Major project

Hong Kong Theme-based project on landslide mitigation

Words from the Project Coordinator (Prof. Charles W. W. Ng)
Hong Kong has a population of about 7 million and a small area of only 1100 km^2, of which 70% is hilly terrain. Every year, the city is drenched by torrential rainfalls. On average, 300 landslides occur every year. Fortunately, with the systematic landslide risk management in Hong Kong, fatalities caused by landslides have not happened over the last two decades. However, the scale and frequency of landslides in Hong Kong could nonetheless grow as climate change continues to intensify.

The devastating consequences of intense rainfalls are best illustrated by a severe rain-storm that bombarded Hong Kong in June 2008. This storm triggered over 2,400 landslides on Lantau Island. A landslide at Cafeteria Old Beach in Tuen Mun resulted in two fatalities and a landslide on Lantau Island blocked the sole access to the Hong Kong International Airport for up to 16 hours causing severe economic disruption. Also, a landslide blocked Keung Shan Road, the only access to Tai O, for several days. Had the rainstorm hit a more densely-populated area of Hong Kong, the consequences would have been immeasurable.

The Department of Civil and Environmental Engineering of The Hong Kong University of Science and Technology (HKUST), was recently awarded a landmark grant from the Research Grants Council of Hong Kong for a Theme-based Research Scheme project named "*Understanding Debris Flow Mechanisms and Mitigating Risks for a Sustainable Hong Kong*". This collaborative five-year project is coordinated by HKUST. Collaborating institutions include the University of Hong Kong, City University of Hong Kong, the Institute of Mountain Hazards and Environment of the Chinese Academy of Sciences, and the Hong Kong Institution of Engineers.

The project mission is to advance our scientific understanding of debris flows and their interaction with state-of-the-art multiple flexible barrier systems. Flexible barriers are steel-net structures that can deform and allow some material to pass through. Both features are instrumental in attenuating the resisting forces. This means that fewer resources are needed to provide greater protection to citizens.

The success of this project will have an immediate effect on local industry practice. It will lead to sustainable mitigation measures, enhanced cost-effectiveness and more environment-friendly works in Hong Kong and elsewhere in the world.

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New paradigm of landslide mitigation

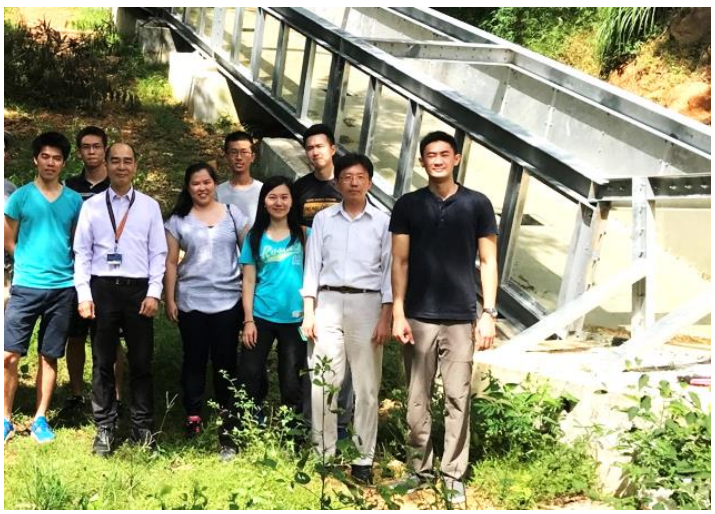
With the increasing availability and the decreasing costs of smartphones, scientists need to embrace this technology to better mitigate and manage landslide disasters. Smartphone-based approaches for mitigating and managing disasters are a relatively new concept, and have only recently been adopted for earthquakes. Crowdsourcing relies on developing smartphone applications that acquire measurements from built-in smartphone sensors, such as acceleration, temperature, and GPS coordinates. Data collected can then be used to enhance early-warning systems, manage landslide disasters, and to help scientists to better understand natural hazards.

