MUTUAL COMPLEMENTARY ROLES OF ENGINEERING GEOLOGISTS AND GEOTECHNICAL ENGINEERS IN VALUE ADDING TO CIVIL ENGINEERING PROJECTS IN MALAYSIA – TWO CASE STUDIES

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ABSTRACT

In developing countries like Malaysia, many civil and infrastructure projects are the main economy sector for the construction industry. During the planning, design and implementation stages of these projects, engineering inputs from the engineering team are crucial in arriving at solutions which are economical, safe and easy to construct. In most of these civil and infrastructure projects, geotechnical work is usually unavoidable and full of uncertainties. As such, efforts by geotechnical engineers and engineering geologists are very important to achieve this common objective. This paper briefly presents the author's opinion on fundamental training, practice and professional roles of geotechnical engineers and engineering geologists in civil engineering works. Finally, two case studies have been chosen to demonstrate how both professions can contribute their professional input and add value to an engineering project.

Keywords: Engineering geology; geotechnical engineering; professional roles

1. INTRODUCTION

Engineering has developed from observations of the ways natural and manmade systems respond and from the development of empirical equations that provide the basis for design. Civil engineering is the broadest of engineering fields. In fact engineering was once divided into only two fields, namely military and civil. Other traditional engineering specialities have derived from Civil Engineering. Civil Engineering is still an umbrella field comprising many related specialities.

Civil Engineering generally refers to the process of planning, analysis, design, detailing and construction of engineering works in relation to building up a physical structure over ground or water for the convenience of most human activities and sheltering. These normally involve residential or office structures, supporting infrastructures, public utilities, facilities, transportation, water works, etc. Due to the high level of association with public safety, special attention has been drawn to ensure that all civil engineering works are undertaken by highly trained and qualified personnel to mitigate engineering risks throughout these engineering processes, particularly pertaining to human life.

There has been a long argument over the role of the two professions, namely geotechnical engineers and engineering geologists, in civil engineering works in Malaysia, particularly on the contentious issues of landslide problems. Every time after news headlines appear about a major landslide event, opinions from the two professions are expressed to the public from different perspectives on the root causes of the landslide. In some circumstances, the general public could have been confused to a certain extent by the expert opinions from the two professions. Usually, engineering geologists tend to approach the landslide problem from the perspective of natural phenomena and inherent geological structures (geological contributing factors) as observed at the area of incident, whereas geotechnical engineers focus more on the

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mechanism of the failed masses by examining the other contributing factors and identifying the triggering factor. It would be interesting to review how the two professions are trained and adopt certain industry practices in their own traditions. From such a basis, it will be possible to be more objective in identifying the appropriate role for the two professions. This paper will review the above-mentioned matters in detail.

2. FUNDAMENTAL TECHNICAL TRAINING

In this section, the undergraduate training of the two professions will be briefly reviewed and compared.

2.1 Engineering Geologists

Engineering Geology is the application of the science of geology to the understanding of geological phenomena and the engineering solution of geological hazards and other geological problems for society. Engineering geological studies may be performed during the planning, environmental impact (EIR/EIS), civil engineering design, value engineering and construction phases of public and private works projects, and during post-construction and forensic phases of projects. Engineering geological studies are performed by a geologist, professionally trained and skilled in the recognition and analysis of geological hazards and adverse geological conditions. Their overall objective is the protection of people and property against damage and the solution of geological problems. Engineering geological studies may be performed for residential, commercial and industrial developments; for governmental and military installations; for public works such as power plants, treatment plants, pipelines, tunnels, canals, dams, reservoirs, buildings, railroads, airports and parks; for mine and quarry excavations, mine reclamation and mine tunneling; for wetland and habitat restoration programs; for coastal engineering, bluff, harbour and waterfront developments; for offshore outfalls, drilling platforms and sub-sea pipelines/cables; and for other types of facilities.

Table 1 shows the common undergraduate curriculum of geology courses in many universities in south-East Asian countries.

