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Geological modelling for site characterization using sufficient and insufficient subsurface exploration data: lesson learned from case histories

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Abstract: Where good quality data have been obtained from careful supervision of subsurface exploration program, it is essential that the exact geological conditions be carefully analyzed. Without this it is impossible to check the design assumptions or to apply the results to a similar situation elsewhere.
This paper presents the use of geological modelling for civil engineering projects. The modelling is useful for any layman involved in engineering to understand the geological conditions, thus hinder all the surprises during the construction stage. It also useful for understanding geological and deposition process for prediction of the history of the ground. However, modelling must be made precisely. Insufficient data must not be treated as sufficient.

INTRODUCTION

Where good quality data has been obtained from careful supervision of a subsurface exploration program, it is essential that the exact geological conditions be fully analyzed. Without this it is impossible to check the design assumptions or to apply the results to similar situations elsewhere.

This paper presents the results of subsurface exploration programs and modelling of the site geology upon completion of two different case histories. The subsurface exploration program is normally designed with the intention of getting precise geotechnical and geological information for proper evaluation of design.

The first case history is geological modelling using sufficient data from subsurface exploration program. The site is located within the vicinity of Kuantan Port, Pahang.

The second case history is an example of geological modelling using insufficient subsurface exploration data. The site is located on the legendary island of Langkawi, Kedah. The subsurface exploration program for this case was carried out in two different phases due to problems related to geological interpretation.

CASE HISTORY NO: 1

This case history is for the site located within the vicinity of Kuantan Port, Pahang. The site is located in a low-lying area comprising of swamps, pipe stockyard, and dumping area adjacent to the existing Kuantan Port premises (Fig. 1). It is mainly overgrown with long grass, 'lalang', swampy bushes and pine trees.

The hill at the southwestern part of the site is being operated as quarry for some years. The old drainage in swampy area comprises a pattern of 0.5 to 1.0 m deep drainage ditches filled with standing water.

Subsurface exploration program

A subsurface exploration program was carried out over a period of 11 weeks between July and September 1998 by deploying 6 drilling rigs, 2 Piezocone rigs and other *in situ* test equipment.

28 numbers of borehole were drilled and 42 piezocone test were performed. Undisturbed and disturbed sampling, Standard Penetration Tests (SPT) and field vane shear test were carried out inside boreholes while dissipation tests were performed during the penetration process of piezocone tests.

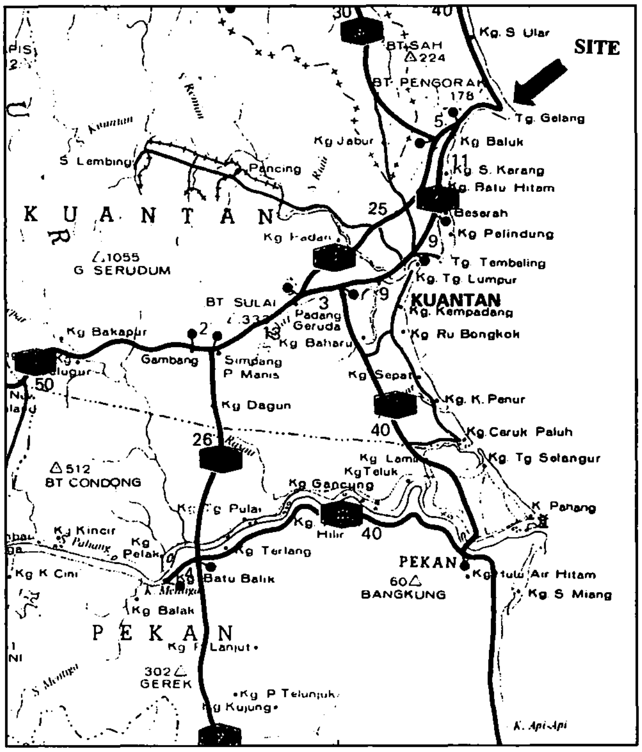

Figure 1. Site location plan for case history no. 1.

The testing locations were arranged in grid to ensure better coverage of the subsurface. The test locations plan is presented in Figure 2.