A pertinent example of how the management of large-scale landslide disasters can benefit from crowdsourcing is the 7.8 magnitude earthquake that hit Kaikoura, New Zealand, in November 2016. This earthquake triggered more than 100,000 landslides. Some landslides blocked off entire towns. For instance, Kaikoura, with a population of about 2,000, was completely cut-off. Furthermore, numerous landslides were triggered by aftershocks as debris flows posed significant threats. Clearly, the scale of such disasters warrants a new approach to enhance the existing state of landslide mitigation and management.

Landslide Information System (LIS)

A recently developed landslide information system (LIS) between the Hong Kong Jockey Club Disaster Preparedness and Response Institute (HKJCDPRI) and HKUST leverages crowdsourcing and location-based GPS technology to provide real-time landslide information to the public.

The LIS comprises a smartphone app for users and a database and interface for administrators. The mobile app is developed for iOS and Android platforms. Experience has shown that this kind of mobile system enhances their situation awareness and emergency responses to landslides.



Visit to the HKUST large-scale debris flow flume facility by HKUST and HKJCDPRI

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The smartphone app interface is powered by the highly-customizable Google Maps™ platform. Google Maps™ information is overlaid with real-time landslide locations and blocked transportation lines. On the main app interface, users can choose between visualising 'known sites' and 'contribution' of landslide data. The visualisation option shows where landslides have occurred, as well as where they might occur in the future.

Cheung Tung Road Landslide, Lantau Island, Hong Kong

When contributing landslide data, users need to log in with a Google email account. After authentication, users have the option to select their current GPS coordinates or manually select any location on Google Maps™. Furthermore, users can report landslide incidents as photos or videos. This multimedia approach allows geotechnical engineers to better assess the validity of landslide reports as well as deliver an appropriate response. After a photo or video has been uploaded, the user can provide additional personal details and description of the incident. Once the user saves the report, the incident is sent to the administrative database for review.

The current version of the smartphone app runs silently in the background and only reports data that the user allows. Settings can also be adjusted so that data is only sent when the phone is connected to a Wi-Fi network. Also, the user can choose whether the app can access their location and modify notification settings.

Outlook

There are further improvements that can be made to the LIS. The LIS is currently being developed to serve as a global landslide database for the debris flow and steep creek hazards. Furthermore, the LIS can be coupled with instruments to enhance early-warning systems and to improve the management of debris-resisting structures. The prospect of crowdsourcing for geo-hazards is not only limited by what smartphones can do in the future.

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Connecting with industry

The immediate-past head of the Hong Kong Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD), Ir. H. N. Wong (JP), was kind enough to share a few thoughts with us on the current state of landslide mitigation and management in Hong Kong.

Interview with Ir. H.N. Wong (left) by Mr. Chao Wang (right)

Chao Wang: (PhD student in the Department of Civil and Environmental Engineering at HKUST): As we all know, GEO has done a great job keeping our slopes safe in Hong Kong. As a member of the public, it appears that slope safety is fully under control in Hong Kong. From an expert's point-of-view, do you think there are any fundamental challenges that still need to be resolved in terms of slope stability?

H.N. Wong: The GEO has been making an effort to control the landslide risk in Hong Kong at a low level. Yet, the battle is not yet over. Although no landslide casualties occurred in the past nine years, there are still on average about 300 man-made slope failures and another 300 natural terrain landslides every year. We continue to face three key challenges:

1. We have many man-made slopes that were built in the old days without proper geotechnical design, which are yet to be upgraded.
2. The growth in population and urban development encroaching on steep natural hillsides will increase landslide risk. There is also a need to address natural terrain landslides.
3. Climate change will increase both the frequency and intensity of extreme rainfall. As the likelihood of slope failure increases exponentially with rainfall intensity, we have to brace ourselves against the challenges from climate change.

Chao Wang: Climate change is currently expected to pose a significant threat to slope safety in Hong Kong. It is expected that debris flows may occur more frequently. As young geotechnical researchers, what are your suggested topics to invest our time to make high-impact contributions to the world?