Table 1: Common undergraduate curriculum of geology course

Compulsory Subjects			**Elective Subjects**
Principles of geology	Geomorphology	Environmental geology	Soil mechanics
Paleontology	Sedimentology	Engineering geology	Rock mechanics
Mineralogy	Stratigraphy	Structural geology	Formation evaluation
Petrography	Petrology	Petroleum geology	Clay mineralogy
Historical geology	Geochemistry	Hydrogeology	Remote sensing
Geotectonics	Geophysics	Economy planning	Estimation of mineral deposits
General mathematics & Statistics	Geology economics	-	-

Unlike geology, which is a fundamental science, engineering geology is an applied science. The discipline derives its methods and skills from geology and several engineering sciences specifically from mining and civil engineering. Simultaneously, the skill and research developed is applied back to mining and civil engineering problems. However, most geology courses and some engineering geology do not have sufficient exposure to the important subjects on design code of practice, preparation of engineering specifications, contractual knowledge and administration.

2.2 Geotechnical Engineers

Geotechnical engineering is in fact, a specialist field branching out from the general civil engineering discipline. The technical training of a geotechnical engineer requires a basic civil engineering degree before he or she goes into the specialised field. As such, the geotechnical engineer has possession of basic engineering knowledge on the integration of every specialised field or aspect of civil engineering. However, due to the complexity of today's civil engineering projects, the original civil engineering generalist has to enter specialised fields to complete a specialised task or work component of an entire project. Table 2 shows the common undergraduate curriculum of civil engineering courses.

Table 2 Common undergraduate curriculum of civil engineering courses

Compulsory Subjects		**Elective Subjects**
Introduction to engineering	Highway engineering	Surveying & practice (II)
Applied mechanics	Structural theory & analysis (I)	Structural theory & analysis (II)
Surveying & practice (I)	Environmental engineering (I)	Reinforced concrete theory and design (II)
Hydrology	Geotechnical engineering	Civil engineering construction
Engineering mathematics (I&II)	Hydraulics engineering	Advanced mechanics of materials
Mechanics of materials	Transportation system	Applied hydraulics
Soil mechanics	Structural theory & fluid mechanics laboratory	Coastal engineering
Probability & statistics	Engineering economics	Basic environmental science
Engineering materials	Water resources engineering	Human environment relations
Computer programming	Environmental engineering (II)	Prestressed concrete
Fluid mechanics	Construction management	Foundation engineering
Engineering material & soil mechanics laboratory	Engineering geology & applications	Finite element analysis
Engineering graphics (I&II)	Computer-aided engineering	Highrise structural design
Reinforced concrete	Steel & timber structure design	-

There are two routes to becoming a geotechnical specialist, namely through taking a post-graduate course on geotechnical engineering to gain the higher level of technical knowledge in the geotechnical realm or alternatively working under guidance of a geotechnical specialist to expose one self to geotechnical engineering over a period of time.

Table 3 tabulates some typical subjects in a post-graduate course in geotechnical engineering. In both cases, it is crucial that the engineer shall frequently update himself/herself with the recent R&D development on the theory and case studies on practical methodology through technical journals. This is part of the continuing professional development (CPD). As a geotechnical engineer, he/she should devote his/her time to understanding the behaviour of the soil materials, be it in-situ material or man-made material.

Table 3 Common post-graduate subjects on geotechnical engineering courses

Applied soil mechanics	Rock mechanics	Slope stability
Theoretical soil mechanics	Tunnel engineering	Prevention & control of landslide disasters
Intermediate soil mechanics	Advanced engineering geology	Geotechnical earthquake engineering
Soil behaviour	Foundation design & construction (I)	Soil dynamics & foundation vibration
Constitutive laws of soil	Foundation design & construction (II)	Numerical methods in geotechnical engineering
Experimental soil mechanics	Applications of geosynthetics	Engineering seismology

3. PROFESSIONAL PRACTICE AND ROLES

3.1 Engineering Geologists

In Malaysia, the draft Geological Act (IGM, 2004) has demarcated the professional roles of the respective geological applications and stipulates that any geological input shall be provided by a registered professional geologist. However, for any engineering works, it is up to the professional engineer to decide whether geological input is required or not. This Act is important so that appropriate accountability of the practice is established.

