a national disaster management authority or its delegated agency in that country". Hong Kong is not listed as a location that has signed up to the Disaster Charter, although China is. It is important that this source of imagery is available in the aftermath of a major disaster.

Recommendation No. 8:
SSTRB recommends that GEO develops a protocol for the acquisition of satellite data in the aftermath of a landslide disaster. SSTRB recommends that GEO establishes whether Hong Kong has access to Disaster Charter data via China and, if so, determines which agency can make a request for data under the terms of the charter.

GEO presented their development of landslide detection system using LoRa based wireless sensor network technology. The system has been trialled at their debris resisting rigid barrier and flexible barrier systems with contractor engagement. The system will be embedded into mobile GInfo as an alert system.

Testing of the pilot flashing light system continues. The performance of the system was tested during Typhoon Mangkhut and the loss of 4G signal and the structural strength have been identified as the bottlenecks of the system. GEO plans to test LoRa and explore satellite communication systems to remove the 4G signal loss issue. Also enhancement of the system with moving message displays to provide more direct messages to the public has been trialled.

SSTRB appreciates GEO's forward looking initiatives to try out new technologies that are still high risk for adoption but can be transformative if successful. SSTRB notes that there are other notable technologies that should be considered for possible slope stability applications and other GEO applications. Based on their recent experience, SSTRB feels that the recent advances in geophysical methods, distributed fibre optic sensor technologies (DTS, DSS and DAS) and computer vision are worth looking into.

Recommendation No. 9:
SSTRB recommends that GEO conducts a literature review of geophysical methods, distributed fibre optic sensor and computer vision and to examine their technology readiness levels for GEO problems.

3.4.4 Engineering implementation

GEO is planning to trial new robotic systems that measure strength of steel bars and concrete cubes as part of their public works laboratory operation. This robotics initiative can potentially transform the laboratory testing industry. This initiative can be an easy win to

demonstrate the value of I&T, considering the recent developments in advanced manufacturing.

Recommendation No. 10:
SSTRB recommends that GEO continues the implementation of robotic laboratory testing systems to demonstrate the advantages of transforming routine human-based GEO activities to automated processes.

3.5 Public communication for enhancing community resilience against landslide risk

GEO provided a detailed briefing to SSTRB on its continuing, extensive work on enhancing community resilience against landslide risk. GEO has now accumulated a lot of experience in public communication and is very professional with all of its activities. Wisely, it has also engaged a communication consultant.

Once again SSTRB notes that GEO is ambitious and effective in this type of work, and SSTRB endorses the wide ranging activities undertaken. GEO has clarity about the purposes of its communication strategy, focusing on reducing the probability of landslides, with a key target audience of private slope owners, and reducing the consequence of landslides, with a key target audience of the general public. To engage with the stakeholders of the two target groups, GEO adopts a multi-faceted approach, including the use of social media, exhibitions, workshops, lectures, visits, community advice, school engagement, etc. GEO produces a wide range of materials, and has been able to demonstrate success.

SSTRB welcomes the successful meeting of the new "Slope Safety Communication Strategy Advisory Committee" (SSCSAC), and endorses the recommendations that the committee has made. SSCSAC noted that proactive engagement with the media and with legislators would be a helpful step, and SSTRB notes that GEO has started to implement these recommendations. Members of SSCSAC have responded positively to GEO since the meeting, and thus represent a powerful set of allies.

Recommendation No. 11:
SSTRB recommends that GEO continues to implement the recommendations from SSCSAC, and would welcome a report on progress against these recommendations in 2019.

SSTRB notes that some of the approaches used to promulgate understanding of landslides, such as the Bowen Road app, have drawn criticism. This appears to be focused primarily upon the low download rate of the app, indicating that the media are suggesting that it has not been a good use of resources. SSTRB notes that such an app will by its very nature attract small numbers of downloads, indicating that the criticism is unfair. Whilst these events are regrettable, SSTRB recognizes the need to be pragmatic. SSTRB suggests that GEO continues this type of work using less high profile means, such as web resources (rather than standalone apps) and hosting on the media resources of other organisations, such as HKO.

In the last year, GEO has been proactive in the development of links with other organisations, such as the HKJC DPRI and the Red Cross. SSTRB was shown the Virtual Reality tool developed to train geotechnical engineers deployed to sites during emergency situations. This tool has been jointly developed with DPRI, who have also supported the development

of the experimental flume facility. The development of enhanced working with the Red Cross, particularly during emergency situations, is welcome.

SSTRB notes that GEO has been proactive in undertaking temporary public exhibitions highlighting landslide preparedness, and notes that these have been effective and well received. The implementation of a permanent exhibition in Chengdu in mainland China is an interesting development. Sichuan has been severely affected by landslides in recent years, with many fatalities, such that there is a strong appetite for disaster risk reduction.

Recommendation No. 12:
In light of the impact of Super Typhoon Mangkhut and the unequivocal international warnings about increasing occurrence of extreme events as a consequence of climate change, SSTRB recommends that GEO engages with appropriate agencies to explore the mounting of a large-scale permanent public exhibition about disaster risk in Hong Kong, including the threats posed by landslides.

This exhibition can draw upon past experiences in Hong Kong and elsewhere, and on our improved understanding of the causes and mechanisms of natural hazards, to both raise awareness of, and enhance resilience to, hazards associated with for example landfalling typhoons, and could gradually be included in education programmes in schools.

As noted above, and following the advice of both SSTRB and SSCSAC, GEO has focused messaging towards two key groups, private slope owners (to reduce landslide occurrence) and vulnerable communities, especially squatters (to reduce landslide consequence). SSTRB commends this approach, but would welcome insight into the effectiveness of different ways to engage with these different stakeholders.

Recommendation No. 13:
SSTRB recommends that systematic work is undertaken to determine the effectiveness of the different ways of communicating with private slope owners and vulnerable communities (squatters) in order to inform future information/education campaigns.

GEO rightly remains concerned about public complacency about landslide risk in the face of a prolonged period of very limited landslide impacts. This is highlighted by Super Typhoon Mangkhut, which represented a near miss by the second largest tropical cyclone globally in 2018. Super Typhoon Mangkhut was associated with very high wind speeds but quite limited levels of rainfall. Many future typhoons will display a different set of characteristics. To this end, GEO is exploring ways to use the Landslide Potential Index (LPI) to explain to the public both the high level of landslide hazard and the explanation for the low level of landsliding in recent years. SSTRB welcomes this approach, whilst recognizing that the LPI will be a challenging concept for the lay person.

Recommendation No. 14:
SSTRB recommends that GEO explores the use of examples of past major rainstorm events of which there will be a community memory, such as the 2008 Lantau storm and typhoons in the 1970s, to illustrate the role of LPI in identifying landslide hazards.

3.6 Emergency preparedness for extreme weather

GEO provided SSTRB with an update on its on-going work to improve emergency preparedness for extreme weather. SSTRB continues to be impressed with the diligence with which this work is undertaken.

The work of GEO in this area is wide-ranging. SSTRB was appraised of GEO's activities within the landslide detection system, the flashing light system and the landslide emergency plan for Queen Mary Hospital. Good progress has been achieved. GEO is actively developing technologies to provide real time warnings of landslide events. GEO also continues to learn lessons from events, such as Super Typhoon Mangkhut. SSTRB is impressed by the methods being deployed, and in particular by the use of comparatively simple approaches (albeit advanced technology) that are potentially cost-effective.

