Advancements in Design and Construction Practice for Deep Excavation

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ABSTRACT

The building of basement or placing infrastructure underground has gained popularity in developed city, as it can maximise the development potential and optimise the planning of useable surface area. However, construction costs in Hong Kong could be prohibitively expensive and practitioners have to optimise the design to achieve a better return on the investment. In 1990, the Geotechnical Engineering Office (GEO) published GCO Publication No. 1/90 – Review of Design Methods for Excavation, which has since become the *de-facto* standard for design of excavation and lateral support (ELS) works. Over the years, significant advancements and novel solutions have emerged in the execution of ELS works. GEO has the undisputable role of shaping the geotechnical practice and certainly sees the need to partner with practitioners in producing practical and cost-effective solutions. Since 2021, GEO has worked with practitioners and regulatory authorities to prepare a new GEO Publication No. 1/2023 – Deep Excavation Design and Construction, which aims to provide guidance on ELS works with a right balance between safety and cost-effectiveness. Attempts were made to address the problems that had troubled many in the execution of excavation works for years. This paper discusses the rationale behind the technical advancements and improvements made in the new publication.

1 INTRODUCTION

Developments in Hong Kong have, in many instances, necessitated the building of basement or placing infrastructure underground. Such arrangement has the advantage of maximising the development potential of the site and allowing better planning and utilisation of the usable surface land. However, the costs of deep excavation for underground structures can be substantial and therefore, it is important to optimise the design in order to balance the benefits and the investment of building structures underground. Local practice of deep excavation started with the construction of the first Mass Transit Railway (MTR) Line in the mid-1970s. Over the years, guidance documents were issued by the Government regulatory authorities that put emphasis on the safe execution of the deep excavation works, as there are always nearby buildings, structures and services to be protected and the consequences of any collapse could be serious and costly. Unavoidably and understandably, conservatism has been allowed in the rules promogulated in the guidance documents.

In recent years, construction cost has increased significantly and there are calls for achieving better economy in the construction industry, especially as excavation gets deeper and more complex in congested urban environment. The practice, that was found to be acceptable in the past, become questionable and the conservatism given in the guidance documents is also under stringent scrutiny to confirm its appropriateness. There were quite a few examples that were open to criticism by practitioners. It is common consent that over-design or overly stringent requirements may not make the construction works any safer. For instance, the construction risk associated with installing piles to a much deeper depth or erecting heavy sections for cross-lot strutting and preloading them will surely be increased. Prolonged suspension of excavation works due to exceedance of unrealistic ground settlement control limit may worsen the impact on adjoining ground, as active dewatering has to be in place during the period of suspension. The overdesign not only increases the construction cost and time, but can also lead to buildability and safety issues.

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The GEO published the GCO Publication No. 1/90 – Review of Design Methods for Excavation in 1990 (GEO, 1990), which has since been used as the *de-facto* standard in the design of excavation and lateral support (ELS) works. In the past thirty years, there are many advancements in the design and construction methods of ELS works, particularly in the field of digital construction, numerical modelling, novel construction methods, limit state partial factors analysis. In view of these developments and the call for higher cost-effectiveness on construction works, the GEO sees that maintaining normalcy in geotechnical practice is not sustainable to satisfy the expectation of society and the productivity gains necessitated for the huge infrastructural investment. Pragmatic enhancement to the practice in deep excavation is warranted. It has been opportune that the GEO has been working with practitioners, academia and other Government authorities in recent years, and made advancements in the geotechnical practice that provide practical and cost-effective solutions in the execution of deep excavations.

A Working Group on Revision of GCO Publication No. 1/90 (denoted as the WG) was set up to update the publication (i.e. GEO, 1990), with members coming from Buildings Department (BD), Architectural Services Department (ArchSD), the Hong Kong Institution of Engineers (HKIE) and the Piling Contractors Committee of the Hong Kong Construction Association. The new version of the publication is entitled as GEO Publication No. 1/2023 "Deep Excavation Design and Construction" (GEO, 2023) (referred as the New Publication hereafter) and was published in end of 2023. The New Publication aims to give guidance that improves the cost-effectiveness of executing ELS works in Hong Kong while ensuring adequate safety to protect the public. It also consolidates local practice and experience in the construction of ELS works and provides recommendations for mitigating the geotechnical risks associated with deep excavation.

Cheung et al. (2023) presented some debated issues and rationale on the improvements that have been incorporated in the New Publication. In the following sections, the consideration and rationale behind some of the changes and improvements to the practice, as promulgated in the New Publication, are presented.