H.N. Wong: With regards to slope safety, natural terrain landslides are very vulnerable to the effects of climate change. Our young researchers will be the ones to tackle the problems, they should gear up their knowledge of natural terrain landslides and the geo-science and management practices involved in dealing with natural terrain landslide risk. Examples of key subjects are: assessing vulnerable terrains (e.g. susceptibility analysis) and their responses to severe rainfall, modelling debris movement, analysing debris-barrier interaction, optimising the structural capacity of debris-resisting barriers, and so on. These subjects are not conventionally covered in tertiary education and are relatively new fronts of research. Studying these subjects would also call for partnering with the geological and other professions.

Chao Wang: In the past, Hong Kong mainly used rigid barriers to resist debris flows, which are expensive and use a lot of space. Are there any other drawbacks?

H.N. Wong: Finding suitable space to construct rigid barriers could be a problem in built-up areas. Also, rigid barriers tend to be visually intrusive. There is a need for using flexible barriers and exploring other innovative mitigation schemes. However, rigid barriers still play an important role, particularly in dealing sizeable debris flows. The mechanisms of rigid barriers in resisting debris movement are reasonably well understood, and their performance is robust. Also, they do not require extensive maintenance.

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Chao Wang: Scientific research should bring benefits to the public. This can be achieved by transferring our knowledge to the industrial practice. Could you please give us some suggestions so that we can apply our understanding of debris flow impact mechanisms to practical design?

H.N. Wong: I really expect something practical and useful to come from our ongoing comprehensive and in-depth research on the subject. One of the key areas of development is to advance our current understanding and modelling of debris-barrier interaction, so as to enhance the design of flexible barriers and thereby render their use in dealing with sizable debris flows more practical, reliable and cost-effective. To facilitate transfer of the research findings into practical applications, researchers should collaborate with practitioners. On the one hand, this will promote awareness among the researchers of the industry's needs and constraints. On the other hand, practitioners will appreciate the latest technological development and hence its possible application to their work. For flexible barriers, maintenance and the associated components, such as brake elements, is critical to the long-term performance of the barriers. There are major implications to the cost, reliability and applicability of the barriers. Not adequately addressing such practical issues will seriously constrain the scope of the use of flexible barriers, despite technological advances made in analysing the debris-barrier interaction.

Chao Wang: Technology is booming now and has changed our life substantially. Will the government try to incorporate those new technologies, such as artificial intelligence, to monitor and stabilise the slopes?

H.N. Wong: Yes, we are benefitting a lot from the technology boom. For instance, advances in electronic and remote sensing technology have brought about new capability and opportunities in geotechnical instrumentation and monitoring. As a result of IT and telecommunication development, continuous, real-time data acquisition and transmission have become routinely available for geotechnical application.

Chao Wang: Do you have any overall suggestions for this project?

H.N. Wong: It is my privilege to have taken part previously in the formulation of the project and currently in its technical review. This theme-based project is an invaluable opportunity for research into multiple related subjects. I look forward to seeing useful outcomes that will advance our understanding and improve professional practice.

Given the scale and complexity of the project with tasks taken up by different research groups, effective coordination among the groups is crucial to ensure that the work is undertaken in an integrated manner and achieving the intended objectives of the theme-based project.

The project also provides an excellent opportunity for nurturing a new generation of researchers. If Hong Kong can retain this pool of expertise and offer a suitable environment for their continual development, we will further excel in our leadership in geotechnical research and make an impact to advancing technology and state of good practice for dealing with landslides and debris flows.

