ROLE OF GEOTECHNICAL ENGINEER IN CIVIL ENGINEERING WORKS IN MALAYSIA

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Abstract : Geotechnical engineering is a specialised profession in the realm of civil engineering works and is gradually gaining popularity and acceptance from the civil engineering fraternity in Malaysia. As a result of rapid economy growth, civil engineers are facing increasing technical challenges than before in performing their professional duties. Much of the challenges are coming from the uncertainties in the ground conditions, which are sometimes the product of mother of nature or man-made, and the ability to adopt timely effective measures to reduce the inherent geotechnical risks. To recognise and understand geo-hazards, and formulate solutions to solve the issues, it takes a geotechnical engineer to start off with solid learning of good fundamentals, practical experience in executing the design in field, lessons learnt from case studies and failures, risk management and communication skill to convey the design content and proposed solution. This paper presents the career development of a geotechnical engineer from the real experience in the past, present and vision for the future. Some experience on the interfacing problems with civil engineers, structural engineers and engineering geologists in dealing with issues in projects will also be highlighted.

Key words : Geotechnical engineering, design codes, lesson learnt, soil structure interaction, innovation

1 INTRODUCTION

Malaysia is still a developing country, which requires extensive infrastructures and industrial development supporting its economic growth; and commercial developments and residential to cope for the population growth in the metropolitan city. Most of the favourable lands with strategic locations had been developed and leaving only the more challenging grounds for the present and future developments. These challenging grounds are either hilly terrain or land with underlying materials of notorious mechanical characteristics, such as soft compressible deposits, loose granular deposits, brown fills, karstic limestone, waste dumps, peaty soils, etc. In addition to these inherent unfavourable ground properties, project clients and local authorities have also demanded a more technically challenging criteria for the designs to ensure safety. The forms of structure proposed in this modern day demands taller and heavier structures, deeper depth of foundation and underground excavation. There are also structural forms and problems on the other opposite scenarios requiring technical solutions dealing with reverse actions from the grounds. Therefore, for projects involving substructure works with foundation and underground space excavation; site formation with cut slope, fill, retaining structures and ground improvement works, geotechnical engineer is usually engaged in ground investigation and geotechnical designs.

This paper aims to present the author's review of the role of a geotechnical engineer in the involvement of multi-disciplinary engineering projects nowadays and how the value adding process in identifying the foreseeable geo-hazards and mitigating the inherent geotechnical risks in the ground. One major distinction of geotechnical engineering practices as compared to general civil engineering practices is that geotechnical engineering requires competent relevant experiences for sound judgments and relatively less reliance to code based design. Along the way, engineering practices in designing and solving construction, problems encountered and exploring solutions in innovative ways, and communication interface with other project stakeholders are briefly discussed.

2 DEFINITION & SCOPE OF GEOTECHNICAL ENGINEER

2.1 Definition

The definition of geotechnical engineer in Malaysia is still somehow ambiguous in the public perception. It is often confused with the role of geologist as the public media tends to relate failures in the ground to geology when reporting ground related failure event. Nevertheless, among the professionals, geotechnical engineer usually means a qualified civil engineer registered with the Board of Engineers Malaysia as either graduate engineer or professional engineer having relevant and competent experience in geotechnical works, which shall encompass the ability to plan ground investigation and characterise the ground conditions for subsequent engineering processes, identify and assess the potential geo-hazards and the possible ground borne interaction to the proposed structures, and offer feasible engineering design solutions to ensure safety and satisfactory performance of the end product of the engineering works including its surrounding.

Relevant experience means the experience gained via the engineering process cycle in dealing with the specific nature of the geotechnical works, instilling such experience in the forthcoming project with similar geotechnical nature and assuring the satisfactory performance of the end product and its surrounding. Such relevant experience may consist of lessons learnt; compilation of statistical representation of engineering data and ground/structural behavioural performance; validation results of design element's performance; good engineering practices; evidence of successful engineering application and etc. Figure 1 presents the realm of the pertinent knowledge in the field of geotechnical engineering.

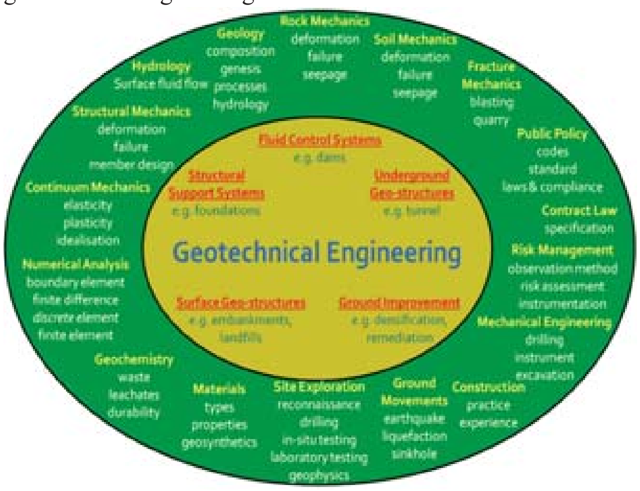


Fig. 1 Realm of Pertinent Knowledge for Geotechnical Engineering (Modified from Morgenstern, 2000)

2.2 Working Methodology

Through the training gained from the earlier career development of a geotechnical engineer, the working approach commonly adopted in dealing with the routine geotechnical works will be best illustrated by the Burland Triangle (Morgenstern, 2000) as shown in Figure 2.

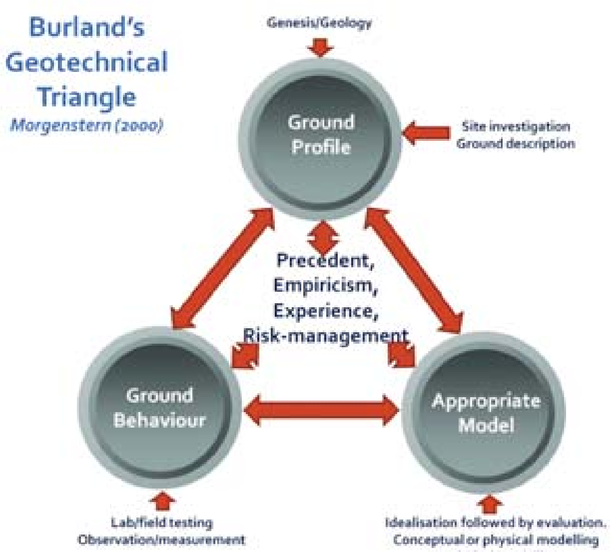


Fig. 2 Typical Working Approach of Geotechnical Engineering (Morgenstern, 2000)

In establishing the ground profile, proper planning and implementation of the ground investigation programme by the geotechnical engineer with occasional input from geologist advising on the genesis of the ground (depend on the ground complexity) will be necessary. Careful interpretation of the ground investigation results by geotechnical engineer is crucial for establishing the operational geotechnical model and identification of geo-hazard for subsequent risk reduction strategy. It is common in geotechnical professional worldwide that local experience and practices with local empiricism cannot be easily replaced by advanced investigation and modelling without local geotechnical input. The inherent variability and uncertainty in the ground lead to great difficulty in describing the ground in quantitative manner and provoke the nature of probability in geotechnical problems. Most of the project stakeholders dislike very much the nature of such uncertainty lying in the geotechnical assessment and designs as compared to the more deterministic approach achieved by the structure engineer. Because of the inherent uncertainty, it is somehow difficult to have a unified code based geotechnical design.

2.3 Scope of Geotechnical Works

The scope of works of a geotechnical engineer for a civil engineering and structural building works usually involves the following categories of works:

- Earthworks – Basement excavation, trench excavation, earth lateral support for underground space, earthwork re-profiling for site formation at hill site involving stability of ground with different levels and gradients, settlement of fill, retaining structures
- Foundations – Any means of geotechnical treatment (piling, ground improvements, buoyancy effect) intended to counter support the structure on land or underground, off-shore under individual or combined loading actions (gravitational or imposed loadings from external factors or environmental forces) to ensure its stability
- Soil-Structure Interaction – The interaction effect between the ground and any structural element(s) with expected design loadings or environmental forces in contact with natural earth materials (soils or rocks), man-made materials, groundwater having impact to the performance of structural elements partially or entirely, usually affecting either or both the ultimate and serviceability limit state conditions of the structures or supporting ground.
- Time dependent behaviour of the ground response or/and ground disturbance of external sources relevant to the potential distress of building structures. (soil consolidation, creep deformation, fill compression, densification, liquefaction, sink holes)
- Groundwater related problems – Drawdown and seepage in underground excavation, fluid containment, transfusion of contaminants, soil liquefaction, well yield or recharge problems

Figure 3 illustrates the overview of potential scope of geotechnical engineering with the abovementioned nature of works not only in Malaysia, but worldwide.