The engineering geologist plays an important role in assessing geological hazards, which typically include fault rupture on seismically active faults, seismic and earthquake hazards (ground shaking, liquefiable soils, lurching, lateral spreading, tsunamis and seiches; landslide, mudflow, rock fall and avalanche hazards; unstable slopes; erosion; slaking and heave of geological formations; ground subsidence due to groundwater drawdown, decomposition of organic soils and tectonic; volcanic hazards (volcanic eruptions, debris flows, earthquakes and ash falls); collapsible soils; shallow ground water/seepage; and other types of geological constraints. Engineering geologists, often working in conjunction with a geophysicist, may evaluate conditions such as the excavatability or rippability of rock and earth materials to assess the need for blasting during earthwork construction, as well as associated impacts due to vibration during blasting on projects.

The methods used by engineering geologists in their studies usually include geological field mapping of geological structures, geological formations, soil units and hazards, the review of geological literature/memoirs, geological maps, geotechnical reports, engineering plans, environmental reports, stereoscopic aerial photographs, remote sensing data, topographic maps and satellite imagery; the excavation, sampling and logging of earth/rock materials in drilled borings, backhoe test pits and trenches, and bulldozer pits; geophysical surveys (such as seismic refraction traverses, resistivity surveys, ground penetrating radar (GPR) surveys, magnetometer surveys, electromagnetic (EM) surveys, high-resolution sub-bottom profiling, and other geophysical methods); and other methods. The field work typically culminates in analysis of the data and the preparation of an engineering geological report, fault hazard report or seismic hazard report, geophysical report or hydro-geological report. The engineering geological report is often prepared in conjunction with a geotechnical engineering report by a geotechnical engineer. The report describes the objectives, methodology, references cited, tests performed, findings and recommendations.

3.2 Geotechnical Engineers

Currently, all civil engineers and the specialists in various disciplines of civil engineering shall be adequately trained under a senior engineer possessing the relevant skills and knowledge. Under the

Registration of Engineers Act (revision 2002), all registered professional engineers are required to comply with the Act and be registered by Board of Engineers Malaysia. There is a properly established accreditation and assessment procedure to qualify the graduate engineer, who has gained sufficient technical knowledge to practise, to be a licensed engineer. When a professional engineer undertakes any engineering project, he/she has to carry the life time professional liability for his/her design and supervision. This is to ensure accountability on due care, diligence and compliance of design requirements. As such, all authority submission related to construction of residential/commercial structures, public facilities and transportation shall be undertaken by a licensed professional engineer, who possesses the relevant and competent skills in his/her field of specialisation.

For any engineering works, the engineer shall have a full involvement through the complete cycle from feasibility study, planning, site investigation, interpretation, analysis, design and detailing, preparation of tender document primarily consisting of specifications, bills of quantities and engineering drawings, tendering, evaluation and finally to construction implementation and supervision. During this engineering cycle, interaction with other specialities shall be carried on at each stage for proper coordination and integration with other components of the entire works.

4. COMPARISON OF THE NATURE OF WORK

Engineering geology can, in fact, be defined as the application of geology to engineering practice. There are geological factors that affect the site location, orientation, design, construction and maintenance of engineering works, encompassing the broad range of geological disciplines, like petrology, sedimentology, structural geology, hydrogeology, geomorphology and stratigraphy. Knowledge of engineering geology has also been successfully applied in sourcing of construction materials, investigations, planning and construction. Based on the definition of the Institute of Materials, Minerals and Mining, Hong Kong branch, an engineering geologist is a geologist with appropriate engineering training and relevant experience, which refers to the experience gained in applying engineering geological skills, principles and interpretation to civil and geotechnical engineering upon being confirmed by relevant professional qualifications.

