

Enhanced Urban Slope Surface Drainage Design Against Extreme Rainfall Events

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ABSTRACT: An effective urban slope surface drainage system is crucial for maintaining slope stability. A well-designed drainage system effectively diverts surface water from upslope catchments to designated outlets, reducing infiltration and preventing surface erosion. Conversely, inadequate drainage design can lead to concentrated runoff, which may result in washouts and landslides. On 7-9 September 2023, a record-breaking rainstorm struck Hong Kong, resulting in 238 reported landslides. Notably, 45 incidents involved uncontrolled surface runoff from natural hillsides, roads and upslope platforms. Among these, 17 major failures had volumes up to 4,000 m³. This paper investigates three of these landslide cases that failed due to inadequate drainage detailing. Exact causes included overtopping of surface channels, flow choking at catchpits, uncontrolled overflows at topographic low points, and blockages of roadside drains, all of which hindered the effective diversion of surface water away from the slopes. The paper also presents results of three-dimensional computational fluid dynamics analyses that simulated the flow behaviours at key drainage components at the two landslide locations and identified enhanced measures to address the overflow issues. Additionally, this paper gives an update on the Intensity-Duration-Frequency (IDF) curves for urban slope drainage design in Hong Kong, taking cognizance of the influence of the record-breaking rainstorm in September 2023. The proposed measures in this paper along with the updated IDF curves aim to strengthen slope stability with similar surface drainage layout, with a view to mitigating landslide risk under unprecedented rainfall intensities associated with climate change effects.

KEYWORDS: Landslide risk mitigation, slope stability, urban slope surface drainage, climate change impact, geotechnical resilience

1 INTRODUCTION

Hong Kong is a densely populated city with a subtropical climate, which brings a rainy season from April to October each year. The mean annual rainfall at the Hong Kong Observatory between 1991 and 2020 is about 2,400 mm, with a significant spatiotemporal variation across different regions and seasons of Hong Kong. According to the Hong Kong Observatory, the mean annual rainfall is generally higher in mountainous regions and lower in the northwest and southeast of the territory with about 80% of rain falling between May and September. Developments in Hong Kong are in close proximity to steep hilly terrain with thick weathering profile, including man-made slopes and natural hillsides. The combination of intense seasonal rainfall and hilly, saprolitic landscapes necessitates an effective urban slope surface drainage system, which is crucial for safely diverting surface runoff from upslope catchments to appropriate discharge points within the urban drainage network. An inadequate slope surface drainage system can lead to uncontrolled, concentrated runoff, which can result in surface erosion or even landslides.

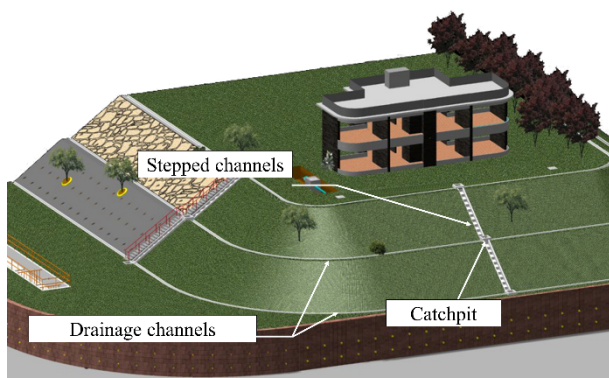


Figure 1. Slope surface drainage system in Hong Kong

Figure 1 shows a typical layout of a slope surface drainage system in Hong Kong. It consists of drainage channels that collect runoff from upslope catchments and stepped channels that divert the collected water down the slope to designated discharge locations. Higher slopes are often constructed with

multiple slope batters, each equipped with its drainage channels that converge at a chamber-like structure known as catchpits. This combined surface runoff then flows to the downslope stepped channels and ultimately to the slope toe. The Geotechnical Manual for Slopes (GEO, 2011/1984) provides guidance on the design of slope surface drainage systems in Hong Kong, with additional guidelines provided through Geotechnical Engineering Office (GEO) Technical Guidance Notes (TGN) (GEO, 2006; GEO, 2014).

