MINISTRY OF WORKS

CIDB MALAYSIA

CREAM CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA

GUIDELINES FOR CONSTRUCTION ON PEAT AND ORGANIC SOILS IN MALAYSIA

SECOND EDITION

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SECOND EDITION

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Foreword

Peat occurs over 25,000 square km in Malaysia corresponding to about 8% of the country's land area. Malaysia despite being a relatively small country has, on a country basis, the 9th largest peat area in the world. About 69 % of Malaysia's peat area is in Sarawak.

Construction on peat is always more challenging than on soft clay in terms of access, earthworks and settlement. Over the last 25 years the industry has made appreciable advances in methods of construction over peat. This document "GUIDELINES FOR CONSTRUCTION ON PEAT AND ORGANIC SOILS IN MALAYSIA" commissioned by Construction Research Institute of Malaysia (CREAM) a research institute fully funded by CIDB Malaysia and supported by the Ministry of Works Malaysia was prepared by a committee of practising engineers, geologists and academicians. The guidelines constitute an embodiment of design and construction experience developed from practice in Malaysia over the last 30 years.

This document is an updated version of "GUIDELINES FOR CONSTRUCTION ON PEAT AND ORGANIC SOILS IN MALAYSIA" developed in 2015. This new version supersedes the 2015 first publication. The main changes of this updated version incorporate new information obtained from research and revision carried out by local universities, government agencies and private consultants.

This second edition contains high resolution and refined maps for all peat land in Malaysia. These updated maps were contributed by Jabatan Mineral dan Geosains Malaysia (JMG).

Local universities such as Universiti Tun Hussien Onn Malaysia, Universiti Malaysia Pahang, Universiti Malaysia Sarawak and Monash University Malaysia contributed on the engineering properties of peat. More local data were incorporated in this new document. Correlations on design properties were updated as reference for engineers and designers.

Construction Research Institute of Malaysia (CREAM)

December 2019

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Contents

List of Symbols

Symbol	
ha	Hectare
km	Kilometre
m	Metre
S_u	Undrained shear strength (total stress)
S_{uv}	Vane shear strength
Φ’	Effective fiction angle
σ_{vo}’	Initial in-situ effective vertical stress
C_c	Coefficient of primary consolidation
C_α	Coefficient of secondary consolidation
C	Correction factor for the calculation of organic content
c_v	Coefficient of Consolidation
e_o	Initial void ratio
e	Void ratio’
$\Delta\sigma_v$	Increment in vertical stress
t	Time
t_p	Time corresponding to end of primary consolidation
k	Coefficient of permeability
M	Critical state strength parameter
H	Thickness of soft clay
γd, ρd	Dry density
γb, ρ	Bulk density
f_s	Sleeve friction
G_s	Specific gravity
q_t	Tip resistance
R_f	Cone penetration test friction ratio
τ_h	Horizontal shear stress
τ_v	Vertical shear stress
ϕ’	Effective friction angle
μ	Pore Pressure

List of Abbreviations

Abbreviation	
CPT	Cone Penetration Test
LL	Liquid limit
LOI	Loss on Ignition
N	SPT N Value
OC	Organic content
SPT	Standard Penetration Test
JMG	Jabatan Mineral dan Geosains Malaysia
msl	Mean sea level
PSF	Peat swamp forest
CRS	Constant Rate of Strain
CD	Drained triaxial test
CU	Consolidated undrained triaxial test

Chapter 1

Engineering Classification of Peat and Organic Soils

1.1. DEFINITIONS

1.1.1 Peat

The term peat is described as "organic soil" and as a histosol; a naturally occurring highly organic substance, which consist of undecomposed, partially decomposed, and highly decomposed plant remains (Zulkifley et al., 2013). Peat distinguished from other organic soil materials by organic matter of more than 75% and ash content is less than 25% by dry weight (Jarrett, 1995 – Geoguide 6: Site Investigation for Organic Soils and Peat; ASTM D4427). From field identification, peat is completely organic, black or dark brown in color, contains many recognizable plant remains and has low density.

1.1.2 Organic Soils

Organic soil is a soil that contains a significant amount of organic material derived from plant remains. In general, soils with an organic content of greater than 20% and less than 75% are termed organic soil. In the field, a slightly organic silts or clays will appear as inorganic fine grained soils, probably black or dark brown in color, have an organic odor and possibly some visible organic remains.

1.2. PEAT AND ORGANIC SOILS CLASSIFICATION

1.2.1 Peat Classification

Peat commonly occurs as extremely soft, wet, unconsolidated superficial deposits normally as an integral of wetland systems. They may also occur as strata beneath other superficial deposits. It is formed when organic (usually plant) matter accumulates more quickly than it humidifies (decays). This usually occurs when organic matter is preserved below high water table like in swamps or wetlands. Peat is brownish-black in dye which consists of decayed organic and mineral substance. Basically, peat is predominantly made up entirely of plant remains such as leaves and stems. It is produced by the incomplete decomposition and disintegration of sedges, trees, mosses and other plants growing in wet place and marshes in the condition of lack of oxygen (Kazemian et al., 2011a).

Therefore, the color of peat is usually dark brown or black with a distinctive odour (Craig, 1992). Since the main component is organic matter, peat is very spongy, highly compressible and combustible in characteristic. This characteristic also makes peat posessing its own distinctive geotechnical properties compared to other inorganic soils like clay and sandy soils which are made up only by soil particles (Deboucha, 2008).

Decomposition is the breakdown process of the plant remains by the soil micro flora, bacteria and fungi in the aerobic decay. In this procedure, as mentioned earlier, there is disappearance of the peat structure and change in the primary chemical composition of peat. At the end, carbon dioxide and water are the products of the decomposition process. The degree of decomposition varies throughout peat since some plants or some parts of the plants are more resistant than others. Also, the degree of decomposition of peat depends on a combination of conditions, such as the chemistry of the water supply, the temperature of the region, aeration and the biochemical stability of the peat-forming plant (Lishtvan, 1985).

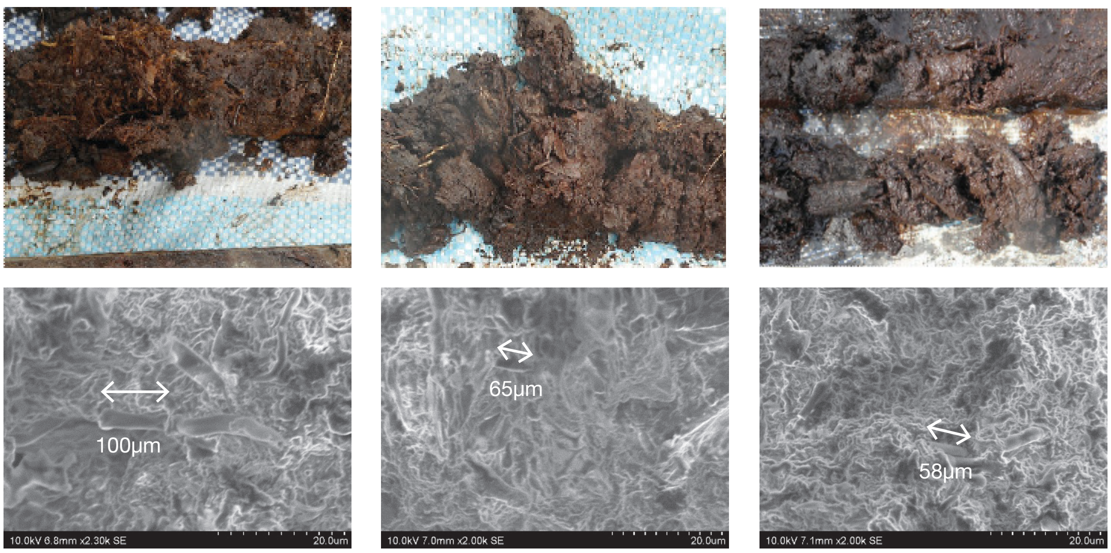
The basis for classification of peat (refer Table 1-1) is developed based on three classes: (i) fibre content, (ii) ash content, and (iii) acidity of peat in accordance to American Society for Testing and Materials standard (ASTM D4427, 2007). Also, Table 1-2 presented by Andrejko *et al*., (1983); Landva *et al*., (1983) on classification system of peat based on ash and organic content.

Table 1-1 Classification of peat based on ASTM standards

Fiber Content (ASTM D1997)	· Fibric: Peat with greater than 67% fibers · Hemic: Peat with between 33% and 67% fibers · Sapric: Peat with less than 33% fibers
Ash Content (ASTM D2974)	· Low Ash: Peat with less than 5% ash · Medium Ash: Peat with between 5% and 15% ash · High Ash: Peat with more than 15% ash
Acidity (ASTM D2976)	· Highly Acidic: Peat with a PH less than 4.5 · Moderately Acidic: Peat with a PH between 4.5 and 5.5 · Slightly Acidic: Peat with a PH greater than 5.5 and less than 7

Note: These fiber content categories related to widely used field assessment of the degree of humification (H) developed by von Post (1922). Fibric corresponds approximately to H1 – H3; Hemic to H4 – H6 and Sapric to H7 – H10.

The classification of peat is usually assessed using Von Post (1922) scale, which is based on botanical composition, degree of humification and the colour of peat water and examined in-field. This method requires the user to verify the scale of humification of ten degree (*H1* to *H10*) based on the apperance of peat water and peat that escaped between fingers upon squeezing in the hand. Field identification using von Post scale is described in Table 1-3. In addition, Jarrett (1995) developed the extended Malaysian Soil Classification System in which various peats are differentiated by degree of humification whereby fibric or fibrous peat (Ptf): humification range H1-H3, hemic or moderately decomposed peats (Pth): H4-H6 and sapric or amorphous peats (Pta): H7-H10) (refer to Table 1-3). The Field-Emission Scanning Electron Microscope (FESEM) of the peat collected; (i) fibric (ii) hemic and (iii) sapric is shown in Figure 1-1.



(i) Fibric: fibrous (> 67% fibers); least decomposed	(ii) Hemic: semi-fibrous (between 33% and 67% fibers); intermediate decomposed	(iii) Sapric: amorphous (< 33% fibers); most decomposed

Figure 1-1 Field-Emission Scanning Electron Microscope (FESEM) of the peat

Note: The peat samples is provided by Sarawak Tropical Peat Research Institute (TROPI) and FeSEM images by Monash University Malaysia.