All these initiatives are progressing well, and should continue. SSTRB noted the potential impacts of the multiple failures of, for example, mobile data services impacting the ability to respond and to communicate effectively with the affected population. Maybe a LoRa network for GEO communication could be an option to explore, as a start.

Recommendation No. 15:
SSTRB recommends that GEO explores the potential benefits and drawbacks of establishing a dedicated LoRa network for GEO communication.

At the core of emergency preparedness for extreme weather is the development of the Common Operational Picture (COP), a system designed to raise awareness and facilitate communication and information exchange among responsible agencies during extreme weather. The COP is perceived by SSTRB to be a key mechanism to ensure response preparedness under an extreme event.

SSTRB finds that remarkable progress has been achieved so far, and is happy to see the planned roadmap, with a trial operation in early 2019 and commissioning in 2020. SSTRB is pleased to see the engagement of the Security Bureau in the COP, and the wide support the COP has received, including high-level support from the Chief Secretary for Administration, the Secretary for Security and the Secretary for the Environment.

SSTRB fully endorses the work that GEO has undertaken so far to develop the system, with clear plans and an identified timeline to roll it out. SSTRB welcomes the stronger involvement of other agencies, and looks forward to see the results of the trial implementation in 2019. The lessons learnt under the "mini-COP" exercise showed the need for improved information sharing and communication in real time among the agencies and for improved coordinated response. This is similar to the experience from the simulation of response under extreme events elsewhere in the world.

Originally, the COP was an initiative by DEVB to ensure common awareness within the Works departments. The initiative has grown to include emergency entities over a wide range of sectors. The purpose of the COP is to establish a common understanding of the emergency, to share information and increase cooperation and enable risk-informed decisions. The COP is not intended to replace existing operational systems, but should ensure

that all parties achieve the same understanding of the emergency. SSTRB recognizes that it was essential that DEVB put this issue on the agenda, but notes that GEO should not necessarily have the responsibility of leading the initiative in the future. SSTRB therefore suggests that efforts be made to create a common understanding of the motivation for the COP.

Recommendation No. 16
SSTRB recommends the following within the context of the COP:
- *Clarify the purpose of the COP system with all participants.*
- *Initiate discussion to identify the responsible agency to manage the next steps in the roadmap.*
- *Follow the existing roadmap, with trial in 2019 and commissioning in 2020.*
- *Ensure budgeting and continued support to achieve the planned goals by 2020.*

3.7 Technical development of natural terrain mitigation measures

GEO is continuing the development of both rigid and flexible barriers as natural terrain hazard mitigation measures.

3.7.1 Rigid barriers

The major outcomes from the rigid barrier work in 2018 are the development of a framework for rationalizing the rigid debris resisting barrier design and the verification by a series of physical tests. SSTRB finds this framework to be useful in evaluating the progress of the development. The framework involves geotechnical stability and structural integrity design for soil debris and boulder impact cases. GEO has supported HKUST in the development of flume facilities in Hong Kong and mainland China. In Hong Kong, a 20 m long debris impact flume facility was commissioned in August 2018 at Kadoorie. The flume includes unique features such as watertight trap door, accommodation of debris mix that matches with local debris flow materials and large-scale L-shaped rigid model barrier.

In 2018, two flume tests were performed using model soil debris mix with and without boulders. The preliminary test results show the appropriateness of the proposed design on soil debris impact by comparing them to other reported data from different countries as well as the centrifuge test data conducted in Hong Kong.

For the boulder impact design, GEO proposes to use the displacement approach that considers energy transfer in the impact process to evaluate the translational and rotational movement of rigid barriers. The overturning design part of this displacement approach was verified in 2017 from the tests conducted at the University of Melbourne. In 2018, the 20 m long flume facility in Hong Kong was used to verify the sliding part of this displacement approach. A total of 3 tests was conducted so far and the preliminary data interpretation shows promising results. Two more tests are planned.

The structural integrity design for boulder impact utilizes a newly developed enhanced flexural stiffness method (EFSM), which considers energy loss during the impact and inertia effect of the barrier. In 2018, a series of large scale impact tests was conducted at the University of Melbourne to verify the EFSM approach. The experimental results match well with the predictions made by EFSM. In addition, both localized damage tests and destructive

tests were performed on model concrete rigid barriers to examine possible structural damage patterns upon boulder impact. To reduce the flexural response in rigid barriers, it is proposed to place rock gabions as cushion material. Four series of impact tests were conducted on this design and the results show significant reduction in barrier's flexural response. These results are useful to develop an effective cushioned barrier design. A series of small scale flume tests was conducted to optimize deflector design. SSTRB notes that GEO is making very good progress on the development of the rigid barrier design framework. The verification of the proposed design approaches is starting to happen using large scale physical model tests.

Recommendation No. 17:
SSTRB recommends that GEO continues the verification exercise using the Hong Kong flume facility to demonstrate the soundness of the approaches and to derive the design factors appropriate for the Hong Kong landslide scenarios. GEO should develop a wish list of testing parameters for both soil and boulder impact cases by considering the confidence level of the design approaches.

Recommendation No. 18:
SSTRB recommends that GEO conducts numerical analyses of the flume tests to examine the capability of numerical methods in predicting impact forces and deformation mechanism of rigid barriers

Recommendation No. 19:
SSTRB recommends that GEO develops a detailed research plan for deflectors at the crest of rigid barriers.

Recommendation No. 20:
SSTRB recommends that GEO provides a detailed plan and timeline for the rigid barrier work, and quantifies the technical achievement level of each development against this plan.

3.7.2 Flexible barriers

In 2018, GEO devised a technical development framework for flexible barriers. The framework includes three different design approaches for flexible barriers, structural form, geotechnical stability and ground anchors, detailing and other design considerations and acceptance system and quality control. GEO presented a series of tests to investigate the problems identified in each part. Although the developed framework is a good start, SSTRB finds it difficult to appreciate the overall progress of the development from the table presented. This may be related to the bullet point nature of the presentation.

Recommendation No. 21:
SSTRB recommends that GEO provides a detailed plan and timeline for the flexible barrier work, in particular a testing plan, and quantifies the technical achievement level of each development against this plan.

GEO presented the performance of their prototype wireless based landslide detection system by testing them during the flume tests in both rigid and flexible barrier settings. Various issues have been identified. New ideas to overcome the issues of reliability, durability,

system performance, maintenance, effectiveness and response have been proposed and they can be examined in 2019.

Recommendation No. 22:
SSTRB recommends that GEO continues to test the issues of reliability, durability, system performance, maintenance, effectiveness and response on their wireless landslide detection system attached to flexible and rigid barrier systems. A possibility of embedding sensors during construction of barriers should be considered. GEO should continue to look into newer sensors that have high accuracy and can be self-powered.

3.8 Natural terrain risk management

SSTRB was apprised of three aspects of natural terrain risk management: (1) modification of historical landslide catchments (HLC) selection criteria; (2) risk assessment; and (3) geological and geomorphological review of landslide clusters in key catchments.

3.8.1 Modification of HLC selection criteria

Following the established principle of "react-to-known hazards", GEO continued its work on developing a complementary selection criterion for vulnerable hillside catchments in the vicinity of facilities. The new criterion is based on, in addition to the proximity to facilities, the size of the catchment, the presence of historical (relict and recent) landslides and the presence of a pronounced drainage line. This new selection criterion supplements the earlier criterion based simply on distances from the debris crown and trail to a facility.