On 7-9 September 2023, Hong Kong experienced an extraordinarily severe rainstorm that shattered historical rainfall records, establishing it as one of the most extreme meteorological events since the late 19th century. Rainfall exceeded 800 mm within 24 hours in some areas, with peak hourly intensities surpassing 150 mm. The storm overwhelmed drainage systems, inundated urban areas, and triggered widespread landslides across the territory. The storm's intensity resulted from a rare combination of meteorological factors, including a potent low-pressure trough and tropical influences, making it one of the most significant natural hazards in Hong Kong's recent history. During this rainstorm, the Government received 238 reported landslides, primarily from the areas hardest hit by the torrential downpours.

In response, the GEO conducted a thorough investigation into these landslides to identify their causes and enhance landslide risk mitigation strategies. The study revealed several contributory factors, including adverse geological materials, unfavourable groundwater conditions, concentrated surface water flow, and inadequate slope maintenance. Notably, about 20% of the landslides involved uncontrolled surface water flow, underscoring the challenges in managing runoff in rugged terrain under climate change and extreme weather events, as well as the opportunities for improving slope surface drainage systems. These findings highlighted the need for a comprehensive review and enhancement of slope surface drainage design in Hong Kong to improve resilience against extreme rainfall.

This paper investigates three of these landslide cases that failed due to inadequate drainage detailing. Exact causes included overtopping of surface channels, flow choking at catchpits, uncontrolled overflows at topographic low points,

and blockages of roadside drains, all of which hindered the effective diversion of surface water away from the slopes. The paper also presents results of three-dimensional computational fluid dynamics analyses that simulated the flow behaviours at key drainage components at the two landslide locations and identified enhanced measures to address the overflow issues. Additionally, this paper gives an update on the Intensity-Duration-Frequency (IDF) curves for urban slope drainage design in Hong Kong, taking cognizance of the influence of the record-breaking rainstorm in September 2023. The proposed measures in this paper along with the updated IDF curves aim to strengthen slope stability with similar surface drainage layout, with a view to mitigating landslide risk under unprecedented rainfall intensities associated with climate change effects.

2 CASE STUDIES OF SELECTED LANDSLIDES

The three landslide cases occurred during the record-breaking rainfall event on 7-9 September 2023. Subsequent landslide investigations have identified uncontrolled surface water flow as the major contributing factor of the landslides. Key details are provided below.

2.1 Case 1: Sliding Failure at a Fill Slope below Wong Tai Sin Road

The landslide occurred on a fill slope adjacent to a stepped channel below Wong Tai Sin Road. The slope features a 900 mm-wide stepped channel designed to drain surface water from the upslope catchment into a culvert.



Figure 2. Landslide scar and stepped channel below Wong Tai Sin Road

Figure 2 shows the overall setting of the landslide site below Wong Tai Sin Road. The landslide scar measured approximately 10 m in length, 6.5 m in width, and 1 m in depth, with an estimated failure volume of 60 m³. The sliding failure was likely triggered by overspill from the stepped channel. Overtopping from the stepped channel may have wetted the near-surface fill material, allowing water to infiltrate the slope body, and leading to failure. This landslide case suggests that the depth of the stepped channel was insufficient to contain the surface runoff from upslope catchments and safely divert it to the urban drainage system.

2.2 Case 2: Washout Failure at a Cut Slope above Tai Po Road

The landslide, classified as a washout failure, occurred on the western portion of a cut slope located between an access road at the crest and Tai Po Road at the toe. The landslide was likely triggered by the overflow of surface runoff from the slope crest. The slope feature has two slope batters and is equipped with a

surface drainage system that includes 225 mm-wide U-channels, 300 mm-wide stepped channels, and catchpits to direct water to a designated discharge point. The catchpits are used to join the upslope and downslope stepped channels at the slope berm.