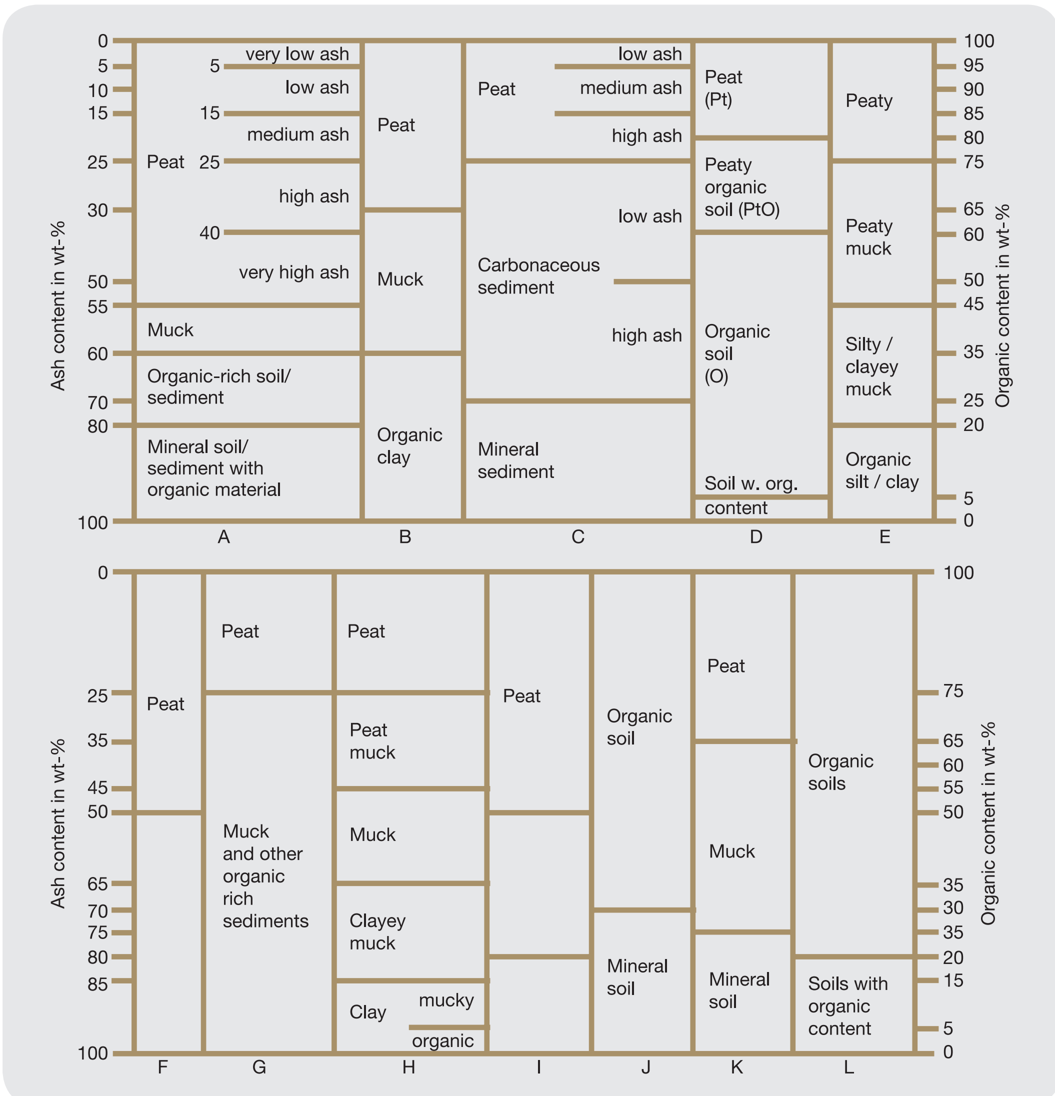
Photos of peat is extract from PLANMalaysia@Selangor (2018)

1.2.2 Organic Soils Classification

It is difficult to identify organic soil in the field as it has combination of mineral soil and organic matters which content is wide range. Table 1-2 provides the classification system for organic soils based on ash and organic content determination presented by Andrejko *et al*., (1983) and Landva *et al*., (1983).

From Jarrett (1995), definitive categorization can only be made after the organic content is measured in the laboratory. The extended Malaysian Soil Classification System by Jarrett (1995) classifies the organic soils into two categories based on organic content which are (1) SLIGHTLY ORGANIC SOILS with organic content of 3%-20% and (2) ORGANIC SOILS with organic content of 20%-75%. The classification is further refined based on liquid limit as tabulated in Table 1-4. Tables 1-2 until 1-4 show the various classification system of peat and organic soils.

Table 1-2 Various classification system of peat and organic soils based on ash and organic content (Andrejko *et al.*, 1983; Landva *et al.*, 1983)



Notes to Table 1-2:

(A) Proposed classification of this study, (B) the Moris classification (Moris, 1989), (C) the classification of the Organic Sediments Research Center of the University of South Carolina (Andrejko et al., 1983), (D) the system of the American Society for Testing and Materials (Landva et al., 1983), (E) the Jarrett system (Jarrett, 1983), (F) the Russian classification (Mankinen and Gelfer, 1982), (G) the previous classification of the American Society for Testing and Materials (ASTM, 1982), (H) the Louisiana Geological Survey system (Kearns et al., 1982), (I) the classification of the International Peat Society (Kivinen, 1968), (J) the Canadian System of Soil Classification (CSSC, 1987), (K) the Davis classification (Davis, 1946) and (L) the Arman system (Arman, 1923).

Table 1-3 Comparison of classification scheme based on the degree of humification for peat deposits according to the von Post system (1922), the US Soil Taxonomy system (Soil Survey Staff. 1990), the Esterle system (Esterle, 1990) and Wüst et al system (2003)

Von Post (1922)	US Soil Tax. (1990)	Esterle (1990)			Wüst et al, (2003)
H1 Completely undecomposed peat which releases almost clear water. Plant remains easily identifiable. No amorphous material present.	***FIBRIC*** *Mostly Sphagnum* *High fiber content*	**Peat, organic soil material containing less than 25% wt-%ash**	**Fibric** Reddish-brown peat with >66% fibres: long slender roots and rootlets with diameter 1-10 mm embedded in fibrous or granular matrix from clear water can be extracted	**Peat, muck, organic soil material containing less than 65% wt-%ash**	**Fibric**
H2 Almost completely undecomposed peat which releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.					
H3 Very slightly decomposed peat which releases muddy brown water but for which no peat passes between the fingers. Plant remains still identifiable and no amorphous material present.					
H4 Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of their identifiable features.	***HEMIC*** *Mostly reed-sedge* *Moderate fiber content*		**Coarse Hemic** Hemic peat with long, slender roots and rootlets **Hemic** Reddish-brown peat with 33-66% fibres; short or equant fragments of roots and rootlets, bark and leaf fragments generally, less than 1cm embedded in granular matrix from which clear to murky water can be extracted Fine hemic Fine grained hemic peat with sapric matrix, partially extrudes through fingers		**Hemic**
H5 Moderately decomposed peat which, when squeezed, releases very "muddy" water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recogncониze certain features. The residue is very pasty.					
H6 Moderately decomposed peat which a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The structure more distinctly than before squeezing.					
H7 Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When sequeezed, about one – half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.	***SAPRIC*** *Low fiber content* *Often high ash*				
H8 Very highly decomposed peat with large quantity of amorphous material with very indistinct plant structure. When squeezed, about two thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibers that resist decomposition.			**Sapric** Dark brown to black, with <35% fibres; fine granular material with the consistency of paste from which water can not extruded and deforms as paste upon squeezing		**Sapric**
H9 Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed it is fairly uniform paste.					
H10 Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.					

The extended Malaysian Soil Classification System for Engineering Purposes and Field Identification (Jarrett 1995) includes organic content and degree of humification in classification of peat, is tabulated in Table 1-4 and followed by Figure 1-2.

In addition to the organic and fibre content, and degree of humification, other index parameters such as water content, liquid limits, specific gravity, unit weights are also useful parameters for peat and organic soils. Hobbs (1986) and Edil (2003) suggested the following characteristics should be included in a full description of peat.

a) Color, which indicates the state of the peat.
b) Degree of humification, which as described above, represents the degree to which the organic content has decayed (fibric, hemic, sapric).
c) Water content determined by oven drying method at 105 ˚C.
d) Organic content as percentage of dry weight, determined from loss of ignition at 450-550 ˚C as percentage of oven dried mass at 105 ˚C.
e) Liquid limit and plastic limit (optional).
f) Fibre content determined from dry weight of fibre retained on #100 sieve (>0.15 mm) as percentage of oven dried mass (optional).

Table 1-4. Extended Malaysian Soil Classification System for engineering purpose and field identification (Jarrett, 1995)

Soil Group	Subgroup and laboratory identification						Field Identification
	Description	Group symbol	Subgroup symbol	Liquid Limit (%)	Degree of humification	Subgroup name	
ORGANIC SOILS AND PEATS							
SLIGHTLY ORGANIC SOILS Organic Content 3%-20%	Slightly organic SILT	Mo	Mo			Slightly organic SILT (subdivide like Co)	Usually very dark to black in colour, small amount of organic matter maybe visible. Often has distinctive organic smell
	Slightly organic CLAY	Fo	CLo	<35		Slightly organic CLAY of low plasticity	
			Clo	35-50		Slightly organic CLAY of intermediate plasticity	
		Co	Cho	50-70		Slightly organic CLAY of high plasticity	
			Cvo	70-90		Slightly organic CLAY of very high plasticity	
			CEo	>90		Slightly organic CLAY of extremely high plasticity	
ORGANIC SOILS Organic Content 20%-75%	ORGANIC SOILS	O				Subdivision of organic soil is difficult, as neither the plasticity tests nor the humification tests are reliable for them. As such, the best attempt is the probable outcome of subdivision leading to descriptions such as "fibrous ORGANIC SOILS" or " amorphous ORGANIC SOILS of intermediate plasticity.	
PEATS Organic content More than 75%	PEAT	Pt	Ptf		H1-H3	Fibric or Fibrous Peat	Dark brown to black in color. Material has low density so seems light. Majority of mass is organic so if fibrous the whole mess will be recognizable plant remains. More likely to smell strongly if highly humified.
			Pth		H4-H6	Hemic or Moderately Decomposed Peats	
			Pta		H7-H10	Sapric or Amorphous Peats	