2 RECENT ADVANCEMENT IN DESIGN PRACTICE

2.1 Limit state design approach

Limit state design approach is commonly adopted in the design of ELS works, which should satisfy the fundamental requirements of stability and serviceability (i.e. Ultimate Limit State (ULS) and Serviceability Limit State (SLS)). In the New Publication, it has clarified that either the Global Factor Method (GFM) or the Partial Factor Method (PFM) can be used to check the limit states of the ELS works. The GFM is more widely adopted in local practice for checking of ULS because it allows simple stability checks based on a single factor of safety (FOS) to cater for all uncertainties. On the other hand, the PFM permits uncertainties to be considered for individual loadings and material characteristics and provides a more rational basis for design. The New Publication documented advancements in the design practice using GFM and PFM, particularly on the elaboration of the recommended minimum safety factors to be applied under GFM and PFM.

2.2 Global factor method

The New Publication harmonised the global factor requirements specified in different guidance documents for overturning and toe stability checks. Global factor of 1.5 is commonly adopted in the design of ELS works of public works projects, which follows the recommendations given in GCO Publication No. 1/90 using GFM. For private projects, the Practice Notes No. PNAP APP-57 (BD, 2012) stipulates that the stability checks should comply with the Building (Construction) Regulation 15, which required that the FOS against overturning stability should not be less than 2 for loadings other than transient wind loads. The Buildings Ordinance and the relevant subsidiary legislations were amended in 2020, which was redrafted to implement the performance-based principles on building control to facilitate innovation in building technology and provide flexibility in design. The Building (Construction) Regulation (2020) no longer prescribes the requirements on the FOS for stability checks. As such, the New Publication took the opportunity to unify the technical requirements for public and private projects and retained the same set of recommended minimum FOS in the New Publication as shown in Table 1. In collaboration with GEO, BD is making the corresponding amendments to the relevant PNAPs for adoptions of recommendations given in the New Publication.

Table 1 : Recommended minimum global factors of safety

Limit States		Minimum Global Factor of Safety
Ultimate Limit State	Overturning / Toe instability	1.5 for effective stress analysis 2.0 for total stress analysis
	Hydraulic failure	1.5
	Base heave	1.5
Serviceability Limit State		1.0

2.3 Partial factor method

Geotechnical design based on PFM has been adopted in the design of retaining wall and reinforced fill and slopes since 1990s. In addition, GEO is also in the process of revising the Geotechnical Manual for Slopes, which will incorporate the use of partial factor method in slope design. In preparing the guidelines for using PFM in the New Publication, it is determined that the recommended values of partial factors given in the New Publication should be based on those from Geoguide 1 (2nd Edition) (GEO, 2020), in order to ensure consistency on the partial factors amongst various guidance documents. Notwithstanding that, there are still rooms for reviewing and rationalising some partial factors in the New Publication with consideration of the temporary nature of deep excavation and the recent advancements in field testing techniques in Hong Kong.

The shear strength (s_u) value for clayey material can be quite variable and is influenced by many factors, e.g. soil minerals, the initial moisture content, the degree of saturation, the over-consolidation ratio, the initial void ratio, the porosity, the loading conditions, etc. Hence, a partial factor of 2.0 on s_u is recommended in Geoguide 1. In recent years, site-specific Cone Penetration Tests (CPT) have gained popularity amongst practitioners when designing geotechnical works in reclaimed land. It is well documented that CPT can provide a continuous profile of the ground and assessment of soil behaviour based on CPT values. CPT test has been widely adopted in a number of major infrastructure projects in reclaimed land, including Three-runway System, Shatin to Central Link, Tuen Mun-Chek Lap Kok Link, Central-Wanchai Bypass, Central Kowloon Route. With the advancement in knowledge of applying field tests and correlation with laboratory tests, it is considered that there is room to review the recommended partial factor on s_u. A conducive arrangement has been adopted in the New Publication such that where sufficient site-specific CPTs are carried out and calibrated with representative laboratory test results, the minimum partial factor of s_u could be reduced from 2.0 to 1.5. It is intended that the experience gained on using and calibrating CPT with laboratory triaxial strength tests would further rationalise the design of ELS works in future and enhance the cost-effectiveness.

Another deviation from the Geoguide 1 is the partial load factor on surcharge load. CIRIA C760 (Gaba et al. 2017) recommended values of 1.0 and 1.3 for permanent load and variable load, respectively, for design of ELS works. These are less than the partial load factor of 1.5 as recommended in Geoguide 1. In Hong Kong, a quality supervision system is a requisite for deep excavation projects and only qualified professionals and contractors, are responsible for supervising and executing the excavation works in accordance with the approved drawings and design assumptions. Therefore, the surcharge load imposed on the ELS works is generally more controllable and any irregularity of overloading should be prevented on site or rectified promptly. Therefore, it is considered reasonable to adopt 1.3 as the partial factor on surcharge load, similar to the recommended value given in CIRIA C760. The recommended minimum partial factors in the New Publication are given in Table 2.