Interpretation of site geological history and modelling

Based on the subsurface exploration program, the geology of the site can be divided into two major geological zones namely bedrock geology and surface geology (or superficial geology). The bedrock geology comprises of granitoid intrusion, metasedimentary rocks and basaltic flows while the surface geology comprises of old collovium and alluvial deposits in a marine environment. The top soil with thicknesses ranging from 2.0 m to 6.0 m consists mainly of sand filled material.

The interbedded carbonaceous metasedimentary rocks consists of phyllite, schist and quartzite from the Argillaceous Series of Kuantan Group and is the oldest rock at the site. The age of the rock is believed to be Carboniferous. The granite batholith then intruded and uplifted the metasedimentary rocks during Permian or Late Cretaceous. Basalt actively flowed to the area during Late Tertiary age of Miocene to Pliocene.

The Old Collovium, believed to be of Middle to Late Pleistocene age consists of heterogeneous material of angular to sub-angular variably decomposed medium to coarse grain sized of rock or quartz fragments (varying in size) in matrix of clayey soil. It results from the physical disintegration and transportation down-slope of the parent bedrock. The origin of the rock fragments are mainly from granite, metasedimentary rocks and minor occurrence of tuff. The marine alluvial deposits, generally consisting of variable proportions of sub-rounded sand, silt and clay overlies the colloviul deposits. The deposition of this alluvium is believed to be during Holocene or late Quaternary. The simplified subsurface profile and geological model of this area is presented in Figures 3 and 4 respectively.

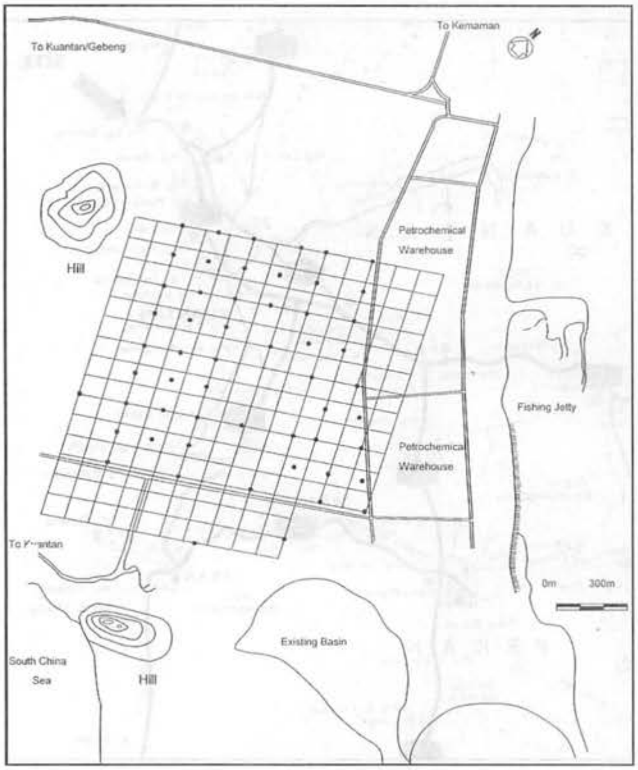

Figure 2. Testing location plan for case history no. 1.