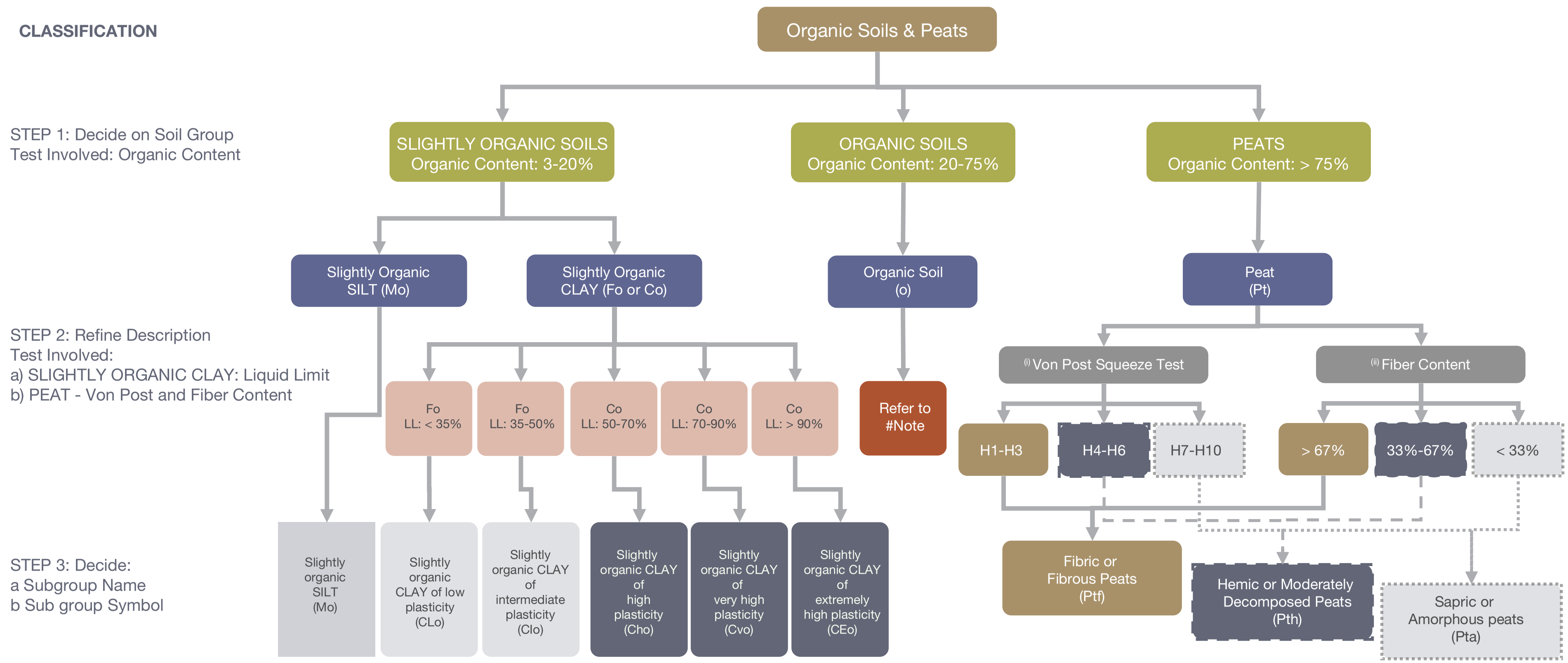


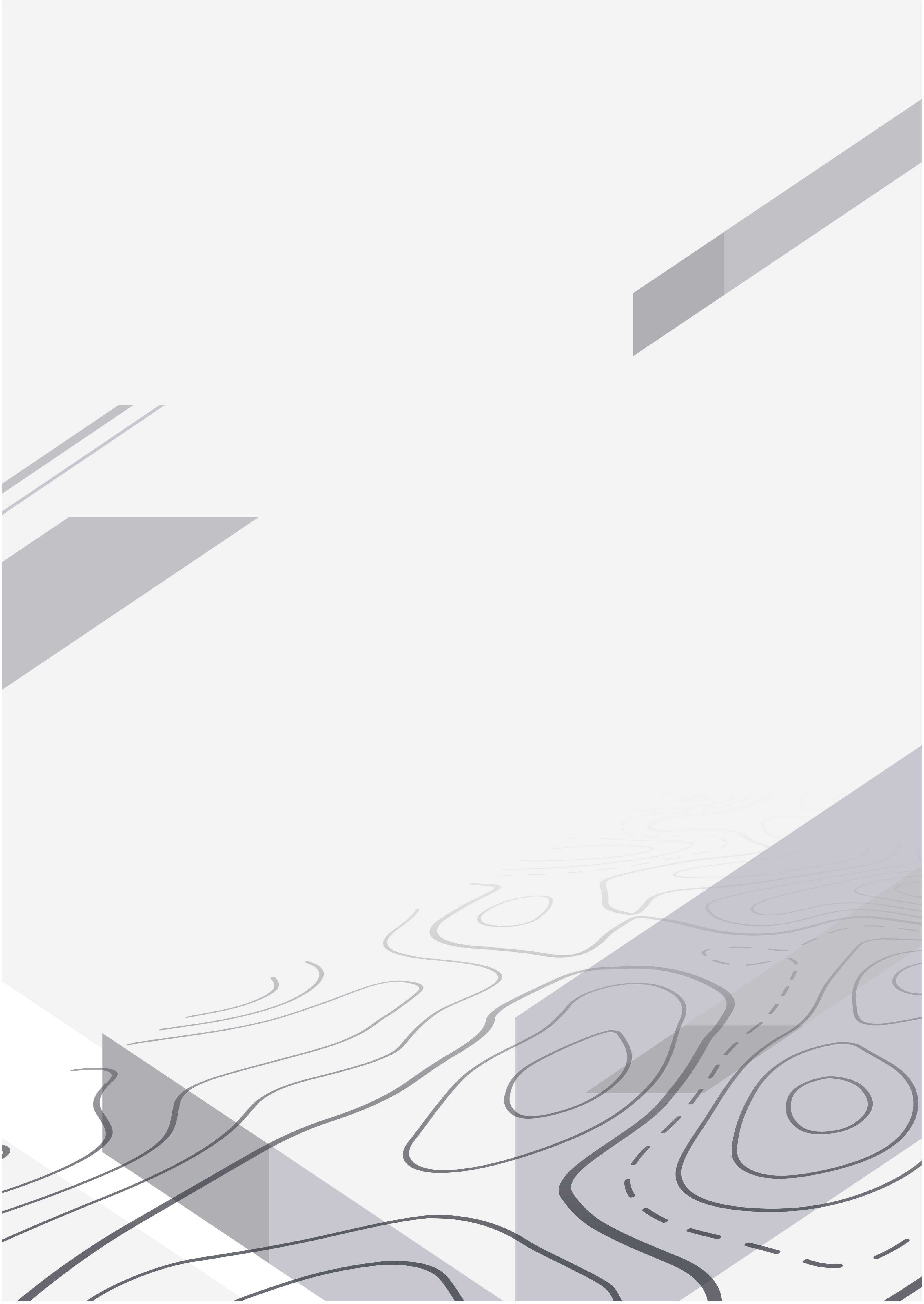
Figure 1-2 Flowchart – Organic Soils and Peat Classification

#Note: Subdivision of organic soil is difficult, as neither the plasticity tests nor the humification tests are reliable for them. As such, the best attempt is the probable outcome of subdivision leading to descriptions such as “fibrous ORGANIC SOILS” or “ amorphous ORGANIC SOILS of intermediate plasticity.

STEP 1 to **STEP 3** is in accordance to Extended Malaysian Soil Classification System for engineering purpose and field identification (Jarrett, 1995) (refer Table 1-4).

(i)Von Post Squeeze Tests is based on the degree of humification for peat deposits of the von Post system (1922) (refer Table 1-3).

(ii)Fiber Content is referring to ASTM D1997 (refer Table 1-1).



Chapter 2

Formation and Distribution of Peat and Organic Soil

2.1 INTRODUCTION

Peat is found in many countries throughout the world and peatlands constitute about 3% of the land surface of the Earth. More than 95% of the total peatlands of the world are concentrated in the temperate climates of the Northern Hemisphere, which Canada and Russia having the greatest concentration of peatlands with a combined area of over 300 million ha.

Peat also can be found in the tropical climates, wherever the conditions are favourable for its formation. The tropical peatlands are scattered in a few areas in Africa and parts of Central America, but two thirds of its world's total area of 30 million ha is reported to be found in Southeast Asia. Table 2 - 1 shows the distribution of peatlands around the world.

Table 2 - 1. Distribution of peat deposit around the world (Mesri and Ajlouni, 2007)

Country	Area (km^2)	Country	Area (km^2)
Canada	1,500,000	Germany	16,000
U.S.S.R (the former)	1,500,000	Brazil	15,000
United States	600,000	Ireland	14,000
Indonesia	170,000	Uganda	14,000
Finland	100,000	Poland	13,000
Sweden	70,000	Falklands	12,000
China	42,000	Chile	11,000
Norway	30,000	Zambia	11,000
Malaysia	25,000	26 other countries	220 to 10,000

The largest area of tropical peatland is located on the islands of Borneo and Sumatra. It can also be found significantly in other parts of Indonesia, Malaysia, Vietnam, Thailand and Philippines.

2.2 FORMATION OF PEAT

In the tropics like Malaysia and Indonesia, peat deposits also occur in both highlands and lowland areas. They are generally termed as basin and valley peat respectively. However, the lowland or basin peat is more extensive and occurs in low-lying poorly drained depressions or basin in the coastal areas. Basin peat is usually found on the inward edge of the mangrove swamps along the coast. The individual peat bodies may range from a few to 100,000 ha and they generally have a dome-shaped surface.

The peat is generally classified as the ombrogenous or rain fed peat, and is poor in nutrients (oligotrophic). Due to coastal and alluvial geomorphology they are often elongated and irregular, rather than having the ideal round bog shape. The depth of the peat is generally shallower near the coast and increases inland, locally exceeding more than 20m. The coastal peat land is generally elevated well above adjacent river courses. Steep gradients are found at the periphery while the central peat plain is almost flat. Water plays a fundamental role in the development and maintenance of tropical peat. A balance of rainfall and evapotranspiration is critical to their sustainability. Rainfall and surface topography regulate the overall hydrological characteristics of the peat land.