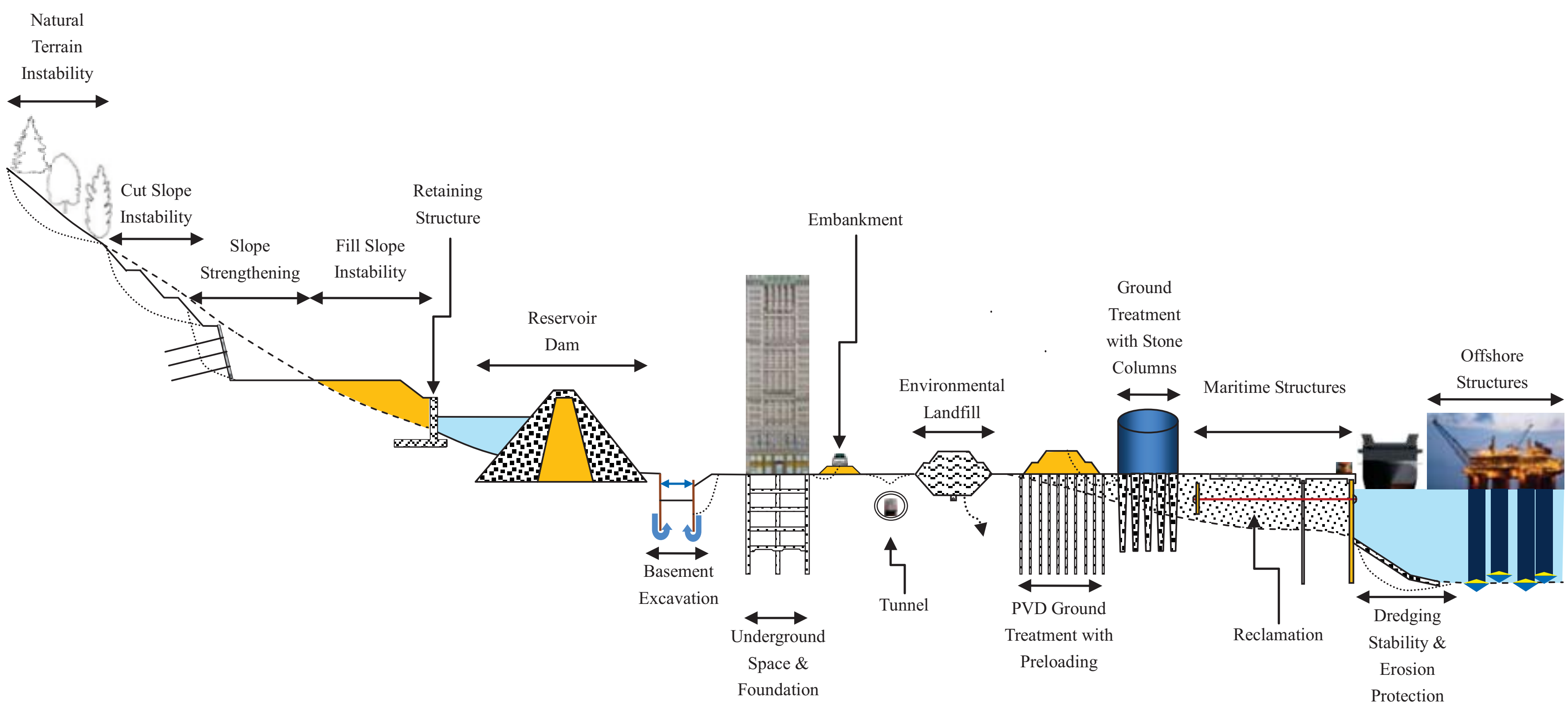


Fig. 3 Potential Scope of Geotechnical Engineering (modified from Atkinson, 2006)

2.4 Deliverables for Geotechnical Works

Generally, the expected deliverables for a geotechnical work in Malaysia can be classified into the following formats:

A. Geotechnical Interpretative Report – A report describing the approaches and standards taken to investigate the geotechnical aspects of the site and its surrounding where applicable, the interpreted geological model (extracted from geological report as supplementary report if appropriate) with due highlight of potential geo-hazards and geotechnical model characterising the ground with appropriate engineering parameters for engineering assessment or/and analysis. Sometimes, interpretative report is also produced for the assessment of the validation tests or instrumentation results in reviewing or reassessing the geotechnical design.
B. Geotechnical Assessment Report – A report describing the approaches and standards in assessing the geotechnical risks, options to mitigate the undue risk, recommendations of provision on design validation tests/inspection during construction, precautionary measures and monitoring requirements during construction and post-construction.
C. Geotechnical Analysis & Design Report – A report presenting the design assumptions for specific geotechnical design elements with caution notes for validation requirements, design calculations, analysis results, design detailing, critical work sequence, specification requirements, drawings/sketches for geotechnical element design.
D. Geotechnical Review Report – A report presenting the independent review on interpretation of subsurface conditions, engineering assessment, design detailing by other qualified person in the form of above mentioned documents, specifications, drawings and etc to ensure compliance to norm standard and safety aspects.

In some cases, Documents A, B and C can be combined in one comprehensive report addressing all the respective contents in the individual report as aforementioned. Figure 4 shows the relationship and sequence of the respective deliverables of typical geotechnical works.

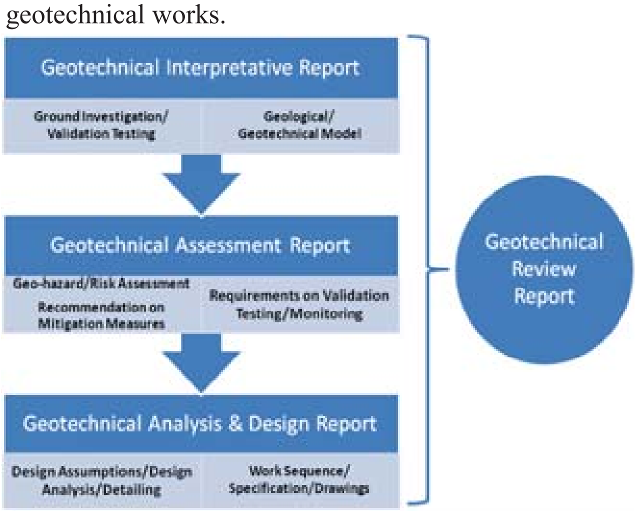


Fig. 4 Relationship of Deliverables of Typical Geotechnical Engineering Works

2.5 Supervision for Geotechnical Works

In the past history of construction, very simple but harsh punishment with the philosophy of retaliation was applied to the builder, who is also the designer. Here are the two cases:

- Babylonian King, Hammurabi (1792-1750BC): - "If a contractor builds a house and it collapses killing its owner, the contractor will be killed. If the son of the owner is killed, then so will be the son of the contractor."
- Napoleonic code (1804):- "If a structure had a loss of serviceability within 10 years of its completion, due to poor workmanship or foundation failure, then the builder would be sent to prison."

Presently, the professional liability of a professional engineer to the project he/she undertakes is perpetual in Malaysia. The same applies to the professional engineer practices in geotechnical works including supervision of SI works. Usually, geotechnical engineer is considered as specialist assisting the principal civil and structural consultant, who is usually the submitting person to the local authorities and is assuming the full professional liability for his project submission. Unless for advisory role, the geotechnical engineer shall be accountable for the construction compliance and correctness of the as-built drawings of geotechnical works by the work contractor. This can only be done if the works are supervised by the geotechnical engineer, who designs the works.

3 NATURE OF GEOTECHNICAL WORKS

The value of appointing a geotechnical engineer in a project would be illustrated in this section. It is important to understand the role of the geotechnical engineer in relation to the term of reference of the appointment when performing the geotechnical design with different parties. Such illustration can be divided into geo-hazard identification and approaches taken to mitigate the identified risks, how value engineering process and innovation can be incorporated in the design process, and well though tender strategy and contract arrangement for competitive pricing and possible value engineering by the tenderers.

