

# Adopting Underslab Drainage System to Tackle Groundwater Uplift Force: A Holistic Overview and Experience Consolidation

Andrew T F Wong, Alvin K M Lam & Tony K S Mak  
*Ove Arup & Partners Hong Kong Limited, Hong Kong*

doi: <https://doi.org/10.21467/proceedings.171.23>

## ABSTRACT

Groundwater uplift is one of the key factors affecting the foundation design of building works, especially for deep basements with limited building self-weight. In Hong Kong, it is common to use tension piles to resist groundwater uplift for building projects or provide additional counterweight to overcome the uplift with adequate safety factor. However, tension pile can be costly, which renders the initiatives to devise a more cost-effective and sustainable alternative. This paper presents a comprehensive review of the novel strategies for uplift control, aiming for producing a more economic foundation solution through a synthesis of theoretical frameworks, case studies, and practical experiences. The review focuses on the application of underslab drainage system beneath the basement slab in Hong Kong. The design principles of the system, the construction control and considerations, and the routine maintenance are discussed. Through a meticulous consolidation of experiences, the paper showcases a few successful applications of underslab drainage system from design prediction, through site verification and finally to implementation stage. In one of the case examples, prolonged groundwater monitoring has been carried out to demonstrate the reliability and the effectiveness of the system.

## 1 INTRODUCTION

Owing to the limited land supply in urban area, the use of underground space for car parking or shopping arcade has become more common in Hong Kong over the last decade. For sites with high groundwater table and deep basement, when the groundwater uplift pressure beneath the structure exceeds the pressure exerted by its own self-weight, the foundation system needs to account for net buoyancy. If the groundwater uplift is not properly considered, it can lead to various stability and serviceability issues such as structural instability, excessive movement, and water ingress at basement. In Hong Kong, the traditional approach to mitigating high groundwater uplift force usually involves the use of deep foundations to acquire sufficient anchorage from deeper and more stable layers of soil or rock. Despite constructing piles to resist uplift forces are on most occasions technically feasible, deep foundations in some cases can be costly and require extensive site preparation and construction efforts. Moreover, constructing piles may not be always suitable for sites with complicated geological conditions or space constraints. Therefore, this paper aims to explore alternative strategies for uplift control, with a focus on achieving more economic and sustainable foundation solutions.

The use of underslab drainage system is one of the alternatives. Such system is designed to effectively lower the groundwater table inside the basement, reducing the uplift pressure and thereby the need for extensive tension pile. In Hong Kong, the application of underslab drainage system can be traced back to the 1970s. The New World Centre in Tsim Sha Tsui East, constructed in 1974, was the first project adopting such system to reduce uplift pressure according to Chan et al. (2007). Subsequently, the system was implemented in other commercial and residential developments such as Dragon Centre, Festival Walk, Imperial Cullinan, Century Link, Park Yoho, etc.

## 2 APPLICATION OF UNDERSLAB DRAINAGE SYSTEM

### 2.1 Principle of Underslab Drainage System

The principle of the underslab drainage system is to release the groundwater pressure by introducing a drainage layer comprising crushed rock-fill or no-fines concrete with high permeability beneath the basement slab. The groundwater is collected through a network of perforated piping systems inside the drainage layer, junction pits



© 2024 Copyright held by the author(s). Published by AIJR Publisher in "Proceedings of The HKIE Geotechnical Division 44<sup>th</sup> Annual Seminar - Elevating Geotechnical Excellence: Novel Practices & Innovative Solutions" (GDAS2024). Organized by the Geotechnical Division, The Hong Kong Institution of Engineers, Hong Kong on May 31, 2024.

Proceedings DOI: [10.21467/proceedings.171](https://doi.org/10.21467/proceedings.171); Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-970666-7-2

and sump pits and discharged through submersible pumps to the existing ground and finally diverted to the public drainage system. The uplift pressure exerting on the basement slab can hence be eliminated. To ensure the effectiveness of the system, a permanent groundwater cut-off wall along the perimeter of the basement is required.

The success of the system relies on the prompt evacuation of the groundwater underneath the basement slab from the in-situ ground via the drainage layer. Therefore, in the case of future basement soffit being underlain by clayey deposits such as marine clay or alluvial clay, this layer of clayey deposit may act as a low-permeability barrier to obstruct the groundwater flow. In such cases, groundwater may not be effectively diverted away from the soil mass beneath the basement. The uplift pressure may continue to act on the basement structure, undermining the underslab drainage system's purpose.