Peat land is also generally known as wetland or peat swamp because of its water table, which is close to, or above the peat surface throughout the year and fluctuates with the intensity and frequency of rainfall. Peat swamp is an important component of the world's wetlands – the dynamic link between land and water, a transition zone where the flow of water, the cycling of nutrients and the energy of the sun combined to produce a unique ecosystem of hydrology, soils and vegetation. The build-up of layers of peat and the degree of decomposition depend principally on the local composition of the peat and the degree of waterlogging (Figure 2 - 1).

Peat formed in very wet conditions accumulates considerably faster and is less decomposed than peat accumulating in drier places. The peat acts as a natural sponge, retaining moisture at times of low rainfall but, because it is normally waterlogged already, with a very limited capacity to absorb additional heavy rainfall during periods such as a tropical monsoon. Peat swamp forests develop on these sites where dead vegetation has become waterlogged and is accumulating as peat. Water in peat swamps is generally high in humic substances (humus and humic acids) that give a typically dark brown to black colour to the water. Peat swamps are characterized by diverse features that relate to the nature of the water supply, such as flooding by surface or groundwater, or solely from rainfall; type of landscape in which the peat swamp occurs, such as shallow depressions close to rivers; type of landscape that the swamp creates, such as accumulation of peat above groundwater level so that vegetation, often with prominent aerial roots, becomes wholly dependent on rainfall.

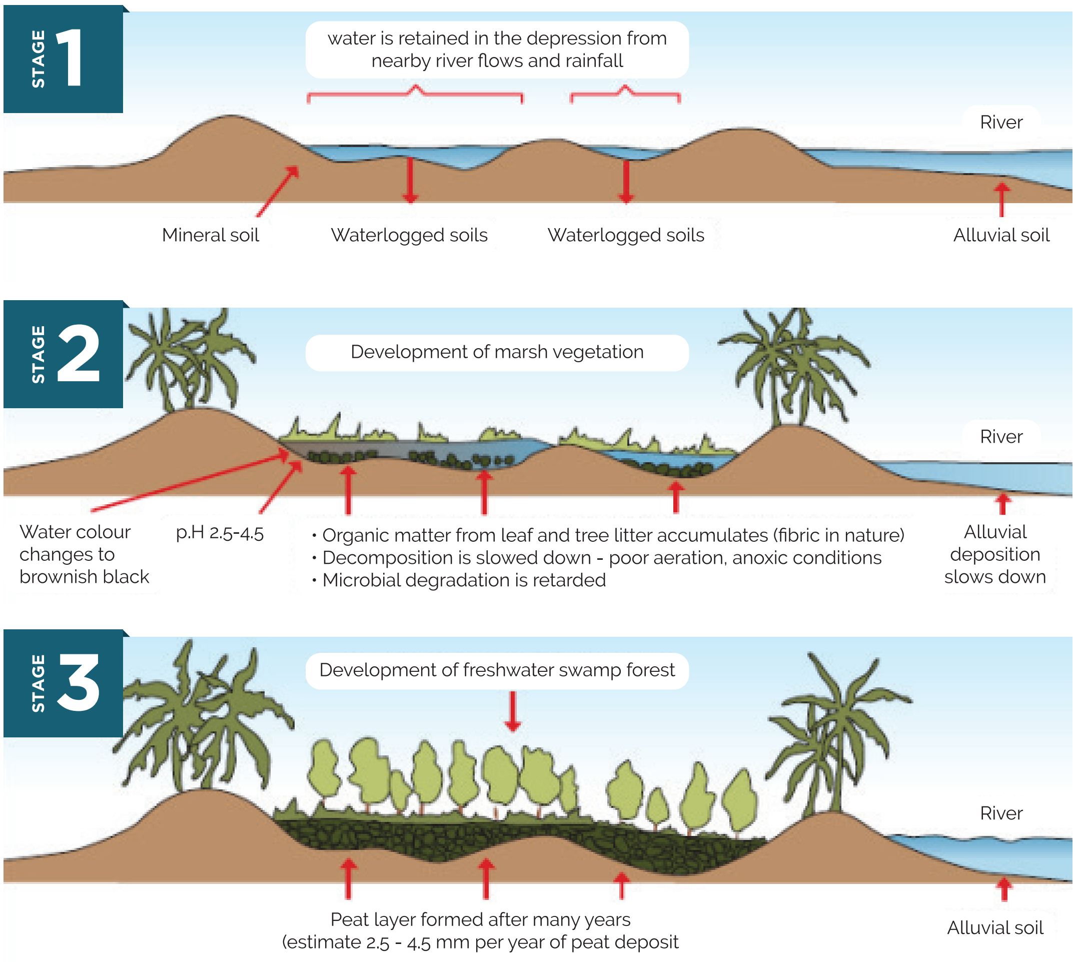


Figure 2 - 1. Peat swamps formation (Leete, 2006)

Basin peat form domes, which according to Mutalib *et al*., (1991), are up to 15 m high whilst valley peat is flat or interlayer with river deposits. Normally, sandy ridges bound basin peat at their seaward side or they gradually merge into muddy coastal flats. Low lying levees flank these domes along the rivers. The complexity of the domes becomes more pronounced as the distance from the sea increases as shown in Figure 2 - 2. Tropical (basin) peat domes are found to have typically well-developed internal stratification. Peat deposit is shown to be lenticular and dome surfaced with a typical concave base. The centre of the dome however is usually flat. The internal stratification is typically three fold with a fine grained hemic/ sapric layer overlying a thick zone of fine to medium grained woody hemic - fibric, over fine grained hemic peat. The base of the peat dome is typically dark grey clay and sand with a thin layer of clayey peat or peaty clay.

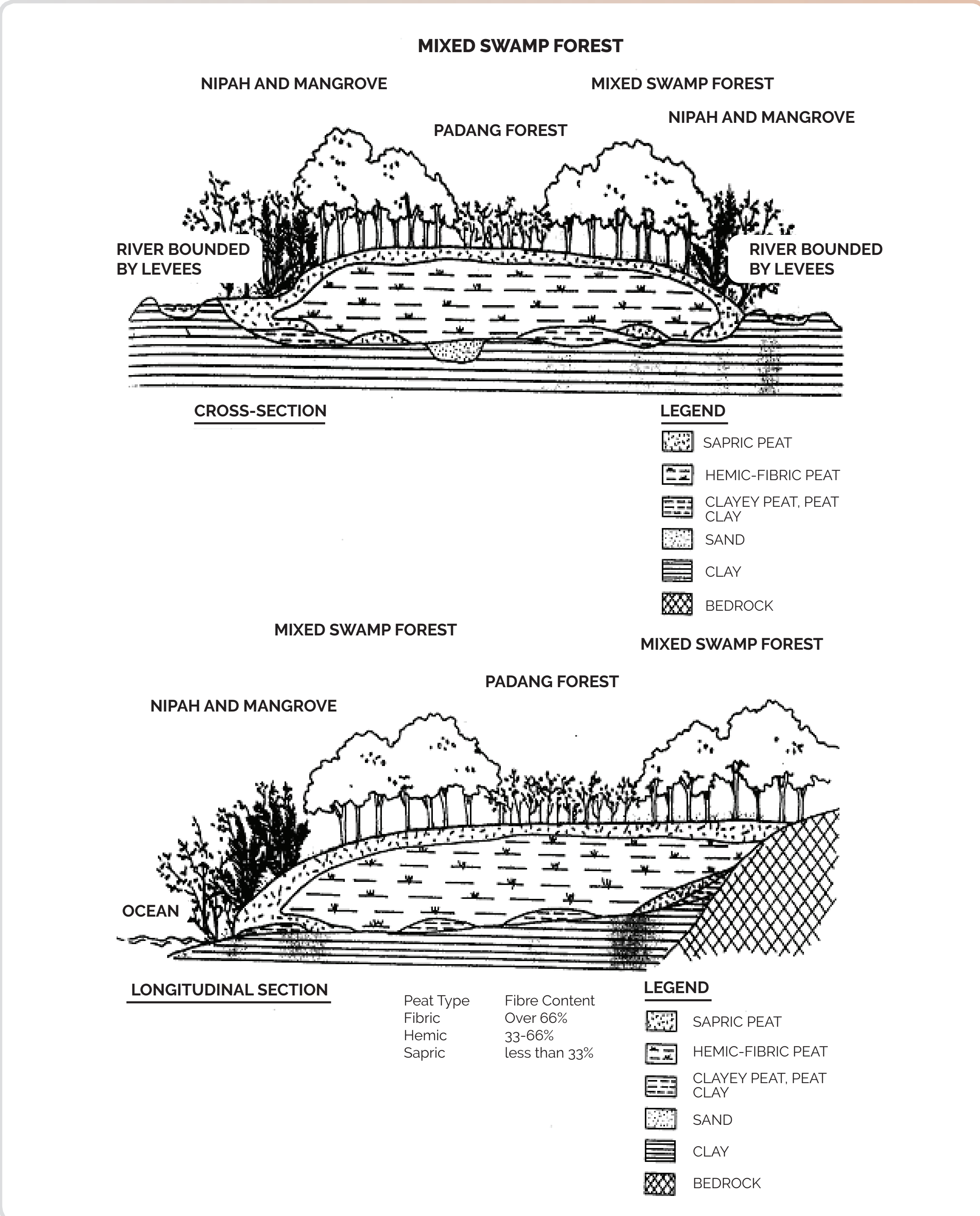


Figure 2 - 2. Typical cross section and longitudinal sections of a basin peat (Yogeswaran, 1995)

Lam (1989) postulates the possible event leading to the development of peat deposits as a result of sea level changes. The last global glaciations resulted in rapid denudation and deep incision of the parent rock formation. After the last maximum glaciations (some 20,000 years BP), sea level rose rapidly and reached a maximum level 5,500 years BP. This affected the result in transportation and deposition of a large amount of sediment, which formed deltas and flood plains. Peat swamps were initiated in the depression and basin between isolated hills and levees, and in the deltas. During the initial stage, plants developed in mineral soils. The areas were still under influence of rivers with influx of clastic (mineral) sediments during flood. The accumulation of clastic sediments and plant remains resulted in formation of clayey peat (topogenous peat). As plant remained accumulated, the ground surface levels were elevated. This led to formation of peat, which was free or low of the clastic sediments (ombrogenous peat), and highly acidic (Huat *et al*., 2014).The peat forming vegetation consists mainly of large trees, resulting in high lignin content which is twice that of the bog peat.

