Common Problems of Site Investigation Works in a Linear Infrastructure Project

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Synopsis

Malaysia is a developing country still required extensive construction of basic infrastructures. Out of all infrastructure necessities, transportation, transmission and utility infrastructures play vital role in the national economic growth. As the nature of this type of linear infrastructure projects stretches over different geographical and geological domains, the associated risks and uncertainties on the ground related disruptions during design, construction and operation stages are relatively high. Therefore, site investigation (SI) work is inevitably critical to reduce the risk on ground related hazard. However, there exist some common problems in the planning of SI work for this type of linear project. This paper will discuss these problems and present some case studies for clear illustration.

Keywords

Site investigation, infrastructure, geology.

1. Introduction

In most civil engineering projects, SI work plays an important role in understanding the ground conditions and identifying the impact to the proposed structures to be erected on the site. By definition, SI is a physical inspection and investigation of all relevant aspects of the site, which have impacts to the design, construction and operation of an engineering structure. However, the SI resources allocated for linear project is normally limited. Therefore, if the planning is not thorough and well thought-off, the effectiveness of achieving the objective would be very much reduced. There are also a lot of myths in planning and implementation of the SI works for the linear infrastructure projects. The following sections will discuss on these aspects in details.

2. Inadequate Desk Study

In Malaysia, the available existing information and resources to carry out the desk study are usually very limited. This is partly due to poor archiving system and ineffective dissemination of information from the government agencies to the public. At the same times, the engineering fraternity has no serious emphasis on desk study or does not even have the culture in performing desk study as a proper desk study would require commitment of substantiate resource in cases where information of good quality is available. Usually, the design team would prefer to cut short the work flow by directly carrying out the SI field works. This might be partly due to inadequate time frame allowed by the client. In the eye of some project clients, desk study does not produce useful output as compare to physical works and they view it as a virtual work.

In actual fact, desk study can be very useful and handy in order to have a more efficient and effective planning of SI works. It is appropriate to have the desk study performed for a preliminary appreciation of the geological and geotechnical conditions of the project site. Lots of geological imagination would be required during the desk study. However, the SI work is to confirm the preliminary expectation from desk study and to identify surprises at the project site. For instance, pre-development topographic map would be very useful for alignment selection, and interpreting the geomorphology from the site contour can be useful in revealing possibility of colluvium existence. Figure 1 shows an aerial photograph with interpretation showing the existence of fault from evidence of dislodged river channel and ridge of the hill at areas 1 and 2 respectively.