3.8.2 Risk assessment

In 2018, a pilot assessment on the relative risk posed by additional catchments identified by the new criterion was conducted. A study framework for existing and additional catchments was also proposed. SSTRB supports this work of identifying adverse site settings and including them in the inventory of catchments and prioritising the most critical catchments in the LPMitP. The proposed framework for a design event, based on "credible failure volume" and "debris mobility" and using GEO's QRA procedures, appears sound. SSTRB looks forward to the continuation of the stress testing work in cooperation with HKUST.

SSTRB also reviewed the uncertainty analyses described in the briefing papers and finds this work solid and of great interest. SSTRB looks forward to the forthcoming work with the proposed approach in the next few years.

Recommendation No. 23:
SSTRB recommends that a return period be associated with the estimated "credible failure volumes". The forthcoming pilot studies should include a study of consequences and suggestions of potential remedial measures, and where relevant, the installation of a warning system. A consideration of cascading or multi-risk should also be undertaken, again where relevant. The experience from actual recent events, such as the rainfall induced landslides in Japan, should be included.

3.8.3 Geological and geomorphological review of landslide clusters in key catchments

GEO presented to SSTRB its ongoing work examining the potential causes of clustering of landslides during heavy rainfall in natural terrain. In line with the SSTRB recommendation in 2017, three new catchments were mapped in detail by a team of geologists. This team-based approach has had the advantage of sharing best practice amongst GEO staff, an approach that SSTRB endorses. The initial analyses have shown that clustering may not have a consistent cause across all of the studied catchments; in some cases anthropogenic activity may have been a key factor, in other cases geology is important, whilst in others the landslides appear to cluster in locations in which there is active erosion at the drainage head.

The approach adopted has relied upon an eight-fold classification of landslide characteristics. Not unusually, practice has shown that this classification system is suboptimal for detailed analysis.

Interestingly, the Fan Kam Road landslides in August 2018 also show a high level of clustering, with similar catchments close-by showing little landslide activity. The Landslide Investigation Consultant investigating these landslides has hypothesized that this clustering may be associated with a shallow (c.0.5 m) regolith above a permeability boundary that acts as both a drainage barrier and a potential failure plane. This is a different explanation to those proposed by the GEO team for other catchments, but it may be a characteristic of active erosion at the drainage head, and so may be consistent in detail. The analysis by the GEO team has noted considerable anthropogenic disturbance at Fan Kam Road, which may have migrated to cause active headward erosion.

GEO intends to develop the geological and geomorphological study to two further catchments. SSTRB supports this work.

Recommendation No. 24:
SSTRB recommends that GEO further develops the classification system, and then applies it to the catchments mapped to date (and going forward). Furthermore, SSTRB recommends that GEO works with the Landslide Investigation Consultant to understand the landslide cluster at Fan Kam Road, and ensures that, for the purposes of this study, the catchment is analysed using the same approaches as for the other catchments.

3.9 Rock cavern and underground space development

Over the recent years, SSTRB has followed the work the GEO has undertaken to improve land supply through the exploration of the potential for development of rock caverns and underground space. This has been a long term programme undertaken with enthusiasm and diligence, and SSTRB notes the support that this approach has garnered from both politicians and the public. In 2017 SSTRB made three recommendations with regard to the development of this programme, and notes the progress that has been made in each case. SSTRB feels that considerable momentum has been gained over the last year, and that GEO will enter 2019 with increased confidence in this domain. SSTRB welcomes the successful hosting of the International Conference on Urban Underground Space in November 2018, and the acclaim that GEO has received internationally and in Hong Kong for its work.

In January 2018 GEO released a revised version of Geoguide 4 (Guide to Cavern Engineering), following the release in December 2017 of the Cavern Master Plan for Hong Kong. The latter identified 48 strategic cavern areas. In December 2017 DEVB released a Technical Circular on Rock Cavern Development, a key aspect of which is to safeguard the development potential of potential cavern sites.

Recommendation No. 25:
SSTRB recommends that GEO continues to work with DEVB to consider the optimal ways in which government can manage rezoning of areas for cavern development to minimize disincentives to potential private developers who might be discouraged by complex planning processes.

SSTRB notes that GEO has continued to develop the "get the ball rolling" strategy with a set of initial projects, and is impressed that at least one project, the relocation of the Sha Tin Sewage Treatment Works, is proceeding to the construction stage. The potential relocation of the Public Works Central Facility is also a key project that would serve to demonstrate the potential of such relocation projects. SSTRB looks forward to receiving a further update in 2019.

GEO has also made considerable progress on the development of underground space in strategic urban areas, and has progressed the study of a new, large community space beneath Kowloon Park as the first potential project. SSTRB endorses the need for this project, as a demonstrator, to create valuable space and to reduce congestion on for example Haiphong Road.

However, as this project would require extensive open excavations within Kowloon Park, some opposition seems inevitable (with increased traffic, dust, potential damage to trees). SSTRB notes that these controversies would be reduced if large underground excavations can be avoided. A key to minimise controversy may be to emphasise the benefits to the population of Hong Kong, rather than to commercial organisations or overseas visitors, of this project.

Recommendation No. 26:
SSTRB recommends that GEO develops a strategy, with timelines and key responsibilities, for the development of public engagement in the potential Kowloon Park underground space project. SSTRB also recommends that GEO continues to explore whether there may be innovative processes that allow the development of the Kowloon Park project without large scale excavations.

It is important that these developments are closely aligned to the long term strategic plans for the economic and social development of Hong Kong. It is clear to SSTRB that there are no major technical reasons why these projects cannot proceed. The substantive issues are mostly focused on socio-economic and political topics, which will require careful management. The combination of the "get the ball rolling" and the cavern masterplan approaches, with appropriate consultation, has been effective in socialising these ideas.

3.10 Landslip warning system

The landslide frequency - rainfall correlation that underpins the landslip warning system was presented to SSTRB as part of the introduction programme, and was also shown by HKO as part of the decision process for issuing landslip warning. The landslide frequency versus the rolling 24-hour rainfall curves are shown in Figure 1 for four types of slopes.