2.3 DISTRIBUTION OF PEATLAND IN MALAYSIA

Peat and soft soil are two integral components of the Quaternary deposits which are generally found in the coastal plains of Malaysia. Geographically, tropical peat deposits are commonly found in poorly – drained lowlands such as the river valleys and estuaries. Some can also be found on small isolated areas in steep mountainous region above 1000m from mean sea level (msl). The former is known as basin peats, while the latter is called valley peats. Most of the lowland peatland in Malaysia initially formed behind mangrove swamp forest along the coast, and later developed as far as 100km in land on the alluvial plains between rivers flowing to the sea. The inland peat typically developed as a dome-like structure underlain by a thick mineral soil but some may be fairly uniform in depth and elevation.

In Malaysia, approximately 8% amounted to about 2,457,730 ha of the 32,975,800 ha of the country total land area is covered with peat. The extent and distribution of peat areas in Malaysia is summarised in Table 2 - 2. The state of Sarawak has the largest area of peat soils that amounted to 1,697,847 ha, followed by Peninsular Malaysia (642,918 ha); then Sabah (116,965 ha), which are 69.08%, 26.16% and 4.76% of the total peatland area in Malaysia, respectively. Most of the tropical peat in Malaysia is predominantly peat swamp forest, whereas natural vegetation of sedges, grasses and shrubs can only be found on the inundated areas and commonly occurs as the uppermost layer of these sediments

Table 2 - 2. The area (ha) of peat soil in Peninsula Malaysia, Sarawak and Sabah (Wetlands International, 2010)

Region	Total Area of Peat (ha)	%
Sarawak	1,697,847	69.08
Peninsular Malaysia	642,918	26.16
Sabah	116,965	4.76
Total	2,457,730	

2.3.1 Peninsular Malaysia

Figure 2 - 3 shows the distribution of peat area in Peninsular Malaysia. as coral reefs, sea grass beds, mangrove swamp forest, riparian fringes, and peat swamp forest.

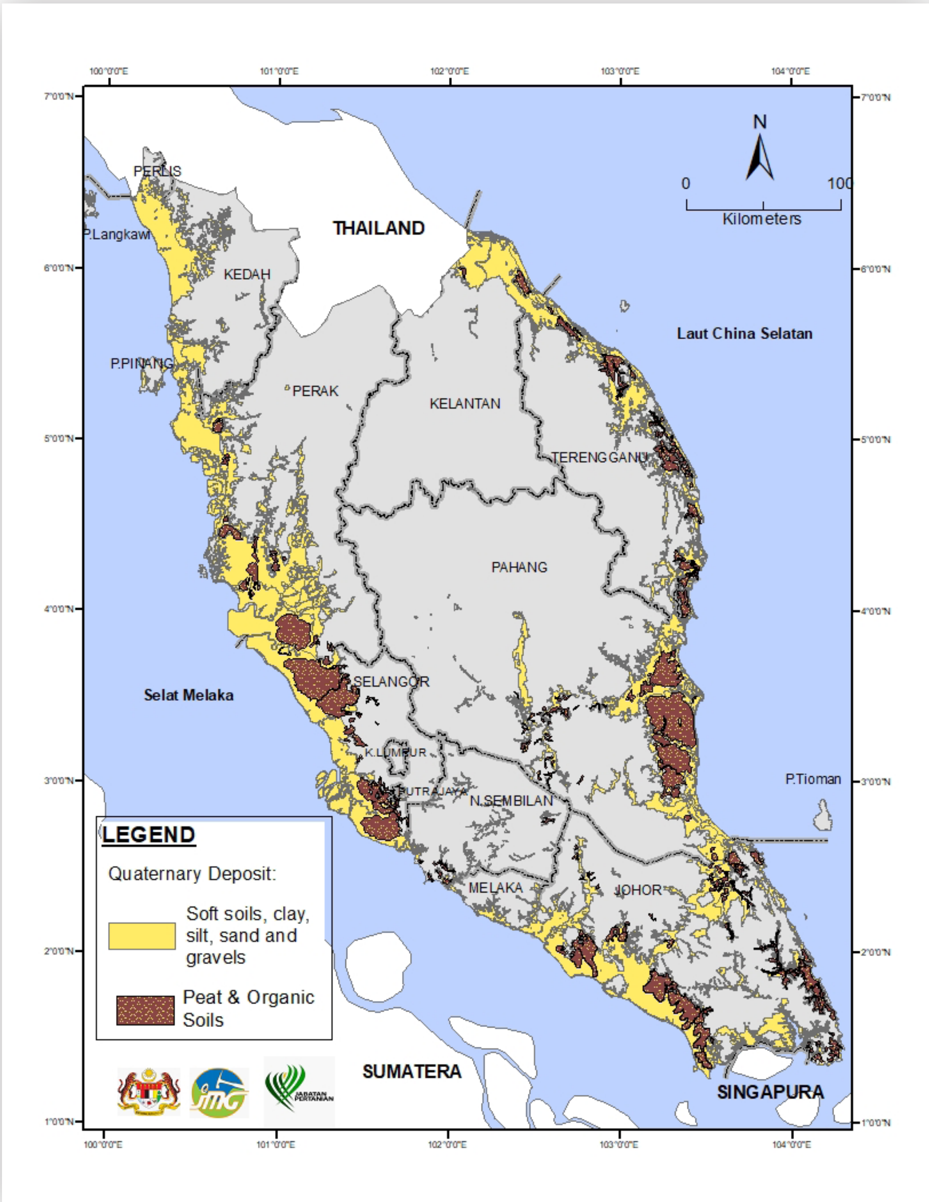


Figure 2 - 3. General Distribution of Peat & Organic Soils and Soft Soils: Clay, Silt, Sand & Gravel in Peninsular Malaysia (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

Johor has the largest area of coastal estuarine ecosystems in Peninsular Malaysia with varied wetlands types, such as coral reefs, sea grass beds, mangrove swamp forest, riparian fringes, and peat swamp forest. Peat land in Johor has developed on marine soils, acid sulphate soils, and marine clays. The Johor west coast peat overlies acid sulphate soil and the east coast peat overlies sand and clay (Figure 2-4).

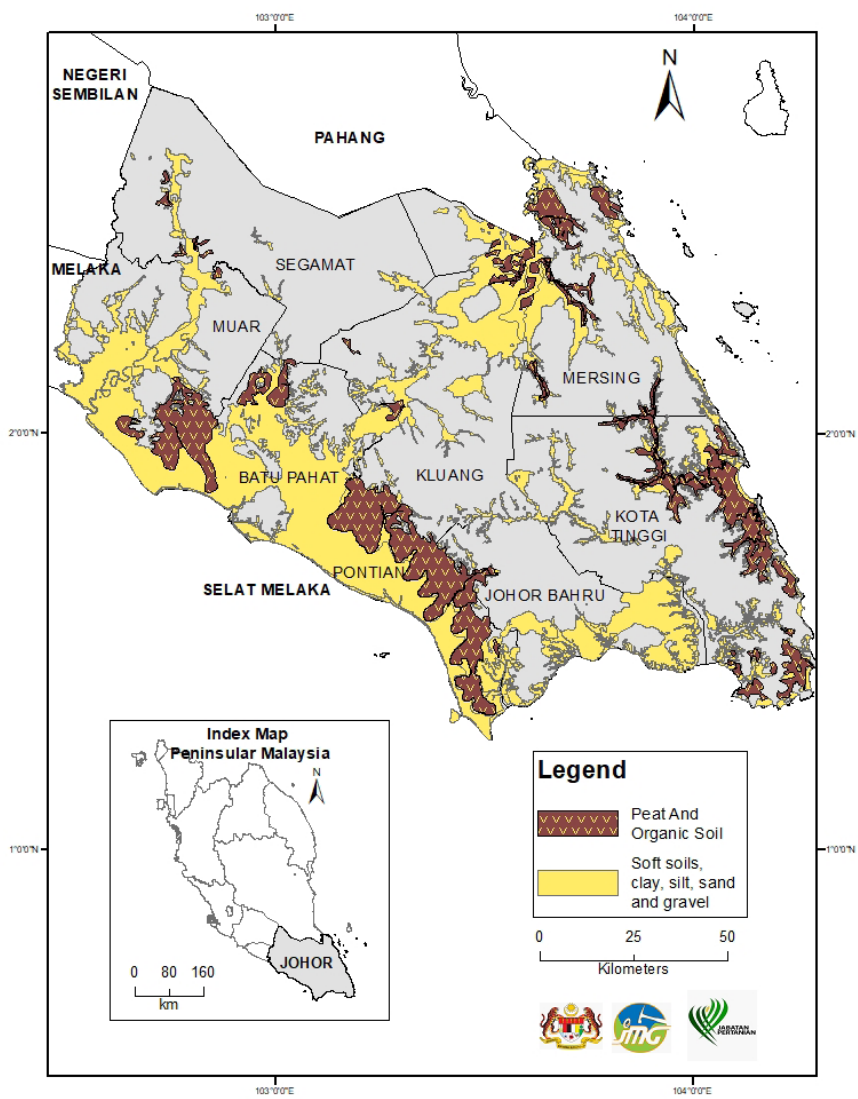


Figure 2 - 4. Peat & Organic Soils and Soft Soils areas in Johor (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

Meanwhile, Negeri Sembilan, peat is found in near to Malacca border and Jempol area. (Figure 2 -5). Peat formation in Selangor occurred in the river basins of Selangor River in the north and Langat River in the south (Figure 2- 6).

