Geotechnical Engineering Office, Civil Engineering and Development Department
The Government of the Hong Kong Special Administrative Region

GEO Technical Guidance Note No. 49 (TGN 49)
Supplementary Guidelines on Precautionary Measures for Mitigating the Risks of Excessive Ground Loss and Sinkhole Formation Associated with Deep Excavations

1. SCOPE

1.1 This Technical Guidance Note (TGN) provides supplementary technical guidelines on the precautionary measures for mitigating the risks of excessive ground loss and formation of sinkholes associated with deep excavations, especially where difficult site conditions are encountered.

1.2 For the purpose of this TGN, deep excavations refer to excavations deeper than 4.5 m, including the installation of piles and bulk excavation works.

1.3 Any feedback on this TGN should be directed to Chief Geotechnical Engineer/Mainland East of the Geotechnical Engineering Office (GEO).

2. TECHNICAL POLICY

2.1 The technical recommendations promulgated in this TGN were agreed by the Geotechnical Control Conference (GCC) of GEO on 6 November 2023.

3. RELATED DOCUMENTS

3.1 BD (2009a). *Code of Practice for Site Supervision 2009*. Buildings Department, Hong Kong, 120 p.

3.2 BD (2009b). *Technical Memorandum for Supervision Plans 2009*. Buildings Department, Hong Kong, 34 p.

3.3 BD (2012). *Requirements for an Excavation and Lateral Support Plan, Building (Administration) Regulation 8(l)(bc) (PNAP APP-57).* Buildings Department, Hong Kong, 7 p.

3.4 GEO (2002). *QRA of Collapses and Excessive Displacements of Deep Excavations (GEO Report No. 124)*. Geotechnical Engineering Office, Hong Kong, 109 p.

3.5 GEO (2023). *Deep Excavation Design and Construction (GEO Publication No. 1/2023)*. Geotechnical Engineering Office, Civil Engineering and Development Department, HKSAR Government, 144 p.

3.6 HKSARG (2022). *Project Administration Handbook for Civil Engineering Works – Chapter 7 (2022 Edition).* The Government of the Hong Kong Special Administrative Region, 434 p.

3.7 Lee, M.Y.K. (2019). *A Further Review of Collapses and Excessive Deformation of Deep Excavations. (Discussion Note No. DN 1/2019).* Geotechnical Engineering Office, Hong Kong, 38 p.

3.8 Man, K.F. & Yip, P.L. (1992). *Review of Collapses and Excessive Deformation of Excavations (Administrative Report No. AR 2/92).* Geotechnical Engineering Office, Hong Kong, 31 p.

4. BACKGROUND

4.1 Incidents of excessive ground loss and sinkhole formation associated with deep excavations are not uncommon in Hong Kong. Some of the incidents have caused injuries to members of the public and damage to properties/facilities such as pavements and roads. However, as no detailed investigation was conducted for most of these incidents at the time of their occurrence, the actual causes of the incidents are difficult to establish now.

4.2 A review was carried out by GEO on incidents occurred between 2007 and 2019 with relevant records available. Lee (2019) documented the finding of the review. The objective of the review was to look for any common attributes in terms of site conditions and construction methods which may contribute to excessive ground loss or formation of sinkholes. Some of the key contributory factors identified are summarised below:

- Difficult site conditions particularly vulnerable to ground loss
- Disturbance to adjacent soil during piling operations
- Ingress of soil through gaps between non-interlocking piles
- Excessive groundwater ingress and improperly constructed or damaged grout curtains
- Inadequate site supervision and lack of contingency plan.

4.3 The issues associated with the above factors are discussed in Section 5, and supplementary guidelines recommended based on the outcome of the review are given in Section 6 below. The recommended guidelines are further enhanced based on the lessons learnt from the fatal incident at a Kai Tak construction site and the incidents occurred since 2020.

5. KEY CONTRIBUTORY FACTORS TO EXCESSIVE GROUND LOSS OR SINKHOLE FORMATION

5.1 Difficult Site Conditions Particularly Vulnerable to Ground Loss

5.1.1 Difficult site conditions are often encountered at sites with a relatively thick layer of loose soil and a high groundwater table, and sometimes coupled with the presence of underground obstructions.

5.1.2 It was observed that difficult site conditions were identified in almost all the cases under the review. These sites are often located in urban areas with congested utilities and services under the adjacent ground, and the need for frequent repairs could result in a layer of loose fill. The presence of loose fill or boulders makes the ground susceptible to excessive ground loss during the piling operations and bulk excavation, especially when coupled with factors such as bursting or significant leakage of buried water-carrying services, and/or the presence of pre-existing underground cavities.

5.1.3 Difficult site conditions are also encountered on reclaimed land. Sites that are close to the sea are subject to high groundwater level that is strongly influenced by tidal actions. A thick layer of loose fill is also anticipated as the land is often formed by the hydraulic filling method.

5.2 Disturbance to Adjacent Soil during Piling Operations

5.2.1 Compressed air is commonly used in piling operations for flushing and extracting cuttings from drillholes/boreholes. High air flushing pressure could cause excessive disturbance to the adjacent ground and loss of soil around/beneath the drill bit, resulting in a well-known "overbreak" phenomenon (see Annex TGN 49 A1). When boulders or a mixed soil/rock stratum are encountered, a higher air pressure and a longer time are often needed to advance the drill bit. This process may significantly increase the risk of ground loss.

5.2.2 During a bored piling operation, excavation ahead of the toe of temporary casing may cause excessive ingress of groundwater and soil into the drillhole/borehole. Similar problem may also arise where a steep rockhead is encountered during reverse circulation drilling (RCD) to form a rock socket.

5.2.3 In addition, it is observed that drillholes formed by eccentric drilling method are considerably larger than the casing, causing excessive disturbance to adjacent soil when cuttings are extracted, and resulting in overbreak.

5.3 Ingress of Soil through Gaps between Non-interlocking Piles

5.3.1 There have been reported cases of sudden excessive ingress of the retained soil through the gaps of non-interlocking piles under difficult site conditions.

5.3.2 The maximum spacing between non-interlocking piles depends on the arching effect that could be mobilised within the retained soil. However, little arching effect can be mobilised in loose fill.

5.3.3 Improper construction of lagging walls between non-interlocking piles may lead to ingress of groundwater and the retained soil into the excavation.

5.4 Excessive Groundwater Ingress and Improperly Constructed or Damaged Grout Curtains

5.4.1 Even where the excavation design has been checked against piping and the pumping test results are found acceptable, there could still be the possibility of excessive groundwater ingress during bulk excavation due to defects in the water cut-off measures such as grout curtains. This may then cause significant ground loss when the retained soil particles are continuously carried away by groundwater flowing into the excavation.

5.4.2 Defects are often found in the constructed grout curtains as it is difficult to control the quality of grouting works on site, particularly when the ground is highly heterogeneous.

5.4.3 Grout curtains could also be easily damaged by subsequent construction activities, such as installation of lagging walls and the adjacent pile foundation works. For deep excavations, movement of the embedded retaining wall during bulk excavation or preloading of struts may also cause damage to the grout curtains. Furthermore, high groundwater pressure on the retained side may affect the stability of grout curtains.

5.5 Inadequate Site Supervision and Lack of Contingency Plan

5.5.1 Excessive ground loss may take place for some time before sinkhole formation. It is not uncommon to see these incidents occurred during the bulk excavation stage, as soil arching effect may temporarily avoid the collapse of any cavities formed in the ground. Proper site supervision and monitoring of construction activities are important for identifying problems at early stage and taking prompt actions. There had been cases whereby some monitoring stations, e.g. piezometers, were not properly installed/monitored or were damaged without replacement, and the problems were not identified until incidents of severe consequences occurred. Also, drilling operator and supervisory staff did not properly control the critical aspects of concentric drilling, including the air pressure applied, the advancement rate achieved, and soil cutting removed. The lack of a contingency plan and inadequate planning may also lead to slow emergency response in undertaking the necessary mitigation measures.