The failure, with an estimated volume of about 200 m³, was caused by the blockage of a drainage outlet, located 150 m from the access road, due to another landslide. This obstruction caused surface water to overflow, concentrating runoff along the access road at a topographical low point directly above the cut slope. While the drainage channel at the slope crest and the stepped channel along the slope functioned well, the drainage channel likely failed to fully intercept the intense runoff, causing over-spillage over the slope. The crest drainage channel intercepted successfully a portion of the runoff to the stepped channel. However, there were intense splashing and over-spillage at the catchpit when the water flowed across the slope berm. This indicates that the catchpit likely “choked” the intercepted water flow from the upstream and critical flow over-spilled onto the slope, exacerbating the surface erosion.

The intense runoff eroded the slope, leaving a deep scar measuring 22 m in length, 7 m in width, and up to 1.5 m in depth. Figure 3 illustrates the deep landslide scar above Tai Po Road.

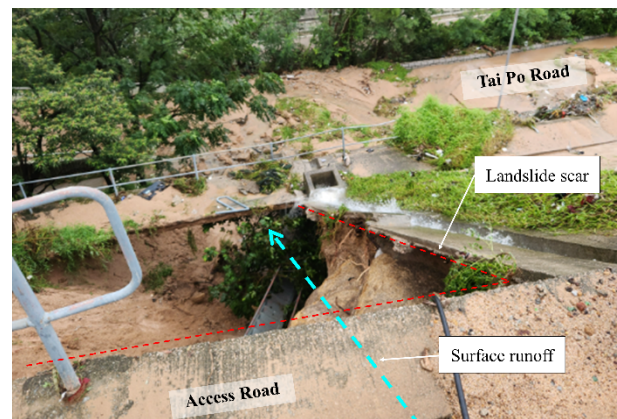


Figure 3. Landslide scar above Tai Po Road

This case emphasises the importance of holistic planning in surface water management during slope design. Even distant drainage systems, located at a distance, can significantly impact a slope if blockages cause water to be unexpectedly redirected. This highlights challenges in effectively containing flow due to the unpredictability of surface water pathways. Additionally, the flow choking at the catchpit during intense runoff brings up questions about its hydraulic performance, which remains inadequately understood (Tang & Cheung, 2007).

2.3 Case 3: Sliding Failure at a Fill Slope below Shek O Road

The landslide occurred on a fill slope below Shek O Road, which runs along the slope crest and descends slightly to the southeast. The landslide was likely triggered by the overflow of surface runoff from Shek O Road down the fill slope. Surface water from the upslope natural hillside flows along a rocky natural stream course. It is intercepted by a 600 mm-diameter cross-road drain that directs water beneath Shek O Road towards Tai Tam Tuk Reservoir. Notably, the fill slope lacks surface channels to manage surface runoff.

Figure 4 illustrates the overall setting of the landslide site below Shek O Road. The landslide scar measured approximately 20 m in length, 16 m in width, and reached a depth of 5 m, with an estimated failure volume of 650 m³. The

main scarp, inclined at about 60°, exposed a combination of fill and colluvium overlying bedrock.

The failure was primarily driven by an ineffective cross-road drain that became significantly obstructed by foliage and debris. This blockage caused water to pond at the upslope inlet, leading to overflow onto Shek O Road, where most roadside gullies were also blocked at the time of the intense rainfall. Without a roadside upstand at the slope crest and surface channels, surface water spilled over a cracked hard slope cover at a topographical low point, saturating the fill slope and triggering the landslide.

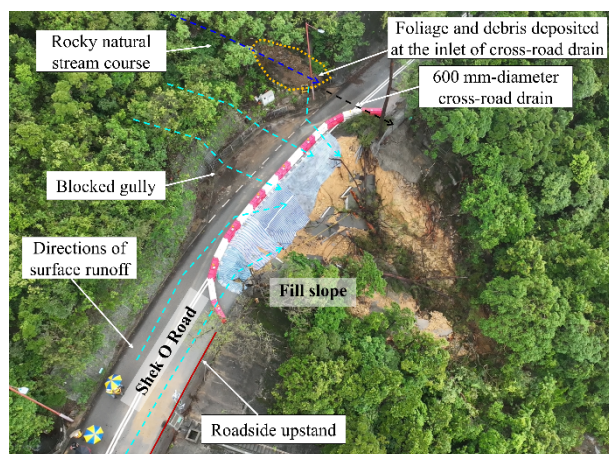


Figure 4. Overall setting of landslide site below Shek O Road

This case highlights the critical importance of regular maintenance of slopes to ensure roadside drainage systems (such as cross-road drains and roadside gullies) are clean from debris and foliage. In case of blockage of drainage systems at the slope crest, ponding can easily occur at topographical low points, resulting in concentrated surface water flow onto the slope, which may further trigger landslides.