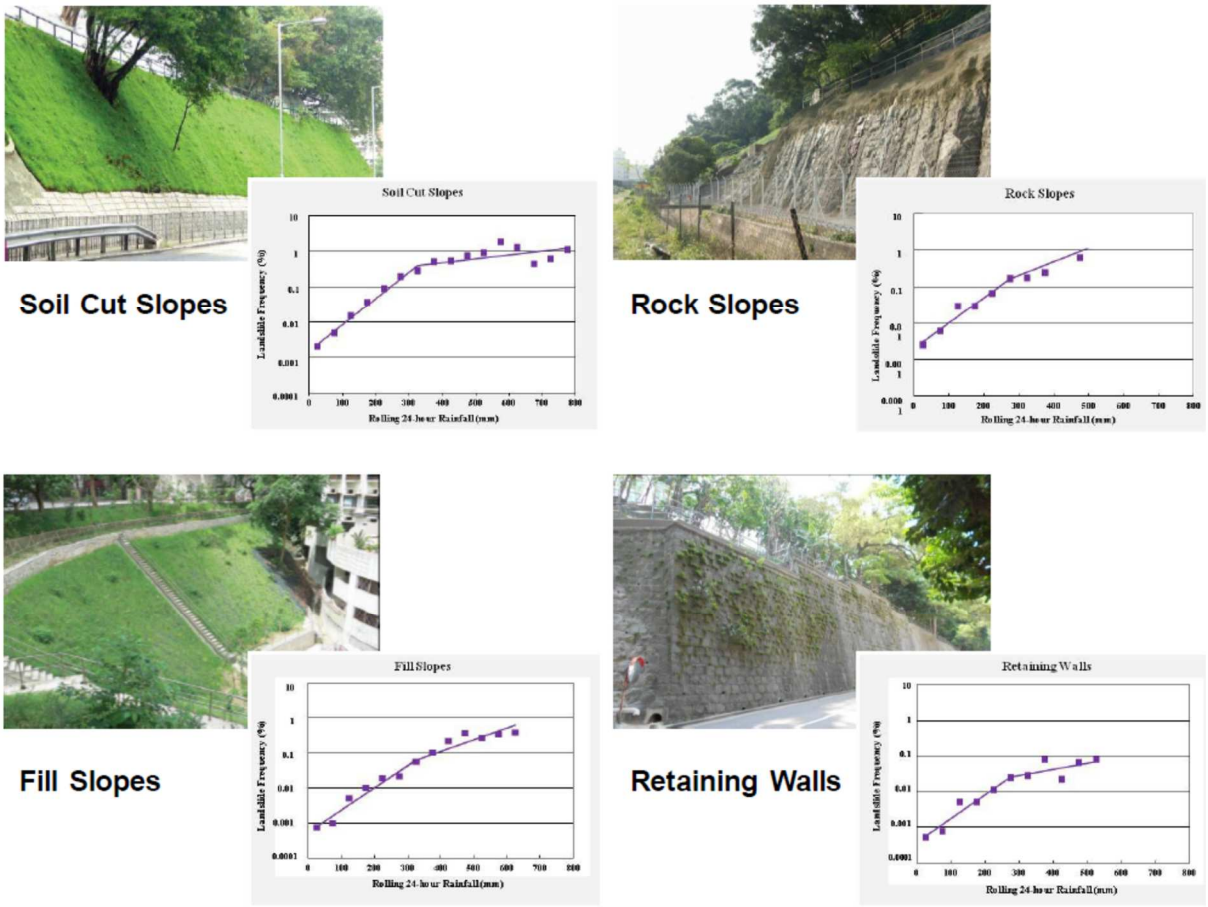

Figure 1. GEO's landslide-rainfall correlations for slopes and retaining walls.

Recommendation No. 27:
SSTRB recommends that GEO checks the robustness of the four curves and establishes uncertainty ranges for each data point on each of the curves. GEO should consider the possible physical explanation of the curvature (or seemingly bi-linearity) of the curves. Statistical curve-fitting should be done.

3.11 Technical aspects of slope safety

SSTRB has a responsibility to advise GEO on the technical aspects of slope safety. It has now been some time since SSTRB has been apprised of GEO's calculation procedures. New developments are being steadily made on both calculation approaches and software, in Hong Kong and abroad. SSTRB makes the following recommendation, to be considered over the course of the next three years and in the order that is appropriate to GEO's on-going priorities.

Recommendation No. 28:
SSTRB recommends that the technical aspects of slope safety be gradually reviewed by SSTRB, including e.g. methods, hypotheses and approximations, preferred computer codes, data, uncertainties as well as example calculations, for:

- *Slope stability;*
- *Deformation and runout analysis;*
- *Landslide susceptibility and QRA;*
- *Design of mitigation measures.*

GEO should articulate a plan for this work over the next three years of the 7th SSTRB.

3.12 Other matters

Visit to HKO

On 28 November 2018 SSTRB undertook a visit to HKO. SSTRB was shown the range of traditional and new rain gauges utilized by HKO; the weather forecasting suite (including a demonstration of the work flows used in generating rainfall warnings); the broadcast studio; and the earthquake and tsunami monitoring facility. SSTRB was impressed by the facilities, and by the enthusiasm and diligence of the staff at HKO. SSTRB had the opportunity to discuss key issues, such as the rationale behind decisions in some cases not to issue black rainfall warnings when heavy rainfall affects smaller areas of the New Territories with low population density. SSTRB remains impressed by the quality and depth of the collaboration between GEO and HKO.

4. INSTITUTIONAL ISSUES

4.1 Meeting with Permanent Secretary for Development (Works)

On 29 November 2018, SSTRB met with:

Mr S.H. Lam, Permanent Secretary for Development (Works)
Mr Vincent Mak, Deputy Secretary for Development (Works)
Mr Victor Chan, Principal Assistant Secretary (Works)
Ms Irene Pang, Chief Assistant Secretary (Works)
Mr Eric Cheng, Assistant Secretary (Works)
Mr Ricky Lau, Director of Civil Engineering and Development
Mr W.K. Pun, Head of GEO, CEDD
Mr Philip Chung, Deputy Head (Planning and Standards) of GEO, CEDD

Three topics were on the agenda for the meeting between PS(W), GEO/CEDD and SSTRB:

1. Innovation and Technology for Slope Safety Management
2. Emergency Preparedness for Extreme Weather
3. Public Communication for Enhancing Community Resilience against Landslide Risk

SSTRB had reviewed the briefing papers prepared by GEO and the oral presentations on 26 and 27 November 2018 to prepare a briefing note that was sent to the Permanent Secretary for Development (Works) on 27 November 2018.

4.2 Meeting with Hong Kong Professional Bodies

On 28 November 2018, a meeting was convened by GEO with representatives of the Hong Kong Institution of Engineers (Geotechnical Division) (HKIE (GD)), the Association of Geotechnical and Geoenvironmental Specialists (Hong Kong) (AGS (HK)), the Hong Kong Regional Group of the Geological Society of London (HKRG-GSL), the Hong Kong Geotechnical Society (HKGES), the Institute of Materials, Minerals and Mining - Hong Kong Branch (IoM^3-HK), and the Professional Branch of the Geological Society of Hong Kong.

SSTRB is impressed with the range of activities undertaken to support the development of professionals involved in slope stability in Hong Kong, and in the collegial manner in which the professional bodies operate.

In the meeting, the following topics were addressed:

- The need for more innovation in LPMit projects (see Recommendation No. 3)
- The wish for improved digital access to site investigations data in Hong Kong.
- Is there a need for a reliability-based design guideline?

5. CONCLUSIONS

SSTRB expresses its approval of the results presented by GEO. SSTRB is satisfied with the continuing excellence displayed by GEO in its management of slope safety in Hong Kong. The level of expertise on slope safety at GEO is unique on an international scale. SSTRB finds that GEO continues to lead international practice on slope safety and is a model that other countries aspire to follow.

SSTRB endorses the work done to date. During its 2018 review, SSTRB has made 28 recommendations. These are outlined in italics in Sections 2 and 3.

6. NEXT SSTRB MEETING

The date for the next meeting is suggested for the week of 8 to 13 December 2019, in Hong Kong.

