Common Problems of Basement Excavation Projects in Malaysia

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ABSTRACT

This paper presents the common problems in design and construction practices of basement excavation projects in Malaysia. Water leakage in the basement structure remains as practical issues in basement excavation projects during construction stages and post-construction stage. There are always arguments on acceptance criteria of water leakage among the designers, contractors and owners/operators. Sustained water leakage in the basement structure can be serious if unattended, especially sign of fine migration in the leakage inflow is observed. Excessive piezometric uplift onto the basement slab can also be dangerous, which may lead to structural failure of basement slab or even partially uplifting the basement structure with inadequate dead load. Design detailing can contribute to numbers of myths in the unfavourable performance of the integrated basement shoring support. Construction monitoring using absolute magnitude of maximum predicted wall deflection at each construction stage is a common blind spot approach, which does not directly relate to important wall stresses (bending, shear, torsion, axial) with respect to the wall deflection profile. Some innovative ideas of drained basement and jacked pipe anchorage in basement design will also be discussed for future development and improvement of basement design and construction technology.

Keywords: water leakage, piezometric uplift, shoring supports, wall collapse, top-down

1 INTRODUCTION

Basement structures are usually submerged below sustained groundwater table, thus water tightness of the underground space becomes important aspects of design and, also the construction. The sustained piezometric head of groundwater table provides a pre-requisite condition of leakage and, also uplift pressure to the substructure. In view of the adverse impacts where leakage of underground space can bring to the concerns of safety and, also serviceability acceptance, this paper reveals some common problems in underground structure relating to groundwater.

2 IMPACTS OF GROUNDWATER LEAKAGE

There are generally three important aspects where the groundwater can impact the design, construction and operation of underground space facilities. Firstly, the uplift force leads to localized cracking of lowest slab/raft, or even uplifting the entire underground basement if the dead weight of the substructure is insufficient to hold it in place. Secondly, the leakage into the underground space causes serviceability problem to usage, requiring long-term pumping, and durability of the substructures and facilities under high humidity promoting fungus growth. Thirdly, occurrence of external sinkholes due to fine migration of retained soils through the developed internal piping erosion.

2.1 Design Aspects

The most common walling system in Malaysia can be either of the following:

i. Reinforced concrete basement wall construction with open cut excavation and backfilling if space for temporary excavation or temporary sheet piling is permitted and excavation depth is not excessive. Waterproofing membrane can be applied over the retaining side of wall surface. The success of this type of wall in withstanding the standing groundwater relies on proper detailing and construction of swellable water-stop strip along all cold joints and construction joints with good continuity, the concrete quality and workmanship of avoiding honey-combed concrete, and the water-proofing membrane application.
ii. The embedded wall type, including diaphragm wall, secant pile wall, contiguous bored pile wall, permanent sheet pile wall, are usually adopted for underground space with deeper excavation except for sheet pile wall with limited practical excavation depth due to its relatively low wall stiffness. The potential leakage path through the concrete wall are usually found at the cold joints between the two adjacent cast-in-situ vertical wall elements, mostly due to construction verticality, honey-combed tremie concrete, opening of cold joints after excavation induced wall deformation, etc. Sometimes post grouting along the cold joints can only be carried out on best effort basis. It is also not uncommon to cast another water-tight reinforced concrete skin wall over the retaining wall with

proper structural anchorage as an integrated wall. However, improper design and detailing of such skin wall and space constraint resulting in limitation of appropriate watertight thickness of the skin wall are the key factors of unsatisfactory performance.

For a cast-in-situ reinforced concrete wall, crack width design under the interaction of external earth pressure, water pressure and the internal propping forces from substructure slabs are important to control overall wall leakage if the treatment along the cold joint can be adequately managed. The other problem is the design of proper anchorage to the lowest substructure slab/raft to withstand the groundwater uplift. The design shall consider using anchorage to the slab/raft from the foundation piles to avoid localized failure or cracking permitting leakage. The foundation piles shall have adequate tension capacity to hold the entire basement slab/raft in place after netting off the dead weight of the superstructure.

Often the changes of hydrogeological conditions due to change of site formation that might not be captured in the design as the initial subsurface investigation before site earthworks do not reflect the final groundwater condition. Filling in valley terrain with inherent active seepage flow normally experiences rise of groundwater table within the new fill as a result of retarding seepage flow with the fill placement. Hence provision of adequate sub-terrain drainage along the natural valley trough avoiding perched water regime is critical design consideration in site formation.