3.1 Geo-hazard Identification and Mitigation Measures

The basic training of a geotechnical engineer is to have the capability to identify the potential geo-hazard associated in the ground where an activity or construction is intended to happen there. Within the practical financial allocation and constraints given, the geotechnical engineer shall be able to propose risk mitigation options for project client to consider. Ability to explore options on the potential mitigation measures is always important as there is no unique way of handling the identified geotechnical risks. This aspect of works has been addressed in the earlier Section 2.2. The common geotechnical problems encountered in Malaysia with the author's personal experience either as project engineer or forensic investigator in failures related to geotechnical works are presented in Table 1.

Table 1 Common Problems of Geotechnical Works in Malaysia

Geotechnical Elements	Common Problems in Malaysia
Ground Investigation	• Improper drilling technique to advance borehole causing disturbance before sampling and problems for in-situ testing. • Poor recovery in disturbed and undisturbed sampling. • Unsatisfactory sample disturbance (inadequate drilled-hole cleaning, handling and storage of samples). • Lack of advanced testing equipment (ring shear for residual strength, resonance column for small strain stiffness measurement). • Lack of knowledge in engineering geology during planning and interpretation of ground investigation. • Improper use of geophysical methods & questionable capability in interpretation of geophysical data by pure geophysicist without geological knowledge. • Unattractive remuneration in ground investigation industry (losing skilled and knowledge professionals). • Shifting of skill personnel to more blooming oil and gas industry.
Geotechnical Testing & Instrumentation	• Project client not willing to invest in validation testing and construction monitoring as this aspect is perceived as necessary but not rewarding in their project feasibility plan. • Real time monitoring for critical works is still uncommon in Malaysia. • Often threshold criteria of the measurement were not specified by the designer or overly general to be included in the interpreted output. • Usually lack of timely review of the monitoring data as the interpretation process is boring or slow in making availability of the monitoring report. • False alerts due to unavoidable measurement fluctuation reduce the sensitivity of the decision maker for necessary timely actions. It is often expected that the true result of the "erratic measurement" may be shown in the next monitoring trip and might therefore lose the timely actions.
Earthworks	• Material classification on soils, hard materials and rocks causes serious dispute in earthworks contract as thick weathering profile in overburden materials are common in Malaysia. Rightfully, the rates for excavating different materials shall tie with the physical effort of removal or excavation, i.e. whether by common excavation, scrapping, ripping, mechanical hacking or blasting. However, the contract rates for removing more difficult materials will rise drastically and attract the work contractor to use excavation method for removing hard materials or even rocks without serious consideration of losing work efficiency. Therefore, a study conducted by Public Work Department (PWD, 2005) has suggested to classify the material type by the production rate in additional to the conventional method of adopted method for material removal. This will encourage the work contractor to adopt the most cost efficient method with consideration of the heavy penalty from the liquidated ascertained damage imposed in the contract. • Improper site clearing (salvaging topsoil, left over tree trunks, roots, etc) prior to major contract production works. • Filling over natural valley with potential existing deposited soft materials and natural seepage (usually no design provision of subsoil drainage for natural seepage within the natural valley). • In earthwork compaction design, standard compaction practice, i.e. either standard or modified Proctor compaction standards is usually adopted. The specified compaction requirements have hardly been checked against the actual strength requirements and stiffness required for the project. • Uncontrolled end tipping practice can be an issue in normal earthwork construction if method statement is dully reviewed or the works are not supervised. • Compaction in trench excavation is usually poorly carried out.
Soft Ground Engineering	• After the development of the bowl-shaped settlement profile, poor discharge efficiency of prefabricated vertical drain in the drainage blanket in traditional PVD ground treatment is usually observed. The simple method to improve the discharge efficiency can be done to place the perforated collection pipes within sand blanket to a collection sump for pumping. • Improper design and analysis of stone columns causing failure to embankment (Gue & Tan 2005). • "Mushroom" problem (uneven surface with large differential settlement like mushroom on the road surface) due to lack of understanding of the soil arching effect for embankment supported by individual pile caps in soft compressible ground. (Gue & Tan, 2005)

(Continue Table 1)

Geotechnical Elements	Common Problems in Malaysia
Slope Engineering	• Subjectivity in determination of rock mass strength for the instability assessment of weathered & fractured rock slope (Liew & Liong, 2006). • Interpretation of soil strength envelope is usually oversimplified, i.e. the nature of non-perfectly linear failure envelope and inappropriate stress range for the problem. • Stress relief due to excessive earth cutting and progressive failure due to different level of strength mobilization of stiff residual soil slope. Progressive failure mechanism associated to strength brittleness of stiff residual soils is not addressed in slope stability assessment (Liew et al., 2004a & Liew, 2004b). • There are primarily three types of soil strengths, namely peak strength, critical state strength and residual strength. Current practice on slope stability assessment in Malaysia is to apply the specified safety factor to the interpreted peak strength. It is crucial to have different safety factor requirements for different strength adopted in the design. For instance, it may be un-conservative to use peak strength for soils with high brittleness index, in which progressive failure can be prominent or over-conservative to apply the specified safety factor to residual strength for failed slope. • Large scale slope creep movement is costly to stabilised (Liew & Gue, 2001). • Perched water regime in overburden soils above bedrock is not identified for slope design (Liew et al., 2004b) • Relict joint/structures are usually undetected during the investigation and considered in design stage. During construction stage, little verification on the design assumptions on these potentially undetected structural geological features is carried out. • Risk assessment and prioritization. • Misused or abuse of prescriptive method in slope design. Basically designing slopes by specifying slope angle without proper analysis. (Gue & Tan, 2007). • Improper design of soil nail facing causing failure to the soil nail slopes. (Tan & Chow, 2009).
Retaining Structures	• Piled wall with poor lateral pile resistance (Two unfortunate cases – Cases E & F were reported in a technical paper by Liew, 2008) • Reinforced wall distress due to groundwater build-up in the wall. (Tan et al., 2007; Tan & Khoo, 2007) • Un-integrated design approach of reinforced soil wall (Mechanical Reinforced Earth/Geo-synthetic wall). This practice is common in the alternative design offered by a proprietary wall specialist to replace the compliance retaining wall design in the tender. The proprietary wall specialist assumes the external wall stability (bearing, overturning and sliding failures) should have been considered in the original design and their responsibility is solely on the internal wall stability. This might not be always the case as assumed if the original retaining design is not the gravity wall type. • Large deformation of geo-synthetic reinforced soil wall can be an issue when building the wall right to the land boundary. The deformation due to mobilized extension strain of the geo-synthetic reinforcement can cause land encroachment with its bulging wall profile and structural distress of brittle concrete elements, likes drains or concrete fencing wall, built over the geo-synthetic reinforced zone. • Brittle masonry wall is not appropriate if proper foundation support with acceptable differential settlement is not allowed in the design.
Basement Excavation	• Leakage of water carrying utilities due to or causing the movements of retained ground. • Improper strutting design (member sizing, support and bracing detailing, pre-stressing strut load) and connection. • Inadequate wall embedment due to design provision or installation obstruction causing excessive seepage inflow or even piping failure, inadequate passive resistance. • Basement wall leakage at wall joints, honey-combing in concrete of wall body in slurry trenched wall. • Lack of understanding on the soil model, soil strength & stiffness parameters used in the FEM analysis causing failure of basement. (Tan & Chow, 2008) • Importance of control of groundwater level in the retained ground to prevent affecting the adjacent structures and utilities. (Gue & Tan 2004a) • Inadequacy of geotechnical design to check for various modes of failures (e.g. overall stability, basal failure, hydraulic failure). (Gue & Tan 2004b). • Lack of construction control and site supervision by Consultant such as over-excavation (e.g. excavate deeper than designed depth) and uncontrolled surcharge at retained soil (e.g. stacking of excavated materials or other materials behind the wall at the retained side). (Gue & Tan 2004b)

(Continue Table 1)