3 REVIEW OF SITE OBSERVATIONS AND PROPOSED DRAINAGE IMPROVEMENT

While the design methodology for slope surface drainage is well-established and well-proven, the selected landslide cases revealed the inadequate considerations of site-specific topographic conditions and flow behaviours in stepped channels and at catchpits in slope surface drainage design in Hong Kong. In view of these, the GEO examined the surface drainage issues in the three landslide cases through a review of the current slope drainage design practice in Hong Kong and numerical simulations using computational fluid dynamics (CFD) of the actual site settings and flow behaviours, with a view to evaluating the validity of the current design method for stepped channels in terms of flow capacity and to identifying areas for improvement to address design details that the current design method does not provide for.

3.1 Review of current slope drainage design practice in Hong Kong

The existing design method for drainage channels in Hong Kong (GEO, 2011/1984; GEO, 2014) largely adopts analytical approaches for hydraulic design. While these methods capture the general behaviour of surface water flow, designers should properly estimate the runoff taking into account adverse topographic conditions that may exacerbate concentrated runoff.

The design of stepped channels follows the guidelines in GEO (2011/1984), which provides a simplified analytical method, with provisions to contain splashing. This method was

updated in 2006 (GEO, 2006) to incorporate empirical formulations from Chanson (1994), taking into account aerated water flow. The formulation assumes a skimming flow regime, commonly used in the design of wide stepped spillways operating under moderate to large discharge conditions. In this regime, water skims over the steps with significant air entrainment, filling the step cavities. The onset of skimming flow depends on the discharge, step geometry and length. As they are applicable for wide stepped spillways, the empirical formulations do not completely fit for the design of narrower channels on slopes. GEO (2011/1984) also recommends incorporating catchpits at channel junctions to accommodate splashing and turbulence. Nevertheless, dimensions of catchpits are largely empirical without rigorous consideration of their hydraulic performance by way of analytical solutions nor numerical simulations. It is inevitable that real-life flow behaviours such as supercritical flow, backwater and flow choking at catchpits are not adequately accounted for. Numerical simulations provide an alternative, reliable approach to examine these site observations.

3.2 Validation of model parameters for computational fluid dynamic analysis

The numerical study adopted the software, FLOW3D HYDRO (Version 2024R1), to set up representative CFD models, calibrate model parameters with physical tests conducted on stepped spillways by Charmani & Rajaratnam (1999) and undertake numerical simulations of flow behaviours along stepped channels and at catchpits in the two landslide cases. Charmani & Rajaratnam (1999) provides representative laboratory test results for skimming flow for calibrating the CFD models as the physical stepped channel model in the laboratory featured steep channel gradients, small step heights and in narrow width, which resemble the geometry of stepped channels on slopes in Hong Kong. Sensitivity tests were conducted to evaluate the effects of different turbulence models and air entrainment rates. The calibrated model parameters showed a high level of consistency in flow behavior in terms of flow velocity and aerated flow depth when compared with the physical test data. The calibrated model parameters are listed in Table 1.

Table 1. CFD model parameters

Parameter	Value
Gravity	-9.81 m/s ²
Turbulence Model	Reynolds-averaged Navier-Stokes (RANS) k- ω turbulence model
Maximum turbulent mixing length	Step roughness height
Air entrainment rate	0.2
Escape rate coefficient	10
Minimum volume fraction of liquid	0.1
Density evaluation	As a function of other quantities (i.e. entrained air volume fraction)
Surface roughness	0.0015

3.3 Overtopping of stepped channel

To examine the overflow behaviour of stepped channels, a CFD model was set up based on the geometry of the stepped channel in Wong Tai Sin Road (Case 1). According to slope records, the slope was constructed between 1980 and 1984. The inflow conditions and stepped channel geometries used in the simulation were assumed based on GEO (2011/1984) and the discharge at the inlet did not exceed the channel design

capacity. The simulation was run until a steady state was achieved, defined by the stabilisation of the total fluid volume and mass-averaged turbulent kinetic energy.