## 2.2 Major Components

One of the key elements in an underslab drainage system is the drainage layer installed beneath the basement slab. It facilitates groundwater flow through its highly permeable material in horizontal, inclined, or vertical manner to suit the basement design. The drainage material inside the drainage layer consists of clean and durable aggregates or no-fines concrete. In order to ensure that no excessive groundwater pressure is developed at areas with no drainage layer such as beneath the footings, pile caps or suction pits, the drainage layer shall be designed to cover the majority of the basement footprint. Though there is no available guideline to determine the thickness of the underslab drainage layer, it shall be thick enough to house the perforated pipe with a fall gradient to facilitate the groundwater flow to the junction or sump pits. From past projects, the thickness of the drainage layer typically ranges between 500mm and 800mm. The typical detail of drainage layer is shown in Figure 1. Comparing to Geoguide 1, a nominal granular drainage blanket with thickness of 300mm is considered acceptable behind the earth retaining wall. However for an underslab drainage system, sufficient provision shall be made to cover the risk of blockage in the long-term causing economic loss, the difficulty of repairing and extreme weather resulting in rise of groundwater table in assessing the thickness of the drainage layer.

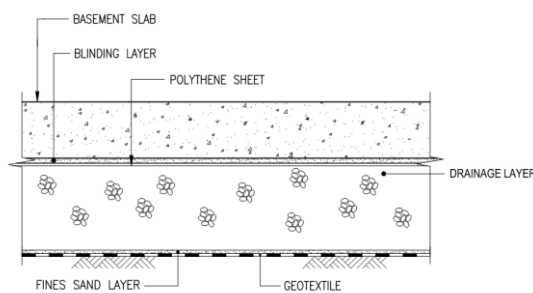


Figure 1: Typical detail of drainage layer installed underneath the basement slab

To prevent the infiltration of soil fines into the drainage layer, a geotextile filter fabric is essential and shall be positioned at the interface with the in-situ soil. This filter layer acts as a barrier, preventing the ingress of fine-grained soil particles into the drainage system. The design specifications for the filter, including criteria for retention and permeability in relation to the opening size of the geotextile, can be referenced to Table 11 of GEO Publication No. 1/93.

In addition, a polythene sheet shall be laid atop the drainage layer to act as a protective barrier against the infiltration of concrete during the concreting process of the basement slab. This precaution ensures the integrity and functionality of the drainage system by preventing concrete from encroaching into the drainage layer. However, to safeguard the polythene sheet from damage during the rebar fixing phase of the basement slab, a blinding layer shall be provided above the polythene sheet. This blinding layer serves as an additional protective measure, shielding the polythene sheet from potential punctures or tears caused by the rebars. The typical joint detail for geotextile filter and polythene sheet shall refer to Figure 2.

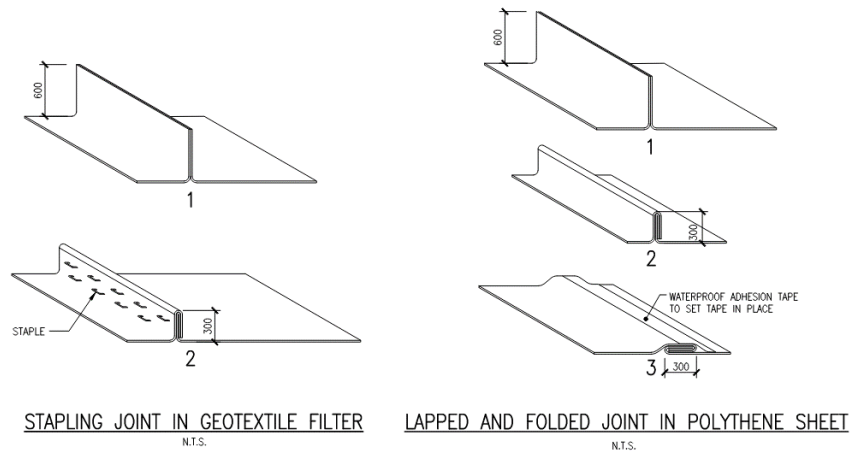


Figure 2: Typical joint detail for geotextile filter and polythene sheet

The embedded perforated drainage pipes inside the drainage layer serves to efficiently transport the collected groundwater to the discharge point via the pipe network. In general, the perforated pipes are crafted from unplasticized polyvinyl chloride (uPVC), corrugated high-density polyethylene (HDPE) or similar material. The material shall be durable and capable to sustain the design life of the system. The perforated pipes are recommended to be laid as low as practicable within the drainage layer while maintaining the fall gradient to maintain a low groundwater table within the drainage layer. The spacing between these perforated pipes shall be carefully planned to ensure there would be no excessive uplift pressure built up at areas with no drainage layer. In most past projects, the perforated pipes adhere to a minimum fall gradient of 1:200 to avoid ponding inside the pipe. Despite the relatively gentle pipe gradient, a 150mm diameter pipe is usually sufficient to meet the capacity requirements. To facilitate long-term maintenance of the perforated pipes, rodding eyes are typically installed to the upstream end of the pipe (see Figure 3 and Plate 1). Rodding eyes allow maintenance personnel to easily insert cleaning tools or apply pressurized water to remove blockages and flush away debris, ensuring the drainage pipes remain clear and functional.