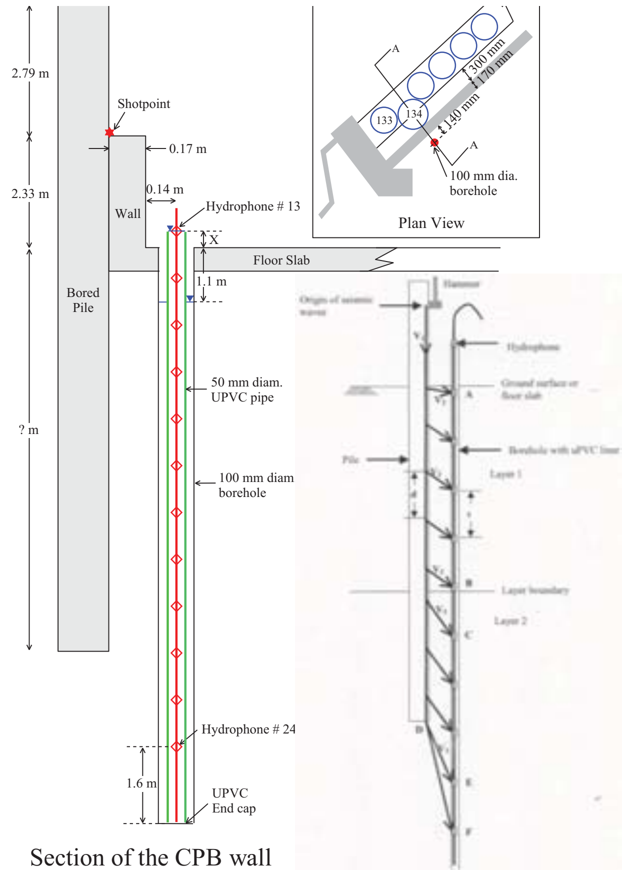
Geotechnical Elements	Common Problems in Malaysia
Foundation	• Pile group effects are either not considered or overly emphasized (rendering unrealistic pile differential settlements) in the pile foundation design. • Pile heave & lateral soil displacement problems due to installation of closely spaced piles and rapid pile installation in fine grain soils are not considered in pile design process • Downdrag on foundation piles in settling ground (Gue et al., 2000 & Liew 2002c) • Raft-soil interaction effect for raft or slab on grade foundation design is commonly treated by structural engineer by requesting a value of subgrade modulus from geotechnical engineer. • Strong association of construction method to the design pile resistances in bored cast-in-situ concrete piles is difficult in foundation design. • Soluble limestone problems and its treatment prior to foundation installation. • Piling problem related to karstic features of limestone. (Tan & Chow, 2008)
Maritime Works	• Improper use of proprietary shore protection system leads to uplifting of the protection layer from the side slope underneath wharf deck and migration of hydraulic fill from upper slope to slope toe as a result of unbalance water head between the sea side and the reclaimed land. The primary reason of the uplifting of the protection layer is the potential clogging of the geo-synthetic filters of limited provision in the protection materials.
Environmental Works	• Landfill materials are fairly difficult in characterizing their engineering behaviours, particularly the compressibility and strength due to heterogeneity of material composition and time dependent decomposition rate. The unpredictable differential settlement at the landfill closure surface results in unacceptable serviceability limit condition of the gravity flow of surface runoff and leachate, damage of maintenance access and closure lining cover, tilting of landfill gas vents, etc. • The side slope of the uncontrolled landfill is usually very steep and high without benches as a result of dumping process by end tipping and push-over. Encroachment of waste line with steep side slope of the waste leads to the need of significant re-profiling of the waste dump for stability. • Hydro-geological aspects of the leachate contamination of the unlined landfill is very challenging because the hotspots for uncontrolled landfill are usually valley in the remote plantation land, existing mining ponds, riverbank, coastal lines.

3.2 Innovation and Value Engineering

Innovation on analytical methodology and construction techniques can only be materialised with some degree of flexibility of the control imposed by authority. Geotechnical engineers in Malaysia have been enjoying such flexibility without much governance control from the authority on the design and construction methodology for geotechnical works. Some examples of innovative application in geotechnical engineering works are given here to illustrate how to think out of box in the process of innovation.

Case 1 - A compressive P-wave application to determine the as-built lengths of constructed piles in abandoned projects being revived is presented in Figure 5. In this case, the as-built pile construction records were unavailable and the interpretation of normal dynamic pile testing was difficult because the pile was structurally connected by the concrete capping beam with other piles forming a contiguous bored pile (CBP) wall which was in turn connected to the concrete basement slab. For the proposed innovative method to investigate the pile length, a borehole was drilled 300mm from the edge of the pile reaching a depth beyond the design length of the pile. An array of hydrophones at 1m intervals in the borehole filled with water detected the seismic signal created with a sledge hammer impacting at the upper portion of the pile. The test was repeated with the hydrophone array raised by 0.5m in the hole. In Figure 6, the first arrivals from the two tests are combined and plotted against the depths of the hydrophones to yield the equivalent of a single set from a string of 48 hydrophones of 0.5 m intervals. It is assumed that the first arrival of the travelling wave picked up by the hydrophones located within a similar soil layering will be a linear line on the plot as Figure 6. The boundaries between the three subsoil layers were identified by offsets (flatter sections) of the resulting first wave arrival of every hydrophone, each offset indicating a change in velocity from one soil layer to another. The depth of the pile toe was where the plot deviated from a straight line because seismic wave travels at lower velocity in the soil beyond the pile toe compared to the higher velocity in the pile concrete material. The lower graph in Figure 6 shows the P-wave travelling path through pile and various layers of subsoils.

Fig. 5 Contiguous Bored Piles with Structural Concrete Capping Beam and Skin Wall



Section of the CPB wall and hydrophone array

P-wave travelling path

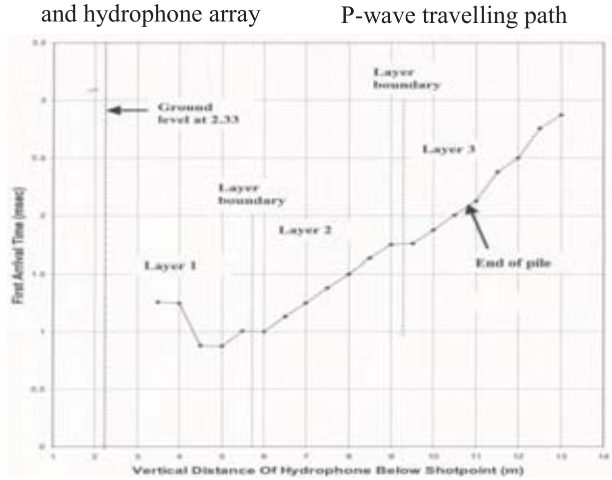


Fig. 6 Pile Toe Detection by P-Wave technique

Case 2 – An innovative instrumentation scheme for downdrag measurement of two hollow circular pre-stressed spun piles at a bridge abutment as reported by Gue et al. (2000). Liew (2002c) has further demonstrated the significance of downdrag on piles in settling soils with this case history. The instrumentation results yield useful findings that downdrag does exist in residual soils, which are capable of supporting a 9m high Reinforced Earth wall approach embankment and the “hang up” effect is observed between the middle pile and the edge pile among the group piles. Figure 7 shows the sectional and perspective views of the proposed scheme for downdrag measurement.