Appendix A

Record of Activities of the Slope Safety Technical Review Board

SSTRB Meeting November 2018
Report No. 28

25/11/2018 Sunday		26/11/2018 Monday		27/11/2018 Tuesday		28/11/2018 Wednesday		29/11/2018 Thursday		30/11/2018 Friday	
8:30	Site visit Kadoorie Testing Facility Fan Kam Road	9:00	Opening remarks (H(GEO)) Rainfall in 2018 (CGE/S&T) Landslides in 2018 and selected landslide investigation studies (CGE/LPM1) Overview of LPMitP (CGE/LPM1) Meeting with DCED	9:00	Public communication for enhancing community resilience against landslide risk (CGE/SS) Emergency preparedness for extreme weather (CGE/S&T)	9:00	Visit to HKO Rock cavern and underground space development (CGE/P)	9:00 11:30	SSTRB report writing Meeting with PS(W)	9:00	SSTRB report writing
12:30	Lunch	12:30	Lunch with DCED, DDCED, AD/T and GEO's Senior Management					12:30	Lunch with SDEV and PS(W)		
PM	Preparation of briefing notes to PS(W)	2:00	Innovation and technology for Slope Safety Management (DH(M), CGE/ME, CGE/P, CGE/S&T)	2:00 4:00	Technical development of natural terrain mitigation measures (CGE/S&T) Rigid barrier Flexible barrier Natural terrain risk management (CGE/S&T, CGE/P)	2:00 3:00	Sensing technologies (CGE/P) SSTRB report writing	2:00	SSTRB report writing	2:00 4:00	Debriefing Finalising report
				6:00	Joint Technical Seminar [CEDD-GEO, HKIE(GD), HKGES] Trends in large-deformation analysis of landslide mass movements with particular emphasis on the material point method (Prof. Soga)	6:00	Meeting with local professional bodies (GSLHK, HKIE, AGS, HKGES, GSHK, IoM3]				

Meeting venue: Room 1513, Civil Engineering and Development Building

Appendix B

List of Documents Provided for Meeting No. 28

Reference Documents

Rainfall and Landslides

1. GEO Special Project Report No. SPR 1/2018: Factual Report on Hong Kong Rainfall and Landslides in 2017

2. GEO Technical Note No. TN 2/2018: Tropical Cyclone and Non-Tropical Cyclone Rainfall Trends in Hong Kong

3. GEO Discussion Note No. DN 1/2018: Preliminary Observations from Hong Kong Observatory's Mean Annual Rainfalls (1952-2010)

Design Guidance

4. GEO Technical Guidance Note No. TGN 30: New Intensity-Duration-Frequency Curves for Slope Drainage Design

Landslide Debris-Barrier Interaction

5. GEO Technical Note No. TN 1/2018: Pilot Numerical Study of Debris-resisting Flexible Barriers from an Energy Perspective

6. GEO Technical Note No. TN 3/2018: Study of Flexural Response of Rigid Barriers Subject to Boulder Impact

7. GEO Technical Note No. TN 5/2018: Spillage Mechanism of Landslide Debris Intercepted by Rigid Barriers and Deflectors to Prevent Spillage

8. Cheung, A.K.C., Yiu, J., Lam, H.W.K. & Sze, E.H.Y. (2018). Advanced Numerical Analysis of Landslide Debris Mobility and Barrier Interaction. *HKIE Transactions*, 25(2), pp. 76-89.

9. Kwan, J.S.H., Lam, H.W.K., Ng, C.W.W., Lam, N.T.K., Chan, S.L., Yiu, J. & Cheuk, J.C.Y. (2018). Recent Technical Advancement in Natural Terrain Landslide Risk Mitigation Measures in Hong Kong. *HKIE Transactions*, 25(2), pp. 90-101.

10. Kwan, J.S.H., Sze, E.H.Y. & Lam, C. (2018). Finite Element Analysis for Rockfall and Debris Flow Mitigation Works. *Canadian Geotechnical Journal*, https://doi.org/10.1139/cgj-2017-0628 (published online ahead of print).

11. Ng, C.W.W., Choi, C.E., Koo, R.C.H., Goodwin, G.R., Song, D. & Kwan, J.S.H. (2018). Dry Granular Flow Interaction with Dual-barrier Systems. *Géotechnique*, 68(5), pp. 386-399.

12. Sze, E.H.Y., Koo, R.C.H., Leung, J.M.Y. & Ho, K.K.S. (2018). Design of Flexible Barriers against Sizeable Landslides in Hong Kong. *HKIE Transactions*, 25(2), pp. 115-128.

13. Lam, C., Yong, A.C.Y., Kwan, J.S.H. & Lam, N.T.K. (2018). Overturning stability of L-shaped rigid barriers subjected to rockfall impacts, *Landslides*, 15(7), pp. 1347-1357.

Geological Report

14. Geological Report No. GR 1/2018: Study of Geological Controls on the Occurrence of Natural Terrain Landslide Clusters – A Pilot Study at a Catchment above Keung Shan Road, West Lantau

Response to SSTRB Report No. 27

15. Actions taken on SSTRB Report No. 27 Recommendations

Briefing Papers

16. Briefing Paper on the Development of GEO's Innovation and Technology Strategy for Slope Safety Management

17. Briefing Paper on Emergency Preparedness for Extreme Weather

18. Briefing Paper on Public Communication for Enhancing Community Resilience against Landslide Risk

19. Briefing Paper on Technical Development of Natural Terrain Mitigation Measures for Rigid Barriers

20. Briefing Paper on Technical Development of Natural Terrain Mitigation Measures for Flexible Barriers

21. Briefing Paper on Natural Terrain Risk Management

22. Briefing Paper on Assessment and Management of Complex, Cascading Hazard Events under Emergency Preparedness for Extreme Weather

23. Briefing Paper on Secondary Landslide-affecting Factors and Their Impacts on Landslides in Hong Kong under Climate Change

24. Briefing Paper on Rock Cavern and Underground Space Development in Hong Kong

Briefing Notes for Meeting between SSTRB and PS(W)

25. Innovation and Technology for Slope Safety Management

26. Emergency Preparedness for Extreme Weather

27. Public Communication for Enhancing Community Resilience against Landslide Risk

Appendix C

Responses by GEO to the Recommendations in SSTRB's Report No. 27

Actions Taken on SSTRB Report No. 27 Recommendations

SSTRB's Recommendations	Actions by GEO
1) SSTRB recommends that GEO continues to work proactively with Consultants and Contractors to ensure that the transition to NEC proceeds without causing any interruptions to the LPMitP. (Section 3.3)	To ensure smooth transition, two sets of sample tender documents using NEC contract form were prepared and issued to all LPMit Project Teams and Consultants in March 2018. In addition, four sharing sessions and workshops were organised to brief the Consultants, Contractors, in-house Professional Staff and Resident Site Staff on the latest development of NEC. All LPMit works contracts have been migrated to NEC contract form.
2) SSTRB recommends that GEO considers carefully about how best to use the expertise of the members of the new Slope Safety Communication Strategy Advisory Committee (SSCSAC) to promulgate its Slope Safety messages, especially in relation to the use of social media. (Section 3.4)	SSCSAC held the first meeting in April 2018 and had a fruitful discussion on effective public communication for promulgating slope safety messages. A range of activities have been or are being organised/planned through the connections or in collaboration with the organisations led by SSCSAC Members. Details are given in the Briefing Paper on Public Communication.
3) SSTRB recommends that GEO continues the development of the Bowen Road app, and that it gains feedback from a trial group of children in the target age group as well as teachers. (Section 3.4)	Site visits to Bowen Road Study Trail were organised for secondary school teachers and students in April 2018. Views and suggestions were collected for enhancing contents and user-friendliness of the app. As recommended by the SSCSAC, the app was converted to a mobile internet website in August 2018.
4) SSTRB recommends that GEO seeks to engage further with the Hong Kong Red Cross and the Hong Kong Jockey Club Disaster Preparedness and Response Institute, and that it reports back to the Board on these activities at the meeting in 2018. (Section 3.4)	Meetings and exchange visits were conducted with the Hong Kong Red Cross and the Hong Kong Jockey Club Disaster Preparedness and Response Institute (JCDPRI) to share ideas on our work plans for disaster preparedness. A range of activities have been jointly organised with the two organisations, as detailed in the Briefing Paper on Public Communication.