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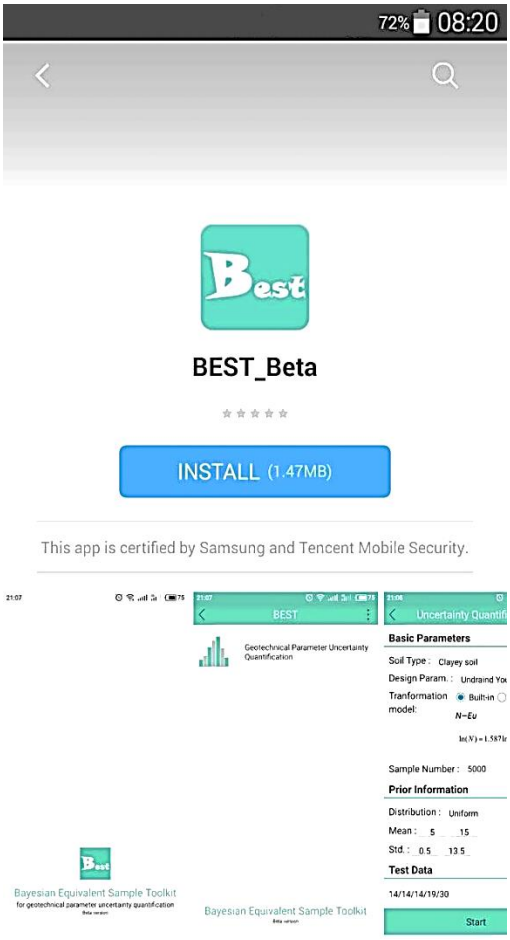
Smartphone apps for managing engineering data

In 2017 the world was amazed by AlphaGo when it beat Ke Jie, the world's top-ranked human Go player at the time, with a straight 3:0 in a three-game match. The victory of AlphaGo has demonstrated the rapid development of artificial intelligence and machine learning, which now seem mature enough to outperform human beings. They are ready to make a real difference to the well-being of society - including assessment and mitigation of landslide risk. A research team led by Dr Yu Wang at the City University of Hong Kong has been exploring the potential of machine learning in geotechnical engineering during the last few years and has developed a suite of Bayesian methods for analytics and simulation of geo-data. The research team has collaborated with Wuhan University and recently launched a smartphone app called BEST, an acronym of Bayesian Equivalent Sample Toolkit, for estimation of soil and rock properties as input to geotechnical analyses, such as landslide risk assessment and mitigation.



Snapshot of smartphone app "BEST"

Soils and rocks are natural geo-materials. Their properties are affected by their parent materials, weathering and erosion processes, transportation agents, and sedimentation conditions. Soil and rock properties vary for every project site. Site-specific measurement data are, however, often limited in engineering practice, particularly for natural terrain, and it is difficult to properly determine the characteristic values of soil and rock properties for geotechnical analysis from limited data.

The Bayesian equivalent sample method and BEST smartphone app aim to address this difficulty and leverage existing data from diverse sources, such as prior information on the site (e.g., existing data on sites with comparable site conditions, local experience and engineering judgment).

The BEST app provides geotechnical practitioners with a user-friendly tool of Bayesian machine learning for fusion of limited site-specific measurements with data from diverse sources.

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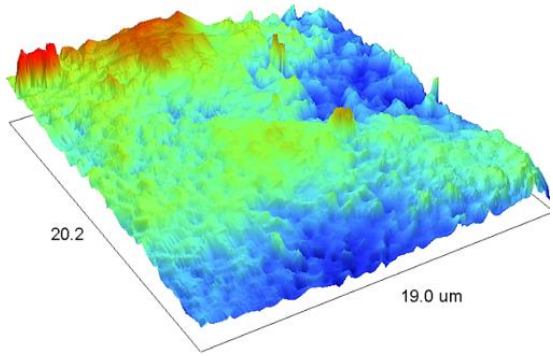
Characterisation of debris flow materials

Debris flows involve the movement of a large volume of fragments and soil grains. This is a very complex phenomenon to be simulated, understood and predicted and it depends on the physical characteristics and properties of the fragments and-grains. At the City University of Hong Kong (CityU), advanced facilities and experimental techniques have been developed, which allow us to study the properties of the individual fragments and grains from real debris flows in Hong Kong and many other local geological materials which may potentially be involved in a new landslide.

We scale down landslides to the size of individual grains involved and study their properties and interactions. This output from CityU is then utilised in larger-scale simulations by other collaborating research teams to try to fully understand this phenomenon. Examples are given in the following images on the way the debris-flow problem is scaled down and studied at the level of individual fragments and grains in the laboratories at CityU. The features of the grains at this small scale can affect the whole debris flow as massive movement.