6. TECHNICAL RECOMMENDATIONS

6.1 Desk Study and Ground Investigation to Identify Difficult Site Conditions Particularly Vulnerable to Ground Loss

6.1.1 When planning deep excavation works, the designer should carry out detailed desk study and ground investigation to identify any difficult site conditions that are prone to excessive ground loss or sinkhole formation.

6.1.2 The nature and condition of the adjacent structures, buildings and facilities, which may be affected by the construction works, should be assessed in relation to their vulnerability to ground loss.

6.1.3 Where the excavation is liable to affect any water mains or buried drains, the relevant government departments, e.g. WSD, DSD and HyD, should be approached for information about their utilities and services. Pertinent information includes the allowable maximum movements, records of any pipe burst or leakage incident within the affected area, causes of the incidents and remedial actions taken by the responsible departments.

6.1.4 Ground investigation should be carried out to ascertain the condition of the ground and underground utilities, with particular attention paid to any recent incidents of bursting/ significant leakage of buried water-carrying services and the possible presence of pre-existing underground cavities.

6.1.5 Ground penetration radar (GPR) and GCO probe may be used to help detect the presence of pre-existing cavities, whereas CCTV survey may be conducted to ascertain the condition of underground drains. These investigations are usually carried out as part of the precondition survey of the site prior to the commencement of site works. The GPR and CCTV inspection should also be repeated when the installation of the embedded wall is completed and at regular intervals (e.g. once every three months) during bulk excavation with active dewatering. Where the results indicate anomaly, GCO probing test or SPT should be conducted to identify the presence of any cavities at depths**.**

6.2 Possible Measures To Mitigate Disturbance To Adjacent Soil During Piling Operations

6.2.1 Where the piling operation involves the use of air pressure to remove the cutting (e.g. concentric drilling system), it is important to properly control the applied air pressure and the advancement rate of the pile, in order to minimise the disturbance to the adjacent ground. The air pressure gauge should be housed inside the operator's cabin of the piling rig, such that the operator can monitor and vary the applied pressure when needed. Video recording of the air pressure gauge, the advancement of the pile and soil removed should be made whenever drilling is in progress. These video records should be properly kept, preferably on Internet cloud storage, and should be provided for inspection when required**.**

6.2.2 Test boring is necessary to establish these site-specific parameters for different types of soils and rocks encountered. During the test, drilling should commence with a lower air pressure that can start the pile hammer and gradually increase to obtain the minimum air pressure that can advance the pile. These site-specific minimum air pressure and advancement rate should be used in the subsequent installation of working piles. The operator and site supervisory staff should be informed of these site-specific parameters. Besides the ground settlement monitoring stations installed at the surface surrounding the test boring location, GCO probing test or SPT should be conducted before and after the

test boring for comparing the compactness of the soils, so as to identify any ground disturbance at depths.

6.2.3 Water could be used to replace air as the flushing medium, but due consideration should be given to its effect on the groundwater regime and that on adjacent structures/facilities. If deemed appropriate, a suitable excess water head should be maintained within the boreholes throughout the piling operations through the soil stratum.

6.2.4 Ground treatment should be considered for coping with difficult site conditions. For instance, pre-grouting may be carried out for mixed ground of soil/rock. Grouting at the toe of temporary casing down to the rockhead should be considered where a steep rockhead is encountered. No excavation should be allowed ahead of the toe of temporary casing during bored piling operations in soil stratum.

6.2.5 Concentric drilling should be used instead of eccentric drilling to reduce the risk of excessive overbreak.

6.2.6 Prior to deep excavation works, installation of cut-off barriers, such as sheet-piles or grout curtains, should be considered as an effective means to minimise groundwater drawdown and ingress of loose soil from outside the excavation site.

6.3 Possible Measures to Reduce Ingress of Soil through Gaps of Non-interlocking Piles

6.3.1 Where difficult site conditions are encountered, the spacing of non-interlocking piles should be small enough to reduce possible ingress of soil between the piles.

6.3.2 Grout curtains should be installed to reduce the permeability of soil between non-interlocking piles and minimise the water seepage into the excavation. It is preferable to install two staggered rows of grout pipes for forming the grout curtain.

6.3.3 Interlocking piling system, e.g. sheet-piles or interlocking pipe piles, should be considered in difficult ground conditions, as they provide a more robust water cut-off barrier than non-interlocking piles. Interlocking pipe pile wall system has the advantage of readily overcoming underground obstructions and minimising disturbance to the ground as compared to sheet-piling with pre-boring.

6.4 Possible Measures to Reduce Groundwater Ingress and Improve Effectiveness of Grout Curtains

6.4.1 To reduce groundwater ingress, it is important to improve the quality and effectiveness of grout curtains. Grout pipes of suitable quality should be used and properly maintained after the grouting works, such that they could still be used for subsequent re-grouting if needed. A grout curtain with closer spaced grout holes and a deeper penetration will also enhance its effectiveness.

6.4.2 To avoid possible damage to grout curtains, disruptive works in the adjacent areas should be minimised as far as practicable. Construction activities such as installation of lagging walls should be carried out with due care to avoid damage to and excessive trimming of the grout curtains around non-interlocking piles.

6.4.3 Other measures for reducing groundwater ingress include the use of interlocking pile wall systems and increasing the penetration depth into a relatively impermeable stratum.

6.4.4 During excavation, the rate of groundwater inflow/drawdown should be closely monitored particularly for sites located close to the sea which acts as a major source of water recharge. Anomalies such as the sudden increase of groundwater inflow/drawdown, ingress of a large amount of soil and the excessive removal of grouted soil by adjacent construction activities may be evidence of defective or damaged groundwater cut-off measures. Re-grouting should be carried out prior to or during bulk excavation works if any of such evidence is observed.

6.5 Close Site Supervision and Contingency Plan

6.5.1 Strict compliance with the site supervision requirements is a key factor to mitigate the risks of excessive ground loss and sinkhole formation. The relevant site supervision requirements and duties of the site supervisory personnel for private and public works are set out in BD (2009a), BD (2009b), and HKSARG (2022), as well as the conditions imposed in the approval/acceptance letter of BD/GEO.

6.5.2 Site supervisory personnel should pay particular attention to any signs of possible ground loss and formation of sinkholes, including any abnormal groundwater ingress/drawdown, significant amount of soil particles observed from seepage or sump pump, or abnormal amount of cuttings extracted from drillholes/boreholes, excessive movement of adjacent structures or facilities, etc. It is also important for the site supervisory personnel to check and upkeep the adequacy and functionality of all the monitoring instruments. The measurement of the monitoring stations (including ground, building and services) should be conducted and certified periodically (i.e. every month) by professionally qualified land surveyors to enhance the reliability and accuracy of the monitoring.

6.5.3 A contingency plan should be carefully devised with adequate provisions for prompt actions to deal with any signs of ground loss observed. The contingency provisions should include emergency measures that can be quickly mobilised, and the plant and equipment necessary for carrying out the emergency works should be maintained in a good and ready condition, e.g. grout pipes should be kept unblocked for re-grouting.