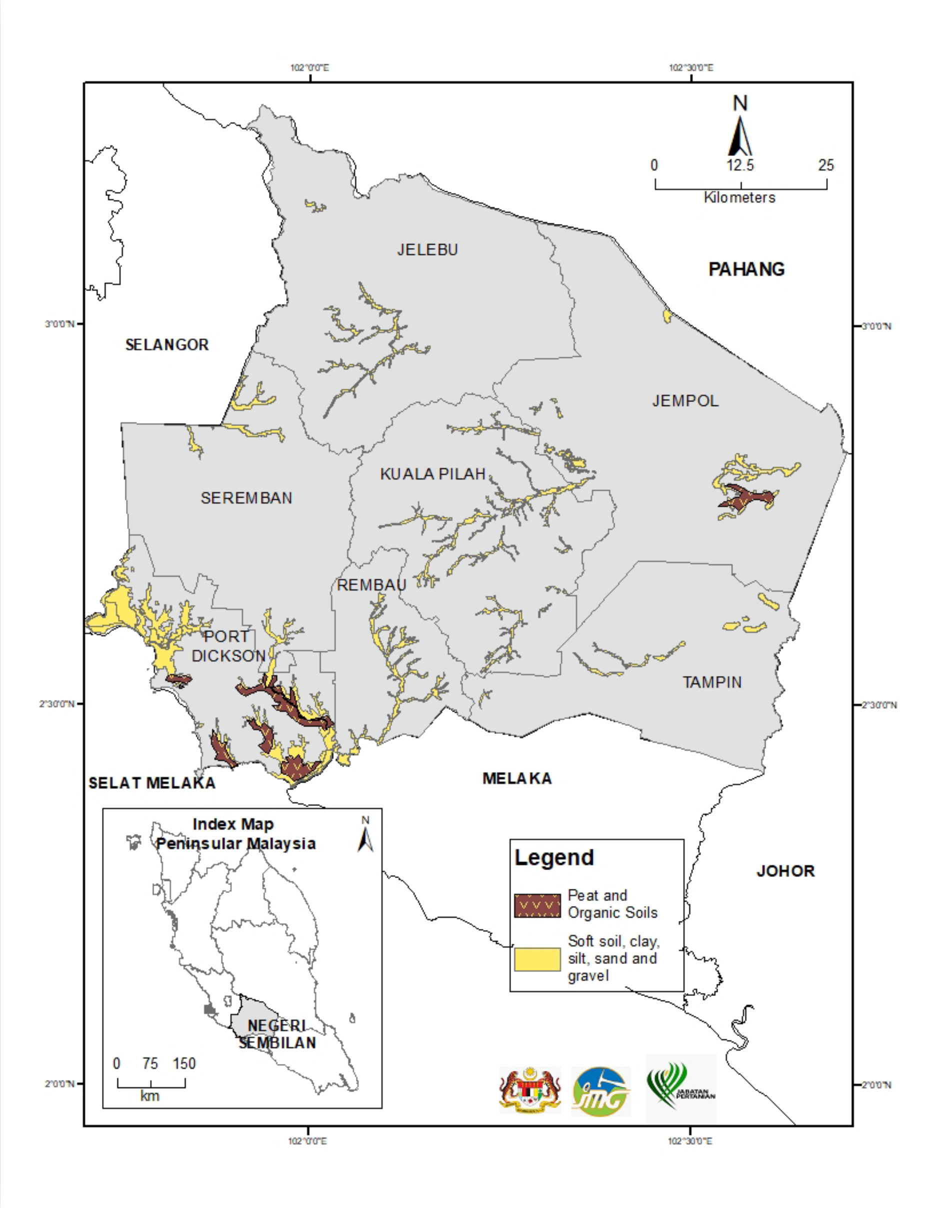


Figure 2 - 5. Peat ,Organic Soils and Soft Soils areas in Negeri Sembilan (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

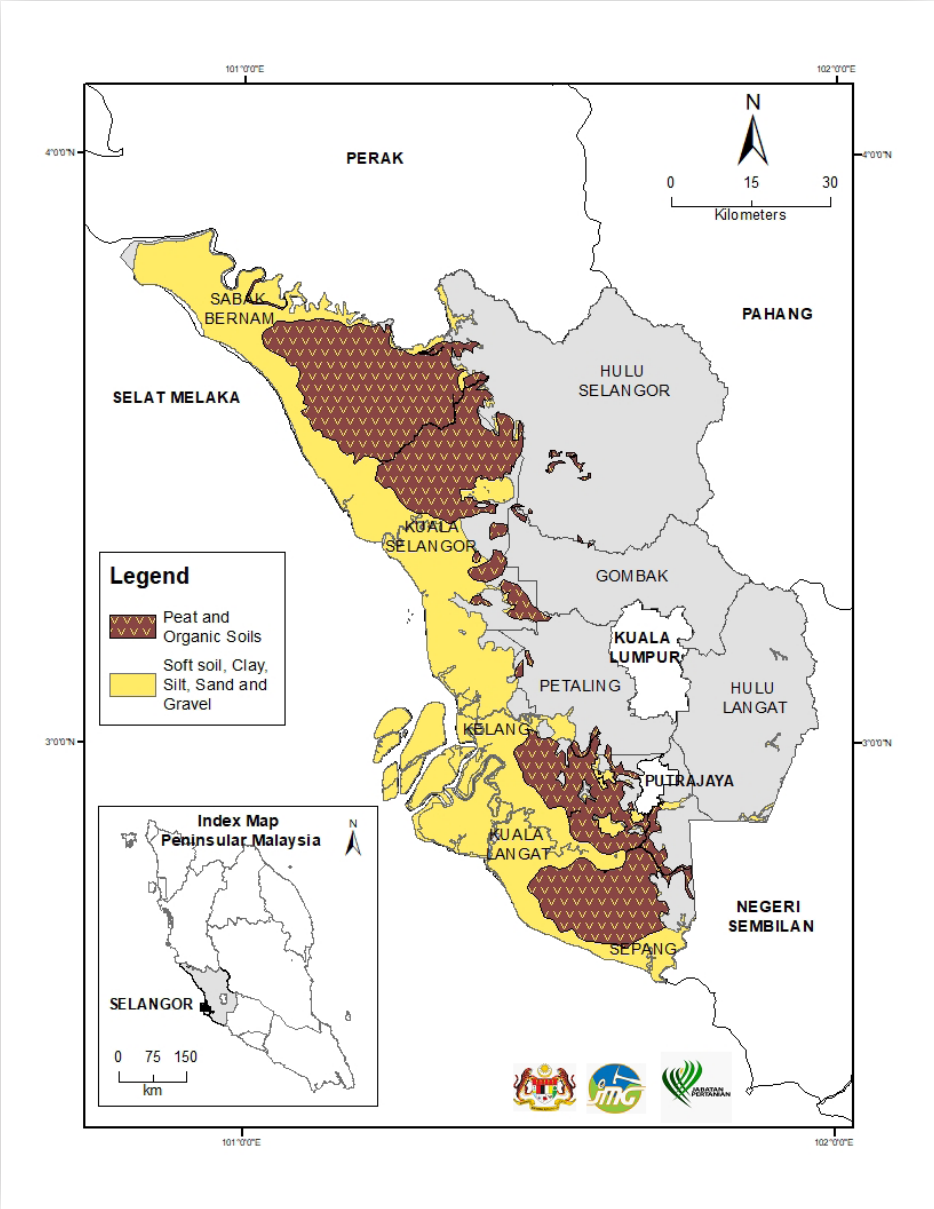


Figure 2 - 6. Peat, Organic Soils and Soft Soils areas in Selangor (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

Figure 2 -7 shows the Kuala Langat North Peatlands that is located within the Federal Territory (Putrajaya). A portion of this peatland is located under infrastructure, within the new townships of Cyberjaya and Putrajaya.

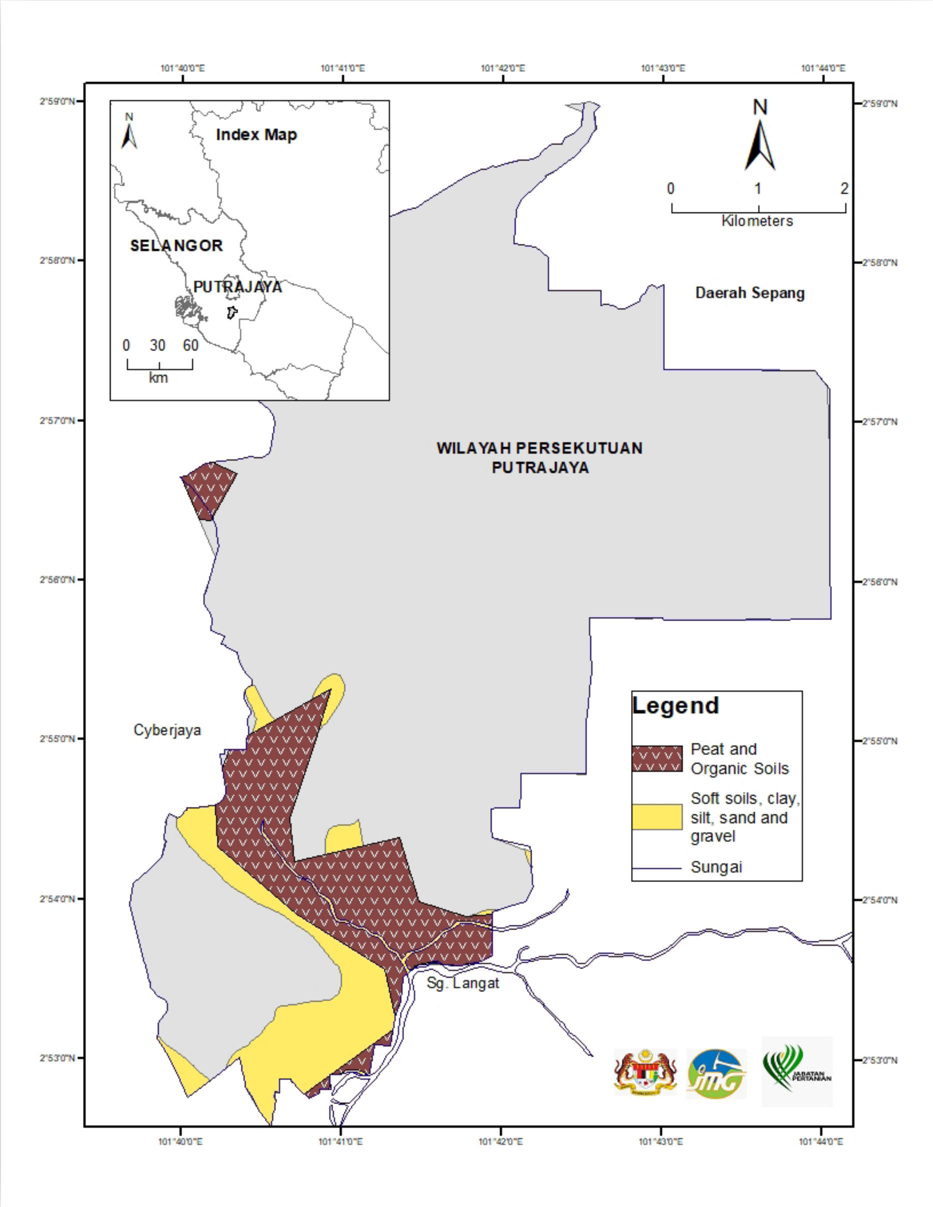


Figure 2 - 7. Peat, Organic Soils and Soft Soils areas in Federal Territory Putrajaya (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

Peat swamp forest in Perak is located mainly along the coastal areas of the state (Figure 2 - 8). Among the famous peatland in Perak is Beriah peat swamp forest which is located at the northern border of the State.