Two weathered volcanic grains under uniaxial compression



Microstructure of an individual grain (width of captured part of the grain equal to 20 x 10^{-3} mm, means it is 100 times smaller than the size of the real

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Plant growth on landslide trails in Hong Kong
Landslides destroy vegetation that grows on hillsides or natural terrain, and with it seed banks, nutrients and microbial communities. Of course, this means that there is a chance for new biological communities to grow!

Disturbance to hillside ecological systems has attracted more attention in recent decades, especially in wet, mountainous regions such as Hong Kong. Apart from research on preventing and mitigating the impact of landslides on humans and dwellings, ecological restoration of damaged landscapes is also required.

The two dominating fern species during early successional stage on natural terrain landslides

The research team at the University of Hong Kong (HKU) has been documenting the establishment and change of vegetation on nine landslide trails for more than eight years after each landslide event. They conducted surveys to measure the survival and height of all woody vegetation on the sites. They found that there was little variation in the density of the stems or the variety of species. However, most of the individual trees died after a short period of time. Landslide zones became dominated by fern thickets, which tended to stop woody plants from growing in the area.

The HKU team has identified fast-growing trees and shrub species with the highest survival rates. These can potentially be used for future ecological restoration. They may allow seeds to be distributed by birds, and prevent fern thickets from spreading. They suggest that given the difficulties in clearing ferns from landslides zones, it is vital to plant tree and shrub seeds directly on landslide trails soon after landslides occur.

Natural terrain landslides were mostly occupied by herbaceous plants 8 years after a landslide hit the area. Woody plants were not able to thrive because of fast-growing ferns, which took over the area

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Smart barriers

There are barriers all over Hong Kong that intercept debris flows before they can reach human settlements. Their capacities are designed based on previous landslide events. Climate change is a critical issue for Hong Kong, since it may increase the size and number of landslides that happen each year. This means that under exceptionally heavy rainfall, debris flows might be able to overflow. It is vital that Hong Kong be even better prepared, and for engineers to be able to respond even faster to these threats.

The "Landslide Detection System" (LDS), which is being developed by the Geotechnical Engineering Office (GEO), will allow barriers to instantly alert engineers if they are hit by debris flows. This will allow a faster response to the event, allowing extra time for emergency action and evacuating nearby residents. Trials of the LDS are currently being run at Sham Tseng San Tsuen.

The LDS uses a simple, energy-saving design. It includes a wireless impact switch, a laser debris depth gauge and a digital camera, all of which are widely available.

The wireless impact switch triggers the laser debris depth gauge and digital camera if it is physically impacted by a debris flow. The laser debris depth gauge then measures the thickness of the flow at regular intervals, whilst the camera captures photographic images of the barrier retention zone.

Pilot test of Landslide Detection System in Sham Tseng San Tsuen

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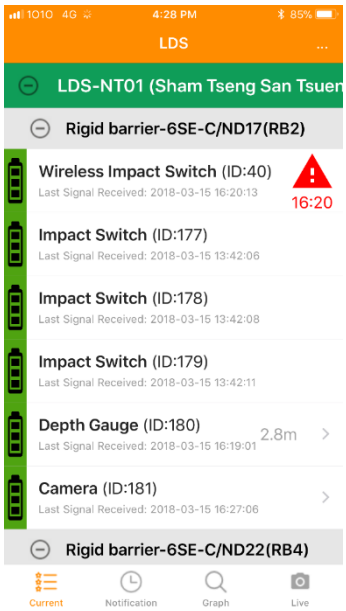
This information is then transmitted to the GEO via a mobile network and is displayed on applications installed on desktop computers and mobile devices. The GEO can then immediately deploy geotechnical engineers to inspect the site if necessary.



Screen shot of LDS app in Sham Tseng San Tsuen

There are other benefits to the LDS. For example, engineers in Hong Kong have traditionally relied on routine inspections, or reports from the public, to see how much soil has been intercepted by barriers. However, since many barriers are in remote areas, it is possible to underestimate the retention volume, leading to potential overflow later.