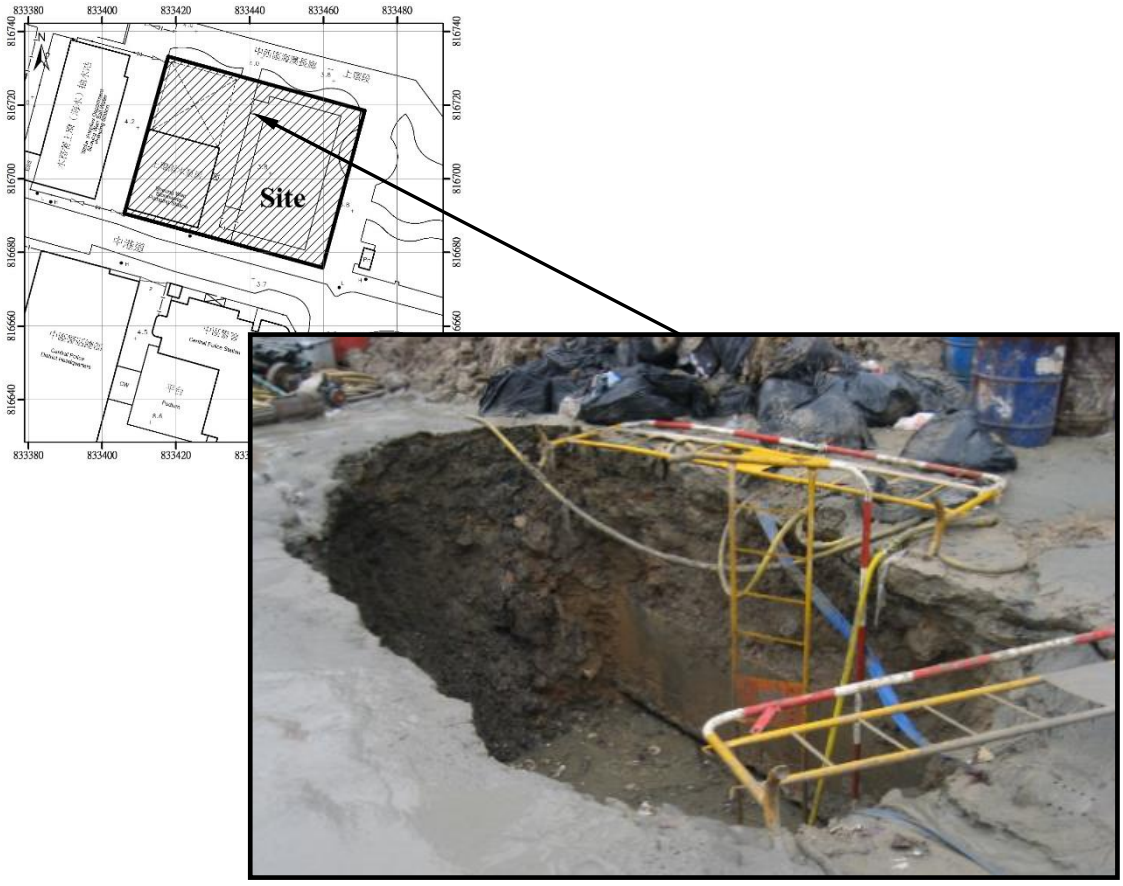
7. ANNEXES

7.1 TGN 49 A1 - Summary of Sinkhole Incidents that Occurred between 2007 and 2023

(Raymond W M Cheung)
Head, Geotechnical Engineering Office

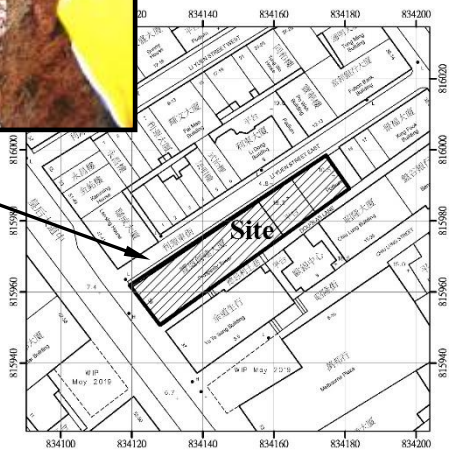
Annex TGN 49 A1 – Summary of Sinkhole Incidents that Occurred between 2007 and 2023

Case No. 1: Sheung Wan Stormwater Pumping Station



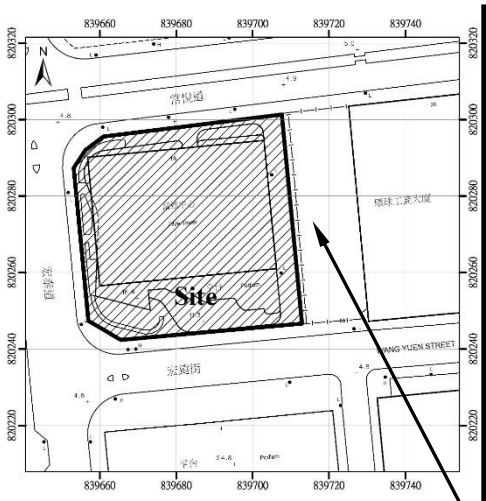
Date of incident	*2007*	***Ground Conditions***	
Size of sinkhole	*3m x 2m x 2m deep*	**Top soil layers**	*14-35m FILL, 0-14m MD*
Consequences	*Site area affected*		
Major preceding construction activities	*Pre-boring of H-pile foundation in progress*	**Depth of rockhead**	*60m*
Drilling method/ flushing medium	*Concentric drilling/ air*	**Depth of groundwater table**	*1.5 to 3.5m*

Case No. 2: Li Yuen Street East



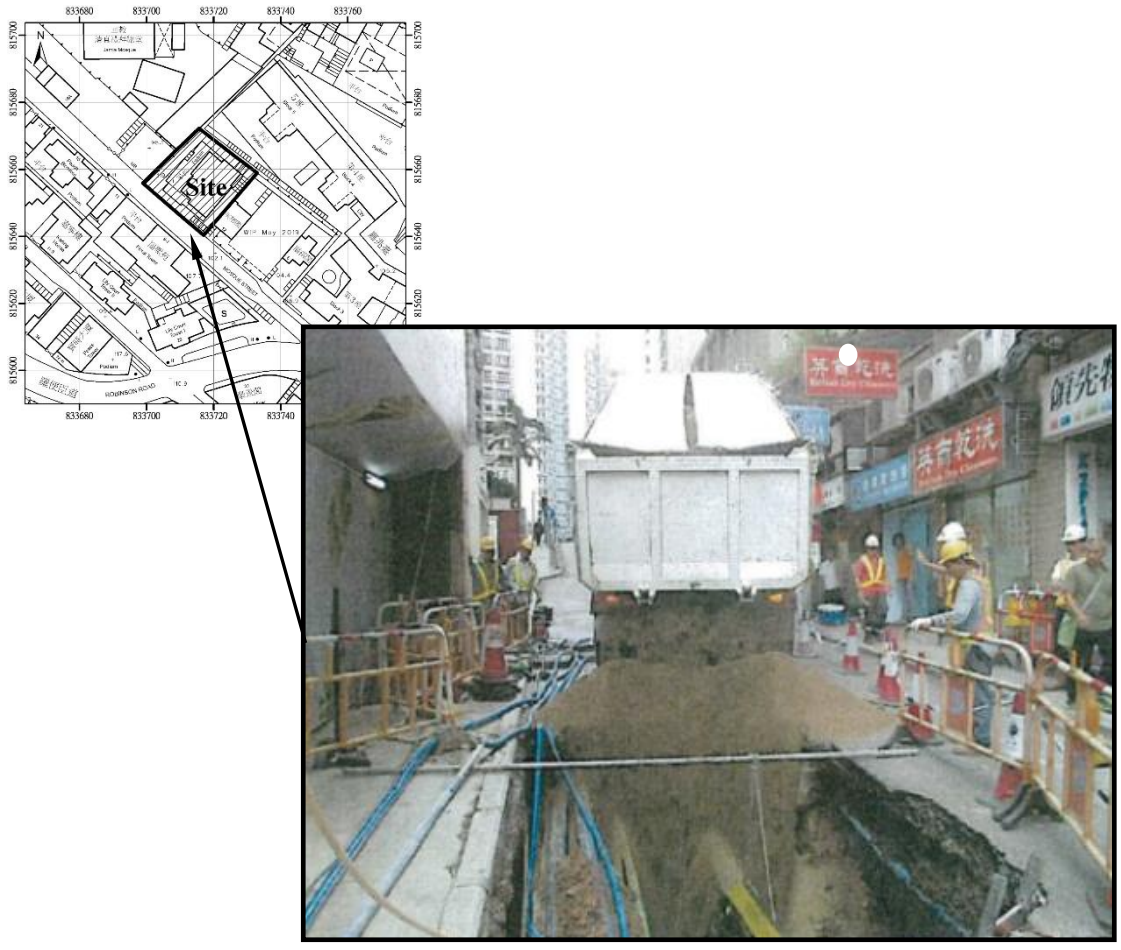
Date of incident	*24 April 2007*	***Ground Conditions***	
Size of sinkhole	*8 m x 3.5 m x 3.5 m deep*	**Top soil layer**	*9m ALL*
Consequences	*Several hawker stalls and 4 hawkers fell into the sinkhole. The hawkers suffered injuries and property loss.*		
Major preceding construction activities	*Pre-boring of H-pile foundation in progress*	**Depth of rockhead**	*40m*
Drilling method/ flushing medium	*ODEX drilling/ air*	**Depth of groundwater table**	*1 to 4m*