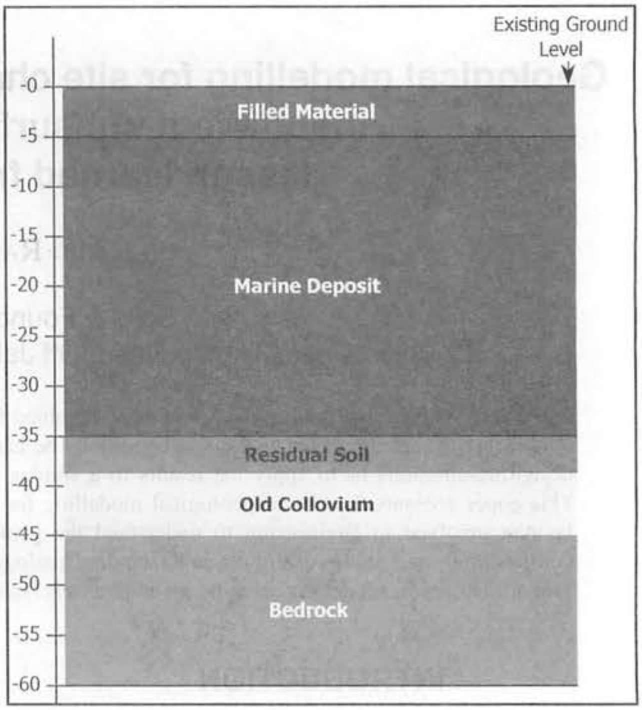

Figure 3. Simplified subsurface profile for case history no. 1.

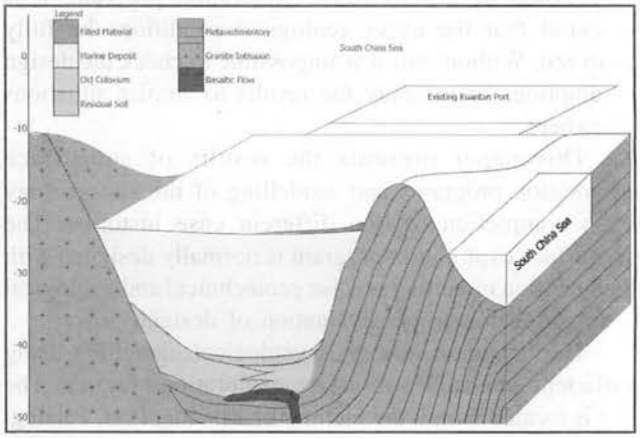

Figure 4. Interpreted geological model of the site of case history no. 1.

CASE HISTORY NO: 2

This case history is based on experience gathered while implementing a subsurface exploration program on the island of Langkawi. The site is located at the southwestern part of the Langkawi Island (Fig. 5). The site extends approximately 120 m to 200 m from the existing jetty or shoreline.