Embedded wall system in ground with potential seepage flow will intercept the flow resulting perched water table, thus increase water pressure behind wall and, also uplift pressure beneath the basement slab/raft. Similarly, this hydrogeological condition is usually not reflected in the soil investigation.

The design philosophy and purpose of capping beam has not been fully understood by the designer. There is no internal stresses along the capping beam in most 2D wall structural analysis without any differential deflection, thus no structural requirement to take any structural stress. However, if the designer considers load path approach of discrete wall elements and the not truly 2D plan strain shoring system, differential shearing actions can be surely established for designing the reinforcement and member sizing.

2.2 Construction Aspects and Controls

Potential distresses from construction involves many aspects ranging from materials, workmanship, works sequences, any temporary works resulting in inherent defects. This paper will share the experiences from a few forensic investigation projects to illustrate the real problems. Construction monitoring instrumentation used to measure the actual performance as construction control is normally misrepresented by certain absolute maximal values in the deformation. Often overly simplified values of deformation will likely misrepresent the structural behaviors of the basement system. It is the local curvature of the deformation profile shall govern the induced stresses, not the absolute value of the lateral deformation.

For water resistant construction, CIRIA Report 139 (1995) provides very good guidelines for design and construction of water resisting basements.

3 CASE STUDY

Four case studies will be discussed here to illustrate the basement slab distresses due to uplift pressure from original hydrogeological regime, high humidity in underground space, the fine migration in a leaking basement and the perched water regime resulted from fill over valley terrain and cutting off seepage flow by embedded basement wall system.

3.1 Case Study 1 – Hogging Basement Slab

This case study involves three blocks of 3 to 4 story office and commercial complex with one level basement with finished level at RL17.55m. The top level of central open basement slab on grid beams was at RL17.65m to RL17.84m, which had suffered structural cracking with hogging deformation due to uplift pressure as shown in Figures 1 and 2. The primary crack pattern was almost resemblance to the typical structural yield line failure of slab under uniform distributed uplift pressure with restraints from the grid beams. The site is primarily underlain by thin fill on very loose sandy alluvial soils with SPT-N from 4 to 8 overlying a weathered meta-sedimentary formation. Shallow groundwater table was observed as the site location is only merely 300m from the Klang River in Kuala Lumpur. Open standpipe monitoring over a month duration indicated groundwater level at approximate RL18.2m to RL18.4m. From previous basement flooding incidents, evidence of water marks on building columns at 800mm above top of basement slab was observed and matched well with the measured groundwater level at RL18.4m.

Coring of basement slab was conducted to check the concrete strength and, also to determine the as-built reinforcement placement and dimensions. Three cored specimens were taken with two showing raft thickness of 230mm and the third one 290mm. Two layers of reinforcements were found with the bottom reinforcement at 15 to 30mm above the soffit and top reinforcement about 100mm to 115mm above the bottom reinforcement. The basement substructure was supported on 175mm reinforced concrete (RC) square foundation piles at the open basement area and 300mm RC square foundation piles at the building superstructure with working compressive capacity of 350kN and 1000kN respectively. Most pile penetration length is about 10m to 25m below ground. Under uplift tension loading condition, the computed ultimate tension geotechnical pile capacity of the shortest 10m long 175mm RC pile with SPT-N of 6 is about 85kN as against the computed net uplift force ranging from 68.3 to 290kN for water level from 1m to 1.8m above the basement slab soffit. For ultimate tension capacity of 85kN to fail, it just requires water table at 1.05m above the basement slab soffit, which was not impossible for the water table rising beyond this threshold in view of its proximity to Klang River. From the level survey over the heaved slab as shown in Figure 3, there was a maximum net upheave of 130mm near the central portion of the open basement slab, which implies the reality of some tension uplifting of the 175mm RC piles upon reaching the threshold of uplift pressure. In addition to the excessive concrete cover of top reinforcement of slab, probably due to inadequate bar chairs and subsequently undue pressing down of mesh reinforcements by workers during slab concreting. This leads to flexural cracking under hogging deformation by uplift pressure. The final solution to this problem is to put a counterweight of central garden landscape over the triangle open basement to counter the uplift.