Table 2: Recommended minimum partial factors

Strength Properties and Load Conditions		Ultimate Limit States	Serviceability Limit States
Partial material factor (γ_m)	Unit weight	1.0(1)	1.0
	Drained shear strength(2)	1.2	1.0
	Undrained shear strength	2.0(3)	1.0
	Shear strength of rock joint	1.2	1.0
	Soil and rock stiffness parameters	1.0	1.0
Partial load factor (γ_l)	Dead load	1.0	1.0
	Surcharge(4)	1.3	1.0
	Water pressure	1.0	1.0

Notes:
(1) $\gamma_m = 0.67$ should be applied to the effective vertical stress which provides a stability effect for the hydraulic failure checks (i.e. piping and uplifting).
(2) γ_m should be applied to soil shear strength parameters of c' and tan ϕ'.
(3) γ_m may be reduced to 1.5 where sufficient site-specific representative field tests are carried out (e.g. CPT calibrated with representative laboratory test results).
(4) γ_l should be set to zero for surcharge which provides a stabilising effect.

A benchmarking exercise was carried out to review the implication on wall embedment depth due to the new factors in GFM and PFM. Six cases of different geological conditions and excavation depths are analysed and Figure 1 shows the configuration of the ELS works and the stratigraphy of the ground. Three cases are excavations with depths ranging from 8 m to 20 m at typical geology of colluvium overlain by Completely Decomposed Granite (CDG). The other three cases are excavations in the reclaimed land with typical succession layers of marine deposits and alluvium. Typical soil parameters, which largely followed the recommendations from Geoguide 1, were used in this benchmarking exercise.

Table 3 summarises the required toe penetrations of the temporary embedded retaining wall based on the New Publication and the PNAP APP-57 for the six cases. For GFM, 10% to 25% saving on the wall embedment depth can be achieved by changing the global factor for toe stability checking (effective stress analysis) from 2.0 to 1.5, which has already been adopted in public works projects for long time. Besides, after the update of recommendations on the factors, the outcomes of GFM and PFM become more comparable with each other.

Table 3: Required toe penetrations under recommendations in the New Publication as compared with the current practice

Assumptions			Required wall embedment depth by overturning checking			
			New Publication		Current Practice (PNAP APP-57)	
Case	Surcharge (kPa)	Excavation depth (m)	GFM with global factor of 1.5	PFM with partial factors on (1) surcharge = 1.3 and (2) $s_u = 1.5$	GFM with global factor of 2.0	PFM with partial factors on (1) surcharge = 1.5 and (2) $s_u = 2.0$
1	20	8	3.8	3.8	5.0	4.7
2	20	15	6.7	6.6	9.3	7.9
3	20	20	9.3	9.1	12.9	10.5
4	20	11	13.4	13.0	15.1	13.2
5	20	17	9.2	8.9	12.2	9.9
6	20	12	11.7	12.0	12.8	12.4