Case No. 3: Sheung Yuet Road



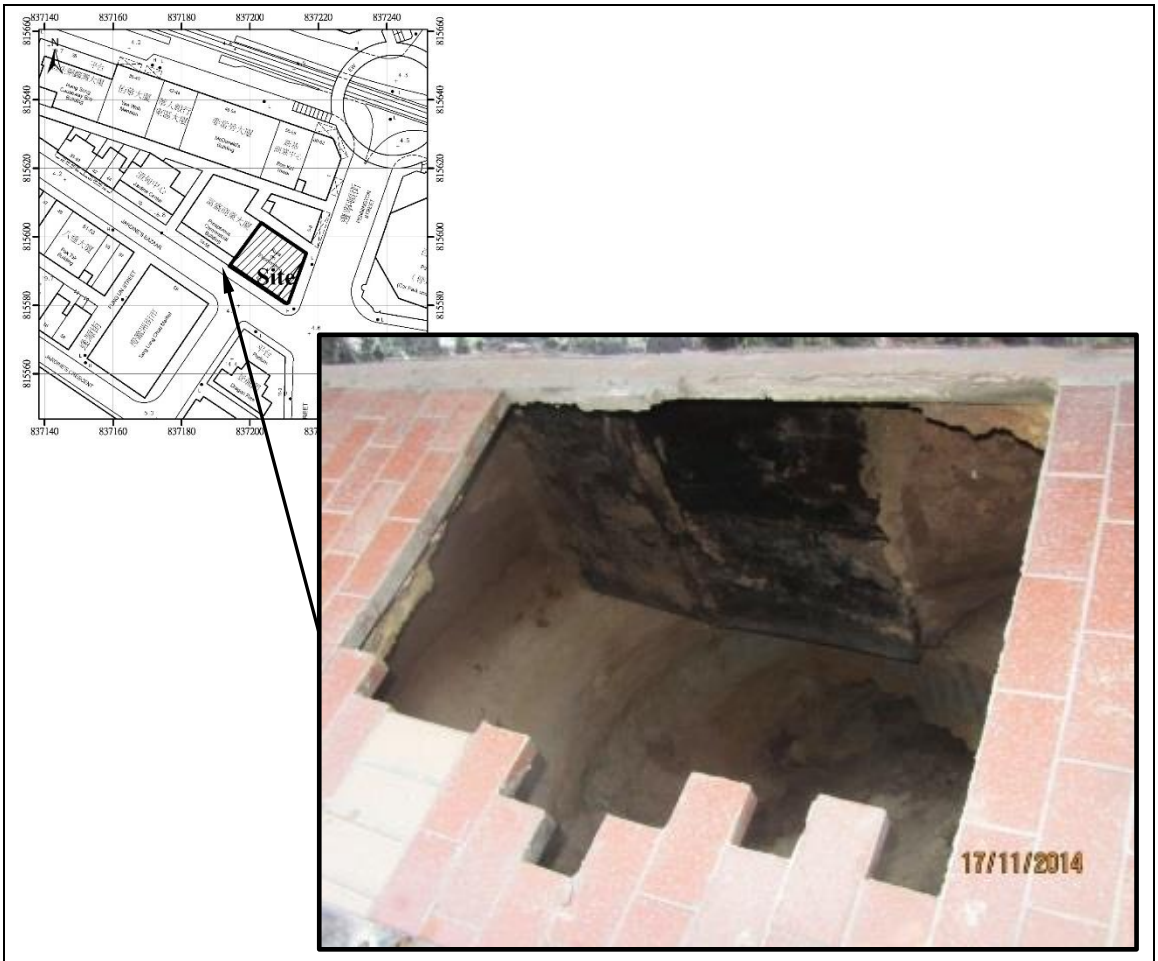
Date of incident	*24 January 2014*	***Ground Conditions***	
Size of sinkhole	*1m x 0.8m x 1m deep*	**Top soil layers**	*15m FILL, 20m ALL*
Consequences	*Adjacent carpark area affected*		
Major preceding construction activities	*Sheet-piling works with pre-drilling in progress*	**Depth of rockhead**	*60m*
Drilling method/ flushing medium	*Concentric drilling/ air*	**Depth of groundwater table**	*Near ground surface*