Fig. 1. Overview of Cracked Open Basement Slab with Three Temporary Relief Well Openings

Fig. 2. Flexural Cracks on Open Basement Slab due to Uplift

Fig. 3. Maximum Heave of 130mm at Central Portion of Open Basement Slab

3.2 Case Study 2 –Piping Erosion of Retained Soils via Seeping Groundwater

This case study presents a migration of soil grains in the running groundwater leakage. When the critical hydraulic gradient of the seepage flow has reached and the soil matrix structure cannot hold the finer soil grains with a stable condition, piping erosion with detached soil grains occur with consequence of undermining the retained soils behind the wall as shown in Figure 4. This type of piping failure is common mechanism is dam engineering. Excessive fine migration can cause sinkholes behind the basement structure and ground settlement if collapse of voids occurs. Figure 5 shows the spillage of excessive seepage water that cannot be contained within the side drains provided on ad-hoc basis. This certainly creates unacceptable nuisance to the carpark users.

Fig. 4. Washout of Fine Sand in the Seepage through Preferential Flow Path with Piping Erosion Features

Fig. 5. Spilling of Seepage Water from Collection Drains

3.3 Case Study 3 – Basement at Valley Terrain with Special Hydrogeological Regime

Valley and downhill terrains usually provide convenient natural setting for semi-underground carpark space construction with the external ingress and egress access roads from the ground at higher elevation. With interaction of landform changes and physical intrusion of structural elements into the ground of engineering project, the initial hydrogeological regime can be altered with several impacts. In this case study, the upstream valley catchment provides abundant supply of infiltrated surface runoff increasing groundwater seepage. Subsequent development earthworks with filling over the natural valley deters not only the seasonal stream flow, but also the seepage within the ground. As such perched water regime above the original ground profile was created, in which the predevelopment subsurface investigation was not able to predetermine the re-established groundwater regime. Furthermore, the use of embedded sheet pile wall as basement walling across the active seepage path further worsen the situation by cutting off the seepage flow. Liew & Khoo (2008) presented two cases of distressed retained ground for semi open carpark basement over filled valley. Thus, it is advisable to review the predevelopment terrain with expected natural surface runoff and, also potential underground seepage regime to avoid adverse impact to the underground space below ground, especially below original ground profile. It is possible the groundwater can be perched to a level beyond imagination if this aspect is simply overlooked. Another hazard with valley for shoring system of underground space is the potential existence of weak and permeable alluvial deposits over the valley floor with alluvial deposition. The weak soil strength requires more stabilizing forces to counteract the earth pressure whereas the permeable alluvial deposits allow high conductivity to transmit piezometric pressure built up from upstream catchment and aquifer onto the walls and lowest basement slab. Figure 6 shows the development layout with footprint sitting across a natural valley for one of the case histories presented.

Due to the basement space usage, further excavation was needed to create the necessary space. Thus, Figure 7 presents the steep cut profile with soil nails and anchored sheet pile wall strengthening loose fill over the previous natural valley. The embedded sheet pile wall forms a cutoff of the underlying seepage path along the valley resulting the rise of water table behind the sheet pile.

The second case history also has the similar filling over the original natural valley. Weak deposits in the valley was also not properly cleared during the site formation earthworks as shown in Figure 8. Temporary Continuous Bored Pile (CBP) wall was constructed to facilitate the open cut basement construction. Due to the weak strength of the unexpected valley floor deposits and the perched groundwater regime after installation of the embedded CBP wall across the valley, unfavourable distresses occurred to the CBP wall with excessive wall movements and settlement of the retained ground as shown in Figure 9.