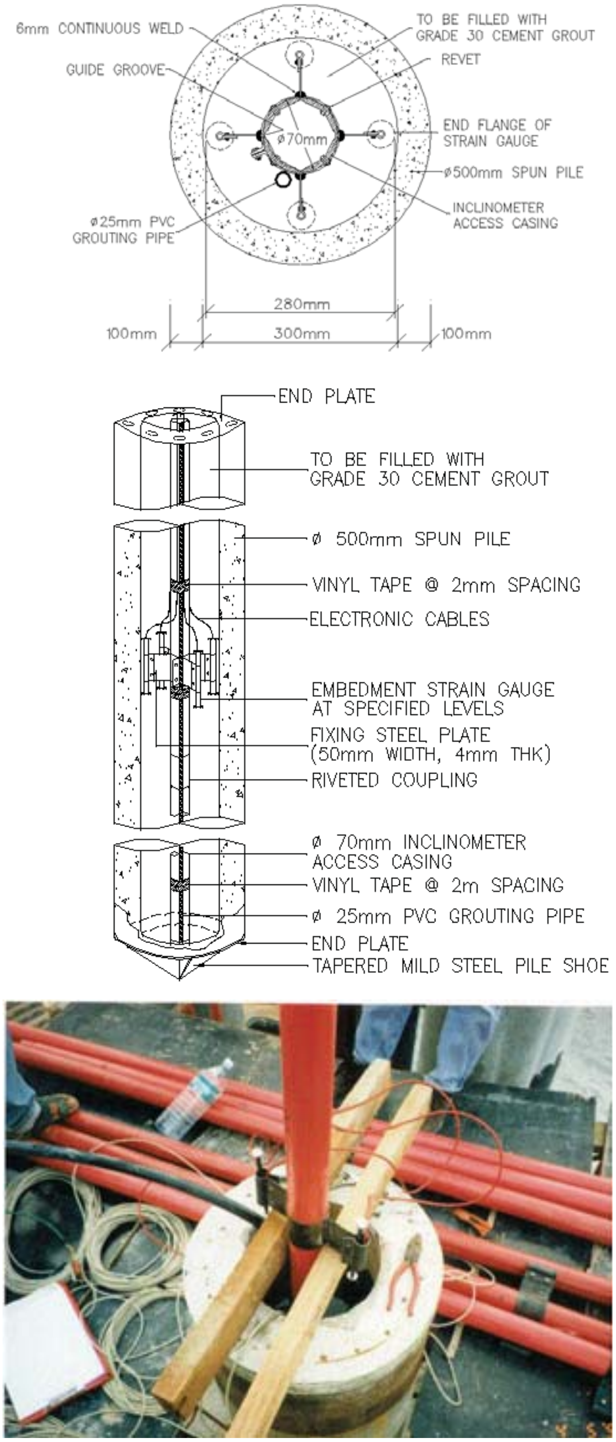


Fig. 7 Sectional and Perspective Views of Instrumented Test Pile and Process of Installing Strain Gauges with Inclinometer in a Spun Pile (Gue et al., 2000)

Case 3 – A proprietary jack-in pipe anchorages, namely SGE Jacked Anchors, was adopted for two open cut excavations with retaining heights of 9m in sandy alluvial deposits and 17m in 10m thick clayey silt fill over weathered meta-sedimentary materials. These two case histories are documented by Liew et al. (2000 & 2003). In the second case history, comparison of the performance between SGE Jacked Anchor and conventional pre-stressed ground anchor was carried out. From the instrumentation results, the jacked anchor wall behaves as a semi reinforced soil wall with better overall performance as compared to the pre-stressed anchored wall. Intensive soil-structure interaction can be observed between the soil and the jacked anchors. As a result, earth pressure immediately behind the jacked anchor CBP wall is much less as compared to the one with pre-stressed ground anchors. This is because part of the resistance to the active zone within the reinforced area has been provided through the interfacial resistance of the jacked anchors before it is fully transferred to the wall.

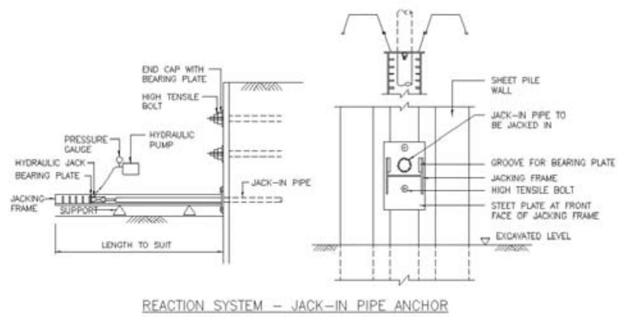


Fig. 8 Jacking-In Process of Pipe Anchorage (Liew et al., 2000)

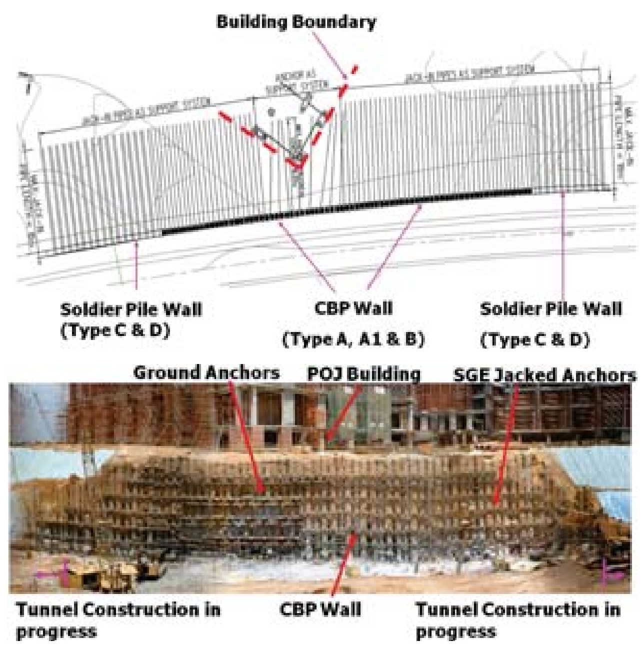


Fig. 9 Jacking-In Process of Pipe Anchorage (Liew et al., 2003)

Case 4 – Value engineering of innovative wharf retaining structure and tank storage foundation using frictional piles of varying lengths. This project was a palm oil mill project with production capacity of 120Ton/hr for extracting the palm oil from Fresh Fruit Brunch (FFB) located at the east coast of Sumatra of Indonesia. Due to the very weak coastal flood plain deposits, it is practically difficult to design a wharf wall for the FFB Unloading crane bay with dredged canal of 3.6m water depth. An innovative design concept of installing the sheet piles in a successive "T" arrangement to act as a container for soil containment was adopted. At the same time, the sheet piles also act as the primary supports for the wharf deck. Figure 10 shows the schematic diagram of the design (top two diagrams). Only 12m long FSP IIIA section sheet pile section was used. This penetration length would not be possible to have adequate wall stability in the conventional cantilever retaining wall design. Figure 10 shows the erected steel frames of the crane system over the canal upon completion.. Liew (2002b) presented the value engineering exercise for this project site with this innovative retaining design as one of the components.

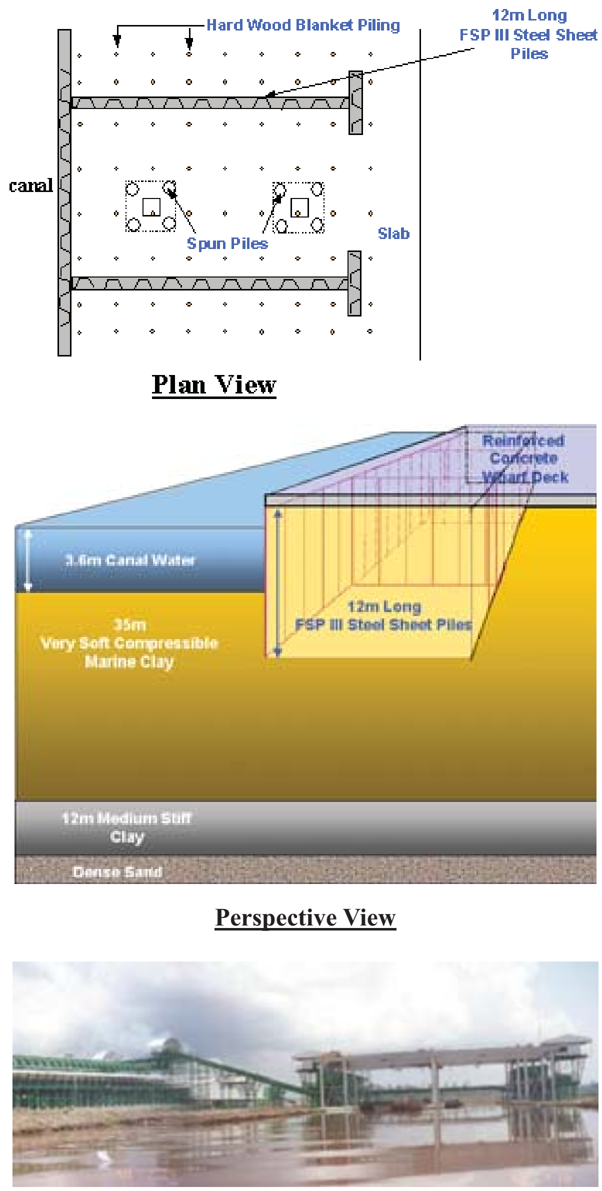


Fig. 10 Plan, Perspective & Overall Views of Fresh Fruit Brunch (FFB) Crane Bay (Liew, 2002b)