The simulated flow pattern, shown in Figure 5, is similar to the field observation. As illustrated in the figure, a transitional to skimming flow regime developed, with step cavities partially filled. However, a uniform flow condition was not achieved at the outlet, as indicated by the fluctuations in flow depth over time. To investigate these temporal fluctuations, a time-series analysis was conducted using the CFD results.

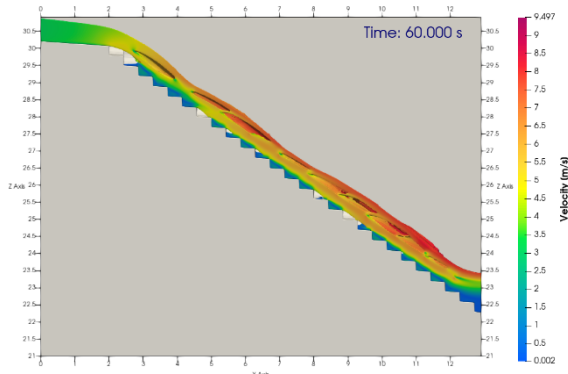


Figure 5. CFD analysis results of the final time step (900 mm-wide stepped channel with gradient of 35° according to slope records)

Flow depths at each channel step were extracted over the final 30 seconds of the simulation, during which total fluid mass and mass-averaged turbulent kinetic energy achieved an approximately stable condition. The mean water surface elevation (\bar{z}) and the standard deviation of the water surface (σ) near the channel wall were calculated. A statistical upper bound of the water surface is taken as $\bar{z} + 2\sigma$, corresponding to the 97.7th percentile for a normally distributed process. This approach aimed to derive a representative water surface while minimising overestimation due to numerical noise. The calculated flow depth is presented in Figure 6.

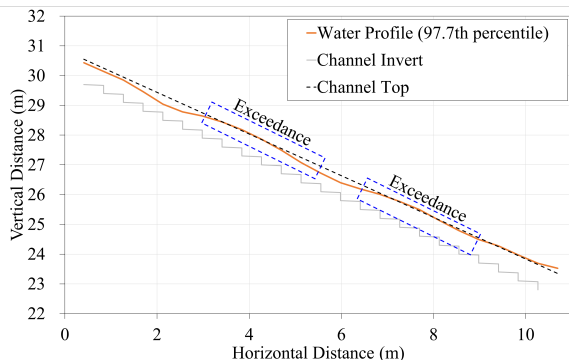


Figure 6. Water surface profile from CFD results with design discharge determined based on GEO (2011/1984)

The results indicate that as water flows down the stepped channel, instability increases, leading to overtopping near the downstream end, with a maximum exceedance of approximately 200 mm. Prolonged splashing may cause erosion at the base of the slope, potentially resulting in slope failure.

A separate CFD analysis was conducted with a revised discharge based on the updated design methodology outlined in GEO (2006). While a full skimming flow was not achieved, the flow was found to be more stable. As before, the statistical upper bound (97.7th percentile) of the water surface was plotted in Figure 7, showing no exceedance in the extracted flow profile. The results indicate that the design methodology

outlined in GEO (2006) provides sufficient channel depth to contain the flow.

Given these findings, it is recommended that slopes with stepped channels, as designed under GEO (2011/1984), be reassessed using the updated methodology in GEO (2006) to ensure the adequacy of the channel design.