The involvement of an engineering geologist is usually in the earlier stage of the project to highlight potential geological hazards in the ground, whereas the geotechnical engineer will devote much of his/her time in the option study and detailed design. Table 4 tabulates the different approaches to work between geotechnical engineers and engineering geologists.

Table 4 Different approaches to work between geotechnical engineers & engineering geologists

	Engineering Geologists	**Geotechnical Engineers**
1	Usually descriptive and qualitative approaches	Prefer analytical and quantitative assessments
2	Tend to use a larger range of values in the description	Tend to use relatively precise figures or narrow range values to describe engineering work
3	Geological time scale of millions of years	Engineering time scale of problem normally in months, years and decades
4	Study past geological events and the evolving process in geological time scale	Provide engineering solution for current and future problems within expected design life span of the structure
5	Apply judgement usually based on trained skill and relevant experience	Decision making based on calculation or quantitative assessment whenever such approach is available
6	Provide opinions based on processes or phenomenon as observed	Derive solutions based on refined geotechnical models with specific boundary conditions
7	Emphasise geological structures, processes and	Emphasise behaviour of earth materials and the

	the cause-and-effect of a geological event	constitutive laws of materials
8	Study the problem in larger geographical scale (macro scale)	Confine study within influence zone of project site (micro scale)
9	The area of study can be at greater depth, normally in bedrock with tectonic stresses	More often deal with shallow overburden subsoil for normal engineering structures (surfacial geology)
10	Confine to limited work scope on most civil engineering projects related to geological engineering and generally lack of training in contractual knowledge	Possess technical knowledge of integration of various specialist fields for overall civil engineering projects and have sufficient contractual knowledge and administration skills for engineering works
11	To maximise output of explored materials for highest return and the work site is less exposed to public, therefore can afford to have lower safety margin against failure	Job duty to safeguard public safety for most engineering structures as top priority, therefore strict adherence to the required design safety margins

The areas of application of engineering geological principles to civil and geotechnical engineering works can be in locating appropriate dam sites and reservoirs, rock tunnelling, underground space, landslide prevention, rock slope engineering, environmental impact assessment (EIA), etc.

5. CASE STUDIES

5.1 Case A – Slope Strengthening Design

This case study presents a slope strengthening work on earth material ranging from completed weathered granitic formation to grade II fractured granite bedrock as discussed by Liew et al (2004). Figure 1 shows the transition of the weathering conditions of the cut surface. Due to tight layout planning and drastic contrast in platform elevation, high vertical cut of as high as 12m is required between the two development parcels. Unfortunately, earth materials of varying weathering grades were encountered across the planned vertical cut surface. Remarkable blast damage had also been experienced at the rock face as a result of bulk blasting. As such, extensive strengthening and shoring works were unavoidable and therefore requiring inputs from both geological and geotechnical aspects.

At the earliest stage of the works, the engineering geologist carried out desk study, field inspection and preliminary geological mapping on the poorly completed earthwork profile by the earthwork contractor as shown in Figure 2 and the cleared rock face as shown in Figure 3. During the geological study, the geological mapping provided input information for kinematic assessment, which was used to investigate the potential failure mechanism of rock masses. The weathering profiles were also useful in demarcating the zone of treatment required and drainage requirements. After that, the geotechnical engineer planned the subsurface investigation (SI) for the purpose of acquiring necessary engineering parameters for stability assessment and engineering design. The SI works were full time supervised by the engineering geologist. During the SI, close communication had been established between the geotechnical engineer and the supervising geologist. The responsibility of the engineering geologist was to ensure that all field works (such as layout, setting out coordinates and levels; borehole logging; reasonable recovery, handling and storage of soil/rock samples; groundwater monitoring) were correctly carried out, and issue site instructions as and when necessary, whereas the engineer was responsible for assigning relevant laboratory testing schedules and interpretation of the field data and laboratory results.