In the same project, there were seven numbers of heavy steel tank structures for the storage of processing water and processed palm oil. The total weight of the tank structure is about 3500Ton including maximum storage capacity of 3000Ton for water or crude palm oil. The steel tanks are seated on 0.5m sand bed coated with bitumen strips in order to have uniform seating between the coned-down tank base and the reinforced concrete (RC) raft with thickness optimized to 500mm. This is rather thin as compared to the similar type of tank structures on frictional piles. Figure 11 shows the schematic diagram of the tank structures, the tank raft and the frictional pile foundation. A total number of 137 of 350mm diameter hollow circular pre-stressed concrete (PC) spun piles with characteristic concrete strength of 60MPa were designed and installed to support the tank through the RC raft. Figure 12 shows the installation of the tank foundation piles. To avoid the bowl shaped deflection profile of the raft as a result of the interaction effect of large floating piles group, the floating piles are designed with varying lengths to control the deflection profile of the raft as part of the design optimization for the raft. The central portion of the raft is supported with longer piles, in which the supporting stiffness is relatively higher than that of the short piles at outer rim of the raft. Figure 13 shows an overall view of the tank farm with partial completion. Detailed documentation on the performance of the tank foundation can refer to the technical paper by Liew et al. (2002a). This case study was also re-analysed by Randolph et al. (2004). The earthworks and foundation designs in the original design was about 75% of the total cost of civil and structure contract package. The alternative designs had achieved a total cost saving of about 30% of the total civil and structure contract cost. With the innovation and costs saving for a foreign project, this project has also won the award of commendation from Association of Consulting Engineers Malaysia.

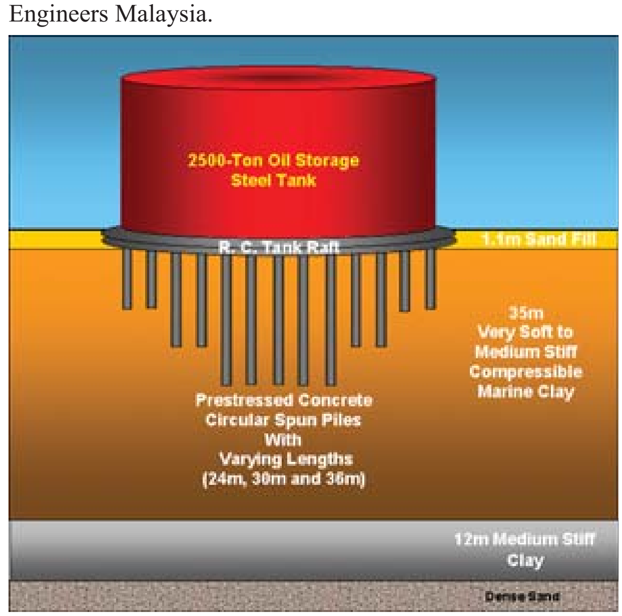


Fig. 11 Schematic Diagram of Frictional Piled Raft Foundation for Storage Tank

Fig. 12 Installation of Frictional Piled Raft Foundation for Storage Tank

Fig. 13 Completed Storage Tank on Frictional Pile foundation

Case 5 - This case history involves construction of a high-rise mixed development with a five-and-half storey basement car park adjacent to an existing commercial development. Figure 14 and 15 show the elevation view of the structure and the original terrain of the project site. The entire excavation is about 250m long over an uncontrolled fill to the depths ranging from 7m to maximum of 14.5m. The inherent seepage in the natural valley had resulted into saturation of the lower fill materials. Groundwater levels were fluctuating and exhibiting seasonal storm responses throughout the construction period. The topographical features of a previous natural valley suggest that collection and concentration of underground seepage may have occurred within the previous valley. This is particularly evident in the soggy and saturated conditions of excavated materials immediately above the valley. Serious surface tension cracks on the road were observed during the earthwork cutting for the basement construction. Subsequent investigation revealed that a thin soft and weak material of about 2m thick was founded deposited at the lower part of the valley area as shown in Figure 16.

The proposed strengthening works for the uncontrolled fill with underlying soft compressible deposits consist of seven rows of 12m long soil nails with gunite surface to provide overall reinforcement to saturated uncontrolled loose fill and lateral support with 12m long FSP IIIA sheet pile wall anchored by two rows of 18m long soil nail and permanent reinforced concrete props against the basement structure for the passive resistance to stabilise the sliding movement of the reinforced loose fill overlying the soft and weak deposits. The cross-section of as-built stabilisation work at the valley area is shown in Figure 17. During strengthening works, further deterioration of the previous distresses was observed, but with much reduced rate as compared to the earlier open cutting before the strengthening works. The instrumentation programme served well in the construction control for this strengthening works. The slight drawbacks of the soil nail strengthening technique are the unavoidable encroachment of the nail reinforcements into the retained ground, which sometimes can be beyond the project boundary, and ground disturbance resulting from the drilling operation. From the cost aspect, the entire stabilisation work for this project site had achieved an estimated cost saving of about 40% when comparing to the conventional continuous bored pile (CBP) wall design for the basement construction in similar loose fill. This case study was reported by Liew & Khoo (2006 & 2008).

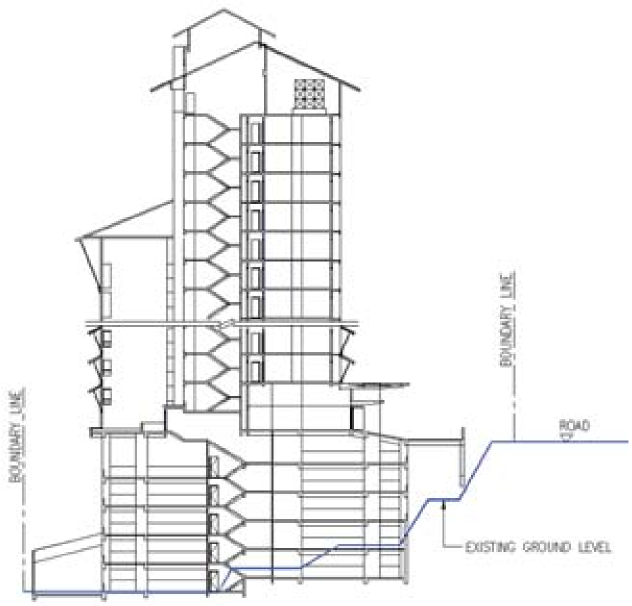


Fig. 14 Elevation View of the Proposed Structure and Ground Profile

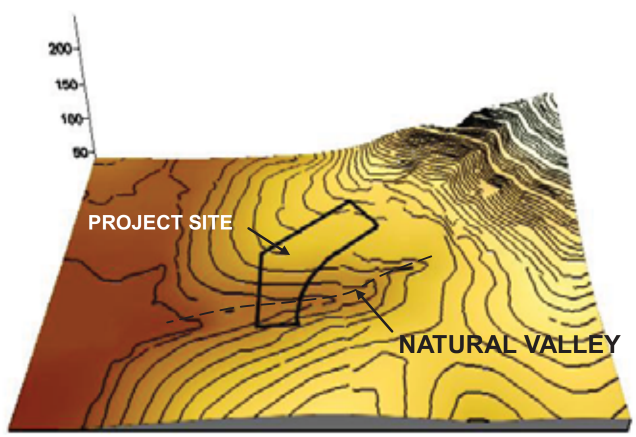


Fig. 15 Original Terrain of the Project Site

Fig. 16 Soft Compressible Deposit at the Valley as exposed during Pilecap Excavation