With the use of the LDS, real-time surveillance and monitoring of the barrier retention zone become practical and cost-effective. The LDS enables prompt notification of debris flows, shortening response time for emergency operations and minimising potential consequences. If the trials show that the setup is durable and reliable, the GEO will consider installing it on barriers around Hong Kong.

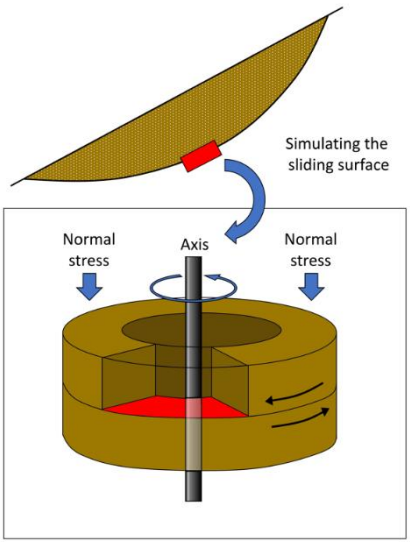
Simulating debris flows in the laboratory

The team at University of Hong Kong (HKU) has been simulating debris flows using a "ring-shear" apparatus.

Using this apparatus, the HKU team has been able to identify the changes that grains of soil in debris flows undergo when travelling over long distance. Their laboratory tests have revealed how the size, shape and surface characteristics of grains of soil change during flow. The team are now expanding their work to include coarser grains of soil.

The use of the ring-shear apparatus has been facilitated by collaboration between teams at HKU, the Chengdu Institute of Technology, the Disaster Prevention Research Institute of Kyoto University and University College London.

The grain of soil above has a hexagonal shape. This suggests it's a fragment of quartz, which is a very common mineral in Hong Kong's soils. The relatively intact shape also suggests that it has not been heavily damaged during the flow.



The ring-shear apparatus is split in two halves rotating in opposite directions. The sliding surface in the ring-shear simulates debris flows moving over the ground

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On the world stage

Two papers by project members from the Department of Civil and Environmental Engineering at the HKUST and their collaborators from the Hong Kong GEO were honoured by best paper awards by leading international journals in geotechnical engineering. This marks the first time the awards were given to teams with members all from Hong Kong!

Prix R. M. Quigley Award (Honourable Mention) from the Canadian Geotechnical Society on 2nd October 2017 in Ottawa, Canada (Middle: Prof. Charles W. W. Ng; 2nd from right: Prof. Clarence E. Choi)

Two papers by professors and PhD students in the Department of Civil and Environmental Engineering at HKUST and their collaborators from the Hong Kong Government were honoured with best paper awards from leading international geotechnical journals. The paper titled "Large-Scale Successive Boulder Impacts on a Rigid Barrier Shielded by Gabions" received the Prix R. M. Quigley Award (Honourable Mention) by Canadian Geotechnical Society. The authors were CLP Holdings Professor of Sustainability Prof. Charles W. W. Ng, Chair Professor and HKUST Associate Vice-President for Research and Graduate Studies, Prof. Clarence Edward Choi, Research Assistant Professor, PhD graduate Andy Yuchen Su, and collaborators from the Civil Engineering and Development Department (CEDD) of the Hong Kong SAR Government. The paper was rated the second best out of 296 peer-reviewed papers in 2016 in the Canadian Geotechnical Journal, which recognises considerable contributions and achievements to the advancement of the geotechnical field. Prof. Ng is the third-time recipient of this award and had gained it previously in 2013 and 2008. However, this is the first time that a team with members all from Hong Kong won this annual award since it was established in 1973.

Another paper titled "Coarse Granular Flow Interaction with Slit Structures" received the Telford Premium Award 2017 presented by the Institution of Civil Engineers, UK. The authors are Prof. Charles W. W. Ng, Prof. Clarence Edward Choi, PhD students George Robert Goodwin and Desmond Ka Ho Cheung, as well as collaborators from GEO Hong Kong government. This is the first time that the award was given to a Hong Kong team – and all members were from Hong Kong.