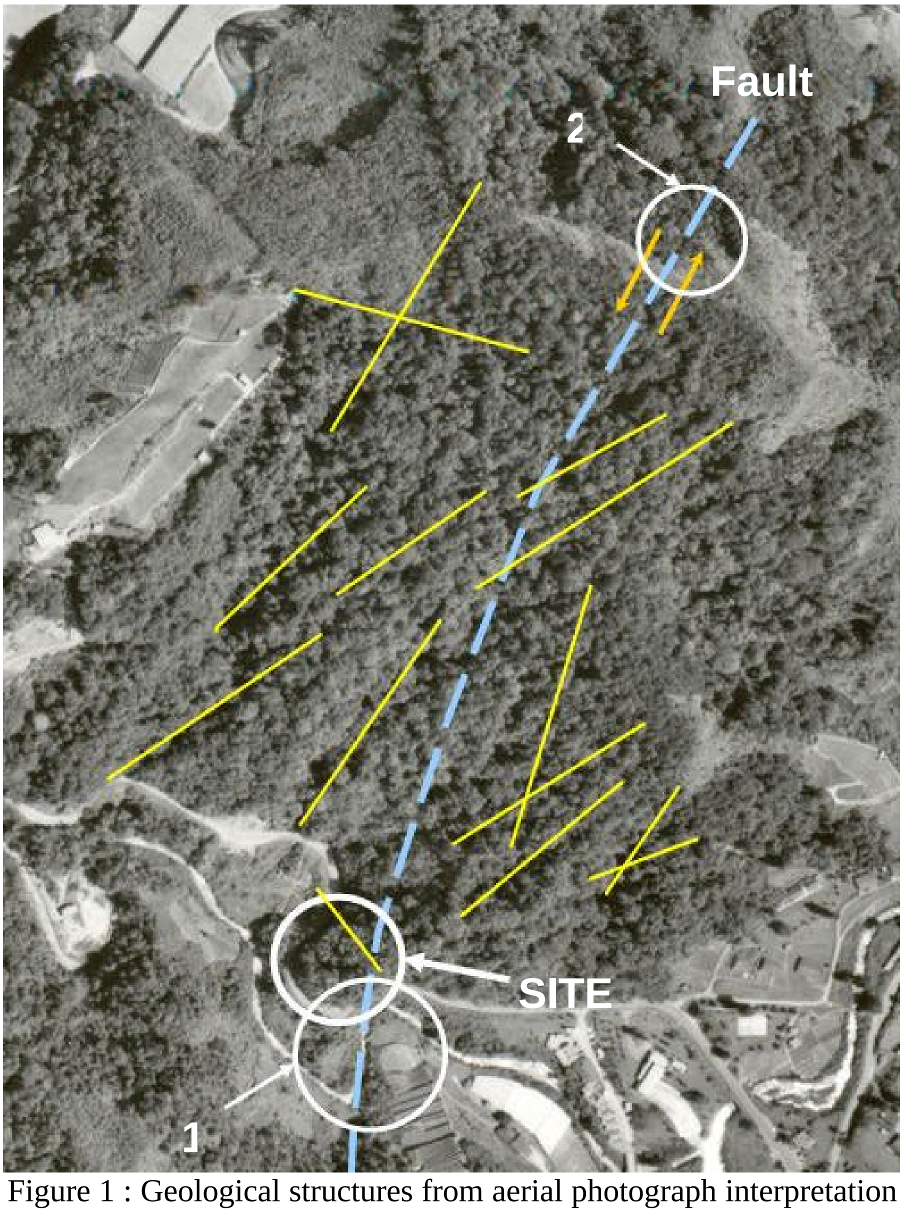


Figure 1 : Geological structures from aerial photograph interpretation

Adequate appreciation on how the ground was naturally formed and subsequently disturbed by natural and human processes would allow the engineering design to be carried out in a more controllable manner and thus possibly reducing failures. Reasonable doubt and imagination are encouraged at this stage in order not to simply rule out any possibility of the occurrence of events, which have impacts to the proposed engineering structures. Table 1 summarises the applications of various information for desk study. The verification process of these possibilities shall be carried out during the investigation stage.

Table 1 Application of Desk Study

Information	Assessment	Application
Topographic Map	Terrain and landform evaluation Crossing over rivers/streams Low-lying waterlogged areas Land use	Terrain classification for slope instability Identify historical landslides Weathering thickness
Geological Map	Lithology & residual overburden Geological structure/setting	Fill materials/source Rock excavation/rippability
Aerial Photograph/ Remote Sensing Image	Vegetation cover Land use Interpretation of surface geology	Identify historical landslide Change of landform with time

3. Multi-Stage of Investigation & Inadequate Provision of Investigation Resources

Due to limited resources and time, it is important to phase the SI work in few stages based on the project sizes and complexity. The stages can be started from reconnaissance, feasibility, preliminary design, detailed design, construction and maintenance. A ringgit well spent at the earlier stages can save ten to hundred at the later stages.

During the reconnaissance stage of site investigation, the desk study on all available geological maps, aerial photographs, remote sensing images, topographical maps and geological memoirs would have been carefully digested and extrapolated to have a continuous geological models traversing through the project alignment. Such preliminary geological model can be completed at the minimum cost with quality information and good professional input. Mining maps at the local areas can be very useful in determining the mine tailing materials, which are usually weak and compressible.

A walkover site survey on the surface geological features would be valuable to confirm the geological model built from the desk study. Observation of ground surface conditions, like fresh rock face, rubbly slope toe, hummocky topography, sag ponds, open tension cracks and mud lobes, springlines at the toe of slumped soil mass and the distinctive plants, can indicate potential slope instability. The observed joint sets, beddings, structural geology can be interpreted to understand the regional geological settings. Outcrops of bedrock and exposures of soil profile in gullies, cliff, river cutting, scar of previous landslides can provide valuable information for preliminary modification of the geological model. Surface observation on potential rubbish dumping ground would require minimum investigation cost and would seldom be miss out if a walkover site survey is conducted. The SI planner shall take opportunity in the walkover site survey to look for possible temporary access, water supply points and preliminarily locating the practical probing locations for the investigation works.