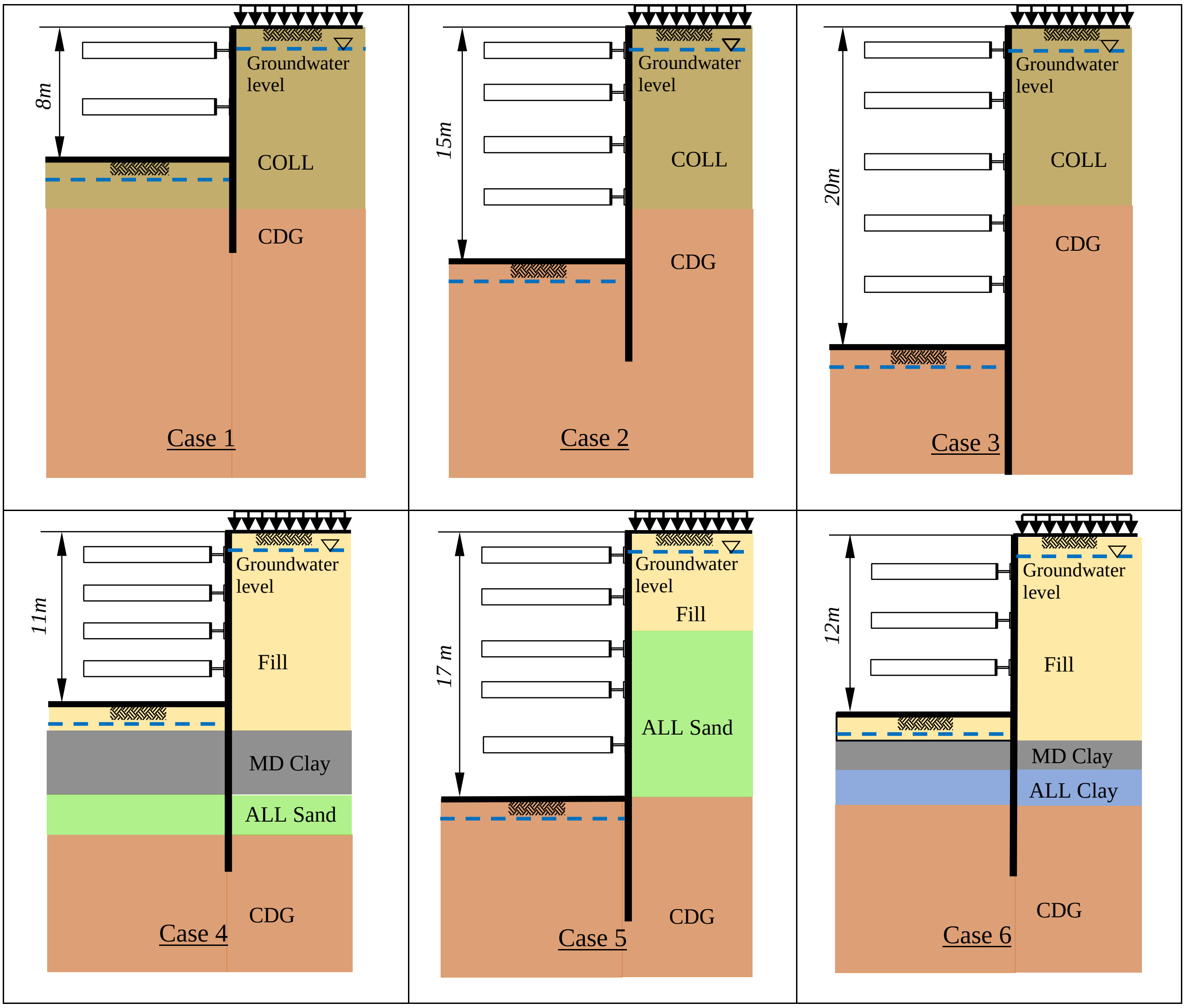

Figure 1: Six cases of excavations for benchmarking exercise

2.4 *Serviceability limit state*

2.4.1 *Estimation of groundwater level*

The groundwater on the retained side of the excavation has a marked influence on the design of ELS works and there was much debate on the appropriate groundwater levels to be used in the design amongst practitioners and the regulators. It is, therefore, one of the focuses when preparing the New Publication to give enhanced guidelines on how to estimate the groundwater levels and their uses in ULS and SLS. However, it must be emphasised that monitoring of the groundwater levels and proper assessment of the results should be conducted anyway, particular for sites where the groundwater regime can be affected by surrounding environments and seepage flow. The damming effect of the temporary embedded retaining wall can be substantial, particularly when it intercepts buried underground water flow channel.

Practitioners may sometimes prefer to adopt a conservative assumption on the groundwater level. However, this is not necessary a safer assumption. For instance, in a multi-level strutted excavation, the soil-structure interaction between the installed struts and the embedded retaining wall is dependent on the soil and water pressure and can be varied at each stage of excavation. The soil pressure acting on the embedded retaining wall can be assessed with good certainty given the availability of numerical modelling tool. However, this is not the case for groundwater pressure, if a conservative level is assumed in the SLS design. The actual loads in struts and deflection profile of the wall may deviate from the design significantly. Therefore, the New Publication advocates to adopt a realistic and reasonably assumed groundwater level in the SLS check and does not encourage using a single groundwater level for both ULS and SLS design.

Given the temporary nature of ELS works, the design groundwater level (DGWL) for a ULS design should represent the highest groundwater level anticipated during the ELS works. GEO has reviewed past designs of ELS works and noted that it has become the common practice by practitioners to adopt the DGWL for ULS by adding a rise of 1 to 2 m to the monitored highest groundwater level; and in circumstances where the monitored groundwater level is found to be lower than the excavation level, the DGWL for ULS is assumed to be at one-third of the excavated depth. These assumptions are found to be satisfactory for performance of most excavation works taking into consideration of their limited duration, unless the works will affect particularly sensitive structures or the environmental setting have great influence on the underground seepage flow. It should be borne in mind that there are usually still additional safety margins on the overall ELS system, although the design water pressure is usually unfactored. Nevertheless, sensitivity check of the design using a range of DGWLs could be carried out to demonstrate the robustness of the ELS works.

2.4.2 Estimation of ground settlement

CIRIA C760 tabulated the case studies of excavation projects in different countries. The database covers quite comprehensively different types of soil stratigraphy, strutting system, and excavated depths of up to about 30 m. The experience indicated that maximum ground settlement due to excavation in loose to medium dense sand was about 0.3% times maximum excavation depth (H_e) immediately adjacent to the wall, and decreasing to zero at a lateral distance of about $2H_e$. This is comparable to the experience as documented in GCO Publication No. 1/90. However, the excavation data given in CIRIA C760 covered mostly overseas projects. It was determined that the New Publication should also consolidate the performance of the local excavation projects. For this reason, a comprehensive review of the deep excavation projects was carried out, as this would better reflect the performance of the design and construction practice in Hong Kong. Twenty-seven excavation projects with quality field monitoring data were selected for the review and they are tabulated in Appendix A of the New Publication.