SSTRB's Recommendations	Actions by GEO
5) SSTRB recommends that GEO continues to explore ways in which it can share information from the COP with the Security Bureau. (Section 3.5)	Though continual dialogue among the GEO, the Security Bureau (SB) and the Development Bureau, the SB showed interest to obtain information from and share information to the COP. Since May 2018, the SB has adopted the prototype mini-COP in its Emergency Monitoring and Support Centre for trial operation.
6) SSTRB recommends that GEO continues with its plans to test the effectiveness of the pilot landslide detection system using the new flume in Hong Kong, once commissioned. (Section 3.5)	Flume tests on prototypes for flexible and rigid barriers were tested in Dec 2017 and Aug 2018 respectively. Details are given in the Briefing Paper on Emergency Preparedness for Extreme Weather.
7) SSTRB recommends that GEO develops a protocol for the response to a positive indication of a landslide event during an extreme weather scenario. (Section 3.5)	A protocol for handling positive indications of landslide events was developed in Sep 2018. Signals of the pilot landslide detection system are monitored by a roster of professionals. In case of positive indications, the team will immediately screen out false alarms and inform a dedicated task force of any genuine alerts to trigger emergency actions.
8) SSTRB recommends that GEO continues with the development and testing of the pilot flashing light system. (Section 3.5)	The performance of the prototype installed in Sai Wan was monitored during the wet season. After a review, the structural frame will be strengthened and LED moving message displays (MMD) will be used instead of the flashing light in order to enhance the visibility of the warnings. A site trial of a pilot MMD is being arranged.
9) SSTRB recommends that GEO undertakes a review of the lessons learnt from the development and deployment of natural hazard warning systems, with a focus on societal aspects of this work. (Section 3.5)	A review on the subject was undertaken with reference to a literature review of the publication by Zschau & Kuppers (2003), the experience exchange during our visits to relevant organisations in the Sichuan Province of Mainland China, as well as the Super Typhoon Mangkhut case this year. Key findings of the review are given in the Briefing Paper on Public Communication.

SSTRB's Recommendations	Actions by GEO
10) SSTRB recommends that the work with QMH to develop an emergency response plan for an extreme landslides event is continued, and that in due course it is expanded to other critical facilities. (Section 3.5)	GEO has worked with staff of QMH to develop an emergency response plan. A drill will be carried out by end 2018. It will be expanded to other critical facilities in due course taking into account the experience gained.
11) SSTRB reiterates its previous recommendations that GEO considers carefully the implications on its operations of the likely loss of power and communications during an extreme weather event. (Section 3.5)	Communication and power supply facilities have been further enhanced. GEO has obtained approval from the Hong Kong Police Force to join their Unified Digital Communication Platform (UDCP) as a member for using their radio services to maintain communications in extreme weather events. To minimize the disruption of GEO's emergency services by temporary power cuts, an Uninterruptible Power Supply (UPS) system is being procured to enhance the continuity of emergency systems in the GEO Emergency Control Centre. Both systems will be in operation before the onset of the 2019 wet season.
12) SSTRB recommends that GEO reviews the latest work on the assessment and management of complex, cascading hazard events, and explores ways in which this work might inform the approach to managing extreme weather in Hong Kong. (Section 3.5)	A literature review on overseas experiences in handling cascading hazards had been conducted. The review is detailed in the Briefing Paper on Assessment and Management of Complex, Cascading Hazard Events under Emergency Preparedness for Extreme Weather.

SSTRB's Recommendations	Actions by GEO
13) SSTRB recommends that GEO and HKO continue to work closely together to develop ways to improve landslide forecasts using the enhanced rainfall nowcasting approaches. SSTRB further recommends that GEO and HKO explore the potential to understand the potential uncertainties in the nowcasts. For example, knowing the standard deviation of a forecast may prove to be a useful tool, whilst a fully probabilistic forecast offers great potential. (Section 3.6)	GEO continues to maintain a close contact with the HKO to take stock any new development of their nowcast tools and methodology and the quantification of the uncertainty in the nowcasts.
14) The HKO undertakes work that is truly ground-breaking. SSTRB found it difficult to understand some of the more technical aspects of the presentation. The Board suggests that HKO and GEO explore ways to explain the work on rainfall nowcasting and forecasting in a manner that is easier for non-specialists to understand. (Section 3.6)	GEO discussed with the HKO on the ways to explain the work on rainfall nowcasting and forecasting. Improvements had been made and HKO delivered a talk on the same topic to GEO's staff in a manner that is easier for non-specialists to understand.
15) SSTRB recommends that GEO prepares a detailed project plan for GEO's purpose for the adjustment of the design guidance for rigid barriers. As work evolves, plans may change, and the schedule and priorities should be adjusted accordingly. The plan should include expected activities, with possible challenges and show-stoppers and perhaps decision-making milestones, to ensure optimum results from this important and unique development work. GEO should have a back-up plan in case some of the key elements in the approach (Steps 3, 4 or 5 in the table above) do not get realised or produce unexpected results. (Section 3.7)	A detailed project plan, including a test plan, parameters to be tests and measurements to be made and pre-test analysis, has been developed for adjustment of the design guidance for rigid barriers. So far, the majority of the planned activities in the plan have been completed. GEO would complete the remaining technical development tasks and would revamp the guidelines by 2019. The project plans including progress of the projects are presented in the Briefing Paper on Technical Development of Natural Terrain Mitigation Measures for Rigid Barriers.

SSTRB's Recommendations	Actions by GEO
16) SSTRB recommends that GEO's preferred programme for physical testing, including tested soil, number of tests at each facility (e.g. few control tests in Hong Kong flume, larger number of tests in large flume in mainland China), parameters to be measured, accuracy of results, expected results etc, be fleshed out, including the preferred type(s) and number of tests. Even if it turns out to be necessary to modify some of the testing parameters as the availability and testing of the equipment reveal constraints, the preferred programme will be very useful to provide an overview of possible costs and results that can be expected. With such plan, it will be easier for GEO to prioritise alternatives when a decision between different solutions needs to be made. (Section 3.7)	See the response to recommendation 15.
17) A good and reliable system for the measurements is crucial to draw conclusions on rigid barrier optimisation. Where and when possible, GEO should seek to get more involved in the decision-making in the instrumentation and data acquisition of the 120 m model flume in mainland China (and if not too late, for the 28 m long model flume in Hong Kong). (Section 3.7)	GEO has been providing technical advice to HKUST on the instrumentation and data acquisition system for the flume test setup in Hong Kong and will continue to provide technical advice for the 120 m model flume to be built in mainland China. Details of the instrumentation plan are given in the Briefing Paper on Technical Development of Natural Terrain Mitigation Measures for Rigid Barriers.