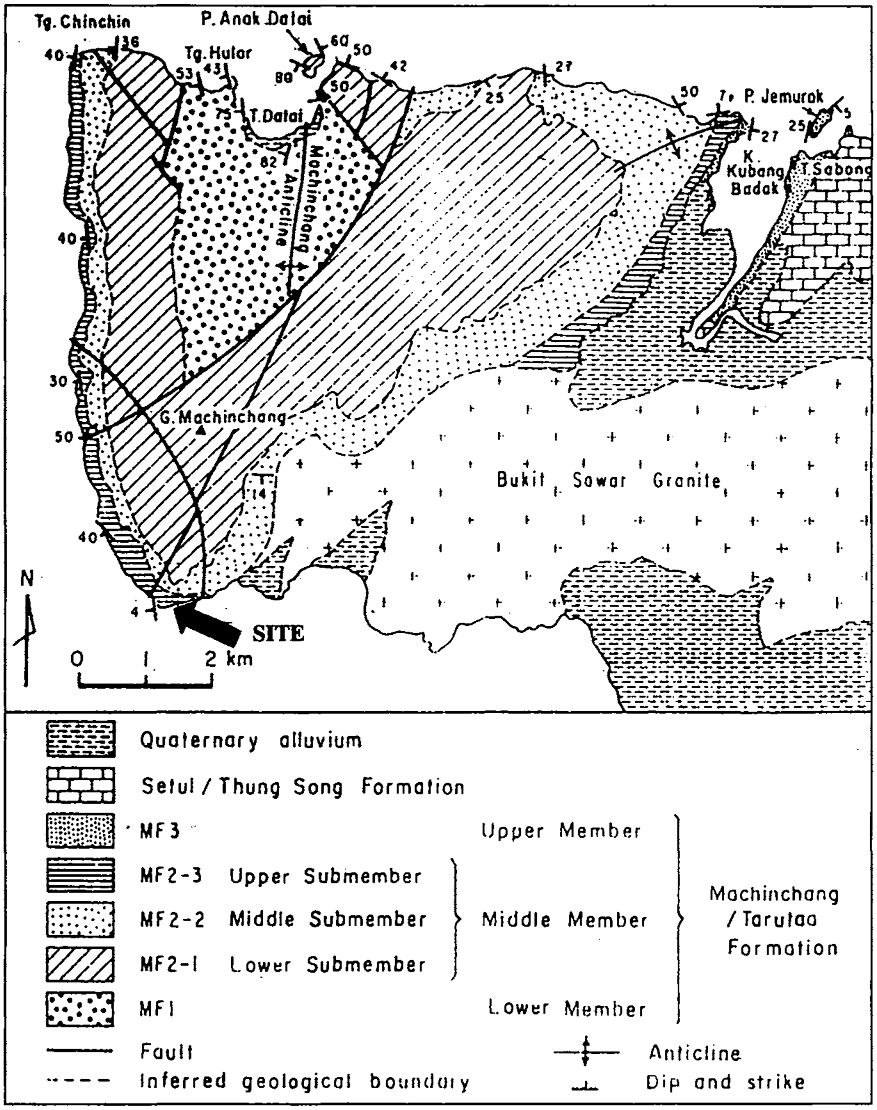

Figure 5. Site location plan for case history no. 2.

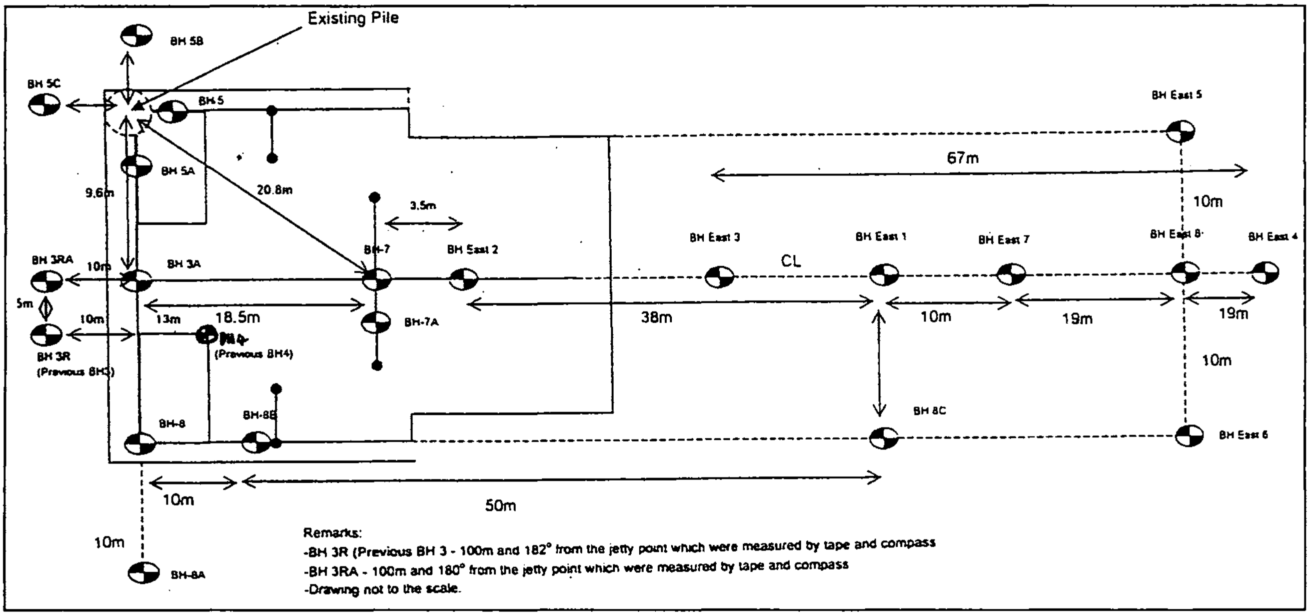

Figure 6. Testing location plan for case history no. 2.

Subsurface exploration program

The subsurface exploration program was carried out in two different phases due to problems associated with interpretation of subsurface conditions and design of foundation system.

The first phase program consists of 4 boreholes with 13 Mackintosh Probe Tests while the second phase comprises of 21 numbers of boreholes. All boreholes were located offshore. The test locations for the first and second stages of subsurface exploration program are presented in Figure 6.