In addition, there are many readily available geophysical survey methods for quick and continuous subsurface conditions between the boreholes. It is crucial that calibration between the geophysical survey results and boreholes shall be carried out.

For a long linear infrastructure project, the allocation of site investigation is usually based on certain numbers of probing or boreholes per unit kilometres. However, along the entire alignment, there could be many cut and fill areas requiring boreholes or probing to define the subsurface conditions and groundwater regime for analysis. In normal cases, it needs about three boreholes, one at the crest, one at the middle of slope and the other at the toe of the slope to delineate geological stratification, weathering profile and groundwater profile over the designed slope profile. It would be impractical to apply the same investigation approach to a linear project. It is suggested that boreholes can be planned at representative clusters of geological units with most critical slope profile to reveal the weathering conditions, groundwater conditions and engineering parameters of a specific formation. The effort of SI shall be as minimum, but sufficient to establish preliminary geological model and geotechnical model for preliminary engineering analysis. More details of the underlying ground conditions will be exposed during the detailed investigation and construction stage. With more information, the earlier interpreted geological and geotechnical models shall be continuously updated for improvement and refinement. Figure 2 shows the layout of a highway project with the interpreted geological model. There is an open electronic data transfer format for SI works and instrumentation (AGS3.1 and AGS-M respectively) as discussed by Hutchinson & Chandler (1999), which will significantly improve the efficiency and reduce human errors in the SI works.

For some deep tunnel project, boreholes are sometimes planned to drill through thick bedrock reaching the tunnel alignment to have brief ideal of the rock quality and permeability. It is time consuming and costly to obtain detail rock conditions at surrounding areas where the tunnel alignment traverses through. As such, borehole exploration could be used as a preliminary investigation. The detailed design information shall be obtained by other means, such as pilot tunnel, observation method through proper instrumentation.