Case No. 4: 14-18 Mosque Street



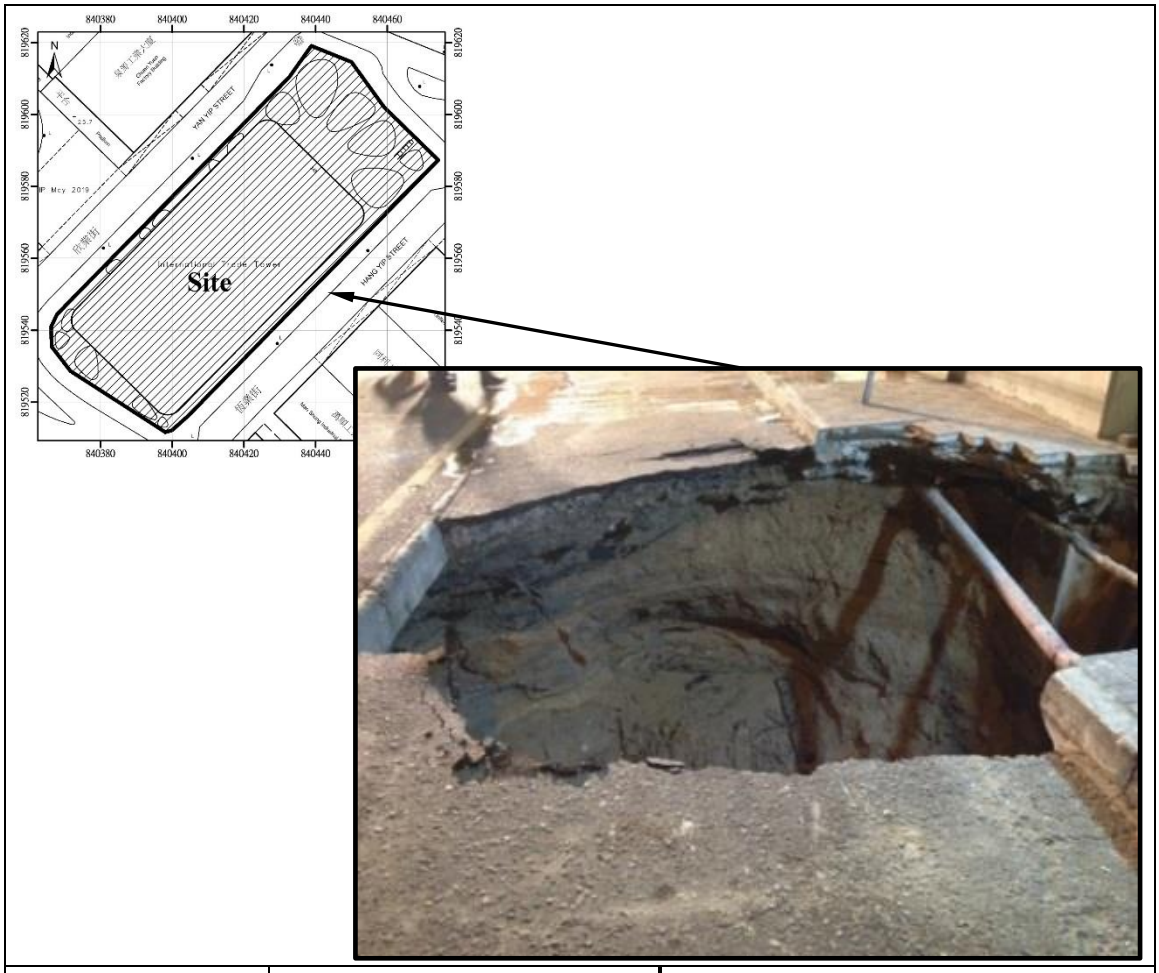
Date of incident	*27 October 2014*	***Ground Conditions***	
Size of sinkhole	*2m x 2m x 2.5m deep*	**Top soil layer**	*16m COLL*
Consequences	*Mosque Street partly closed temporarily*		
Major preceding construction activities	*Drilling works for pipe piles completed recently and that for grout curtain in progress*	**Depth of rockhead**	*60m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*20m*

Case No. 5: 60-66 Jardine's Bazaar



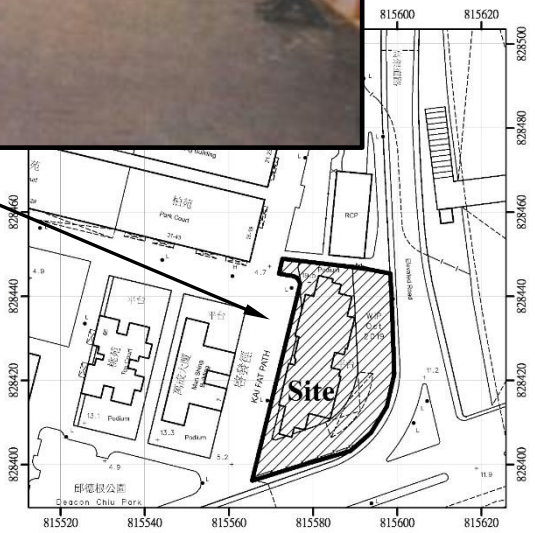
Date of incident	*17 November 2014*	***Ground Conditions***	
Size of sinkhole	*3.5m x 2.5m x 3.7m deep*	**Top soil layers**	*25m FILL/ALL*
Consequences	*A passer-by fell into the sinkhole and suffered injuries*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*40m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*1 to 2.5m*

Case No. 6: Hang Yip Street, Ngau Tau Kok



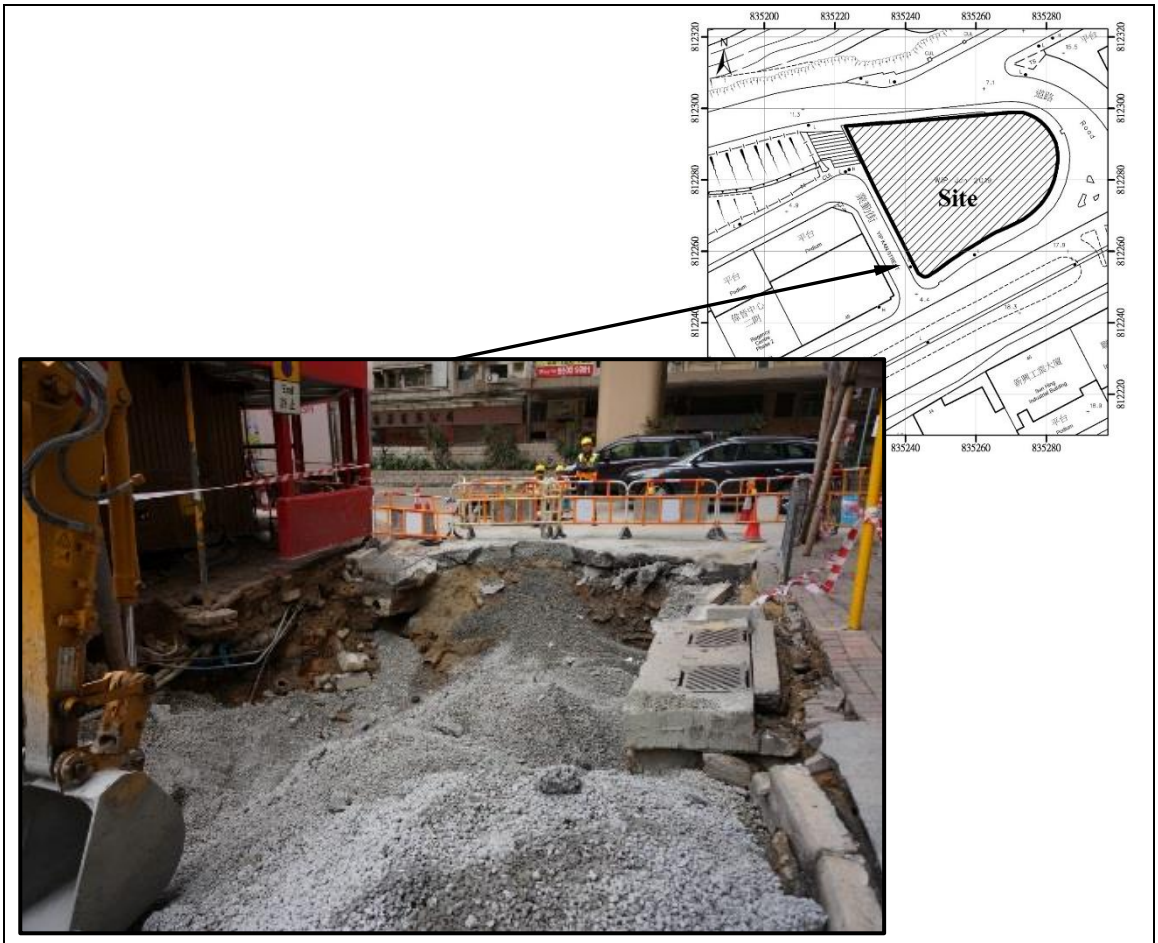
Date of incident	*9 September 2015*	***Ground Conditions***	
Size of sinkhole	*5m x 5m x 4m deep*	**Top soil layers**	*14m FILL/MD*
Consequences	*A large truck and the driver of a pick-up truck fell into the sinkhole*		
Major preceding construction activities	*Bored pile foundation works in progress*	**Depth of rockhead**	*100m*
Drilling method/ flushing medium	*Reverse circulation drilling/ water*	**Depth of groundwater table**	*2 to 3m*