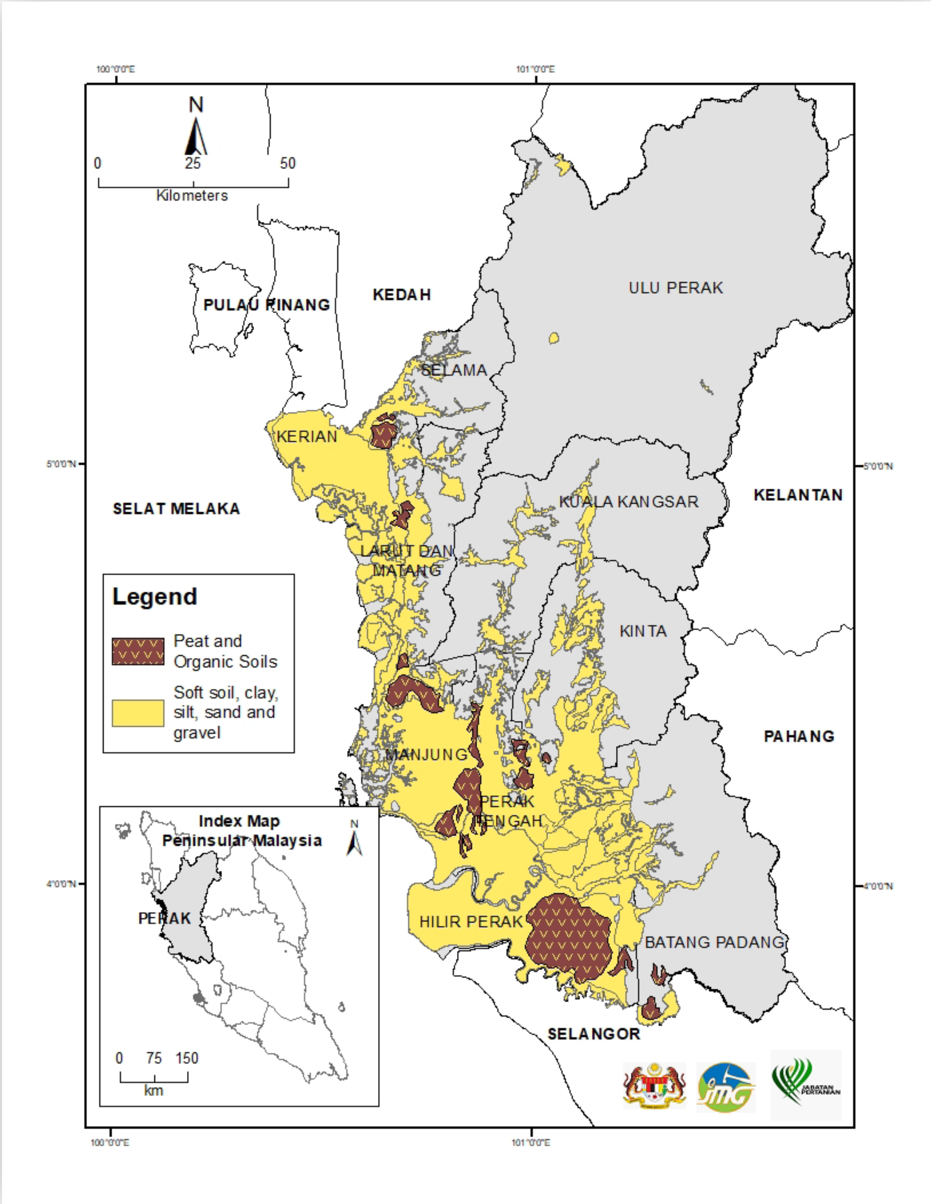


Figure 2 - 8. Peat, Organic Soils and Soft Soils areas in Perak (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

Peat swamp forest in Kelantan covers approximately comprise three principle blocks: Berangan peatland , Pasir Puteh peatland , and Pasir Mas peatland (Figure 2-9).

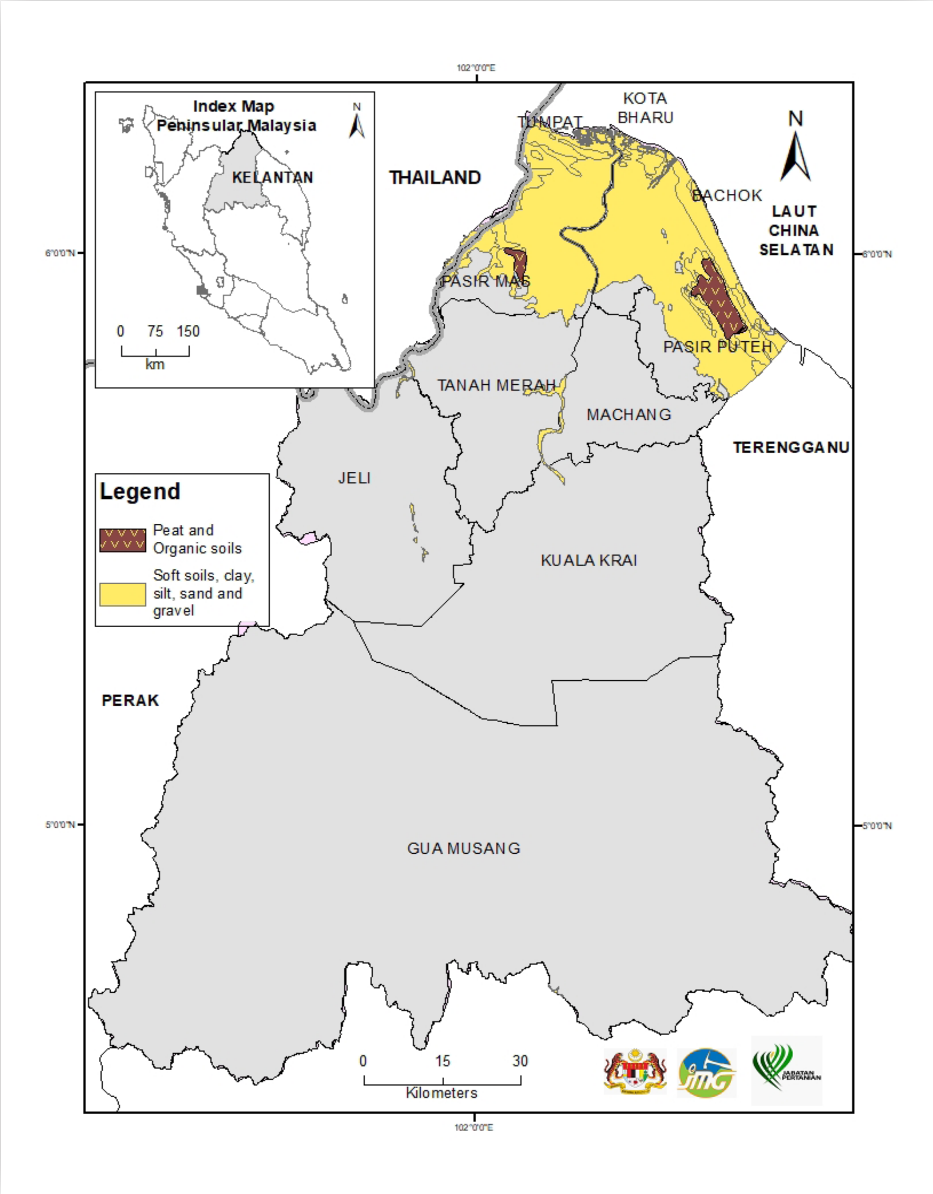


Figure 2 - 9. Peat, Organic Soils and Soft Soils areas in Kelantan (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

The coastal areas of Terengganu comprise a series of raised beaches interspersed with swales. Forest types include mangrove, Melaleuca, peat swamp, and freshwater swamp forests, along the banks of Caluk, Bari and Setiu Rivers (Figure 2 – 10).