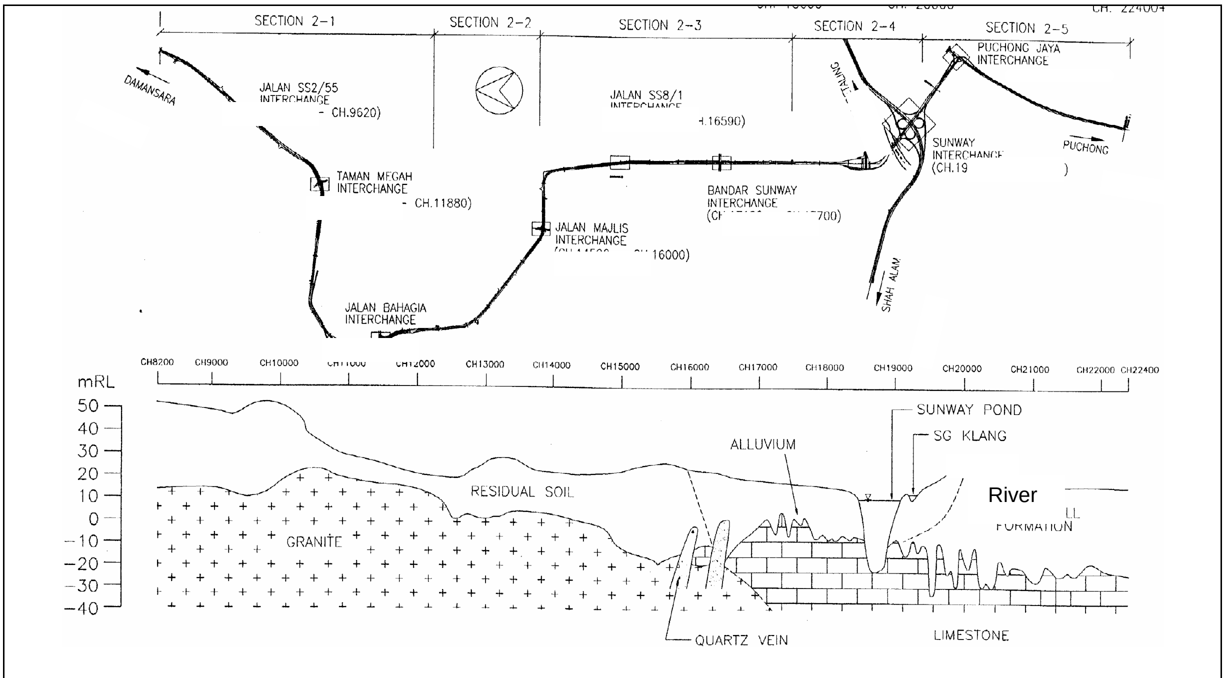


Figure 2 : Geological Model for a Highway Project

4. Incomplete Survey Information

In many linear infrastructure projects, stringent alignment requirements have restrained the possibility of adapting the alignment to the original terrain and therefore led to excessive cutting and filling into the original terrain. If the contour survey is not sufficiently extended beyond both the cutting and filling sides, the extent of cutting and filling would not be clearly defined. Both the footprint of cutting and filling require detailed investigation as these areas have most disturbances to the original equilibrium state of the ground. If the preliminary survey is not adequate, additional survey shall be planned and implemented at these localised, but critical areas to have sufficient information for design.

5. Difficulties in Identification of Complex Geological Settings

There are always surprises in the ground after exposure during excavation. Adverse geological features are usually revealed when the bedrock is reached for the final ground profile as designed. Planar, wedge and toppling failures can readily be seen in the cut slopes with adverse geological setting. Water bearing faults could be encountered in a tunnel excavation posing hazard to the workers. Faults or shear zones can be very unfavourable to the foundation construction of a dam and also tunnelling. Also, artesian water profile can be surprisingly encountered after stress relief at the lower catchment area due to excessive removal of overburden. Adverse geological settings are more prominent in sedimentary and meta-sedimentary formations due to inherent beddings. Geological structural features can be very obvious in fresh bedrock at greater depth, but becoming obscure at shallower depth as the weathering condition gets severe. Therefore, geological controlled failures in Grade I to Grade III weathered bedrocks are common after rock slope excavation. Figure 3 shows the daylighting relict geological bedding towards a road excavation.

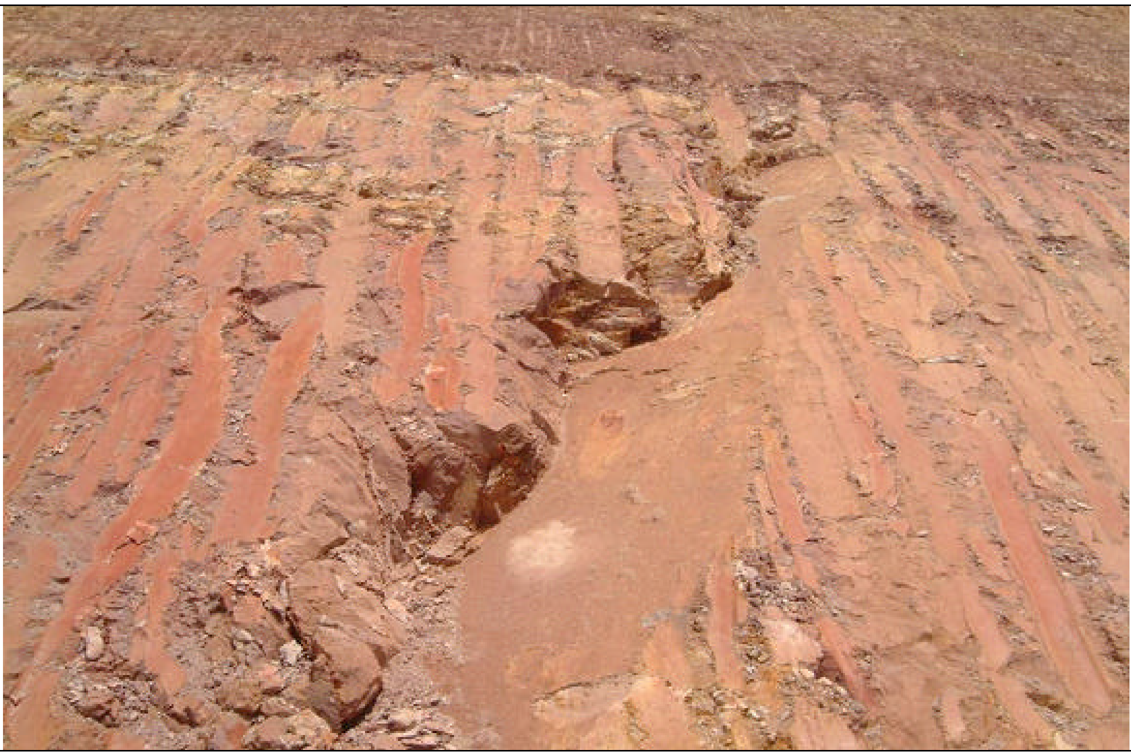


Figure 3 : Localised Wedge Failure contributed from Day-lighting Joint Sets and Beddings of Cut Slope Towards Road Alignment