Figure 2 shows the correlation between maximum ground settlement (δ_v) and maximum excavated depth, H_e, based on the review. The general range of δ_v varies from about $0.05\%H_e$ to $0.45\%H_e$ but most of the measurements are less than $0.25\%H_e$, which is largely comparable with overseas experience. Observations were given in the New Publication of the isolated cases where the correlation exceeded $0.3\%H_e$. As expected, there is a large scatter in the data, which is due to different ground conditions (e.g. reclaimed land with varying ground conditions), wall types (e.g. circular shaft, diaphragm wall and pipe pile wall) and construction methods (e.g. top-down or bottom-up construction sequence). The $0.3\%H_e$ to $0.5\%H_e$ appears to be a reasonable ground settlement range when devising a suitable ELS system, unless particularly sensitive receivers are present (e.g. historical or dilapidated building, MTR rail track, etc.). If the estimated settlement is higher than this range, the design of the ELS works should be critically reviewed and revised. Additional measures, such as ground improvement, preloading, etc. may be needed, so as to bring the estimated ground settlement to below the maximum range. On the contrary, a lighter ELS system may be preferred, if the estimated settlement is well below the common range of ground settlement. However, it should be noted that ground settlement associated with excavation using circular shafts and tied-back walls should be relatively small (e.g. ground settlements of less than $0.1\%H_e$) based on past local projects.

2.5 Implementation of pumping test – Recent enhanced practice

The need for conducting full-scale pumping test prior to bulk excavation should be carefully considered. The difference in water levels across the embedded wall could induce significant deformation, as the lateral support to the embedded retaining wall is not in place. Some practitioners consider that the pumping tests could be used to validate the soil mass permeability as assumed in the groundwater seepage analysis. However, this is seldom the case, as the geology of the site can be highly variable and heterogeneous in nature. In fact, it is much preferable to allow dewatering to be carried out in tandem with the excavation, when the lateral supports are installed as excavation goes on. This would give a better control to the deformation of the embedded retaining wall and ground settlement. The safety of the excavation system is, indeed, safeguarded by the monitoring of the groundwater levels and the deformation of adjoining building, services and ground to be within acceptable range. Hence, in the New Publication, some examples are given for situations that pumping tests are generally considered unnecessary. These include site with (a) mass permeability of the soils that is low or the anticipated groundwater level at the site is below the final excavation level, (b) water cut-off barrier that is installed down to soil strata with low permeability or to a rock formation with suitable rock fissure grouting, or (c) there are no nearby sensitive receivers that could be affected by groundwater drawdown.