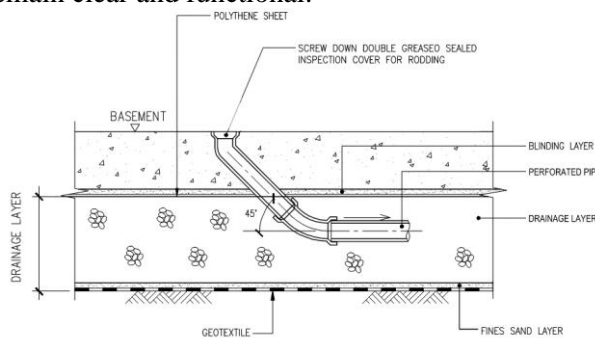


Figure 3: Typical detail of rodding eye connecting to perforated pipe



Plate 1: Rodding eye connected to horizontal perforated pipe inside drainage layer

When perforated pipes are redirected to accommodate other structural components like footings, pile caps, and tie-beams, junction pits are typically provided at the turns to facilitate future maintenance. These junction pits serve as the access points for inspection and collection for debris or sediment flushed from the perforated pipes. Eventually the pipe network terminates at the sump pits and the groundwater collected will be discharged to the public drainage system located at the ground level via the submersible pumps in the sump pits. Apart from housing the submersible pumps, the sump pits can also serve a similar role as junction pits by collecting debris or sediment flushed from the drainage system. The schematic drainage routing layout and section are shown in Figures 4a & 4b. Flowmeters are usually installed to monitor the groundwater discharge rate throughout the design life cycle of the underslab drainage system. To minimize the risk of blockage of the perforated pipes at critical junction pits and sump pits, double pipes may be considered. For example, if a sump pit connects to only one inlet perforated pipe, the sole blockage of this single inlet could already lead to a complete failure of groundwater discharge from the system. In such cases, adopting double inlet perforate pipes may be considered a better arrangement.

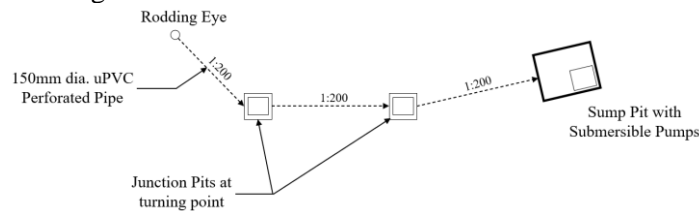


Figure 4a: Schematic underslab drainage routing layout

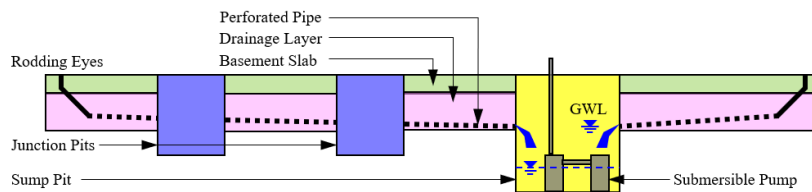


Figure 4b: Schematic underslab drainage routing section

Apart from the aforementioned components, an underslab drainage system typically includes provisions for pressure relief wells, which not only allows discharge of water to relief water pressure beneath the basement slab due to blockage or malfunction of the drainage system but also allows a deep well submersible pump to be installed to enable emergency repair or replacement of the underslab drainage system when required. These wells are usually distributed evenly throughout the basement area. Normally, the pressure relief wells are sealed at the top to prevent unpleasant odors from entering the basement. An alternative arrangement is to raise the outlet of the well above the basement slab (say, 1m) to allow direct discharge of groundwater in case of emergency or sudden raise in pressure head. The raised pipes can be constructed at column location to minimize the operational impact to the basement. Figure 5 and Plate 2 show an example of the raised pressure relief wells.

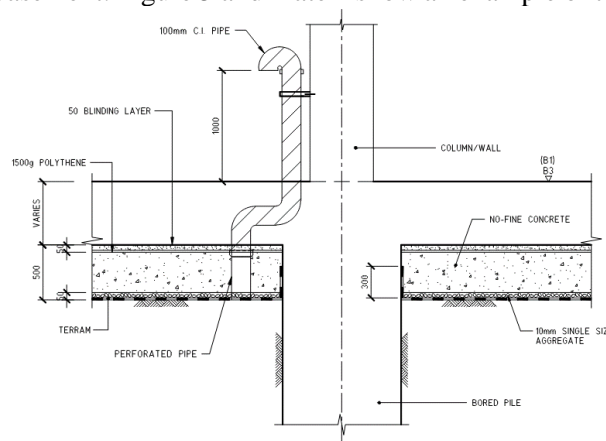


Figure 5: Detail of pressure relief well rising above the top of basement slab



Plate 2: Pressure relief well rising above the basement slab

### 2.3 Provision of Permanent Groundwater Cut-off Wall

A permanent groundwater cut-off wall is required for underslab drainage system. The depth of the cut-off wall is not only designed to meet the requirement of hydraulic stability but also control the drawdown outside the site and the amount of groundwater influx. In Hong Kong, the drawdown for temporary excavation and lateral support works is normally controlled within 1m aiming to control the induced ground settlement due to the increase in effective stress. The drawdown is usually monitored by open standpipe. In fact, the seepage flow also triggers drop in piezometric head. In some situations where clayey deposits such as marine clay or alluvial clay exist, the piezometric head drop outside the site may trigger excessive consolidation settlement in the long term, which may render the use of underslab drainage system becoming infeasible. Nevertheless, for site not sensitive to ground settlement or more settlement buffer is allowed, the control of drawdown is of less concern.