Figure 4 shows the fractured meta-sedimentary formation at a road cutting. Difficulties have been encountered in recovering samples in such materials, particularly the shale materials. Besides, it is also difficult to identify the geological discontinuities and determine the orientation of these structures from the small diameter core samples unless more advanced techniques are used, such as using membrane with hydraulic fluid pressure to snapshot the discontinuities on the indented membrane or special core sampler with orientation indicator. However, these techniques are not common in Malaysia. To acquire the engineering parameters in these complex materials, theoretical framework with empirical calibration to local geological conditions can be adopted. However, there are only very limited statistics of rock mass properties in Malaysia.

Figure 4: Daylighting structures of meta-sedimentary formation

Figure 5 presents the geological conditions for a unstable 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, identification of geological structures from aerial photograph and site verification, grade of weathering based on site inspection, and kinematic assessment from the geological mapping of discontinuities on exposed surfaces. 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 5 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 interpretation of aerial photograph as shown in Figure 1 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 mentioned earlier. 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 as shown in Figure 6.

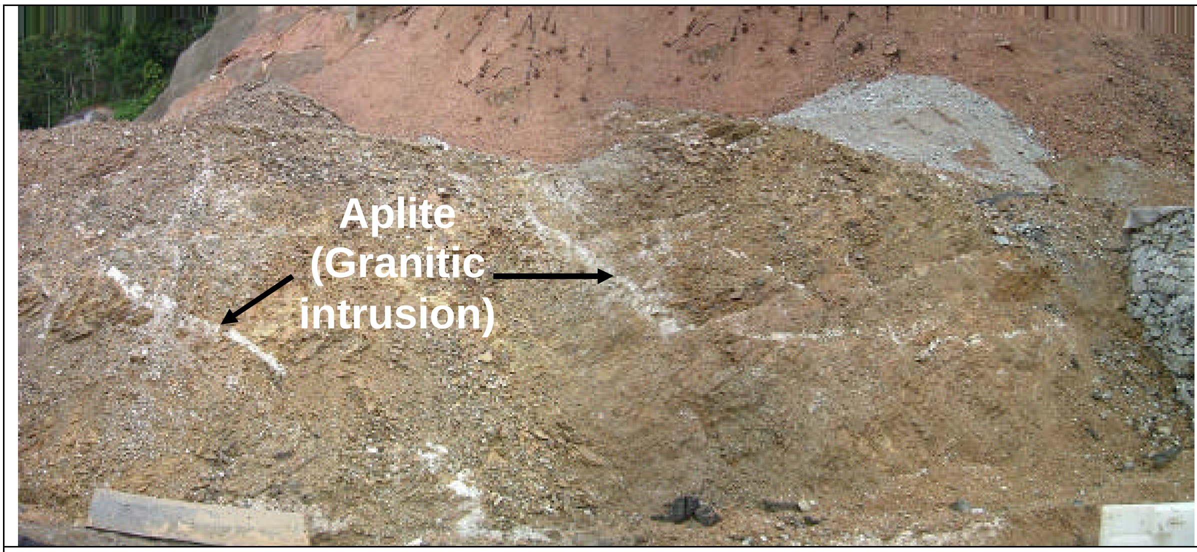
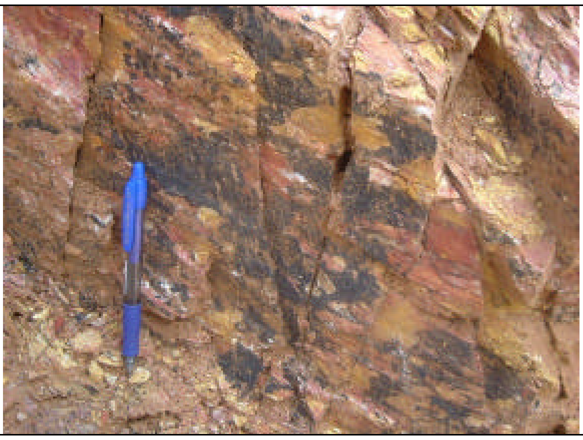