During the analysis and design stage, it was decided that the soil nailing technique was most suitable for the sub-vertical soil surface whereas an anchored wall with rock bolting was required to provide sufficient setback for the upper water tank.

In the implementation stage, valuable input from the engineering geologist had allowed timely adjustment to the actual strengthening work based on the site conditions, particularly in the bolting direction and rock ripping during construction supervision. Another merit of the engineering geologist was the assessment of the groundwater regime in the fractured rock masses. Figure 4 shows the remarkable water discharge from the subsoil drain behind the wall after rain. Figure 5 indicates the perched water profile in the weathered soil above the less permeable bedrock surface.

The contract administration of the SI works and the strengthening work lay with the geotechnical engineer until the work certification. Figure 6 shows the completed soil nailed slope and the anchored wall.

Figure 1: Transition of the weathering profile

Figure 2: Poorly finished earthwork surface

Figure 3: Exposed rock surface after clearing

Figure 4: Water discharge from the subsoil drain behind the anchored wall

Figure 5: Perched water over bedrock surface

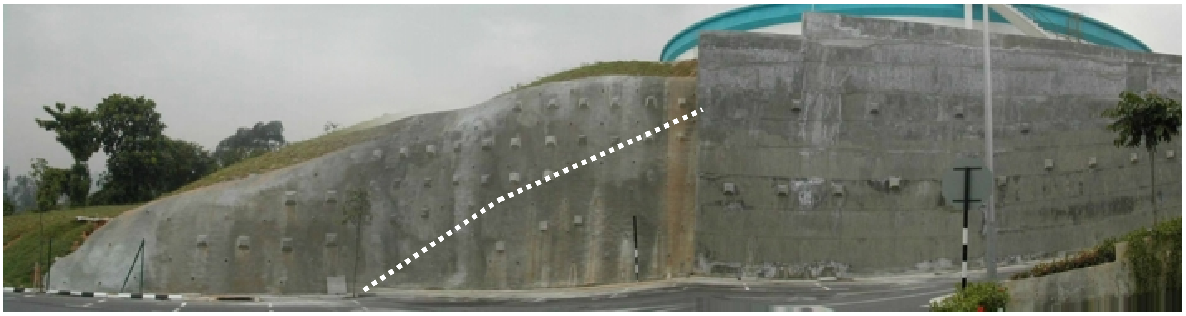

Figure 6: Completed soil nailed slope and anchored wall

5.2 Case B – Forensic Investigation of Rock Mass Stability

This case study presents a forensic investigation of slope instability of a cut slope in metasedimentary formation. After collapse of the cut slope, a series of investigations was planned and carried out by both the engineering geologist and geotechnical engineer. The engineering geologist provided input on the lithology identification using petrography and aerial photograph interpretation (Figure 7), identification of geological structures from aerial photograph (Figure 8) and site verification, grade of weathering based on site inspection (Figure 9), and kinematic assessment from the geological mapping of discontinuities on exposed surfaces (Figures 10 & 11). From the geological model established by the engineering geologist, it was understood that there was extensive intrusion of the granitic formation into the overlying meta-sedimentary formation (schist). The structural form of granitic intrusion into the bedding and discontinuities of the previous sedimentary formation is called "aplite". Figure 12 shows the intrusive whitish quartz vein into the schist. Such an intrusive process had partially metamorphosed the parent sedimentary materials and created massive weak rock masses, which is believed to have contributed to the failure. From the aerial photograph interpretation and field observation, a suspected fault had been identified running through the area of collapse. It was evidenced by the dislodgement of the river course (area 1) and the ridge (area 2) as shown in Figure 8. Beside the suspected fault, many parallel or sub-parallel lineaments were also identified. Observation of a sheared zone at some exposed outcrop along the suspected fault provided good evidence of the tectonic shearing and folding of the meta-sedimentary schist formation.