Fig. 6. Layout of Basement Structure and Predevelopment Topographic Terrain

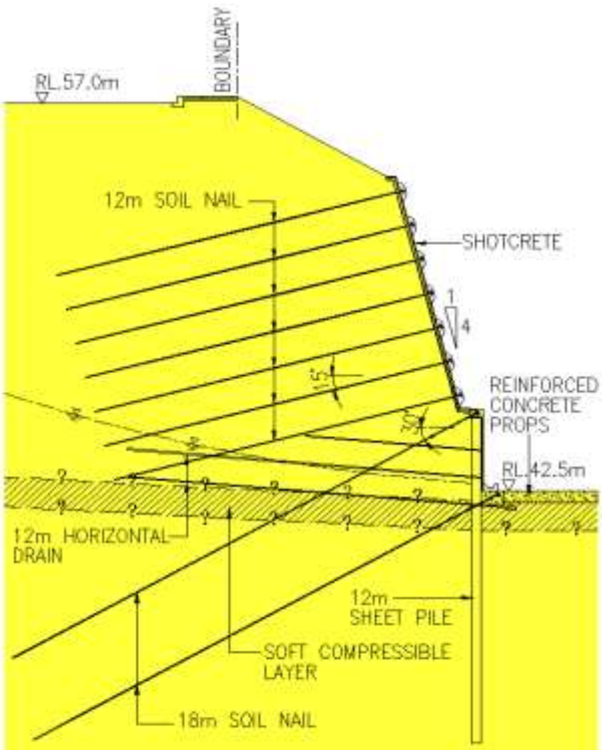

Fig. 7. Section of Reprofiled Terrain with Strengthening Works

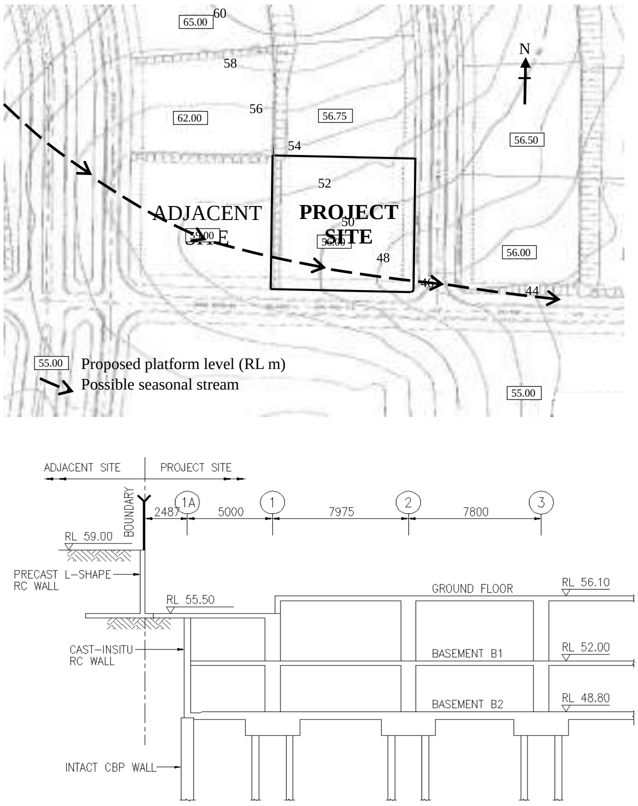

Fig. 8. Predevelopment Topographic Terrain and Section of Finished Basement

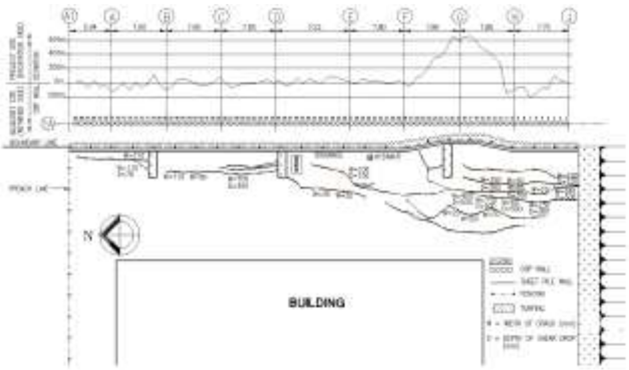

Fig. 9. Crack Mapping on Retained Ground of Distressed CBP Wall

4 CREATIVITY AND INNNOVATION IN BASEMENT CONSTRUCTION

4.1 Drained Basement

Basement as a submerged underground space subjects to severe hydraulic uplift structurally. When hydraulic head difference is created by excavation below the phreatic level, transient seepage commences until attaining either steady state seepage flow or hydrostatic condition without flow. If the perimeter basement retaining wall can be embedded deeply into the ground with adequate reduction of hydraulic gradient by deeper embedment depth or embedding into less permeable stratum to avoid unstable flow or/and control the volume of seepage flow, drain basement concept with a sustainable control of seepage discharge to reduce uplift pressure can be considered with economical design for deep basement. Otherwise very costly tensile anchorage system to hold down the basement slab/raft and heavy structural slab/raft design will be needed. Liew & Ting (2017) have presented a case study of drained raft for a top down basement construction very near to the coastal environment. Despite the design concept can be wishfully implemented, it is worthwhile to note that contingency measures shall be provided in the design to allow controllable distresses for timely necessary action should the drainage system fails to perform.