Figure 5: Intrusion of Quartz Veins into meta-sedimentary formation



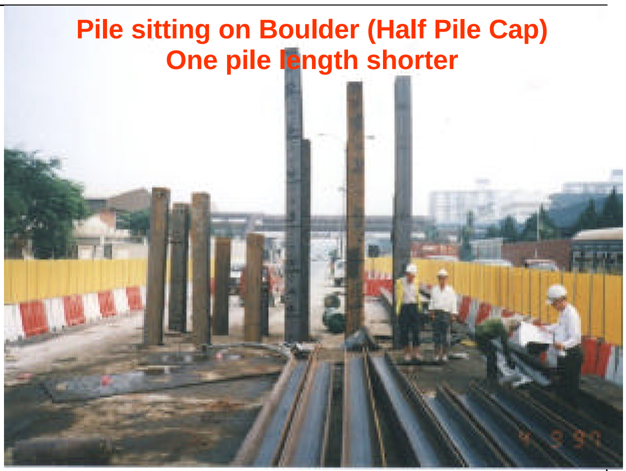
Slickenside surface

Folding of schist formation

Figure 6: Tectonic shearing and folding of the weathered schist formation

Granitic boulders can also be very unpredictable as compare to cavities in limestone. Figure 7 shows the core boulders discovered in a weathering matrix after exposure and also half of the foundation piles sitting over boulders despite SI works being carried out.

Granitic Boulders



Pile Foundation sits on Boulders

Figure 7 : Problems of Granitic Boulders

Figure 8 shows a sedimentary formation with beddings, that are not day-lighting towards the excavation, and has block failure at the lower shale stratum as a results of a widely developed joint sets perpendicular to the beddings. Therefore, cautions have to be exercised when dealing with the shale materials, which are relatively weak and prone to disintegration after subjected to water ingression.

Figure 8 : Block Failure of Sedimentary Formation

6. Weathering Profile

For tropical climate conditions, the weathering profile of the ground playsan important role in earthwork design of a linear infrastructure project, particularly for the slope instability of the constructed slope profile. If the bedrock is shallow and thin overburden is still remained after the ground profile has been trimmed to final design profile, cautions shall be given in the establishment of the groundwater regime. Usually, perched water table can be found over the bedrock surface, which has implication to slope stability. It is also crucial to estimate available volume of suitable soil materials at the borrow source for embankment and filling construction. The primary cost factor of most earthwork operation is the haulage of the imported suitable fill materials. On the other aspects, if one has misinterpreted the bedrock profile, which will cost significant effort and financial burden in excavating the rock materials above the design profile, cost overrun and delay in delivering the project would be unavoidable. In a linear project, chances of such encountering would not be a surprise. It is always advisable to conduct adequate investigation to minimise the risk during the planning and preliminary design stage rather than leaving it until the construction stage. Changes of rock profile can also affect the design excavation profile. Figure 9 shows the interface between grade IV granitic residual soil and grade II granite. This leads to continuity problem in cutting the soil slope in 1V:1.5H and rock slope in 4V:1H along the excavation surface.

Figure 9 : Inconsistent Weathering

Another difficulty of determining the weathering conditions of igneous rocks, sedimentary rock, metamorphic rocks and volcanic rocks for engineering design and construction purpose is the nature of differential weathering of rock materials in joint sets, material types, groundwater movements. The variation of weathering profile can pose problems in trimming the original terrain to the design profile and identifying the need of strengthening works at areas with unfavourable weathering conditions. Boulders in granitic formation and hard iron pan in sedimentary formation can lead to construction dispute in earthwork operation. The clear demarcation of rocks, hard materials and soil materials are the common arguments on its definition. Some of these problematic ground features can not be easily detected and estimated for volume by using small diameter boreholes. Figure 10 shows the different weathering grades of the same formation.