SSTRB's Recommendations	Actions by GEO
18) One of the critical milestones of the proposed approach is the readiness of first the 28 m long flume in Hong Kong (planned for early 2018), and second the 120 m long flume in mainland China (planned for late 2018). SSTRB recommends that GEO helps as far as possible with the realisation of the construction of these flumes, including the testing and calibration of the monitoring system, and the selection of testing parameters (also soil type). The product of the development work is entirely dependent, in the perception of SSTRB, on the results of the physical tests on the two flumes. GEO should contribute to, as far as possible, bringing the two testing facilities to a rapid state of readiness for actual testing. (Section 3.7)	GEO has been providing technical support to HKUST in the realisation of flume facility in Hong Kong and mainland China. Technical advice regarding the construction of the flume and the model barrier, instrumentation and data acquisition system, calibration of instruments, testing parameters, soil debris materials, etc. was given. The flume facility in Hong Kong was commissioned for debris flow impact tests since August 2018.
19) As part of the planning, SSTRB recommends that GEO estimates the required costs for the preferred testing program, and starts to assist the research partners to look for funding. (Section 3.7)	GEO has been providing technical support to HKUST in the cost estimate and cost control of the impact tests. For securing fund of the tests, GEO lined up HKUST and JCDPRI for applying funding from the JCDPRI to support the construction of the flume and associated test setup. On the other hand, colleagues of GEO through HKIE joined hand with local universities to apply for grants under the Areas of Excellence Scheme of the Research Grants Council.

SSTRB's Recommendations	Actions by GEO
20) The 28 m long flume should have its own unique character, and not be a repetition of, for example an existing facility, e.g. the facility at USGS or WSL. GEO should assist, as far as possible, the project management in the research project "Understanding Debris Flow Mechanisms and Mitigating Risks for a Sustainable Hong Kong" to prioritise a set of characteristics that distinguish the new Hong Kong flume facility from similar facilities elsewhere. (Section 3.7)	The following unique features had been incorporated into the flume and associated setup in the Kadoorie Centre of Hong Kong: • New design of trap door is introduced in the storage tank for water-tightness. • Transparent sidewalls are adopted to facilitate examination of dynamic debris impact. • The soil for testing is selected to match with local debris flow materials. In particular, soil debris for tests contained hard inclusions to match, as far as possible, with field observations. • A large-scale L-shaped rigid model barriers is designed and constructed for the impact tests. Details of the flume and test setup in Hong Kong and those from similar flume facilities elsewhere are given in the Briefing Paper on Technical Development of Natural Terrain Mitigation Measures for Rigid Barriers.
21) As part of the planning and the conception of the tests, SSTRB would like to see how the components of the study (centrifuge tests, numerical analyses, physical testing in flumes, a priori and a posteriori calculations and the several smaller studies underway or already completed) are planned to be integrated to produce improved design guidance. Pitfalls and essential results for progress should be identified. (Section 3.7)	GEO has thoroughly reviewed the components of all completed and on-going studies (centrifuge tests, numerical analyses, physical testing in flumes, etc.) and developed a framework for rationalisation of rigid debris-resisting barrier design. This framework covers key areas for improvement including geotechnical stability, structural integrity, detailing and other design considerations. Details are given in the Briefing Paper on Technical Development of Natural Terrain Mitigation Measures for Rigid Barriers.

SSTRB's Recommendations	Actions by GEO
22) For the pilot landslide detection system, SSTRB recommends continued efforts. SSTRB recommends that GEO continues to take a cautious approach to the widespread deployment of the technologies until there is a better understanding of issues of reliability, durability, system performance, maintenance, effectiveness and response. In particular, GEO should continue to look into newer sensors that have high accuracy and can be self-powered. (Section 3.7)	The prototypes installed for site trial were closely monitored. Valuable experience has been gained for improving the set up. The publication 'Wireless Sensor Networks for Civil Infrastructure Monitoring: A Best Practice Guide' by the Cambridge Centre for Smart Infrastructure and Construction was reviewed. It provides a general framework for reference in developing an instrumentation plan. A detailed review and market research on instrumentation technologies pertaining to landslide detection will be conducted. In order to look into better sensors for landslide detection, an extended site trial of landslide detection systems involving different instrumentation suppliers will also be conducted. Details will be reported to SSTRB in the 2018 meeting.
23) SSTRB recommends that GEO also prepares a plan for physical testing for optimisation of flexible barriers under the umbrella of improved Hong Kong practice and design optimisation. (Section 3.7)	The GEO has reviewed and summarised key findings of previous studies conducted in recent years and developed an overall research plan with a view to optimising flexible barrier design. As part of the overall research plan, GEO developed a physical test plan to study flexible barriers, taking advantages of the availability of a large-scale flume facility at the Kadoorie Centre in Hong Kong. Further details are given in the Briefing Paper on Technical Development of Natural Terrain Mitigation Measures for Flexible Barriers.

SSTRB's Recommendations	Actions by GEO
24) A geological review of clusters of relict and recent landslides: SSTRB recommends that GEO undertakes a similar study for two or three other key catchments in order to verify the conclusions reached for the West Lantau catchment. GEO should also consider carefully the role of geomorphological evolution and current landscape processes in the clustering of mapped relict and recent landslides, including the uncertainty it could introduce. (Section 3.8)	A landslide-clusters study has been conducted on three other selected catchments to verify the observations made in the pilot study on the West Lantau catchment and review the applicability of the proposed landslide cluster classification system taking account of the geomorphological evolution and current landscape processes. The findings will be presented in the upcoming briefing to SSTRB.
25) The selection criterion for vulnerable hillside catchments: SSTRB encourages GEO to continue the study of the relative risk of vulnerable hillside catchments using the new selection criterion, with a review of the priority rankings. (Section 3.8)	GEO has conducted a pilot assessment of landslide risk on selected potential vulnerable hillside catchments. Details of the assessment and the findings are presented in the Briefing Paper on Natural Terrain Risk Management.
26) SSTRB recommends that GEO does a review (or state-of-the-art) of recent work on the risk assessment for landslides, the methods used, and how one tackles aspects of uncertainty in the parameters. (Section 3.8)	GEO has conducted a review on the subject. The review and the findings are presented in the Briefing Paper on Natural Terrain Risk Management.
27) SSTRB suggests that GEO considers estimating an uncertainty band (similar to a standard deviation) and then obtaining a risk range on the Hong Kong F-N diagram. In particular, GEO should look into the examples of risk evaluation and uncertainty estimations covered by Professor N.R. Morgenstern in his HKIE Distinguished Lecture on 12 December 2017 (The Evaluation of Slope Stability: A Further 25 Year Perspective"). (Section 3.8)	GEO has conducted an analysis of the propagation of the uncertainties around the best estimates throughout the risk assessment of a Study Area. Monte-Carlo analysis has been employed in the analysis. The assessment and the findings are detailed in the Briefing Paper on Natural Terrain Risk Management.
28) SSTRB recommends including an analysis of the propagation of the uncertainties around the best estimate values and exploring the effect of the uncertainties on the estimated risk. (Section 3.8)	