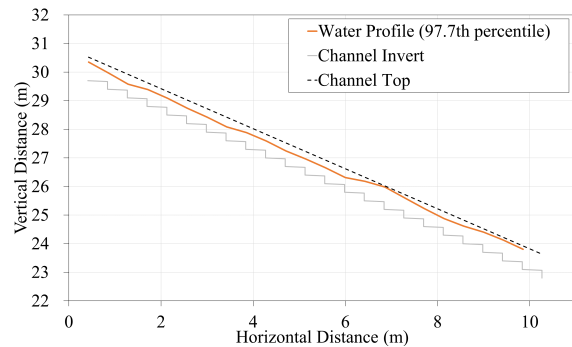


Figure 7. Water surface profile from CFD results with design discharge determined based on GEO (2006)

3.4 Flow choking at catchpits

CFD analyses were conducted to investigate the flow choking behaviour at catchpits, using the same modelling parameters in Table 1. The drainage layout of the slope at Tai Po Road (Case 2) was modelled for numerical simulation. According to slope records, this slope was formed in the 1990s. The inflow condition and geometries were assumed based on GEO (2011/1984). The model was run until a steady state was achieved, and the results are presented in Figure 8.

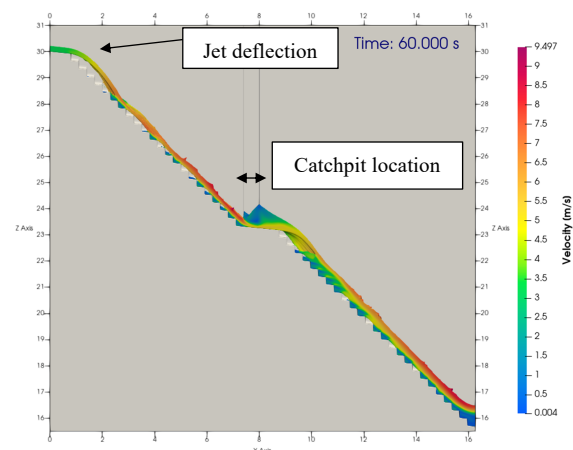


Figure 8. CFD analysis results of the final time step (two slope batters of 300 mm-wide stepped channel with slope angle of 45° according to slope records)

The flow pattern was generally consistent with field observation. A similar flow regime along the stepped channel, as observed in Wong Tai Sin Road (Case 1), was observed. Fluctuations in flow depth indicated that uniform flow was not achieved. To analyse these temporal fluctuations, a time-series analysis was conducted, as described in Section 3.3. The statistical upper bound of the flow depth is shown in Figure 9.

While over-spillage was noted at the upslope stepped channel, increased flow depth occurred within the catchpit due to significant turbulence and splashing. The limited opening of the catchpit was likely responsible for choking the upslope flow at the catchpit. This choking led to runoff from the upslope stepped channel overflowing from the catchpit, which exacerbated surface erosion down the slope.

Unstable flow was also observed at the upslope stepped channel, and the catchpit amplified the flow instability,

resulting in increased flow depth and overflow at the downslope stepped channel.

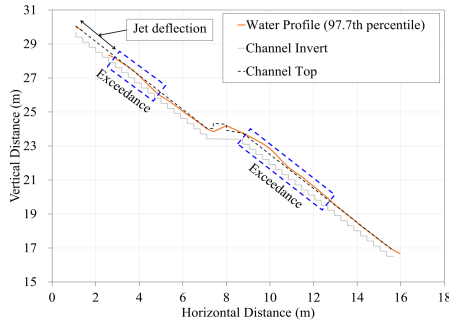


Figure 9. Water surface profile from CFD results

In general, flow choking cannot be avoided for stepped channels connected to catchpits, particularly if the inflow is unstable. This is primarily due to fluid expansion and contraction losses within the catchpit. To address this issue, the height of catchpits can be increased to accommodate the choking of water flow. Additionally, freeboard can be provided along the slope berm and stepped channel as a precautionary measure to contain the overflow from the catchpit. The GEO is currently conducting studies to determine the appropriate height of catchpits and freeboard arrangement to manage flow effectively and mitigate risks associated with overflow.