Grade III	Grade IV	Grade VI

Figure 10: Weathering grade interpreted from field observation

Figure 11 shows the exposed intact bedrock surface at the Kupang granite, which has been intruded by dyke with thickness around 50cm and the dyke rocks are made up of leucogranite. Within the contact zone of dyke, porphyritic granite can be found. Generally, the Kupang granite is cut by a series of dykes, veins, and lenses of leucocratic, microcline-rich, alkali granite or adamellite. Kupang Granite can be described as biotite-rich matrix encapsulated white prismatic feldspar phenocrysts commonly up to 30mm in length and in some places up to 70mm. Smaller phenocrysts of quartz are also commonly present. The long axes of the large feldspars tend to lie in planes parallel to lines of foliation in the matrix, and also to banding in which alternating layers of porphyritic and non-porphyritic material occurred. Another feature worth noting is the tendency of the relatively resistant feldspar phenocrysts to the weathering process. The weathered residual soils are generally course grains, non-cohesive and high permeability. The perched groundwater can be found over the less weathered bedrock after a short intense rainfall.

Dyke Intruding into Country Rock	Feldspar Phenocrysts within Kupang Granite

Figure 11 : Problems of Granitic Boulders

7. Complexity of Rock Mass Properties

The main difficulties encountered in trying to understand the rock mass behaviour with information from exploratory boreholes are the limitation of the small diameter core sample in representing the global scenario of rock mass. It is usually more sensible to establish the rock mass based heavily on the exposed rock face and outcrops. This can be done by geological mapping over the exposed rock surface in various construction stages. At present, the well known Hoek-Brown failure criteria based on site observation on the exposed rock mass surface has been commonly adopted to quantify the mass strength for stability analyses. However, it can attract argument as the evaluation method is still subjective in nature. More statistics are required to calibrate the observed rock mass conditions to the back-analysis results of the failed rock mass to improve the confidence of rock slope design.

8. Poor sample recovery

It is not uncommon that poor sample or core recovery in hard tropical residual soil and fractured bedrock are encountered in many SI works. Usually, the sampling recovery and quality have major attribute in the skill of the drilling operator, condition of sampling tool, speed of drilling. Mazier sampler is common sampling tool for residual soils. It is the author experience that the following problems have been the common reasons responsible for such poor recovery:

i. Friction between the inner sampling wall and the core barrel twisting the soil sample and smearing the soil below the cutting edge of the sampling tube.
ii. The ball valve does not function properly leading to poor venting of water within the sampling tube while pressing the sample into the sampling tube, or the inability to create suction to hold the sample while retracting the core barrel. Sometimes, the

wash boring water flushed out within the sampling tube, thus the flushing away the collected sample.

iii. The sampling tube does not retract under thrust force when hitting hard materials. Therefore, the hard materials can not be cut by the cutter bit.

iv. The drilling rotational speed is too fast and inappropriate thrust is applied to the core barrel.

9. Difficult Natural Soil Materials and Man-made Materials

Certain soils have unfavourable engineering characteristics, which can pose problems during construction. For instance, volcanic soils with high swelling and shrinkage potentials will lead to non-conformance of compaction requirement and have more tendencies to cracking after lost of moisture content. Clay mineral study and shrinkage potential shall be carried out for fill materials. Figure 12 shows shrinkage cracks of the volcanic origin subgrade material compacted a day before.

Figure 12 Shrinkage Cracks at Runway Subgrade

Man-made materials can sometimes be the worse materials for construction. Such problematic materials can readily be found at many localised spots of the developed areas. Figure 13 shows the thick rubbish dump underneath the proposed road alignment. The main problems of such materials are their spatial inconsistency and unpredicted engineering characteristics. Large voids existed in uncontrolled dumping leading to extremely high collapse potential within the materials under loading. It also poses high environmental and health hazards during investigation and construction as some dumped materials producing toxic gases and pollutants. Normal drilling techniques by either wash boring or flushing with high compressed air have difficulties in advancing the drilled hole in rubbish dump. Sampling would even be a more challenging task. Figure 13 shows the rubbish dump discovered at the proposed road alignment and the occurrence of sinkhole within the rubbish dump area. Normally, it is important to identify the lateral and vertical extents of such materials. First option is to replace the materials if possible. Otherwise, the design shall accommodate the long-term settlement and routine maintenance shall be allocated during operation.

Rubbish Dump

Sinkhole Collapse due to Pipe Jacking through Rubbish Dump

Figure 13 Rubbish Dump Materials

10. Hindrance of Existing Utility Services

As some infrastructure projects are deployed over developed areas, in which utility services have been laid underground without detailed as-built information. It is not uncommon to have these unidentified existing services damaged by drilling operation. Some of these services can be mission critical, which can have national interest and safety issue. Therefore, it is advisable to have provision in utility survey and detection before any physical investigation operation. Presently, there are many non-destructive methods or techniques being used to detect utilities. Relocation of services is also an important aspect for redevelopment project and road upgrading project as the physical construction works will likely to interfere with the existing services. Figure 14 shows the unidentified water carrying service across the road alignment during construction which delayed the entire road construction.