SSTRB's Recommendations	Actions by GEO
29) SSTRB suggests that GEO considers doing a Monte-Carlo analysis of the "probability of reaching" a facility. To do this, it may be useful for GEO to study newer tools, for example Latin hypercube Sampling or Python programming, to accelerate Monte Carlo analysis of larger problems such as finite element models. The Monte Carlo could be compared with the present analysis to quantify any differences and can also be used to determine the relative influence of each of the uncertain parameters on the calculated risk. (Section 3.8)	Please refer to the responses to recommend-ations nos. 27 and 28.
30) SSTRB recommends that GEO now makes it clear that there is no compelling evidence for major earthquake-induced landslide in Hong Kong, and that the likelihood of an earthquake triggering major landslides in the foreseeable future is also low. (Section 3.9)	GEO Information Note on "Seismicity of Hong Kong" was updated in August 2018 to spell out that there is no compelling evidence for major earthquake-induced landslide in Hong Kong, and that the likelihood of an earthquake triggering major landslides in the foreseeable future is also low.
31) SSTRB recommends that GEO attempts to introduce a time dimension in its "get the ball rolling" strategy for cavern and underground space use in Hong Kong. (Section 3.10)	A time dimension has been added to the "get the ball rolling strategy". It will be presented to the SSTRB in the coming meeting.
32) SSTRB recommends that GEO uses the release of Geoguide 4 for a PR event to promote the idea of cavern and underground space in Hong Kong, and to enhance trust in GEO's competence in this area. GEO's geoguides are highly respected internationally, and this could be made more widely known to the profession and the public in Hong Kong. (Section 3.10)	The new edition of Geoguide 4 together with the Cavern Master Plan was introduced at a media interview in February 2018 to promote the idea of cavern and underground space in Hong Kong. Two seminars for professionals (viz. a GEO seminar and a joint HKIE-ICE technical seminar) have been organised. A paper on the updated Geoguide 4 was presented at the 16th World Conference of the Associated Research Centers for Underground Space Development (ACUUS 2018) held in Hong Kong on 5-7 November, which could be made more widely known to local and overseas practitioners.

SSTRB's Recommendations	Actions by GEO
33) SSTRB recommends that GEO use the upcoming international conference in Hong Kong in November 2018 ("Integrated Underground Solutions for Compact Metropolitan Cities" www.accus2018.hk) to invite media, authorities and possibly investors for selected lectures to promote the idea and benefits of cavern and underground space in Hong Kong. (Section 3.10)	The 3-day international conference attracted more than 350 delegates from various local and overseas organisations, including government authorities. A few market operators (possibly investors) also joined the conference to explore the prospect of underground space uses. A Singapore-based media, Channel NewsAsia, sent a crew to film the conference for producing a documentary on Hong Kong's master planning of cavern and underground space development. Some GEO colleagues were invited to receive an interview to promote the idea and benefits of cavern and underground space in Hong Kong.
34) SSTRB recommends that the Head of the GEO continues to present a general overview of GEO's strategy at the start of forthcoming SSTRB meetings. (Section 3.11)	The practice to present a general overview will continue.
35) In view of the challenging demography of its senior officers over the next four years, SSTRB recommends that the Head of the GEO apprises SSTRB of recruitment, and leadership-management training, as well as plans for mentoring. (Section 3.11)	SSTRB will be apprised of the recruitment, leadership management training and mentoring plan in the 2018 meeting.
36) GEO should consider seconding members of its professional staff for three to six month periods to key universities and appropriate research organisations abroad to expose them to alternative approaches and landslide risk strategies. (Section 4)	In this year, GEO arranged two geotechnical engineers to receive overseas training: one undertaking a 12-month postgraduate study on risk, disaster and resilience at the University College London and the other attending a 3-month training attachment at the British Geological Survey on geological field mapping and modelling.
37) GEO should consider increasing diversity among its professionals, perhaps seeking to recruit staff with working experience in mainland China and elsewhere. Evidence shows that increased diversity in organisations improves dynamics and favours the exchange of new ideas. (Section 4)	The recruitment of staff has always been based on the capability and potential of the candidates as well as GEO's operational need. Through the recruitment process, the GEO has recruited staff with diverse experience. Some of the staff members have experience working overseas and/or in mainland China.

SSTRB's Recommendations	Actions by GEO
38) SSTRB recommends that GEO explores machine learning, big data and artificial intelligence in the management of slope hazards, and the opportunities these approaches may present within the slope safety system. It may be opportune, as suggested at the Slope Safety Summit, to initiate a pilot study on the possibilities the approach and/or tools may have for improved slope safety in Hong Kong. (Section 4)	GEO has initiated two pilot studies to explore the applicability of machine learning, big data and artificial intelligence in the management of slope hazards: one for automatic identification of recent natural terrain landslides from aerial photographs and the other for identification of rock outcrops on natural terrain in Hong Kong. Details are given in the Briefing Paper on Development of GEO's Innovation and Technology Strategy for Slope Safety Management.
39) SSTRB recommends that GEO reports on the on-going stress testing studies and how the results may influence the slope safety system. (Section 4)	The GEO had performed scenario-based studies based on transposition of two historical extreme rainfall scenarios. The results prompted GEO to streamline its emergency system and fostering of the community resilience through non-engineering means (e.g. the establishment of the Slope Safety Communication Strategy Advisory Committee). Further refinement to the stress testing studies is being made in collaboration with the HKUST.
40) SSTRB recommends that GEO initiates a discussion with the professions in Hong Kong as to whether geotechnical practice is excessively prescriptive, and reports to SSTRB on the results of this discussion. (Section 4)	This issue was discussed with the local engineering community in several occasions including the Communication Meeting Between the HKIE AP/RSE/RGE Committee and the GEO. The GEO observed that there might be divided views within the industry, although majority of the feedback did not consider that the geotechnical practice is excessively prescriptive. On the other hand, an Expert Panel has recently been set up in the GEO to vet the use of new materials, new construction methods or innovative designs where existing guidelines are not available. This aims to facilitate innovations in geotechnical engineering design and construction.

SSTRB's Recommendations	Actions by GEO
41) SSTRB recommends that GEO and HKO summarise the likely impacts of climate change on landslides in Hong Kong, considering the potential roles of secondary factors, such as increased evapotranspiration and vegetation change in addition to increased rainfall intensity. (Section 4)	A review has been conducted to discern the secondary landslide-affecting factors relevant to Hong Kong that are susceptible to the influence of climate change. Their projections under climate change have been consolidated in consultation with the HKO and some experts of the relevant fields. Based on the projections and other available information, an assessment has been made to deduce the potential roles of the secondary factors and hence to evaluate the associated implications to landslides in Hong Kong. The findings of the review are summarised in the Briefing Paper on Secondary Landslide-affecting Factors and Their Impacts on Landslides in Hong Kong under Climate Change.
42) SSTRB suggests that GEO considers whether it is opportune to organise a course over, for example, two days on "newer" approaches, such as statistical analysis of data, probabilistic analysis, reliability-based design and risk analysis, with special focus on the applications of the methods in Hong Kong. (Section 5.2)	In collaboration with HKIE Geotechnical Division, a one-day workshop on "Reliability Design, Risk Analysis and Limit State design" will be held on 7 December 2018. Invited overseas speakers in the workshop include Professor Kok Kwang Phoon of National University of Singapore and Professor Jianye Ching of National Taiwan University. The targeted participants include local practitioners, academia, as well as GEO colleagues.