Their paper was the best paper in 2016 in Géotechnique Letters. The award recognises authors from both industry and academia who have produced work of exceptional quality and which benefits civil engineering, construction and materials science.

Telford Premium Prize from the Institution of Engineers of the United Kingdom on 7th October 2017 in London (From the left: Prof. Charles W.W. Ng; Prof. Clarence E. Choi; Right: Mr. Desmond K.H. Cheung)

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The next generation

I am Nicol, a final year civil engineering student and a member of the WISE (Women in Science and Engineering). My experience at HKUST has been very positive. The most memorable event that I participated in was the model building competition in 2018, which was organised by the Institution of Civil Engineers of the United Kingdom. This competition enabled me to apply what I have learnt in the classroom to solve real-life problems.

In between semesters, HKUST provided me with the opportunity to work for one of the top Hong Kong-based consultant companies, C M Wong & Associates Ltd, as an intern. I was a member of the geotechnical team and learned how to carry out numerical simulations to model complex geotechnical problems. This internship helped me to interact with my mentors and to develop a sense of pride. Now I have an urge to quickly graduate so that I can also be an inspiring geotechnical engineer!

My final year project involves the investigation of debris flows impacting a rigid barrier. I feel excited to be involved in this project because it is very much relevant to the challenges that practitioners are facing in Hong Kong. My research and knowledge will be able to directly improve the current state of design of mitigation measures against debris flows. I hope that upon graduation, I can serve as a mentor and outreach to foster new female talents and to inspire young engineers to contribute back to society by being great civil engineers.

I am Desmond Cheung. Before becoming a research student, I worked in industry at Gammon Construction Ltd. for four years. I was fortunate enough to take part in two mega infrastructure projects in Hong Kong, specifically the West Kowloon Terminus for the Express Rail Way Link and Tuen Mun-Chek Lap Kok Link-Southern Connection. I returned to University in 2016 as a full-time PhD candidate in geotechnical engineering at HKUST.

I was fortunate enough to join the theme-based project where I have been able to meet so many bright minds. I was also provided with opportunities to visit many places around the world to learn more about debris flows. One of the highlights was being a co-author of a prestigious award-winning paper in 2016, where I got to travel to London to receive the award.

I am always asked whether the transition from industry to becoming a research student is difficult. The answer is yes! But the satisfaction in carrying out world-leading research with my peers outweighs the stress and struggles of learning how to be a full-time student again.

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I'm Usman Majeed. My current research topic is on the mitigation of debris flow using rigid and flexible barriers. I am focusing on how large boulders break during impact, to enable the optimisation of barrier designs. Hopefully, my findings will lead to more sustainable and cost-effective designs.

Upon graduation, my goal is to return to industry where I can make the greatest impact. Through my participation in the theme-based project, I will be able to not only help improve the geotechnical industry in Hong Kong, but also to the one-belt-one-road initiative, and eventually developing countries around the world.

After obtaining my bachelor degree in 2014, I worked as a geological engineer in the northern part of Pakistan. During my time spent there, I was surprised that I could still see the remnants of a catastrophic earthquake that occurred in 2005. This earthquake triggered several debris flows that buried entire villages. I was particularly fascinated by the destructive nature of debris flows. I learnt that dealing with debris flows requires a technical background in geotechnical engineering and that the mitigation of this type of hazard is a particularly new research area that still requires a lot of work. This realisation inspired me to better equip myself to contribute and help my country deal with this devastating natural hazard in the future.

With my newfound motivation, I decided to pursue a PhD in the Department of Civil and Environmental Engineering at HKUST, which is spearheading a global research initiative against debris flows. Working under the theme-based research project, which aims to develop understating of debris flows mechanisms and developing new countermeasures for such hazards, is an important step forward for my goal of helping my country. I have spent more than a year studying at HKUST, and I can attest that HKUST is everything that I expected, and even more.