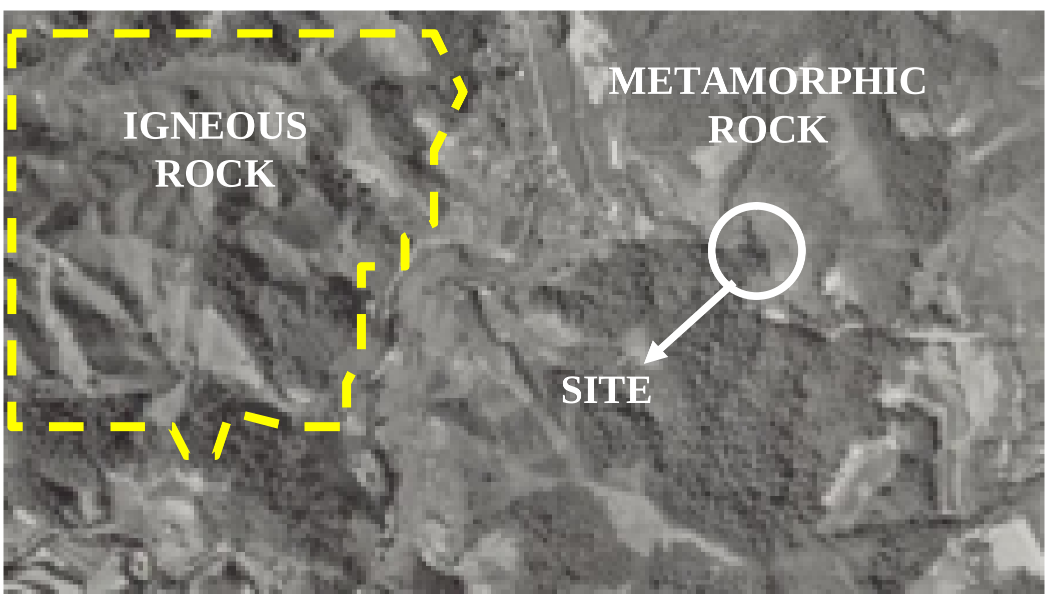

Figure 7: Lithology identification from aerial photograph interpretation

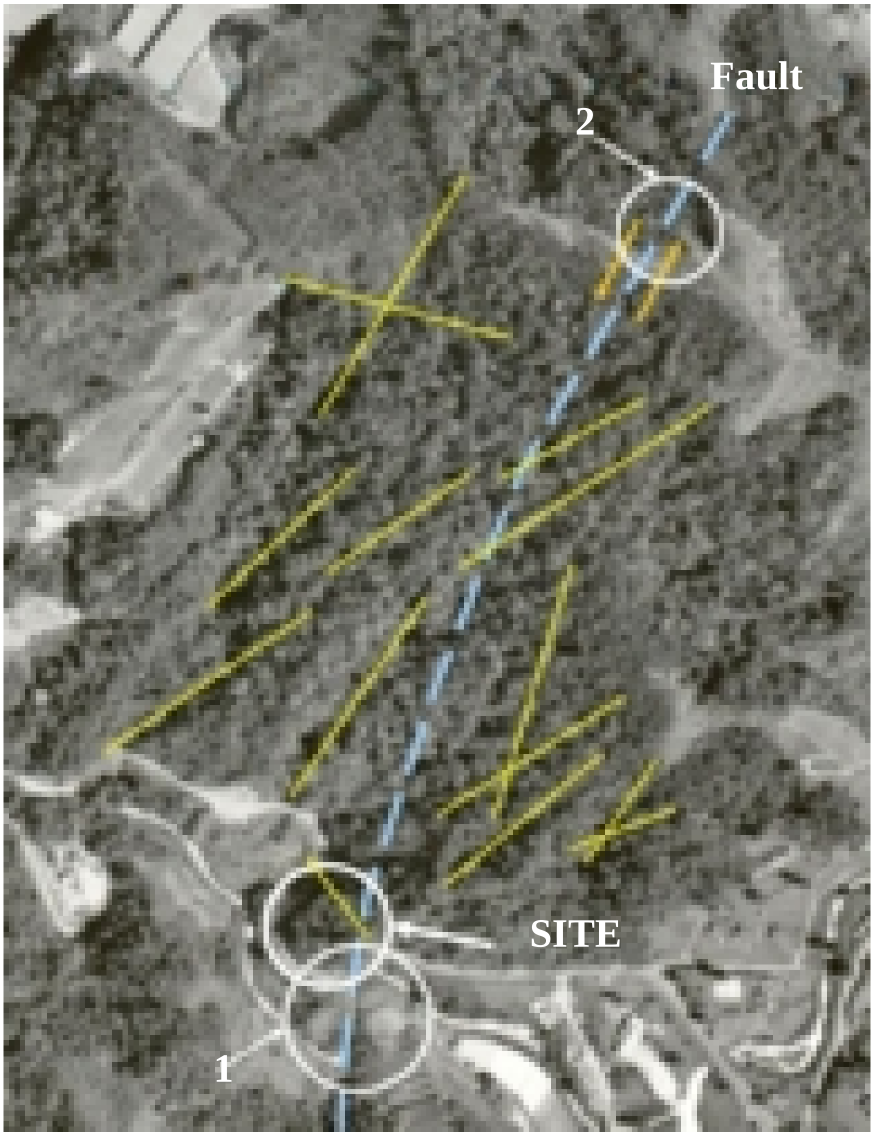

Figure 8: Geological structures from aerial photograph interpretation

Grade III Grade IV Grade VI

Figure 9: Weathering grade interpreted from field observation

Figure 10: Daylighting structures of meta-sedimentary formation

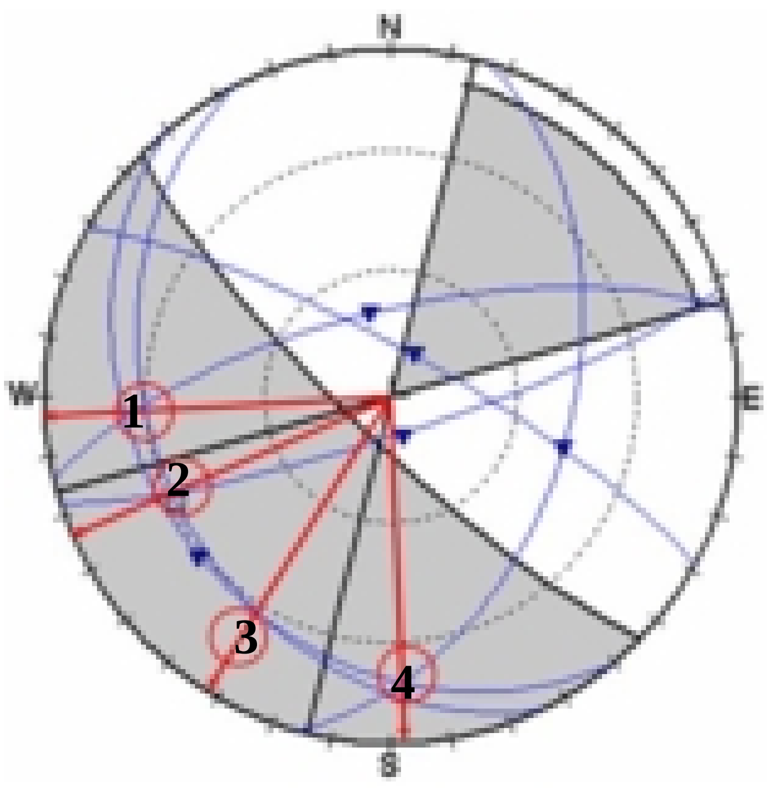

Figure 11: Kinematic analysis from steoreonet

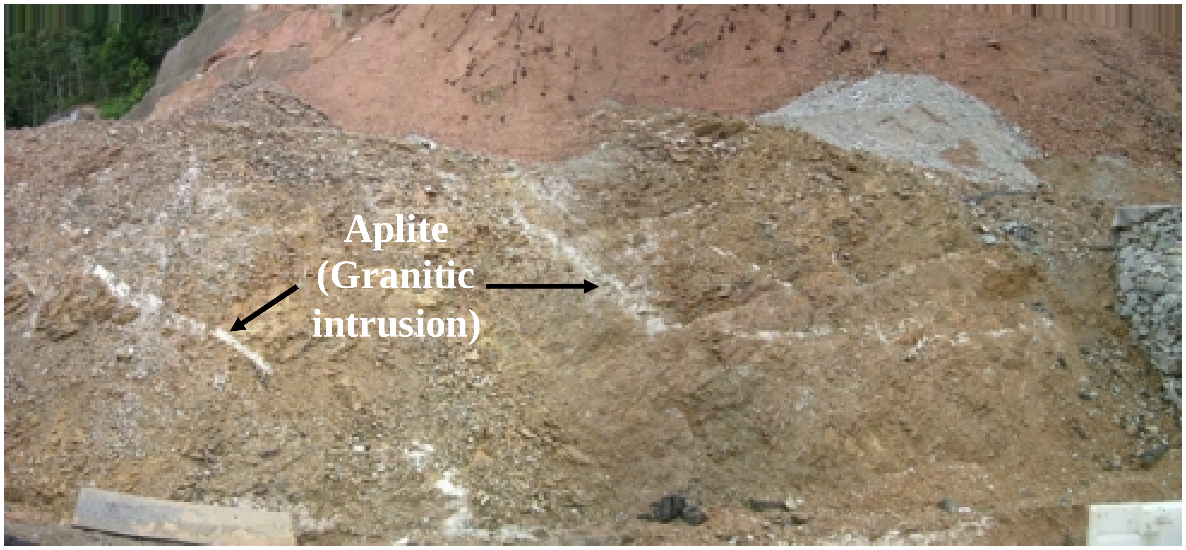

Figure 12: The existence of intrusive aplite into meta-sedimentary formation

Slickenside surface

Folding of schist formation

Figure 13: Tectonic shearing and folding of the weathered schist formation

In the forensic investigation, geotechnical engineer will normally scan through all the relevant information, including previous land use, chronological events pertaining to the failure, subsurface investigation, testing results, construction records, geological assessment of the underlying formation, meteorological information before failure, design drawings and calculations. It is always important to identify the probable contributing factors and figure out the potential triggering factor