3.5 Uncontrolled overflow at topographic low point and blockage of roadside drains

Conventional analytical approaches offer a general understanding of flow behaviour in drainage channels. However, accounting for the influence of adverse site conditions, which may exacerbate concentrated surface runoff, remains a complex challenge. Therefore, implementing precautionary containment measures is crucial to effectively managing surface runoff, particularly during the period of intense rainfall. In two of the landslide cases (Cases 2 and 3), the incorporation of upstand walls at slope crest could effectively reduce uncontrolled runoff overflow onto the slope, mitigating the risk of landslide by minimising surface water infiltration.

In the case of the failure at Shek O Road (Case 3), as illustrated in Figure 4, roadside upstand wall was present at adjacent slope feature, while the failed fill slope lacked such wall. The intercepted surface runoff contained by the upstand wall likely diverted to the failed fill slope, which was in the downhill side, resulting in concentrated runoff. This emphasises the importance of holistic planning in flow containment design. Special attention should be given to how containment measures may impact adjacent slope features, ensuring intercepted water is diverted to the drainage system of the slope or diverted to appropriate discharge point.

The failure at Tai Po Road (Case 2) highlights the uncertainty of surface runoff flow paths, which can travel significant distances. Implementing precautionary flow containment measures is a practical approach to divert surface runoff in the unforeseen condition.

Drainage channels are also susceptible to blockages, underscoring the need for routine maintenance. Preventive measures, such as trash grilles or debris screens at drainage inlets, can help prevent blockages and reduce maintenance effort.

4 UPDATED IDF CURVES

The design rainfall intensity is an essential parameter for the estimation of peak discharge required of the slope surface

drainage systems. To reliably estimate the rainfall intensity under a rainfall event with the designed return period, the IDF curves are typically used.

4.1 Introduction of the use of IDF curves for slope drainage design

The IDF curves were derived from a long-established raingauge located at the Hong Kong Observatory, which has been in operation since 1884 and is considered representative of the territory as a whole. However, recognising significant spatial rainfall variability, Tang & Cheung (2011) conducted a frequency analysis of annual maximum rainfall using rainfall records of 43 raingauges from 1984 to 2009 and established raingauge-specific IDF curves. Given that a considerable number of raingauges reached their record highs for various rolling rainfalls during severe rainstorms in September 2023, an update to the frequency analysis was conducted to account the extreme rainfall values of the 2023 rainstorms. Chan & Chu (2024) presented the updated frequency analysis using rainfall records of 85 raingauges from 1984 to 2023, deriving revised raingauge-specific IDF curves. The IDF curves were derived based on rainfall data from more rain gauges over a more extended period, which helps reduce uncertainties in the return period analysis and provides better spatial coverage of extreme rainfall intensity estimates across Hong Kong.

4.2 Updated frequency analysis and IDF curves for slope drainage design

Upon compiling, cleansing and pre-processing the rainfall data, the updated frequency analysis of annual maximum rainfall was carried out using both the Gumbel distribution and the Generalised Extreme Value (GEV) distribution in order to estimate the extreme rainfall intensities under different combinations of return periods and durations for 85 raingauges. The Gumbel distribution was found to be more appropriate for modelling the frequency of extreme rainfall based on data up to 40 years long; however, it was insufficient to apply the GEV distribution to achieve a good fit for extreme rainfall intensities. The raingauge-specific IDF curves were then fitted using Wisner's formula based on the extreme rainfall intensities derived from the Gumbel distribution.

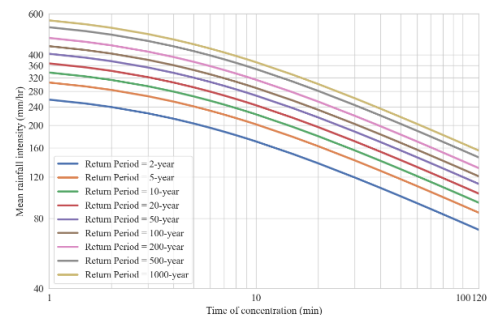


Figure 10. Territory-wide IDF curves for slope drainage design

Figure 10 shows an updated set of territory-wide IDF curves for slope drainage design, derived from the upper bound IDF curves that envelope the IDF curves of all raingauges, except one located at the highest peak, Tai Mo Shan, in Hong Kong. The IDF curves of that raingauge were much higher than the others, possibly due to the orographic effect. It is considered that adopting the upper bound IDF curves for slope drainage design would be a pragmatic approach to prevent drainage-related slope failure incidents. In general, the updated territory-wide IDF curves showed a slight upward shift compared to the territory-wide IDF curves in Tang & Cheung (2011). For a return period of 200 years, the increases in rainfall

intensities for various times of concentration could be as high as about 6%.