The groundwater influx is also a key consideration of the underslab drainage system design. In case all submersible pumps were failed due to electricity breakdown, sufficient time shall be allowed to restore the power to minimize the economical loss. Based on the experience from past projects, when the groundwater drawdown is controlled within 1m, the groundwater raise is generally not exceeding 300mm per day. In Hong Kong, the reliability rate of electricity supply is greater than 99.999% and the duration of any unplanned power interruption is generally less than an hour except a serious power outage incident happened in Northwest New Territories in 2022, where the full recovery was achieved in 13 hours after the incident. In addition, according to the record of the Hong Kong Observatory, the longest hoisting of Hurricane Signal No. 10 lasted for 11 hours in 1999. With the interruption from these extreme incidents, it is therefore considered reasonable to accept the groundwater raise of not more than 200 to 300mm per day.

Since the underslab drainage system relies heavily on the groundwater cut-off performance, an interlocking-natured wall providing reliable and persistent watertightness throughout the operation cycle of the building is essential. The choices often lie among diaphragm wall with water stops between panels or cutter joint, interlocking sheet pile wall or interlocking pipe pile wall. Meanwhile, if contiguous pipe pile wall with grout curtain is adopted for the purpose of permanent cut-off, the long-term performance of the grout curtain shall be considered.

### 2.4 Design for Contingency

Incorporating reasonable safety factor into the design of underslab drainage systems can ensure their reliability and resilience against unforeseen conditions. Drawing from experience gleaned from past projects, a safety factor of 3 to 5 was usually applied to the predicted water influx from the seepage analysis to cover the uncertainty due the variation of geological profile and ground permeability, any deficiency of the groundwater cut-off wall, the differential groundwater flow due to various drainage layer levels and other unexpected flow under normal groundwater condition. Extreme weathers or events shall also be considered in order to ensure that the underslab drainage system can cope with those situations with factor of safety greater than unity.

Additionally, the performance of pumping test either full-scale or partial prior to the excavation provides valuable data to review the ground permeability through back-analysis, the effectiveness of the groundwater cut-off wall as well as the predicted groundwater influx when the target dewatering level to the future drainage layer is reached under steady condition. This data available at the early stage of the project enables further refinement of the underslab drainage design, potentially allowing a more accurate prediction of groundwater flow and a lower safety factor to be adopted whereas appropriate.

### *2.5 Design for Minimum Provisional Uplift*

Despite an underslab drainage system is designed with considerations encompassing uncertainties and contingencies and thereby aims to promote negligible uplift on the structures, it is always a good practice to reserve a minimum provisional uplift in the basement slab design to cater for unexpected blockage resulting in building up of groundwater pressure beneath the basement slab between the window of the routine maintenances, monitoring and inspections. According to past projects, the typical practice for such minimum provisional uplift is 15kPa. This can minimize risk of any structural damage in case of system failure and enhance the robustness and resilience of the system.

### *2.6 Pre-occupancy Performance Review*

After the completion of the basement and its associated underslab drainage system, conducting a performance review to verify the actual performance of the system is imperative. In past projects, the performance review typically lasts for 3 to 6 months. At the beginning of the review period, the dewatering pumps originally deployed to maintain a dry excavation is switched off to allow recovery of groundwater table within the basement cofferdam. The performance review involves monitoring the groundwater pressure inside the basement by piezometers and the flow rates at discharge outlets by flow meters. Whereas possible, the monitoring covering one wet season is preferable to the assessment of the system's performance under seasonal high groundwater table and intense precipitation events. The groundwater table outside the site should also be monitored to obtain the groundwater level fluctuations over the review period.

Based on the performance review's monitoring data, it is advisable to carry out a final review of the design flow rate to back-calculate the ground permeability in order to project the groundwater influx under design condition with due consideration of the seasonal fluctuation and other design contingency and extreme weather condition which may not be encountered during the period of the performance review. It is recommended to estimate the flow rate by seepage analysis with the back-calculated ground permeability based on two groundwater table conditions – the routine groundwater table condition, and the extreme groundwater table condition. The design flow rate should then be determined by adopting the greater value from 1) the flow rate estimated under routine condition multiplied by two, and 2) the flow rate estimated under extreme condition. Submersible pumps of sufficient discharge capacity to meet the design flow rates shall be provided to the corresponding sump pits. This will ensure that the underslab drainage system is capable to handle regular influx while also reserves a sufficient buffer to account for potential surges during extreme weather events.