Case No. 7: Yan Ching Street, Tuen Mun



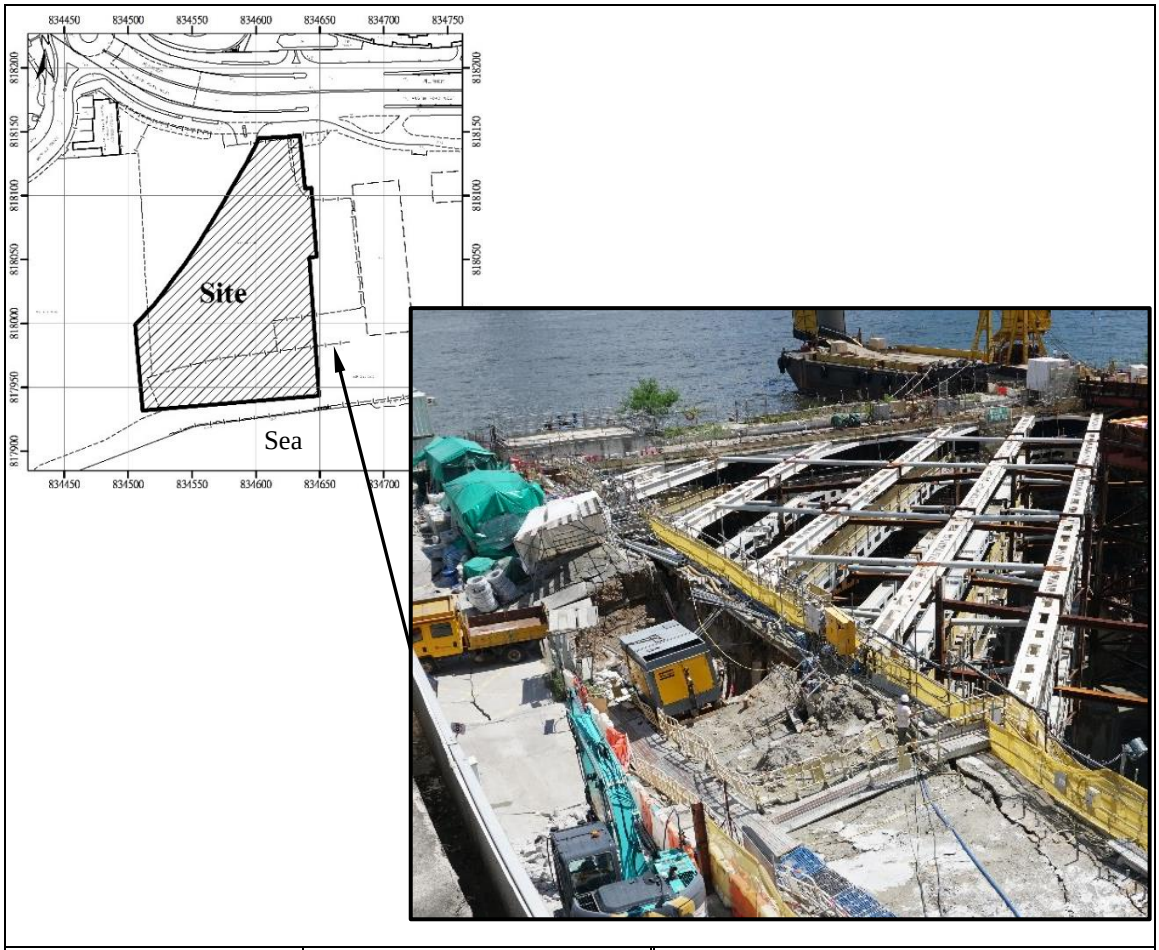
Date of incident	*22 March 2016*	***Ground Conditions***	
Size of sinkhole	*10m x 5m x 1m deep*	**Top soil layers**	*12m FILL/MD/ALL*
Consequences	*Adjacent footpath temporarily closed*		
Major preceding construction activities	*Bored pile foundation works in progress*	**Depth of rockhead**	*50 to 80m*
Drilling method/ flushing medium	*Reverse circulation drilling/ water*	**Depth of groundwater table**	*Near ground surface*

Case No. 8: Yip Kan Street, Aberdeen



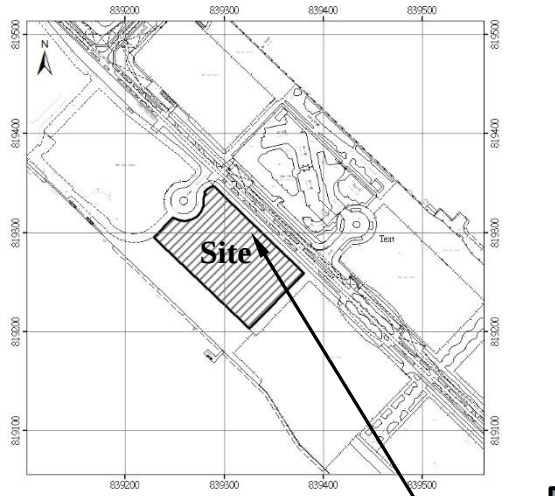
Date of incident	*23 February 2019*	***Ground Conditions***	
Size of sinkhole	*4m x 4m x 6m deep*	**Top soil layers**	*9m FILL/MD*
Consequences	*Yip Kan Street entirely closed temporarily*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*20m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*2 to 3m*

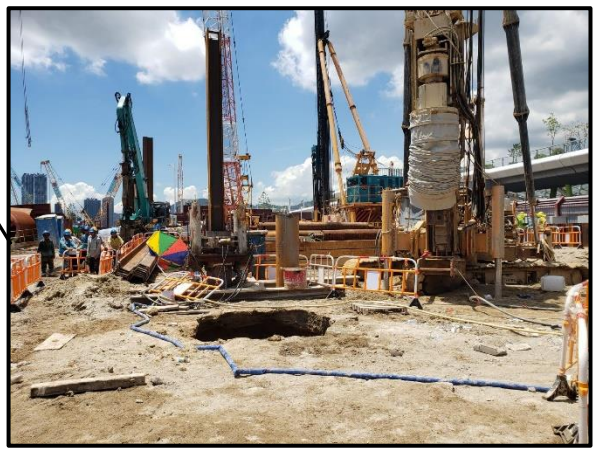
Case No. 9: Lyric Theatre, West Kowloon Cultural District



Date of incident	*25 July 2019*	***Ground Conditions***	
Size of sinkhole	*10m x 5m x 2m deep*	**Top soil layers**	*27m FILL*
Consequences	*Adjacent site area/site office affected*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*45m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*2m*