4.3 Climate change provisions for slope drainage design

To enhance resilience against climate change impacts on slope drainage design in Hong Kong, it is recommended to increase design rainfall intensities by 28.1% from the values obtained from the IDF curves. The increase consists of a 16.0% rainfall increase projected up to the end of the 21st century under the intermediate greenhouse gas emissions scenario, plus a 12.1% design allowance, as referenced in the Sixth Assessment Report by the Intergovernmental Panel on Climate Change (Seneviratne et al., 2021). The design allowance accounts for uncertainties in the range of possible future climate change development and global actions among nations on reducing carbon emissions, specifically the difference between the very high and intermediate greenhouse gas emissions scenarios. Such increase in design rainfall intensities can typically be accommodated by inherent redundancy or a nominal “one-size” increase in channel capacity, which is in addition to the redundancy provided for other purposes.

5 DISCUSSION

5.1 Insights and challenges in slope drainage design

The selected landslide cases highlighted areas for improvement in current slope drainage design. Through the CFD analyses, the flow behaviours in stepped channels and at catchpits observed on site were successfully simulated, offering valuable insights into the hydraulic performance of these critical drainage components that are commonly found in Hong Kong. The analysis demonstrated that stepped channel designed according to GEO (2006) provide sufficient channel depth to contain flows effectively. On the other hand, to address the flow choking at catchpits, catchpits with sufficient height and appropriate freeboard arrangement are required to manage slope surface flow effectively. Moreover, adverse site conditions, such as uncontrolled surface runoff at topographic low points, remain challenging to address. These areas are particularly vulnerable during intense rainfall. Implementing precautionary flow containment measures at the slope crest with proper discharge point is crucial to divert water efficiently and mitigate the risk of unforeseen surface runoff.

5.2 Limitations on CFD modelling

While CFD analyses successfully replicated the flow behaviours observed on site, it is also important to recognise the limitations of numerical simulation. Accurate simulation relies on the validation of modelling parameters against reliable physical test data. Selecting suitable physical test data is also critical to ensure alignment with the objectives of the CFD analysis. Without proper validation, the accuracy of the simulation results may be compromised, limiting their applicability.

5.3 Significance of climate change and extreme weather in slope surface drainage

The record-breaking rainfall event in September 2023 underscored the significant impact of climate change and extreme weather on slope drainage systems. Intense rainfall events are projected to become more frequent and severe, putting increased pressure on existing slope drainage systems. To address these challenges, updating the IDF curves to account for evolving rainfall patterns is essential. This update ensures that slope drainage systems are designed to withstand the

projected increase in rainfall intensity, enhancing their resilience to future extreme weather events.

6 CONCLUSION

The record-breaking rainfall event in September 2023 resulted in 238 reported landslides, with 45 incidents linked to uncontrolled surface runoff. Three notable landslide cases were selected to illustrate the areas for improvement in the current design practice of slope surface drainage systems. Using CFD modelling, the hydraulic performance of key drainage components, including stepped channels and catchpits, were evaluated. The analyses provide valuable insights into potential enhancement measures to mitigate overflow issues. While the design methodology for slope surface drainage is well-established and well-proven, challenges persist, including uncertainties related to surface flow paths and potential channel blockages. In response to the unprecedented rainfall intensities, a comprehensive review of the IDF curves was conducted using the latest rainfall data. The updated curve incorporates the impacts of climate change, projecting a 28.1% increase in rainfall intensity.

The measures proposed in this study, along with the updated IDF curves, aim to enhance the resilience of urban slope drainage design in Hong Kong through addressing overflow risks, thereby improving slope stability under future extreme weather conditions.

7 ACKNOWLEDGEMENTS

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