### *2.7 Post-occupancy Long-term Monitoring and Maintenance*

The implementation of an underslab drainage system necessitates long-term monitoring and routine maintenance protocols. Upon the completion and satisfaction of the pre-occupancy performance review, a maintenance manual will be prepared for the owners to facilitate their future long-term monitoring and maintenance.

Long-term monitoring is typically directed towards two key aspects: monitoring the pressure levels at piezometers inside the basement and measuring the flow rates at drainage outlets. By tracking the groundwater pressure and flow rates, the performance of the system can be evaluated. The typical routine monitoring works and the corresponding frequency are summarized in Table 1. This ongoing surveillance ensures no sign of blockage or malfunction of the underslab drainage system.

Table 1: Typical routine monitoring works

Typical Routine Monitoring Works	Typical Frequency
Measure flow rate from submersible pumps	Once per week
Measure piezometric head in piezometers	Once per week

Additionally, triggering levels such as alert and action levels are usually established to notify the maintenance personnel when groundwater pressure or flow rates reach the predetermined limits. Generally speaking, reaching alert levels provide a signal of potential issues requiring closer monitoring, while reaching action levels trigger immediate corrective measures to prevent any performance degradation. For groundwater monitoring, since the groundwater level is anticipated to be well within the drainage layer, the alert level can generally be set at the soffit level of the basement slab to indicate a full flow condition within the drainage layer. Meanwhile, the action level can be set at 50 – 100mm below the top level of basement slab to prompt suitable actions to prevent groundwater overflow into the basement area. For flow rate monitoring, the action level can be set at the design flow rate or the limiting capacity of the provided submersible pumps, while the alert level could be set at 70 – 80% of the total submersible pump capacity. This early warning can prompt the preparation of additional pumps before the limiting capacity is reached.

It is reminded that the primary purpose of setting an alert level is to provide an early warning to the maintenance personnel, enabling them to prepare for potential worsening conditions before serious incidents occur. The specific alert level adopted should take into account of the estimated response time needed for basement users to take necessary actions before being significantly impacted by groundwater influx. This includes considering how quickly the situation might escalate to the action level and ensuring that there is adequate time for preparation. Depending on the estimated rate of water rise, it might be necessary to set a more stringent alert level to allow earlier warning signals. It should be ensured that there is enough time to address the issue effectively, thereby preventing severe consequences.

Table 2 and Table 3 present the typical activities to be undertaken when these two triggering levels are reached. By adhering to these practices, the maintenance personnel can proactively manage and maintain the effectiveness of the underslab drainage system over time. It should be aware that if the flow rates or piezometric head exceed the action level for a substantial period, a holistic review on the underslab drainage system shall be carried out.

Table 2: Typical follow up activities for alert level

Triggering Level	Follow up Activities
Alert Level	<p>Flow rates by flow meters:</p> <ul style="list-style-type: none"> <li>• Inform the management office and the engineer.</li> <li>• Increase monitoring frequency.</li> <li>• Ensure extra submersible pumps suitable for placing in the sump pits are available and in good order.</li> </ul> <p>Piezometric head in piezometers:</p> <ul style="list-style-type: none"> <li>• Inform the management office and the engineer.</li> <li>• Increase monitoring frequency.</li> <li>• Ensure deep well submersible pumps suitable for inserting into the pressure relief wells are available and in good order.</li> <li>• Carry out rodding of perforated pipes around the area where the alert level is recorded.</li> <li>• Inspect the conditions of submersible pumps, sump pits and junction pits.</li> <li>• Carry out response tests on nearby piezometers. If the permeability of the material around the piezometer has significantly reduced, the engineer shall be informed and the piezometer may need to be replaced.</li> </ul>

Table 3: Typical follow up activities for action level

Triggering Level	Follow up Activities
Action Level	<p>Flow rates by flow meters:</p> <ul style="list-style-type: none"> <li>• Inform the management office and the engineer.</li> <li>• Place sufficient extra submersible pumps in the sump pits to enhance the groundwater discharge capacity. The groundwater collected by the extra submersible pumps should be pumped to nearby sump pit for discharge.</li> </ul> <p>Piezometric head in piezometers:</p> <ul style="list-style-type: none"> <li>• Inform the management office and the engineer.</li> <li>• Place sufficient number of deep well submersible pumps into the pressure relief wells around the area where the action level is recorded. The groundwater collected by the deep well submersible pumps should be pumped to nearby sump pit for discharge.</li> </ul>

Routine maintenance procedures commonly involve directing pressurized water through the rodding eyes or various pits to flush the accumulated debris or sediment within the pipes, and ensuring the proper functioning of pressure relief wells. Regular response test on piezometers shall be performed to ensure they are properly functioning and are truly reflecting the groundwater pressure beneath the basement slab. These monitoring and maintenance practices are essential for ensuring the continued effectiveness and reliability of the drainage system in managing groundwater uplift forces over time. The typical routine maintenance works and the corresponding frequency are summarized in Table 4.