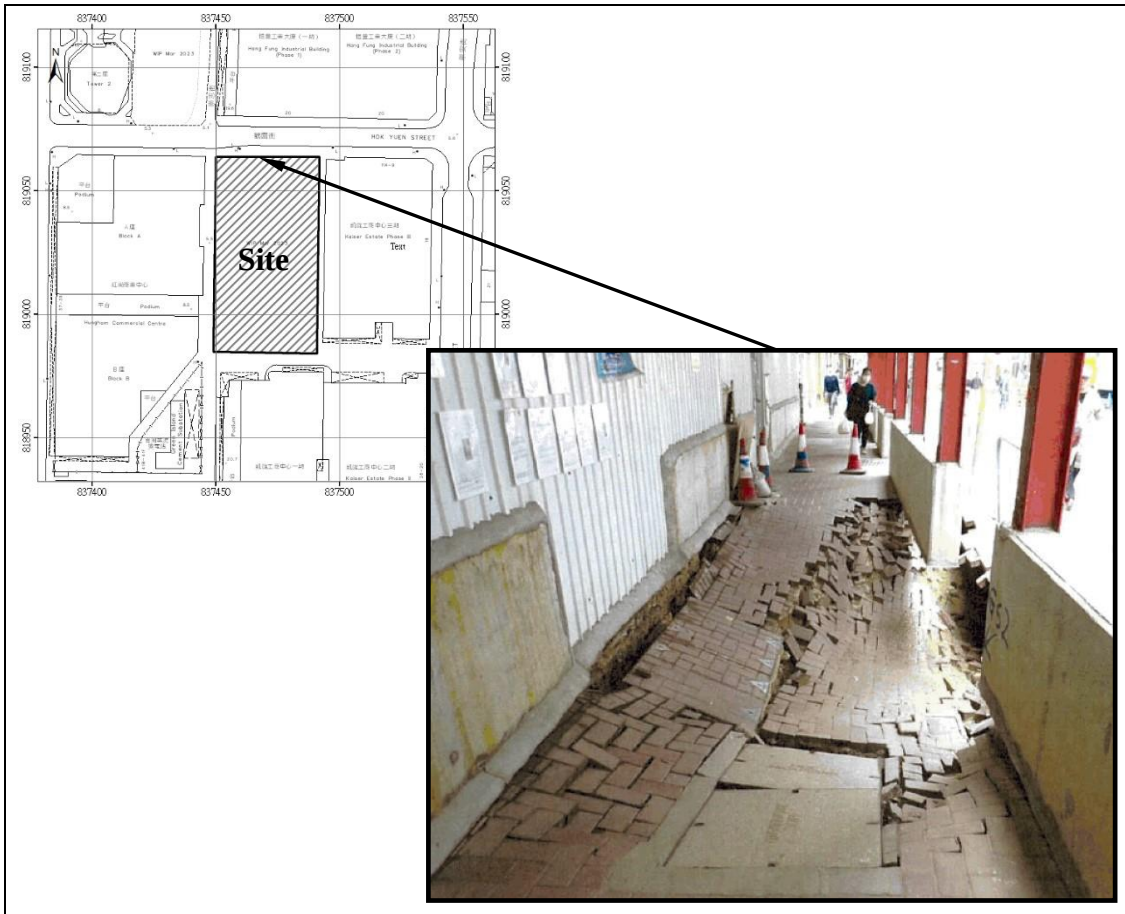
Case No. 10: Shing Fung Road, Kai Tak Former Runway





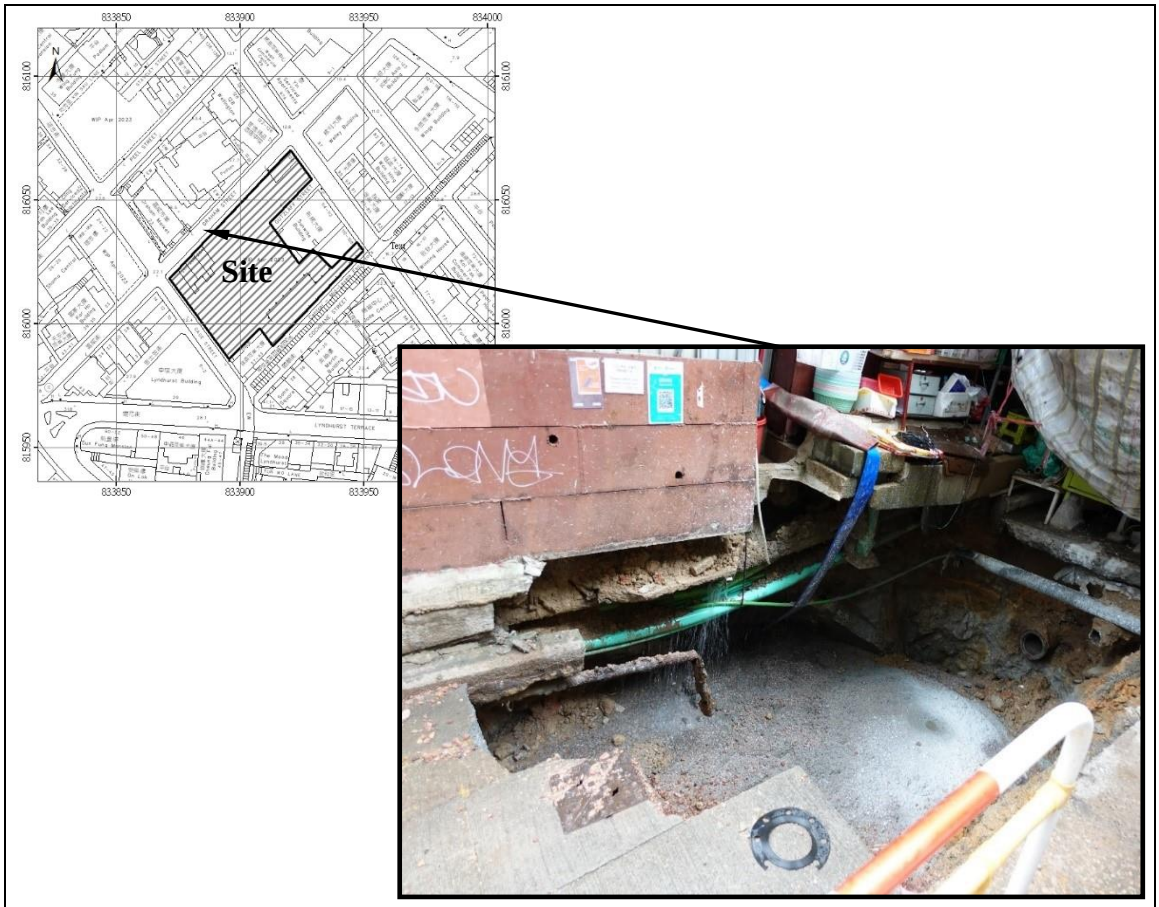
Date of incident	*23 July 2020*	***Ground Conditions***	
Size of sinkhole	*2.5m diameter x 2.7m deep*	**Top soil layers**	*10m FILL* *3-8m MD* *20-25m ALL*
Consequences	*A site personnel fell into the sinkhole and subsequently passed away*		
Major preceding construction activities	*Pipe pile foundation works in progress*	**Depth of rockhead**	*60m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*2 to 3m*

Case No. 11: Hok Yuen Street, Hung Hom



Date of incident	*3 April 2023*	***Ground Conditions***	
Size of sinkhole	*6m x 3.8m x 1.8m deep*	**Top soil layers**	*6-12m FILL*
Consequences	*Adjacent footpath temporarily closed, carriageway undermined and underground utilities damaged*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*32m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*2 to 2.5m*