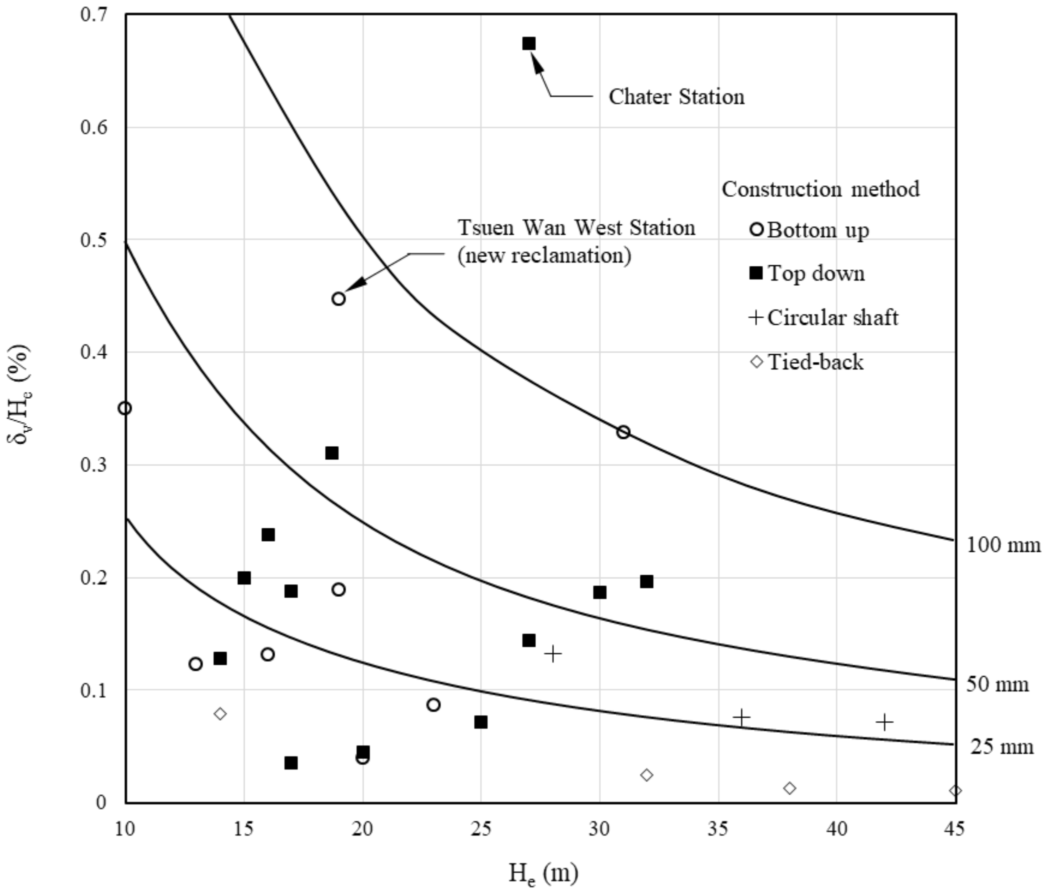

Figure 2: Total ground settlement against maximum excavation depth (H_e) from case study data for projects in Hong Kong

In the event that a full-scale pumping test is deemed necessary, it is also proposed in the New Publication that the duration of active pumping during the pumping test should be minimised as much as possible. Active pumping inside the excavation would promote underground water flow and inevitably cause the loss of fine-grained soils within the soil matrix. There are many reported incidents of ground settlement or subsidence as a consequence of underground water flow. Cheung et al. (2023) reported a review of 24 pumping tests conducted in recent deep excavation projects in Hong Kong. All the tests indicated that whenever steady-state conditions were achieved, there was practically no change to the water level in the subsequent 72-hour period. Therefore, it is recommended in the New Publication that, for a full-scale pumping test in excavation project, maintaining the dewatering for a minimum of 24 hours after achieving steady state seepage is considered adequate and the recovery stage can be commenced thereafter.

3 INNOVATIVE CONSTRUCTION METHODS

Significant advancements and novel solutions have emerged in the construction industry in recent years. There have been a number of projects using multi-cell shaft excavation method and tied-back wall system for excavation exceeding 30 m in depth and they were successfully completed with minimum ground deformation

(Figure 2). The New Publication consolidated the examples of these novel construction projects (Plates 1 and 2), as a reference and evidence that these systems are acceptable to the authorities when situations are considered favourable.

In fact, tied-back wall system may actually be more preferable in some circumstances. For example, where excavation is to be carried out on a steep sloping site, there would be a large unbalanced excavation across the site and inadequate space for constructing cross-lot strutting to support the embedded retaining wall on the higher ground. Some practitioners consider impracticable to install tied-back into unexcavated ground, as permission from the land administration is difficult to obtain. GEO has worked with relevant authority, including the Lands Department (LandsD) and Highways Department (HyD), to workout streamlined procedures for considering application of installing tied-back or soil nails in unallocated government land (UGL). As a pre-requisite, the affected UGL should not have any upcoming proposed developments or land disposal proposal. Upon receiving application for installing tied-back and soil nails in UGL, LandsD would consider positively on such proposal based on the advice of GEO regarding whether the construction work is geotechnically desirable. Such arrangement is currently applicable to public works projects or slope remedial works conducted by private owners for reason of public safety. In parallel, suitable land clauses have also been drafted to facilitate the application process.

Plate 1: Permanent tied-back wall support system for the excavation works at Stubbs Road

Plate 2: Retractable prestressed ground anchor support system at the redevelopment of Grantham Hospital

4 ENHANCED MECHANISM ON GROUND DEFORMATION CONTROL

It is inevitable that some degree of ground deformation would occur in association with excavation, no matter how sophisticated the design was and stringent the excavation works were carried out. It must be borne in mind that geotechnical design is often made with some degree of simplifications and assumptions and the inherent characteristic of the soil can be very variable. Therefore, it has been the standard practice in the design of ELS works of devising a comprehensive instrumentation and monitoring plan, together with a ground control mechanism to predetermine the response actions when the monitored deformation exceeds the predetermined limits. Practitioners usually adopt the three-tier triggering control mechanism (i.e. Alert-Alarm-Action (AAA) Levels) as stipulated in the PNAP APP-137 (BD, 2018) for safeguarding the sensitive receivers during excavation. At Action Level, the ground deformation control mechanism usually calls for suspension of all site works.