Table 4: Typical Routine Maintenance Works

Typical Routine Maintenance Works	Typical Frequency
Clean sump pits and junction pits	Once per 6 months
Clean perforated pipes from rodding eyes	Once per 6 months
Clean flowmeter strainers	Once per month
Response tests for piezometers	Once per 6 months
Check conditions of submersible pumps	Once per 6 months
Check conditions of flowmeters	Once per 3 months

It is considered that long-term monitoring outside the basement cofferdam is unnecessary, owing to the argument that the most extreme hydraulic difference conditions have already been experienced by the ground at the former basement excavation phase. During the bulk excavation, the groundwater table inside the cofferdam has already been lowered to the final excavation level, which is deeper than the permanent underslab drainage level. In addition, with the shut-down of dewatering pumps during the pre-occupancy performance review period, monitoring on the external ground response due to the underslab drainage system has already carried out over a substantial period. Therefore, it is confident that the external ground conditions have already been stabilized and any significant future settlement is unlikely, eliminating the need for long-term monitoring outside the basement cofferdam unless continuous settlement potentially due to consolidation of the ground is still observed.

### 2.8 Reliance on Submersible Pumps and Recommended Arrangements

Failure of submersible pump is possible, which could result from mechanical malfunctions, short-term power outages, or other operational issues. Pump failures can lead to the accumulation of groundwater within the sump pits, causing flooding at the basement and compromising the effectiveness of the underslab drainage system. Additionally, reliance on submersible pump introduces maintenance requirements and associated costs, including regular inspections, repairs, and replacements. With the consideration of the potential interruption from the extreme incidents as discussed earlier on, the dependency on external power sources for pump operation leaves the system vulnerable to disruptions in electricity supply. To mitigate the risk of short-term power outage, it is crucial to ensure that the building has incorporated a backup power system, which is capable of providing sufficient electricity to the submersible pumps for at least 24 hours.

Regarding the submersible pump arrangement, opting for a dual-pump strategy to split the required discharge capacity between two separate smaller pumps instead of one single pump can effectively mitigate the risk of malfunctions. This practice ensures that if one submersible pump malfunctions or fails, there will still be another submersible pump within the same sump pit to continue operating, thereby maintaining the system's basic functionality. Additionally, this arrangement allows for maintenance or replacement of one pump without entirely suspending the drainage system's operation.



Plate 3: Operation of submersible pumps inside a sump pit

## 2.9 Risk of Flooding

In view of the frequent extreme precipitation events occurring over the recent years, the risk of flooding caused by unexpected stormwater ingress becomes higher. In such instances, the capacity of the pumps may be overwhelmed as they need to handle both the subsoil groundwater collected in the sump pits and the sudden inflow of stormwater into the building basement. This increased workload can strain the pumps and diminish their effectiveness in managing the subsoil groundwater discharge. In extreme cases where the stormwater ingress is particularly severe, the pumps may even reach their operational limits for solely discharging the stormwater, leaving no spare capacity to discharge the subsoil groundwater from the underslab drainage system. In addition, the public drainage system may also be saturated under extreme weather. This highlights the importance of incorporating robust and reliable flood prevention measures such as raised basement entrances, automated or self-closing flood gates or demountable flood barriers for projects using subsoil drainage systems.

## 3 CASE STUDY OF SUCCESSFUL APPLICATION

One notable past project demonstrating the successful implementation of underslab drainage systems for uplift control is a commercial development located in Mong Kok. The development features a 5-level deep basement involving an excavation depth of 25m below ground. To support the deep excavation, the development adopted a 1.2m thickness diaphragm wall and a 1.2m diameter secant bored pile wall extending down to the bedrock. To cope with the high regional groundwater table, additional toe grouting was employed in rock to enhance the effectiveness of the groundwater cut-off. The development utilized a comprehensive underslab drainage system to effectively manage groundwater uplift forces since its completion in 2004.

The underslab drainage system consisted of a layer of drainage layer with perforated pipes beneath the basement slab. The drainage layer was filled with 10mm single sized aggregate of 800mm thick. The perforated pipes were 150mm diameter laid at a minimum gradient of 1:200. These pipe segments were connected via junction pits, which were in turn connected to four sump pits equipped with submersible pumps. Additionally, the system included a total of 16 numbers of pressure relief wells, 35 numbers of rodding eyes, and 6 numbers of piezometers, all constructed to facilitate routine maintenance and monitoring. The design flow rate of the system was 40m<sup>3</sup>/hour. The alert and action levels for the flow rate in long-term monitoring were set at 30 and 38m<sup>3</sup>/hour respectively.

The project undertook a full-scale pumping test after completing the perimeter diaphragm wall and bored pile wall prior to excavation. After the completion of the underslab drainage system and basement structure, a 3-month performance review on the system was carried out. Subsequently along with the occupation of the development, long-term monitoring was carried out at weekly intervals.