The first phase subsurface exploration program was carried out for foundation design purposes while the second phase was carried out for confirmation of the first phase results.

Interpretation of site geology using first phase exploration program

The site is underlain by sandstone of Machincang Formation. The sandstone is basically pale gray to gray in colour, strong to very strong and slightly weathered. Some quartz matrix showed re-crystallization features. This sandstone is overlain by marine deposits consisting of clay, silt, sand and boulders.

Based on the first phase subsurface exploration program, the geological model for the site is presented in Figure 7.

Problems related to geological interpretation from the first phase exploration program

After submission of the first subsurface exploration report, the engineers finalized the foundation design and the piling contractor started with piling works.

The foundation systems adopted were a combination of driven spun piles and micro piles. However, after trial of driven spun piles, the piling record showed that there was a difference to the depth of the founding layer or end bearing between the site record and the engineer's design. The piling records showed that the piles went very much deeper then the design end bearing.

A meeting was called and all parties concerned started pointing fingers at each other. Questions that arose during the meeting were:

i) Is the subsurface exploration results reliable?
ii) Is the pile really driven up to the recorded depth or is it broken?
iii) Is the engineering judgement and prediction during design stage lacking?
iv) Who is right and who is wrong? The soil investigation contractor or the piling contractor or the design engineer?

The confirmatory subsurface exploration program (second phase) was proposed. This program was design to confirm the previous geological model and the piling records. The second phase program was carried with full supervision by experience technician under close supervision by a geologist.

A proposal was made to carry out the drilling program using a more proper and stable platform such as a jack-up pontoon or vessel and supplement it with a marine seismic refraction survey. However, the proposal was turn down by the project proponent due to budget constraints.

Interpretation of site geology and modeling from second phase exploration program

The geology of the site basically remained the same as the first phase subsurface exploration program. However, there were significant differences in terms of thicknesses of the marine deposits, bedrock depths and the geological profile of the site. The site geology is more complex than expected. A summary on the comparison of the drilling record for the first and second phase are presented in Table 1.

Based on the geological knowledge of the deposition environment and geological activities during Quaternary as discussed by Tjia (1984), Borch (1988) and Raj & Singh (1990), a geological model was developed to explain and convince all relevant parties involved why the geological conditions were very different even within a short distance. The geological model and processes for the site are presented in Figures 8 and 9.

Even though the geological model was not made using very sound judgement with appropriate evidences, it helps to explain and satisfy all parties concerned.

LESSONS LEARNED AND DISCUSSIONS

Carelessness and mistakes made in interpreting geological conditions during the first phase of subsurface exploration program had made the project cost overrun in the Case History No: 2. The soil investigation contractor also had to bear some of cost incurred, namely approximately RM48,000.00 due to allegations of providing unreliable results during the first phase exploration program.

Should the data received is insufficient, then it should be treated as insufficient. Interpretation made must be reviewed critically before submission to other professionals such as engineers as inexperienced engineers may use it without due consideration.

Geological models must be made precisely. We should use question marks if necessary at the area of uncertainty as illustrated in Figure 10 (Soil Centralab Sdn Bhd, 1998). Good and sufficient data to enable us to predict a precise geological profile is illustrated by Hashimoto (1992) in Figure 11.

Hamel (1998) and Davies & Barton (1998) had presented good discussions on geological modelling. Geological profile or cross sections should be carried out in the field by supervising geologist during subsurface exploration.

The purpose of this field geological profile is to optimize information obtained during a subsurface exploration. After ground surfaces profile are drawn and relevant surface features (e.g. soil, rock exposures, wet

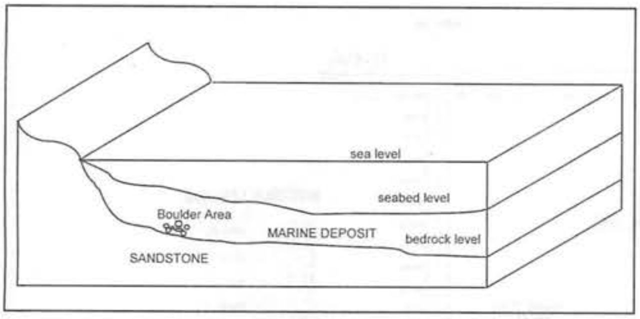

Figure 7. Interpreted geological model for the first phase exploration program of case history no. 2.