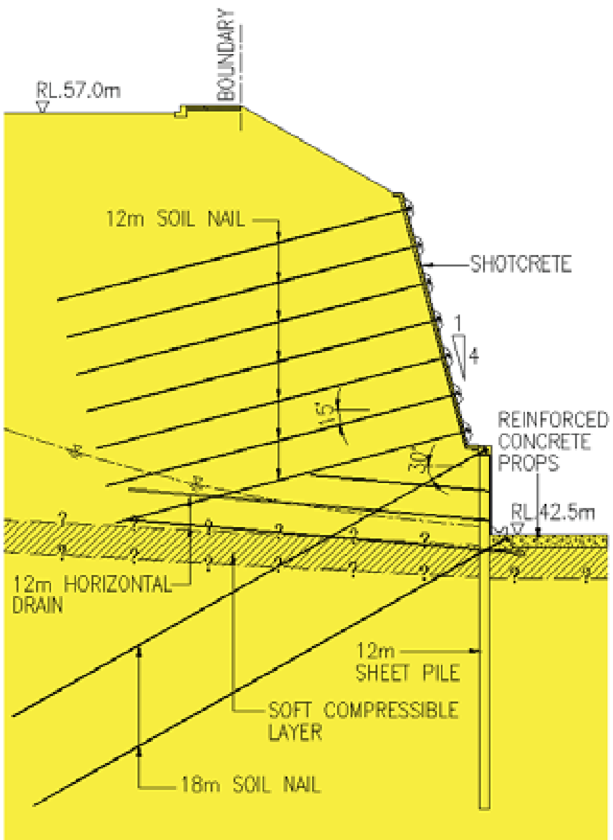


Fig. 17 As-built Details of Strengthening Works

Case 6 – This case history documents an interesting marine breakwater structure using circular pre-stressed concrete spun piles. The proposed breakwater is required to protect the boats and yatchs (10ft to 200ft) parked within the marina bay for the resort development from wave attack. The site is underlain by thick soft marine clay with thin layer of drifted sand material from the hydraulic fill of the adjacent site. The design concept is to install a row of vertical circular piles with gap of specified width for the wave to penetrate through. These vertical piles installed with sufficient embedment to take the wave action were capped by a structural reinforced concrete beam and further supported by a pair of raked piles at certain fixed interval. The interference of the penetrated wave through the small gap along the breakwater wall will tend to cancelling each other resulting to a travelling wave with very much reduced wave magnitude. Figure 17 shows the overall view of the completed breakwater structure.

Fig. 17 Completed Structural Breakwater Structure using Pre-stressed Concrete Spun Piles

3.3 Strategy in Tender and Contract Arrangement

In the competitive business world nowadays, most project clients focus very intensely on how to achieve either of the economic price, faster construction, better functionality and standard of the end product without cost and time increase in the tender package for a construction works. It is usual that engineering consultant will be appointed to undertake the engineering process from desk study, planning of investigation, preliminary and detailed engineering, tendering, construction until maintenance after handing over for operation (sometimes, the design consultant is retained for the operation and post-construction maintenance). It would be advisable that the design consultant shall aim to provide a feasible base design for tender purpose. The design shall be in principle sufficiently generic and buildable for tender invitation to reasonable number of pre-qualified tenderers. Bearing in mind, the principle of economy is always valid that reasonable and fair competition will lead to most cost efficient output. Therefore, it is always to the client's benefit to allow alternative design or value engineering from the tenderers with proper performance specifications on partial design components or entire design to ensure minimum standard of the functionality and quality. The workable base design in the tender forms a reference datum of basic pricing. For tenderers who have ways to offer more competitive price for alternative in additional to the compliance tender as a result of using proprietary system with innovation on materials, construction methodology, construction speed (cutting down overhead cost and double handling cost), efficient logistic or/and resource planning, alternative proposal can be considered together with the pricing for compliance tender offer as price comparison in the tender evaluation. Technicality of the alternative proposal shall be reviewed and approved by the design consultant. In this context, geotechnical engineer shall play vital role in minimizing the exposure of the base design to geotechnical risks and assess the same for the proposed alternative options from the tenderers to avoid preventable problems.

3.4 Forensic Investigation (Latin adjective: “forensis”- of or before the forum)

The best way to learn or comprehend the consequence of ignorance, design overlooks or overconfidence of an engineering works which fail is to run though a complete investigative cycle or procedure looking for factual evidences and rational reasoning of the causation out of the probable possibilities and sequence of the failure events. Forensic investigation can yield very valuable lesson learnt and unforgettable experience for engineer to prevent similar recurrence.

The common problems faced in forensic investigation are: overwhelming of either irrelevant or conflicting information; untimely access to the scene for gathering first hand information. Every single observation at the site on the features of debris formed, traces of previous movements/impacts, water flow or seepage condition will help to re-establish the probable sequence of events. The possible design scenario shall all be exhaustively considered in the investigating process. The approach taken in forensic investigation is somewhat different from formulating a design at the onset of a project. The common types of geotechnical forensic investigation in Malaysia involve landslides, excessive deformation or collapse of foundation, retaining structure, support, geotechnical structures or ground. As some geotechnical structures involve complex action-soil-structure interaction, it is essential to figure out the moment of which certain components in the system reach their corresponding ultimate limit state condition leading to the unacceptable performance. Forensic investigation is often tied up with legal proceeding to recover and apportion the damage and responsibility of a geotechnical structure in distressed condition to the parties at fault. If the insurance claim involves geotechnical failure of complicated nature, the loss adjuster will recommend engagement of geotechnical specialist consultant to produce the investigation report to identify the causation and determine reasonableness of the proposed remedial solution by the insured.

Common findings in geotechnical forensic investigation by the author are as follow:

- Poor understanding of ground conditions due to inadequate ground investigation and laboratory testing,
- Technical deficiencies, likes design errors, mistakes in specification or construction/shop drawings,
- Non-compliance on materials, approved method statement due to lack of supervision,
- Lack of maintenance,
- Improper usage of structure during construction stage by builder or operation stage by owner,
- Vibration and erosion.

In most cases, the first three factors account for the failures.

4 INTERFACING ISSUES WITH OTHER SPECIALISTS/PROJECT STAKEHOLDERS

In most engineering works, there are always interfacing issues between the different engineering disciplines. It is crucial to have a proper protocol of communication to ensure good exchange of concept or idea throughout the entire engineering process. This section will discuss the common problems encountered when interfacing with other disciplines:

4.1 Civil Engineer

The following examples are the common arguments pertaining to geotechnical works with civil engineer:

- During the ground investigation planning, the focus of the investigation is concentrated on the foundation design of road structures along the proposed alignment, like bridges, culverts, retaining walls and fill embankment. Other important aspects, like the cutting into the natural hills or filling the valley with earth embankment for the road formation, are usually neglected and subsequently incurring more cost for expensive rock excavation, strengthening works or remedial works for failures after completion.
- Piled bund wall for tank farm development built over consolidating platform – Civil engineer prefers to use pile foundation in weak ground. In this case, the bund wall may be well supported by the pile foundation without uneven crest level resulted from differential consolidation settlement, but the ground settlement will also leave a gap beneath the soffit of the piled bund wall rendering the unsatisfactory function of oil spill containment.
- Settlement problem between piled structure and settling ground – This is common in the transition zone between the piled structures, like bridge, culvert, piled embankment, and the non-piled support ground. A long transition structure is therefore required to achieve the specified criteria for differential settlement.
- Paradox of laying of embankment fill of certain thickness over soft deposits with on-going consolidation settlement more than the embankment height – This scenario is rather difficult to explain as the phenomenon is against the normal perception despite the technicality of the logic can be substantiated.
- The use of masonry brick drain for long drain requiring deep invert level – It is common practice to use brick drain for surface drainage in road, housing, commercial, industrial development. For deeper drain, concrete bracers at certain interval are used to maintain the drain wall stability. However, there is limit for such bracing to be effective for brick drain of certain depth.

4.2 Structural Engineer for Building Works

When dealing interaction problem of structures in contact with the geotechnical medium, the structural engineer, who usually lead the design direction of the project, will usually made assumptions over the boundary condition at the interface between the structure and the geotechnical medium or estimate the approximate geotechnical loadings, and proceed with structural analysis with the imposed loadings according to the adopted loading codes. Thereafter, the design performance criteria of the geotechnical design are then specified for the geotechnical engineer. There are cases whereby such working framework seems to be on the conservative side in the opinion of structural engineer, but sometimes the geotechnical engineer views it otherwise. Simplification of a complicated engineering problem to ease the solving difficulties is somehow necessary, however compromising of necessary analytical details, overlooking of potential negative consequence and irrational design can arise from oversimplification. In the process of such simplification, the outcome will lead to solving the problem independently by splitting the structural analysis and geotechnical analysis with very little interaction. But at the end of both analyses, a reconciliation of both analyses is inevitably needed to ensure proper overall performance.