4.2 Jacked Anchors as Reinforcing Elements and Anchorage for Retaining Wall

This innovative application involves the use of hollow steel pipes jacked into the retained ground to form reinforcing elements within the active zone of retaining wall system to facilitate excavation, in which the idea was originated from a Malaysia geotechnical specialist known as Special Grouting Specialist Sdn Bhd (SGE). The pipe reinforcements have both the flexural and tensile strengths to structurally reinforce the active retaining zone and, also control the wall deformation and the ground surface movements. By the inclusion of these relatively stiff pipe reinforcements, the active retaining zone becomes a stabilized gravity block. Liew et al (2000 & 2003) presented an earliest application of this jacked pipe anchorages with temporary sheet pile wall for a 9m basement construction (Fig. 10 to 12) and soldier pile wall and contiguous bored pile (CBP) wall for a cut-and-cover tunnel construction of 17m deep (Fig. 13) respectively. Some worth-noting shortcomings of this system shall be highlighted with improvements. As the jacking reaction of the pipe is derived from the wall structure, wall deflection towards the excavation face is therefore increased during the pipe installation. Draining out of groundwater behind of the walls through the hollow annulus of the pipe anchorage can potentially draw the groundwater causing ground settlement. Another problem is the troublesome in backfilling of the voids and ground loss during the extraction of the temporary pipe anchorage system. The first problem can be resolved by spreading the jacking reaction via extended waler beams to more wall area to reduce the wall deflection. In addition, slight tensioning the pipe anchorage after termination of pipe jacking can reduce the subsequent excavation induced wall movement. Manual plugging the pipe by cement mortar can also be considered to stop the groundwater discharge. Grouting of the voids can be performed simultaneously with pipe extraction at alternate sequence. From the two case studies, it was proven the pipe anchorage system had performed very well in terms of overall performance of wall deflection and retained ground settlement. Especially the second case study, comparison between the conventional ground anchorage and the pipe anchorage evidenced the remarkable contrast of system performance.

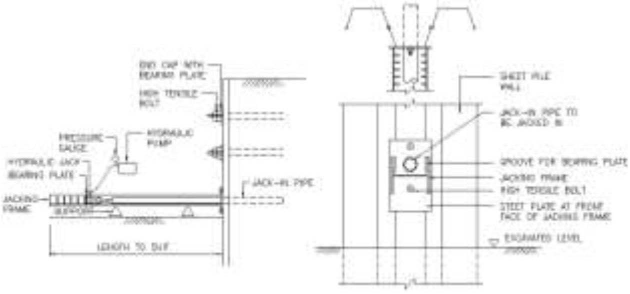

Fig. 10. Reaction System of Jacking-In Pipe Anchorage

Fig. 11. The Installed Jack-In-Pipe Anchorages at the Sheet Pile Retaining Wall of 9m High

Fig. 12. View of the Pull-Out Test Arrangement

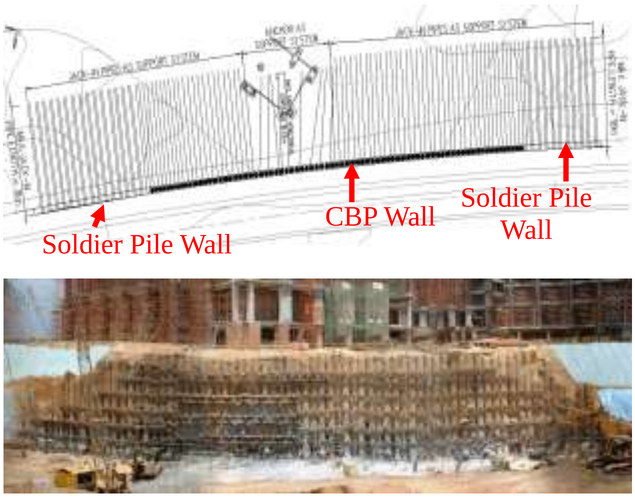

Fig. 13. Plan & Elevation Views of Cut-and-Cover Tunnel

5 CONCLUSIONS

This paper presents case studies with common leakage problem and uplifting heaving distresses in underground structures, special hydrogeological regime due to filling over natural valley terrain, use of embedded wall system resulting in perched water table, migration of fine soils with piping erosion failures. It is therefore very important to perform desktop study over the initial hydrogeological regime in the predevelopment terrain conditions and expect the possible subsequent changes of hydrogeological regime for retaining wall design.

Another innovation is to use the jack-in pipe anchorage to reinforce the retaining ground as gravity block for wall stability. Comparison of the advantages between the jack-in pipe anchorage and conventional ground anchorage is presented. Some improvements over the shortcomings in this pipe anchorage system have overcome the problems and becoming added advantages.

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