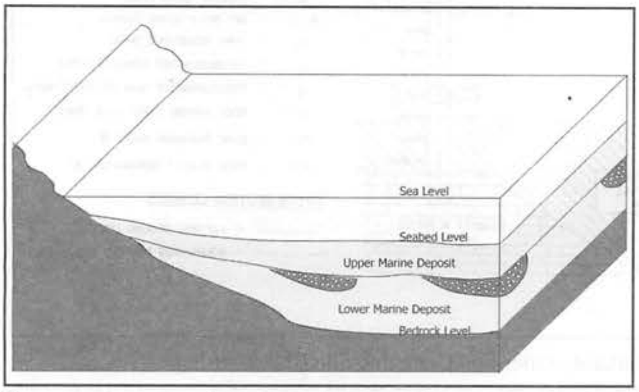

Figure 8. Interpreted geological model for the second phase exploration program of case history no. 2.

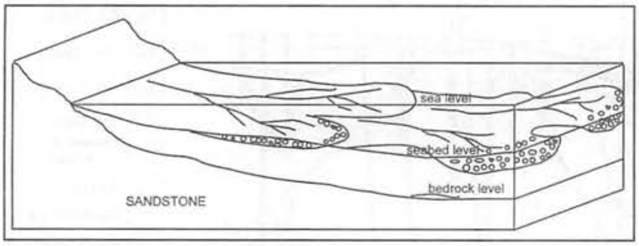

Figure 9. Interpreted geological process for case history no. 2.

Table 1. Summary of drilling record for case history no. 2.

Exploration Program	Borehole No.	Chart Datum (m)	Termination Depth
First Phase	BH 1	-0.327	12.20
	BH 2	-5.377	10.80
	BH 3	-6.177	18.00
	BH 4	-6.077	14.50
Second Phase	BH 3A	-6.200	17.30
	BH 3R	-6.140	13.70
	BH 3RA	-6.150	20.40
	BH 5	-6.330	16.25
	BH 5A	-6.150	27.30
	BH 5B	-5.230	15.50
	BH 5C	-5.400	16.69
	BH 7	-5.560	22.65
	BH 7	-5.600	24.60
	BH 8	-6.470	18.00
	BH 8A	-6.150	18.10
	BH 8B	-5.150	17.35
	BH 8C	-5.500	20.70
	BH EAST 1	-7.200	20.60
	BH EAST 2	-6.800	16.80
	BH EAST 3	-6.300	18.40
	BH EAST 4	-5.820	31.20
	BH EAST 5	-5.750	26.20
	BH EAST 6	-5.650	23.30
	BH EAST 7	-5.750	25.20
	BH EAST 8	-5.440	28.80

areas, streams, fills, waste piles, slope failures etc.) are plotted, the locations and elevations of borings and test excavations (trial pits) should be added as these explorations are completed. Subsurface materials and groundwater conditions encountered in these explorations should be plotted and correlated so that the geological profile and zones are defined during the course of an exploration.

These field geological profiles will help identify data gaps in the exploration program and help to ensure that boring or other test locations and extents in plan and elevation are sufficient to provide the coverage, overlap, and redundancy necessary for the development of the geotechnical framework of the site. It also can help in consistency of logging of soil and rock.

Field geological profiles provided guidance relative to establishment of in situ tests or instrumentation. For example, geological profiles are invaluable in establishing sand zones and tip elevations for piezometers.

For final geological profiles, items to be critically considered during the final drafting of geological profile include geologic processes, landforms, lithologic, stratigraphic and structural zones, features of erosion, deposition, weathering, alteration and groundwater flow. Past, present and future mining activities (if any) and mineral extraction, excavation, fill placement, de-watering, waste disposal and other construction operations or remediation activities should also be included.