With structures getting taller and heavier, it is unreasonable to assume zero or constant foundation settlement under structure load. To achieve such criteria, geotechnical engineer will have to reconfigure the foundation design with due consideration of soil-structure interaction effect. The conventional way of getting the safe working load of a foundation pile to compute the pile quantity under a column may not be sufficient. This is because the actual load path and distribution of the structure loading to the foundation can be significant different if the foundation response under the imposed load is included in the structural analysis. Figure 18 shows the illustration of such condition and indicates potential of under provision of foundation for external columns and over provision for the central column if the foundation provision is based on the column loading from the analytical results with constant stiffness supports. In numbers of case histories for highrise structures in Malaysia (Baker et al., 1994 and Hewitt & Gue, 1996), the monitored column settlement results tend to confirm the centre of the highrise usually settles relatively more than the external columns a result of soil-foundation interaction effect. For the soil-structure interaction problem, there are attempts from the structural engineer to model the interaction effect by multiple cross springs among the foundation support node points with the assumption of linear elastic behaviour in the interaction as shown in Figure 19. However, most geotechnical problems involving the continuum mechanics of semi-half space medium with different loading transfer mechanism from the superstructure makes it difficult to derive the corresponding spring stiffness. As such, the practicality of such approach can be questionable.

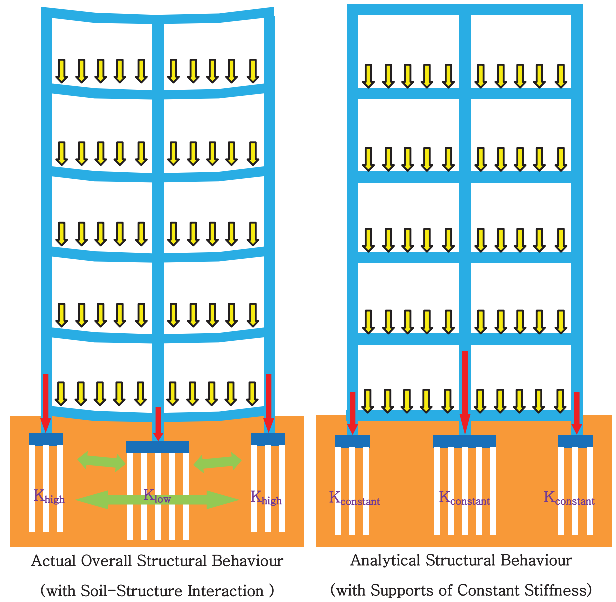
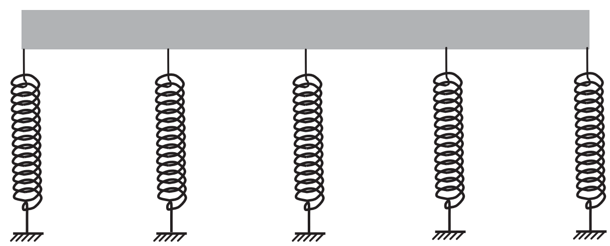
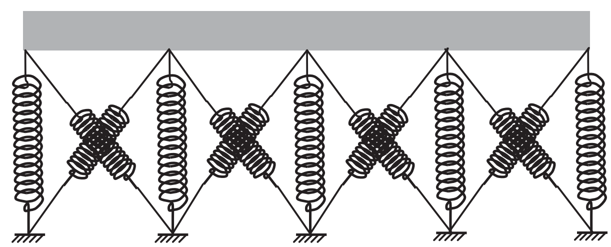


Fig. 18 Structural Approach for modeling Soil-Structure Interaction Effect



(a) Independent Structural Springs



(b) Mutually Interacting Structural Springs

Fig. 19 Structural Approach for modeling Soil-Structure Interaction Effect (ACI, 2002)

In Malaysia, it is common practice for a geotechnical engineer to provide the engineering input in the following ways for the structural engineer to design and details the structural element:

- the geotechnical actions in term of imposed area loading (for instance, pressure from retaining wall over the pile supported base slab for the slab design or lateral earth pressure with water pressure for the design of vertical wall stem, which can be analysed using limit state equilibrium analysis);
- the service structural stresses (flexural, shear, axial forces, torsion) of a structural element with soil-structure interaction analysis by the geotechnical engineer.

The other problem arise is the different approach on the concept of safety margin by both disciplines. As a tradition of code based design approach in structural design, structural engineers are trained to address uncertainties on estimating the imposed loading and material strength of the resisting element by either partial factors applied to loading and material strength or Load Factor and Resistance Design (LFRD). However, inherited from the legacy of previous geotechnical practice, geotechnical design is still very much based on allowable stress design after discounting for the global safety factor regardless of such value is derived from empirical correlation or analytical solution. The problem of such disparity of approaches in dealing uncertainties is probably due to the great uncertainties lying in the earth materials and site specific ground characteristics. Over years, geotechnical knowledge accumulated for geotechnical works covering design, construction and verification has been calibrated with well accepted performance using such approach. Furthermore, most geotechnical designs are primarily governed by the performance at service condition. It is the author's view that a well trained geotechnical engineer has much better feel about the problem with design approach at service condition. For the same reason, it is not surprised that recent the development of geotechnical codes, likes Eurocode EC7, has extensively calibrated the output of the new code against that of the previous or current design approach of individual nation in formulating the national annexes.

4.3 Engineering Geologist

From the author's experience, when a technical input is sought from an engineering geologist pertaining to the ground conditions, the advices are usually more towards qualitative descriptions or advices on the geological sequences, local lithology, weathering grades of the in-situ materials, potential of certain modes of ground failure (kinematic instability in ground surface or underground excavation surface, sinkhole collapse) and hydro-geological regime. It is unlikely more quantitative information is provided to the engineer for immediate engineering design. The geotechnical engineer will have to extract the important information from the geological report to conduct further works to verify and acquire necessary parameters for engineering analysis and design. Geological advices are useful for the geotechnical engineer to foresee potential geological hazard and allow due consideration in their risk assessment during the design. One example is the determination of the faults and its activeness for the engineer to decide the most suitable dam alignment and incorporate the necessary design robustness for the accepted risk if the dam has to be located over the active fault. Very often, the geological report produced tends to over-emphasise the lithology at greater depth below the thick weathered residual soils and has less emphasis on surface geology, which is usually of great interest to the geotechnical engineer. In another category of the geo-hazard, namely landslides, the general approach taken by the geological expert on this matter relies heavily on the terrain mapping (more towards geo-morphological features) and concludes the suitability of the site for development. However, the requested terrain mapping for the development is localised in nature and does not truly reflect the actual risk. For example, the view by the engineering geologist suggests that it is generally prohibited to have any development over land with gradient of exceeding 35° (termed as "Class IV") regardless of the sizes of the area of such category. However, in the eye of geotechnical engineer, engineering solution can always be explored to strengthen the sloping ground to adequate safety requirement for development with the strengthening cost allocation justifying its feasibility to the project owner. Therefore, it is the author's view that the outcome of any risk mapping shall only form a technical basis to demand the involvement of geotechnical engineering by the approving authorities to justify the feasibility of the development, not just a simple disapproval without proper engineering process. The risk assessment is a planning tool, not a decision tool for final approval. Liew (2004a) has discussed in length on the mutual complimentary role of geotechnical engineer and engineering geologist when working on a joint effort project.

5 CONCLUSION

The author has attempted to define the role of geotechnical engineering in the project cycles from project inception, investigation, assessment, design, construction stage till maintenance after completion and highlighted the potential work scope for the value adding process by the geotechnical engineer. Forensic investigation provides good lesson learnt for the geotechnical engineer to minimize serious mistakes and therefore avoiding recurrence. Problems encountered, solution exploration and innovation achieved in some of the projects with the author's personal experience in Malaysia were illustrated. The interfacing problems with other project stakeholders were also highlighted for future improvements with better mutual understanding. Numbers of the cases presented here have demonstrated the important role and value of geotechnical engineer in dealing with the uncertainties in the ground, which serves as the permanent support for all structures on earth or perhaps other planets in the future.

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Note: Some of the literatures in the references can be downloaded at *http://www.gnpgeo.com.my/publication.asp*