In February 2002, a full-scale pumping test was conducted, involving 27 numbers of dewatering wells installed to lower the groundwater table within the cofferdam. The steady state was reached after 8 days of dewatering. Given the distributed arrangement and locations of the dewatering wells across the basement area and the enclosed perimeter wall cut-off extending to bedrock, it was believed that the groundwater table within the cofferdam was successfully drawn down to a level slightly deeper than the final excavation level. According to the pumping test records, the total discharge over the 72-hour steady state period was approximately 1,900m<sup>3</sup>, with a generally consistent discharge rate averaging around 26.8m<sup>3</sup>/hour.

When the underslab drainage system was completed, a performance review was conducted between December 2003 and March 2004. The average discharge rate throughout the 3-month monitoring period was around 20m<sup>3</sup>/hour. A higher pumping rate is observed during the pumping test may be attributed to the deeper level of submersible pumps inside the dewatering wells during the test while the groundwater level during the performance review is close to the soffit of the basement slab. Nevertheless, the pumping test result provides approximate and conservative discharge rates for comparison with the design prediction.

Based on the available long-term monitoring records between 2009 and 2023, the piezometers revealed that the groundwater table was well maintained below the design level. All six piezometers showed that the groundwater table remained within or below the drainage layer without reaching the soffit of the basement slab, demonstrating the effective performance of the underslab drainage system in collecting and diverting groundwater. The weekly monitored piezometric head at various piezometers is illustrated in Figure 6. For the flow rate, the monitoring in the four sump pits was carried out in daily interval. The annual average flow rate summing up all the sump pits ranged between 10.4 to 20.0m<sup>3</sup>/hour as illustrated in Figure 7.