Intersections of geological profiles should always be checked for consistency of geologic interpretation in various directions. Sometimes this checking and subsequent reinterpretation and revision of geological profiling intersections gives valuable insight into the geotechnical framework of the site.

CONCLUSIONS

Geological modelling is useful for site characterization in civil engineering projects. The modelling or profiling is also important during a subsurface exploration program and further revision can be made from time to time.

It is also useful for consistency in interpreting geological processes, prediction of site history and logging. Precise geological models will also prevent surprises during construction activities.

Careful forethought and consideration of various possible geological conditions at specific sites, or a thorough evaluation of all the implications of apparent in consistencies in data, is unfortunately lacking in many

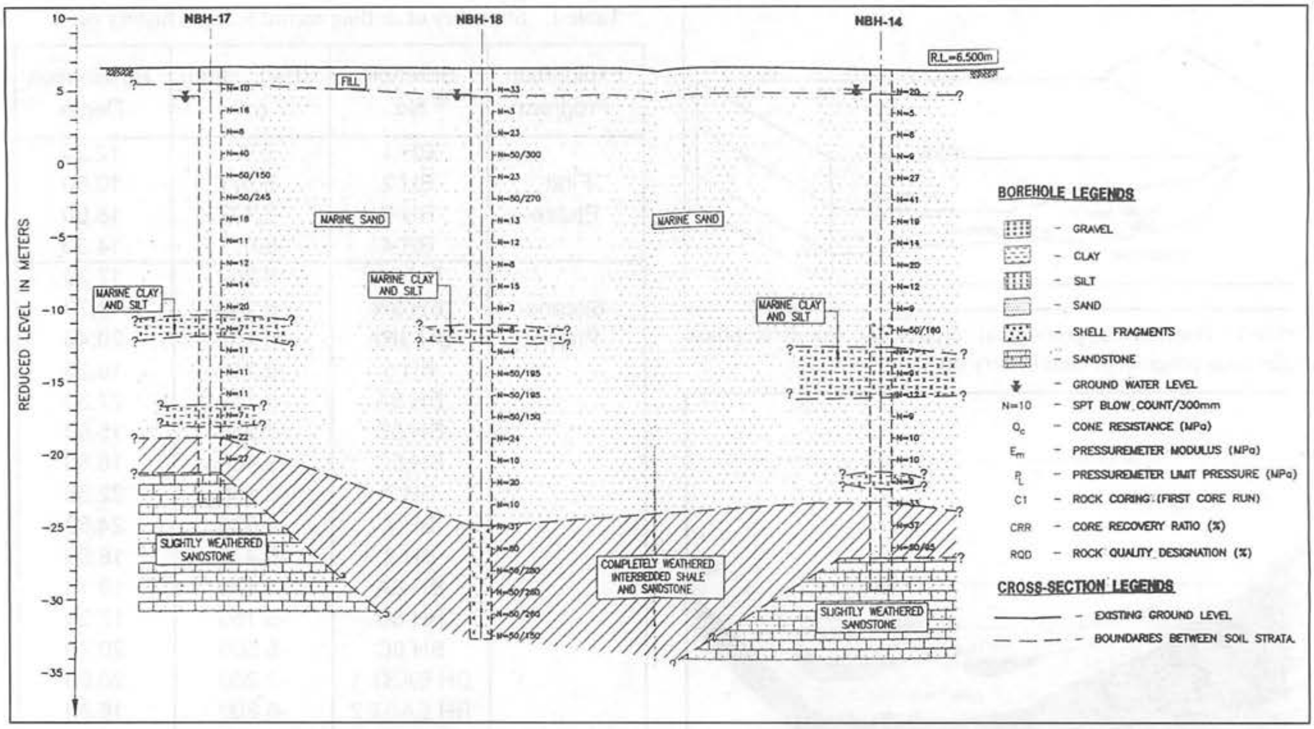

Figure 10. Example of geological profile with uncertainty (after Soil Centralab Sdn Bhd, 1998).