There has been much debate on the ground deformation control mechanism in recent years, particularly there were quite a number of noticeable projects that were suspended due to exceedance of the ground settlement limits. Cheung et al. (2023) discussed the undesirability of adopting the empirical limit of 25 mm for all depths of excavation. The indiscriminate use of 25 mm has resulted in either adopting unnecessary heavy excavation systems or speculating on whether the limit would be breached during construction. Based on past records, many excavations were suspended due to the exceedance of the Action Level for ground settlement, rather than the building structures which are commonly supported on deep foundations. Works suspension is very disruptive on the construction programme and always produces a negative impression to the public. There were many cases that it took months, if not years, to get approval to recommence the project and regardless of the justifications, the public will see the Government and the project proponents moving the goalpost in the interest of construction programme. Also, it is also highly undesirable to have an excavation with active dewatering maintained during suspension, which prolongs the risk of affecting the nearby facilities. Therefore, pragmatic enhancement in ground deformation control mechanism of ELS works is warranted and it has been a major issue to be tackled with by the WG when drafting the New Publication.

The New Publication recommended to enhance the current Alert-Alarm-Action system into a five-level system (5A) by further refining the Action Level into 3 levels with ascending scope of response actions for different monitoring markers. This was the results of months of deliberations and persuasion amongst relevant Government departments (including project office and maintenance office), regulators and utility undertakings. The New Publication provides comprehensive rationale and justifications for adopting the respective empirical limits in the action levels and the corresponding response actions at each action level. Nevertheless, mutual trust between the project team and the stakeholders of the affected sensitive receivers is the most essential element to ensure the 5A approach becoming a practicable control mechanism that is acceptable to all parties, including the owners of the affected sensitive receivers and the regulatory authorities.

4.1 Action Level 1 to address serviceability concern

When it comes to the question on devising an enhanced ground control mechanism, it is important to delineate the magnitude of ground deformation that would raise serviceability concerns from deformation that cause safety issues. Serviceability concerns would normally occur at the early stage of settlement and the problem can be tackled easily. It is absolutely important to understand the concerns of the affected stakeholders, so as to devise a plausible scheme that would be acceptable to them.

Irregularities were reported in the construction of the Shatin-Central Link project and the Government appointed an Expert Advisor Team (EAT) to provide advice to follow up on the alleged irregularities. The EAT recommended the Government to improve the formulation and implementation of the monitoring and control system. In this regard, a realistic Action Level (i.e. the threshold limit for suspension of works) which tallies with the predicted ground response, subject to proper justification of the acceptability of this limit, should be set. It was timely that a task force under the Development Bureau was set up to implement the recommendations of the EAT, which included representatives of HyD, BD, ArchSD, Water Supplies Department (WSD), Drainage Services Department (DSD), Housing Department, Electrical and Mechanical Services Department. The WG members of the New Publication had been actively involved in the task force and undertook a comprehensive review for enhancing the control mechanism of ground deformation. Besides the Government departments, the Joint Utilities Policy Group (JUPG) was also consulted to understand their concerns on the adverse impact to their managed utilities due to excavation works. Members of the JUPG include the undertakings of private and public underground utility, such as gas company, power companies, cables and internet service providers, etc., whom they have laid enormous amount of underground utility.

In the consultation, the grievance of the utility undertakings mainly focused on not being notified promptly and consulted on the necessity of remedial works for their affected utility, until the Action Level was reached or damaged was done. Also, the project team and contractor often argued that the damage or leakage of underground utility was due to the impoverished condition of their utilities, or presence of existing cavities on the ground prior to their excavation. Utility undertakings did not have the time to dispute with the project team, as they had tremendous pressure of reinstating their services. As such, many repairs were carried out by the utility undertakings and the project team often took a hands-off attitude.

When devising the enhanced ground control mechanism and response actions, emphasis have been placed to ensure proper consultation and communication are made between relevant stakeholders, including the project proponents, contractors, consultants and maintenance parties and utility undertakings, when ground deformation reaches different action levels. In fact, serviceability of road, pavement and utility could be promptly rectified, such as sealing cracked in road pavement, relevelling paving blocks, repairing damaged subgrade, realigning or supporting deformed pipelines. The essence of rapidly resolving serviceability concerns is to obtain prior agreements with the relevant stakeholders on when and what to do, when the ground deformation reaches the pre-determined limit; and to implement them accordingly. It will be less costly and more effective to carry out such repair works, other than suspending the site works and arguing the responsibility and scope of the remedial actions.

In some cases, the causation of damages to the utility may not be positively determined after the incident, but early confirmation of the conditions of the ground and underground utility will help eliminate the uncertainty. In the enhanced ground control mechanism, the New Publication highlighted the importance of carrying out the precondition survey of the surroundings and the underground utility, prior to the commencement of the construction works. Relevant government departments, including the WSD, DSD and HyD, would assist project proponents by providing pertinent information of their maintained utilities, such as 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. The information should assist the project team in assessing the condition of the utility and take necessary precautionary measures to minimise the adverse impact to them. Besides the records provided by the government departments, 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 and significant leakage of buried water-carrying services and the possible presence of underground cavities. 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. Where the results indicate anomaly, additional investigations such as GCO probe or SPT should be conducted to confirm the presence of any cavities at depths. These investigations are usually carried out as part of the precondition survey of the site prior to the commencement of site works. Such pre-condition survey and investigations are usually imposed by GEO when processing the application of building plans or excavation proposal and should be completed before commencement of the construction works (including installation of embedded retaining wall). For project with deep excavation and prolonged period of excavation, the New Publication also recommended repeating the GPR and CCTV inspection 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. Any changes between records of the GPR and CCTV would provide an early warning and indication of possible damages or deterioration of the underground utility.