Figure 14 : Water Carrying Services running across the proposed Highway Alignment

11. Difficult site access

If the alignment traverses through virgin grounds, soft swampy areas and water logged areas, the cost of constructing the temporary access can sometimes be more than the cost of the SI works. Soft compressible alluvial deposits at the low-lying ground will make the access even more difficult. Some of these access problems can be partially solved by using lighter rig. Otherwise, pilot track shall be built for temporary access.

12. Inadequate Site Supervision

This could be a general trend and reality in the SI industry in Malaysia. Given a linear distribution of the site investigation activities, it would be more critical as the attention of the supervision team would be distracted and time spent on travelling between the investigation teams is also significant. Some project clients still insist to have one supervising personnel to oversee few drilling rigs located at few hundred metres or even few kilometres apart. For sure, the quality of supervision would be jeopardised and the site instruction would not be timely. As the uncertainties in the ground conditions require the site supervising personnel to give timely instruction for taking appropriate samples with right tools, conducting necessary in-situ tests at specific stratum, and so on. Therefore, adequate supervision team shall be established for the long stretched projects in order to obtain quality SI information for appropriate decision making and design purposes. Skill and competency of the supervision personnel are also important.

13. Conclusions & Recommendations

The common problems normally encountered in the linear infrastructure have been discussed as follows:

- a. Inadequate desk study resulting substandard SI planning.
- b. Preference to have one-off SI works to produce detailed geological and geotechnical models for decision making and design.
- c. Inadequate provision of investigation resources.
- d. Difficulties in identifying complex geological setting beneath the ground surface.
- e. Unpredictable weathering profiles of different formations.
- f. Complex engineering behaviours of rock mass properties.
- g. Poor sample recovery.
- h. Difficult natural soil materials and problematic man-made materials.
- i. Hindrance of existing utility service.
- j. Difficult site access.
- k. Inadequate site supervision.

However, some general recommendations as follows have been provided to cater the abovementioned common problems:

- a. Carry out desk study on available information, such as topographical map, geological map and aerial photographs. This information can be obtained from Jabatan Ukur dan Pemetaan Malaysia.
- b. Plan the SI works in stages with different emphasis to narrow down problems at different stages. The use of open AGS format for electronic data transfer has been suggested to improve efficiency and reduce human errors in SI works.

c. Be generous at areas where more SI resources are required for producing necessary details.
d. Do not over rely on the borehole information for delineating overall geological models. Reasonable doubts shall be reserved in the model for further verification during construction. If the conditions are different from the interpreted, timely design modifications shall be planned and implemented in order not to interrupt the construction progress.
e. For unpredictable weathering of underlying bedrock, the same principle as mentioned in Item (d) shall be applied here.
f. For time being, Hoek-Brown failure criterion is still the authoritive method to characterise the rock mass behaviours. It is advisable to adopt the methodology as proposed by the inventers unless credible statistics on Malaysia local conditions are established.
g. There are few reasons contributing to poor sample recovery. However, approaches to overcome it have been suggested.
h. For natural backfill materials, clay mineral study and shrinkage potential shall be carried out to avoid materials with expansive or shrinkage potentials. Whereas for man-made materials, particularly rubbish dumps, it should not be expected to obtain engineering parameters to predict their behaviours. It is more useful to identify the lateral and vertical extents for decision of possible removal or long-term maintenance.
i. Desk study on the available utility as-built drawings from the utility suppliers and local authorities shall be carried out. Then, sufficient budget shall be allocated for underground utility survey to confirm the as-built utilities and detect undocumented utilities as a due care and diligent procedures before any SI physical works.
j. For difficult access, it can be partially solved by using lighter rig. Otherwise, pilot track shall be built for temporary access.
k. Proper supervision shall not be compromised in any circumstances. Proper interpretation on the SI factual information by competent professionals is another important milestone for a successful SI work. The savings of supervision cost and interpretation can not be comparable to the cost of a wrong decision on incorrect SI findings.

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