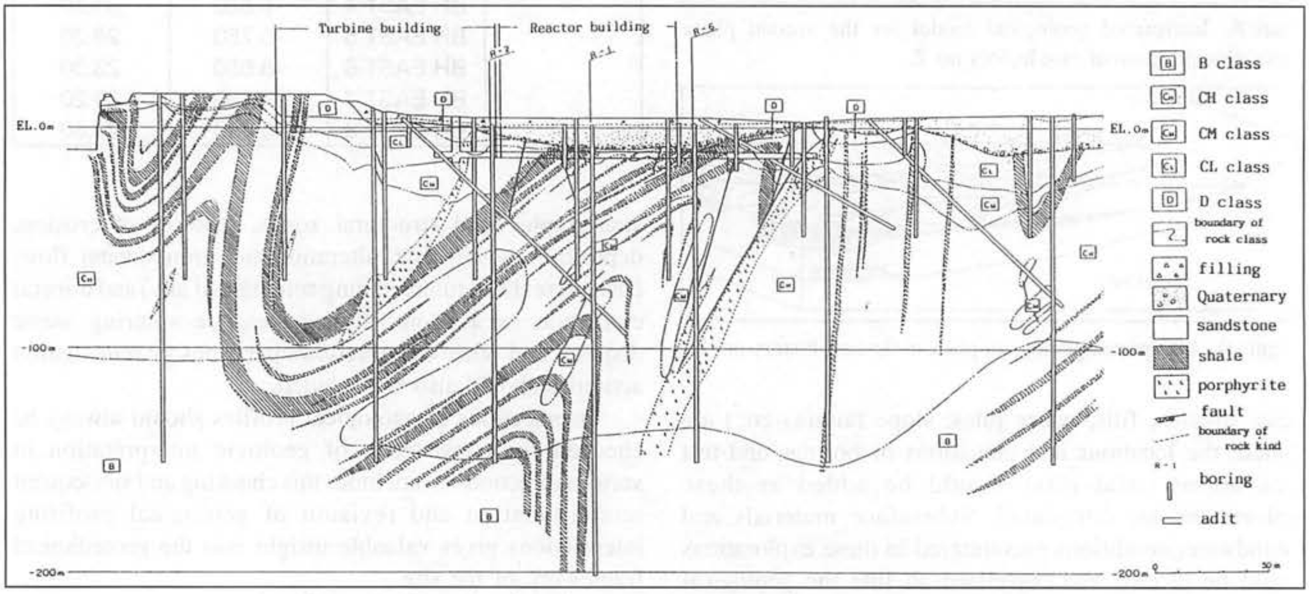

Figure 11. Example of precise geological model (after Hashimoto, 1992).

reports prepared by local geologists in the engineering practice.

REFERENCES

BORCH, J.H.A, 1988. *The Quaternary Deposits in the Coastal Plains of Peninsular Malaysia*, Quaternary Geology Section Report QG/1, Geol. Surv. Dept., Malaysia, 87p (Unpubl.).

DAVIES, T.J. & BARTON, M.E., 1998. Precise Geological Characterization for Wider Application of High Quality Site Data. *Proceeding of The First International Conference on Site Characterization*, ISC '98, USA, Balkeema, 133-138.

HAMEL, J.V., 1998. Geotechnical Cross-Sections Re-Visited. *Proceeding of the First International Conference on Site Characterization*, ISC '98, USA, Balkeema, 159-164.

HASHIMOTO, S, 1992. Rock Mass Classification of the Bedrock for Nuclear Power Plant. *Rock Mass Classification in Japan*, Engineering Geology Special Issue, Japan Society of Engineering Geology, 45-51.

RAJ, J.K. & SINGH, M., 1990. Unconsolidated Holocene sediments along the North South Expressway. *Proceedings of the Seminar on Geotechnical Aspects of the North South Expressway*, Kuala Lumpur, 159-166.

SOIL CENTRALAB SDN BHD, 1998. Final Report on *Soil Investigation Works for Malaysian Olefins Project, Kerteh, Trengganu, Malaysia* (Unpubl.).

TJIA, H.D, 1984. *Aspek Geologi Kuaternari Asia Tenggara*, Syarahan Perdana UKM, Penerbit UKM, 60p.