Case No. 12: Graham Street, Central

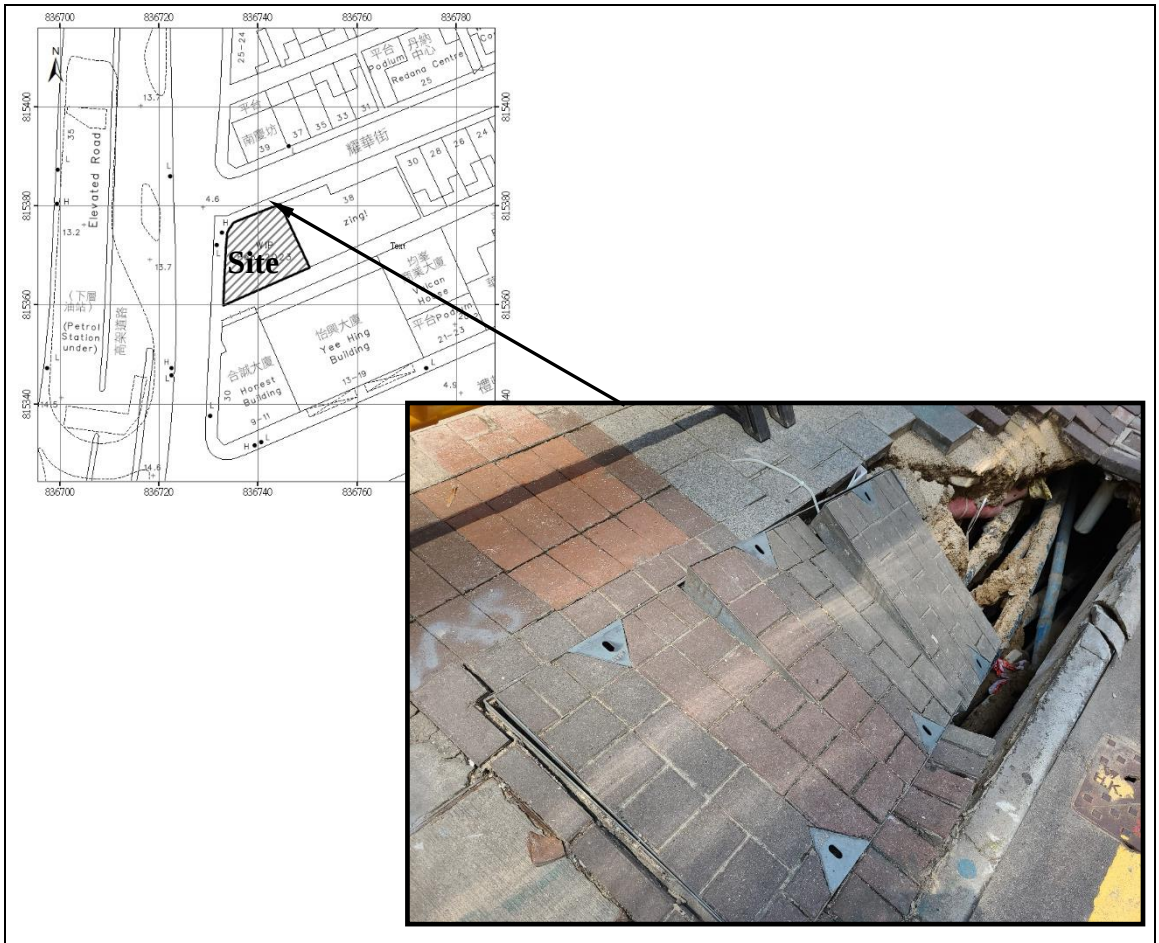


Date of incident	*6 May 2023*	***Ground Conditions***	
Size of sinkhole	*5m x 2m x 7m deep*	**Top soil layers**	*3m FILL*
Consequences	*Two workers fell into the sinkhole; three water pipes broken; adjacent footpath and market stalls affected*		
Major preceding construction activities	*Final excavation level reached; pile cap construction in progress*	**Depth of rockhead**	*>100m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles; oscillator and grab for bored piles*	**Depth of groundwater table**	*0.5 to 1.5m*

Case No. 13: Whampoa Street, Hung Hom

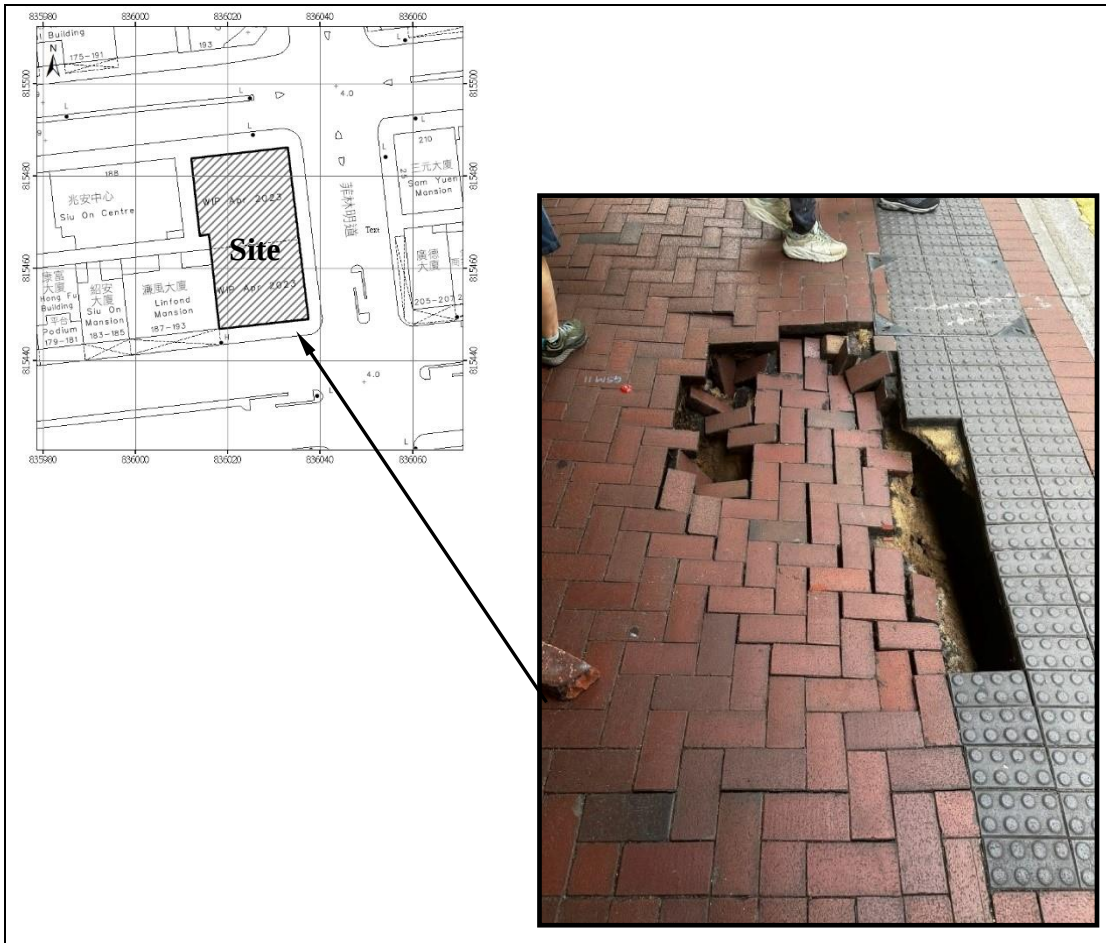
Date of incident	*20 May 2023*	***Ground Conditions***	
Size of sinkhole	*5m x 1m x 5m deep*	**Top soil layers**	*4-5m FILL* *3-4m MD* *4m ALL*
Consequences	*Adjacent service lane temporarily closed and underground utilities damaged*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*18 to 20m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*1.6m*

Case No. 14: Yiu Wa Street, Causeway Bay



Date of incident	*25 May 2023*	***Ground Conditions***	
Size of sinkhole	*4.4m x 2.1m x 2.8m deep*	**Top soil layers**	*10m FILL* *4-9m MD* *4-6m ALL*
Consequences	*Adjacent walkway and part of the road (Yiu Wa Street) was closed*		
Major preceding construction activities	*Bulk excavation and final level reached*	**Depth of rockhead**	*35 to 45m*
Drilling method/ flushing medium	*Press-in method for sheet pile and vibrator for channel planking*	**Depth of groundwater table**	*0.3m*

Case No. 15: Hennessey Road, Wan Chai



Date of incident	*5 June 2023*	***Ground Conditions***	
Size of sinkhole	*1.5m x 1m x 0.7m deep*	**Top soil layers**	*6m FILL* *3m MD* *5m ALL*
Consequences	*Adjacent walkway was temporarily closed*		
Major preceding construction activities	*Bulk excavation within pipe pile & grout curtain cofferdam in progress*	**Depth of rockhead**	*30m*
Drilling method/ flushing medium	*Concentric drilling/air for pipe piles*	**Depth of groundwater table**	*0.3m*