4.2 Action Levels for Safety Concern

It must be emphasised that the project team should not solely base on the monitoring results of the instruments when determining whether the specified response actions in the ground control mechanism should be triggered. There were many incidents that obvious evidence of damages or undue settlement were ignored and the excavation works were allowed to be continued until more serious consequence occurred. Plate 3 shows a damaged pedestrian pavement adjoining an excavation site. The project team argued that all the measured settlement at the monitoring stations did not exceed the AAA levels and hence they were not in the position to suspend the excavation works. Similarly, there were cases where water was observed to have leaked between individual panels of the embedded retaining wall and the site supervisory staff ignored the potential risk of causing cavities on the ground. In the enhanced control mechanism, more specific actions are prescribed when significant or severe leakage occurs; and whenever obvious damage on the road or pavement is identified.

The enhanced ground control mechanism is developed in consultation with the Government departments. While the magnitude of empirical limits for ground settlement have been increased, it should be noted that these values are agreeable with the maintenance departments (e.g. HyD). In the event that the affected road and pavement belong to private owners, agreement from the relevant private owners should be obtained before the 5A approach given in the New Publication can be used, though the same principle of establishing the limits for ground settlement is still applicable. In such circumstance, it would be beneficial to commence the dialogue with the affected private owners at the earliest possible time, so as to ensure smooth implementation of the excavation works. Otherwise, the control mechanism as given in PNAP APP-137 should be followed.

Plate 3: Damage of the pedestrian pavement adjacent to an excavation site

Under the 5A approach, a set of specific and targeted response actions with respect to exceedance of the corresponding trigger values has been prepared in the New Publication to enhance the effectiveness and efficiency of the control mechanism. The recommended typical response actions in respect to the exceedance of the Action Levels 1 to 3 are given in the New Publication. Other project or site-specific response actions could also be included if necessary and appropriate.

5 APPLICABILITY OF 5A APPROACH TO OTHER GEOTECHNICAL WORKS

The GEO published the Technical Guidance Note No. 54 (GEO, 2024), which expands the ground deformation control mechanism to other types of geotechnical works, including piling and TBM tunnelling. Given the same nature of sensitive receivers being affected, the 5A approach for ELS works can also be applied to other geotechnical works. In this connection, it is necessary to establish the corresponding empirical limits for setting trigger levels for Action Level 2 and Action Level 3 that are realistic and practical for the geotechnical works. For foundation works, piles are usually installed at a distance from the site boundary and the maximum ground settlement induced by the construction of common pile types (e.g. driven steel H piles, pipe pile and bored pile) seldom exceeded 30 mm based on local experience. Settlement caused by diaphragm wall construction is documented in the New Publication, which also falls generally within this limit. Given the settlement limit at Action Level 3 is taken as 30 mm, the corresponding limit for Action Level 2 is set as 25 mm. For soft ground tunnelling works using TBM, review of design standards and case histories of local TBM works indicates that the induced ground settlement is best estimated by correlation with the maximum tunnel excavation Volume Loss (VL). The commonly observed range of VL in TBM works varies between 1% and 2% and the maximum ground settlement is usually less than 100 mm, given the typical size of tunnels in Hong Kong. Hence, it is recommended to set 1% VL and 2% VL as the basis for determining the trigger levels of Action Level 2 and Action Level 3 of ground settlement.

6 CONCLUSIONS

The new GEO Publication No. 1/2023 consolidated the experience and practice in the design and construction of deep excavation in Hong Kong. This New Publication was redrafted with the purpose and aspiration of providing updated guidance to practitioners in design of ELS works, such that a right balance between safety and cost-effectiveness is obtained. Attempts were made to address the problems that had troubled many in the execution of excavation works for years. The New Publication highlighted the harmonization of design approaches, advancements in design and construction practices, and the application of innovation solutions, and more importantly, the enhancement of ground deformation control mechanisms. It also put strong emphasis on the proactive and early collaboration with different stakeholders to develop a mutual trust, which is considered important in the safe and successful execution of deep excavation projects. Practitioners are encouraged to provide comments on the contents of the publication to GEO at any time, so that improvements can be made in future editions. In addition, a regular review on the effectiveness of the implementation of the enhanced 5A approach for control mechanism of ground deformation and response actions will be carried out. As in normal practice, the technical standards for public and private development should be the same and GEO is collaborating with BD to review and update the relevant PNAPs, such that the recommendations in the New Publication can be consistently applied to Hong Kong projects.

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