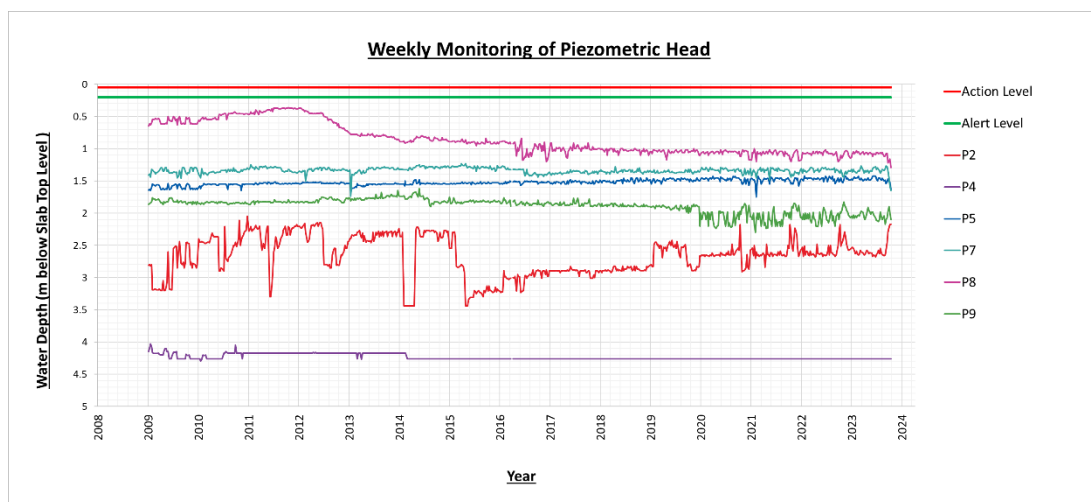


Figure 6: Weekly monitoring of piezometric head between 2009 and 2023

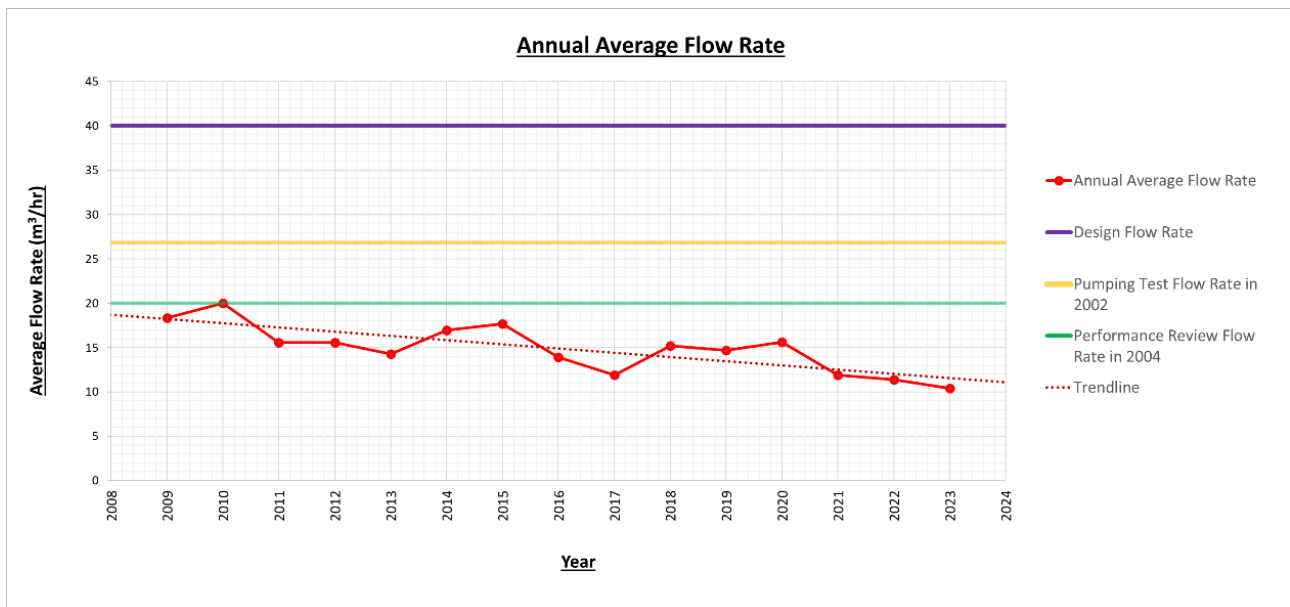


Figure 7: Annual monitoring record of flow rate between 2009 and 2023

The trend in piezometric heads was relatively steady and all levels were well below the basement slab. The range of piezometric head difference in each piezometer was within 1 to 1.5m. There was no substantial variation in the piezometric heads over the past years, reflecting a well-maintained and unimpeded underslab drainage network. Meanwhile, a downtrend in the average flow rate is observed. At the earlier years, the average flow rate is close to that monitored during the performance review period at around 18 – 20m<sup>3</sup>/hour. Afterwards, a decreasing flow rate can be observed between 2011 and 2013, followed by a slight recovery in 2014 and 2015. Although similar up and down can be observed in the subsequent years, the average flow rate is generally diminishing. Considering that no significant underground development has been noticed in the vicinity of the site after this development, the surrounding subsoil condition and underground regime is expected to be similar. One possible reason for the downtrend of groundwater flow may be owing to the continuous seepage flow beneath the permanent groundwater cut-off wall which carried the fine particles to gradually fill up the voids and thereby enhanced the groundwater cut-off performance.

The satisfactory performance indicates a judicious application of underslab drainage system in the project. Ongoing monitoring and assessments of uplift pressure and flow rates would be continued to ensure the effectiveness of the system.

#### 4 CONCLUSION

The application of an underslab drainage system is particularly beneficial in situations where the magnitude of compression forces from the structure is relatively low compared to the uplift forces exerted on the foundation. In such cases, the conventional approach of relying solely on tension piles to counteract uplift can be excessively costly. By strategically incorporating an underslab drainage system into the foundation design, engineers can effectively mitigate uplift pressures and reduce the reliance on tension piles. This not only helps to optimize the structural performance of the foundation but also contributes to significant cost savings by minimizing the number of piles required for uplift control. Therefore, the application of underslab drainage systems offers a practical and cost-effective solution for addressing uplift challenges in geotechnical engineering projects. With the increasing adoption of underslab drainage systems and the accumulation of successful experiences in the industry, the reliability of the systems is expected to grow. As more projects incorporate these innovative solutions to tackle uplift and engineers gain familiarity with their design and implementation, confidence in the effectiveness will strengthen.

## **PUBLISHER'S NOTE**

AIJR remains neutral with regard to jurisdictional claims in published maps & institutional affiliations.

## **HOW TO CITE**

Wong *et al.* (2024). Adopting Underslab Drainage System to Tackle Groundwater Uplift Force: A Holistic Overview and Experience Consolidation. *AIJR Proceedings*, 260-271. <https://doi.org/10.21467/proceedings.171.23>

## **REFERENCES**

- BD 2017. *Code of Practice for Foundations 2017*. Buildings Department, Hong Kong.
- GEO 2020. *Geoguide 1 – Guide to Retaining Wall Design (2020 Version)*. Geotechnical Engineering Office, Civil Engineering and Development Department, The Government of the Hong Kong Special Administrative Region, Hong Kong.
- GEO 1993. *GEO Publication No. 1/93 – Review of Granular and Geotextile Filters*. Geotechnical Engineering Office, Civil Engineering Department, Hong Kong.
- Andrew K. C. Chan, James Y. H. Lui & L. M. Mak. 2007, *Development of Deep Excavation Practice in Hong Kong*, Proceedings of the HKIE Geotechnical Division Annual Seminar 2007, HKIE, 109-118.
- James W.C. Sze & Henry C.F. Lau. 2010, *A Special Cofferdam in a Reclaimed Site at West Kowloon*, Proceedings of the HKIE Geotechnical Division Annual Seminar 2010, HKIE, 87-92.