to the failure through simulating the progressive process in changes of condition, like a rise of groundwater profile and geometrical alteration of the slope profile. During such simulation, the induced stresses in each design element will be checked against the available resistance. The systematic approach of analysing the failure in stages by the geotechnical engineer can reveal the design inadequacy and when the threshold is attained leading to failure. Therefore, accountability for the failure can be objectively established.

There are other forensic investigations by the author on slope instability, in which geological input from the engineering geologist has been proven useful and important in the investigation. The technical papers on these investigations are as follows and can be downloaded from www.gueandpartners.com.my /publications.htm:

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2. Liew S. S., Liong C. H. & Low C. L., (2004) "Four Landslide Investigations in Malaysia", 15th SEAGC, Bangkok.

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6. CONCLUSIONS

This paper has presented a personal opinion on the role of the two professions from the aspects of training and practice. Generally, the following points can be summarised:

- Engineering geologists possess good knowledge of the historical and ongoing geological processes of the earth materials at the project site, and therefore can provide technical advice on the potential geological hazards and preliminary mitigation measures for project planning. However, there is still a continuous role for the engineering geologist in providing geological input through the design and implementation stages. This is particularly true for projects on a large linear scale, like road, tunnel and utilities projects.

- Geotechnical engineers have been trained to understand ground behaviour in depth, possess good training in the integration of various civil engineering disciplines and contractual knowledge. The final engineering decision and detailed design shall therefore be the role of the geotechnical engineer.

Case studies have also been presented to demonstrate the mutual contribution of their technical know-how to civil engineering projects. Therefore, the two professions shall complement each other in completing successful civil engineering projects in present and future.

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