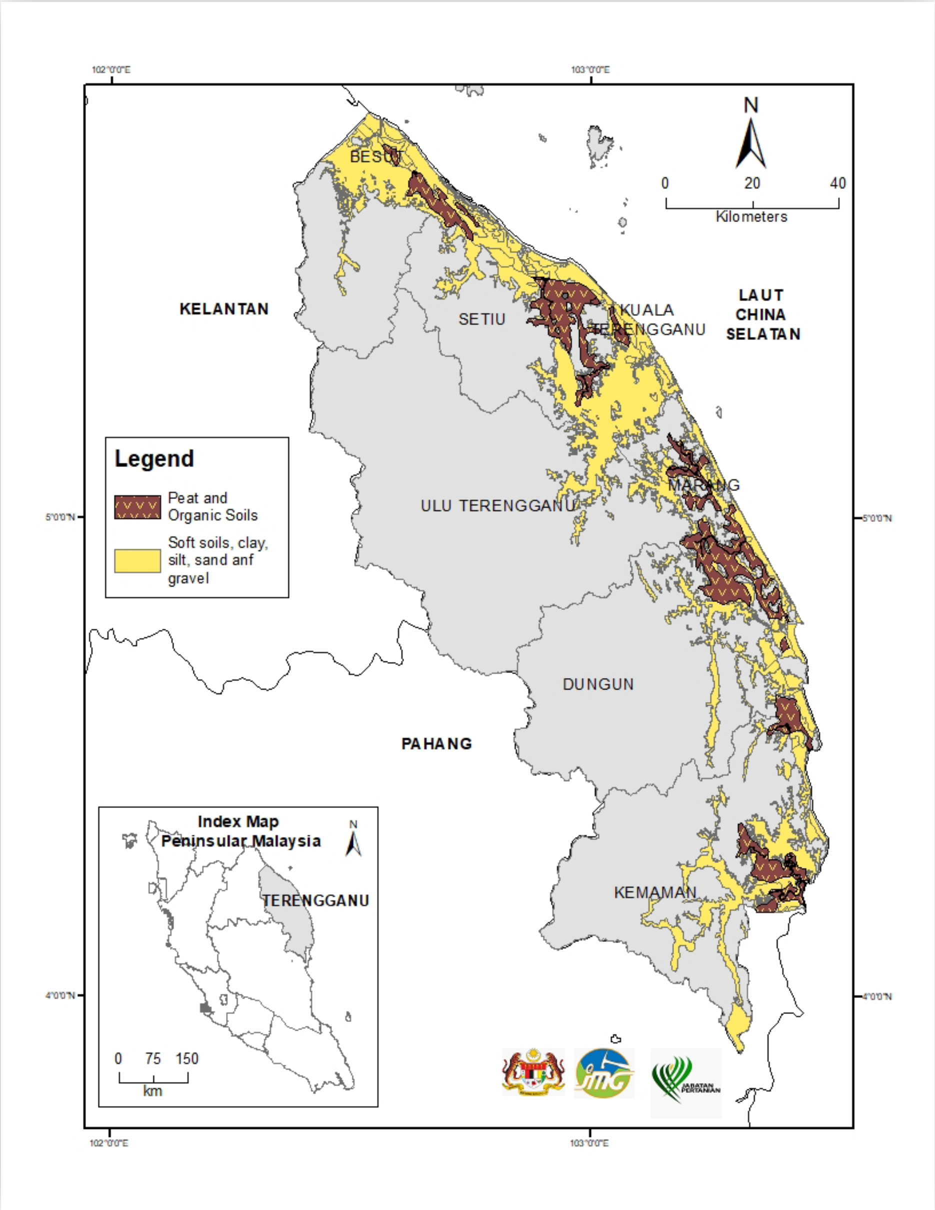


Figure 2 - 10. Peat , Organic Soils and Soft Soils areas in Terengganu (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

In Pahang, peat is found in Pahang River North Peatland, and the Pekan, Nenasi, Kedondong, and Resak Forest Reserves, including several small peatland areas west of the state (Figure 2 - 11). Pekan Forest Reserve is the largest block of peat area.

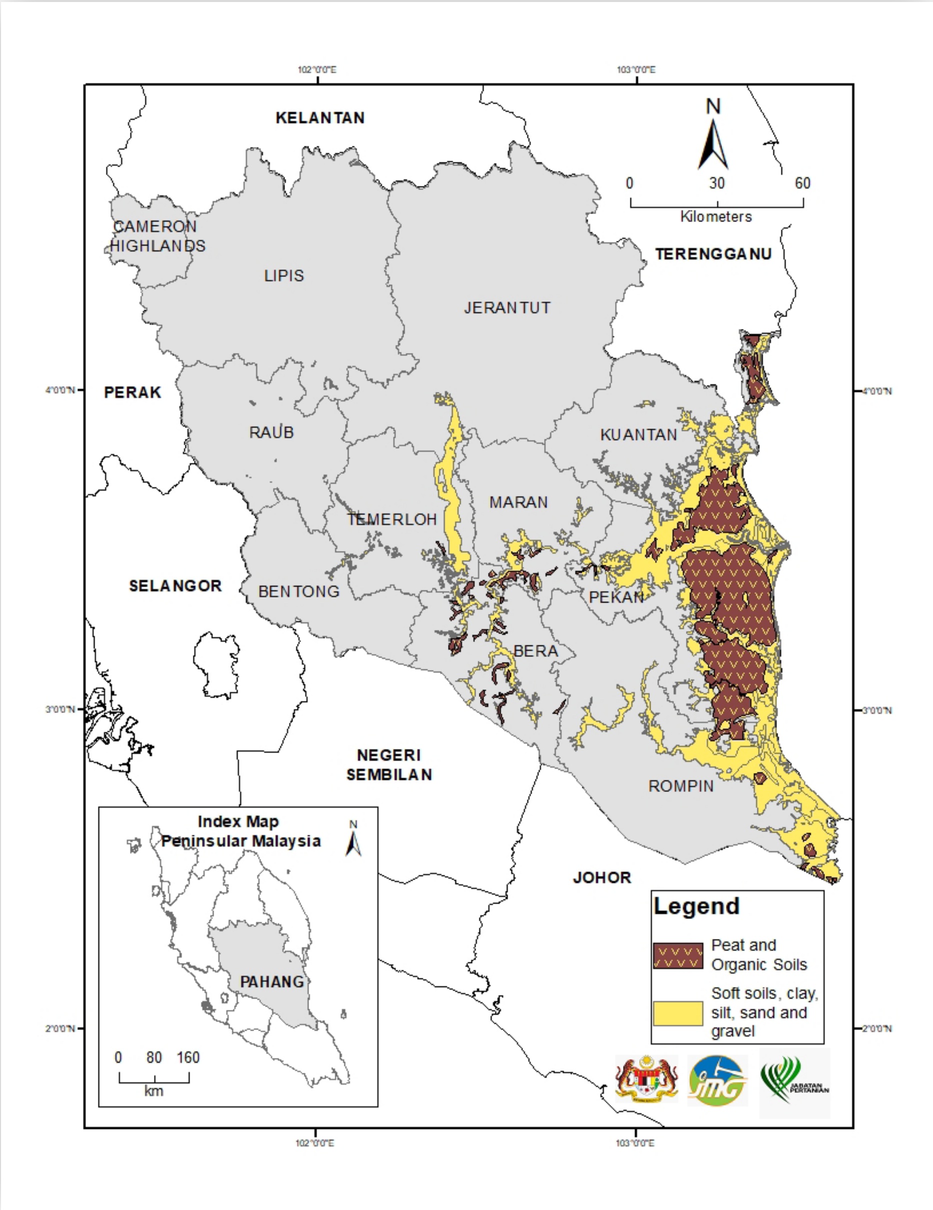


Figure 2 - 11. Peat, Organic Soils and Soft Soils areas in Pahang (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

2.3.2 Sarawak

Peatlands cover 1,697.847 ha (13.7%) of Sarawak, principally near the coast (Figure 2-12) Estimated area of peatland in Sarawak in the literature varies substantially. Sibu and Mukah has the largest peat area.

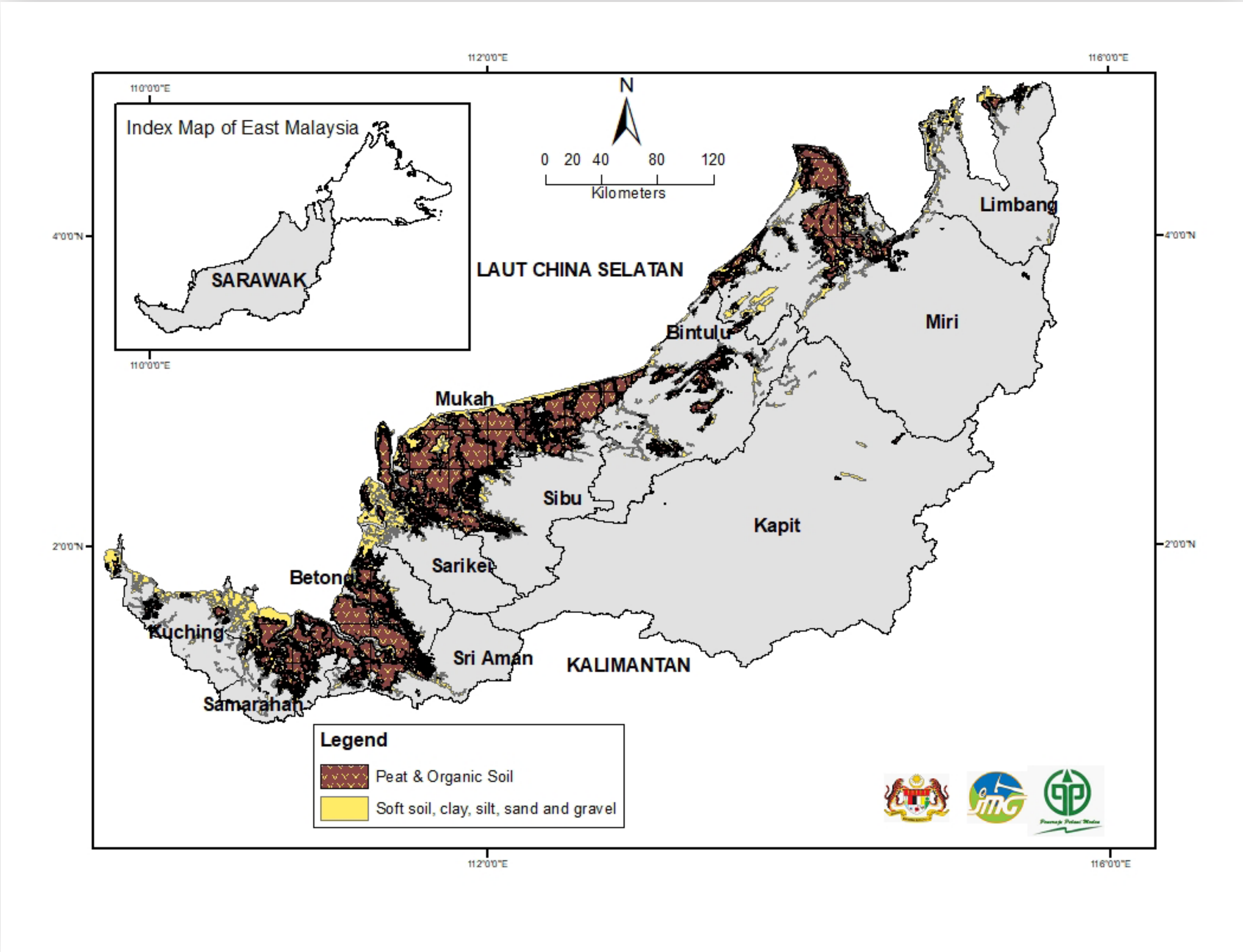


Figure 2 - 12. General Distribution of Peat & Organic Soils and Soft Soils : Clay, Silt, Sand & Gravel in Sarawak (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

2.3.3 Sabah

There are 116,965 ha of peat soils in Sabah. The largest is located in the Klias Peninsula and, in the Kinabatangan–Segama Valleys (Figure 2-13). The Klias peninsula historically included 60,500 ha of peat swamp forest, 14,500 ha of freshwater swamp forest, 8,700 ha of mangrove swamp and 28,000 ha of transitional coastal swamp. There are five forest reserves located in this wetland region, of which the largest are Padas Damit freshwater swamp (9,027 ha) and Binsuluk Forest Reserve (12,106 ha). Today the Klias Forest Reserve consists of only 3,630 ha peat swamp forest.

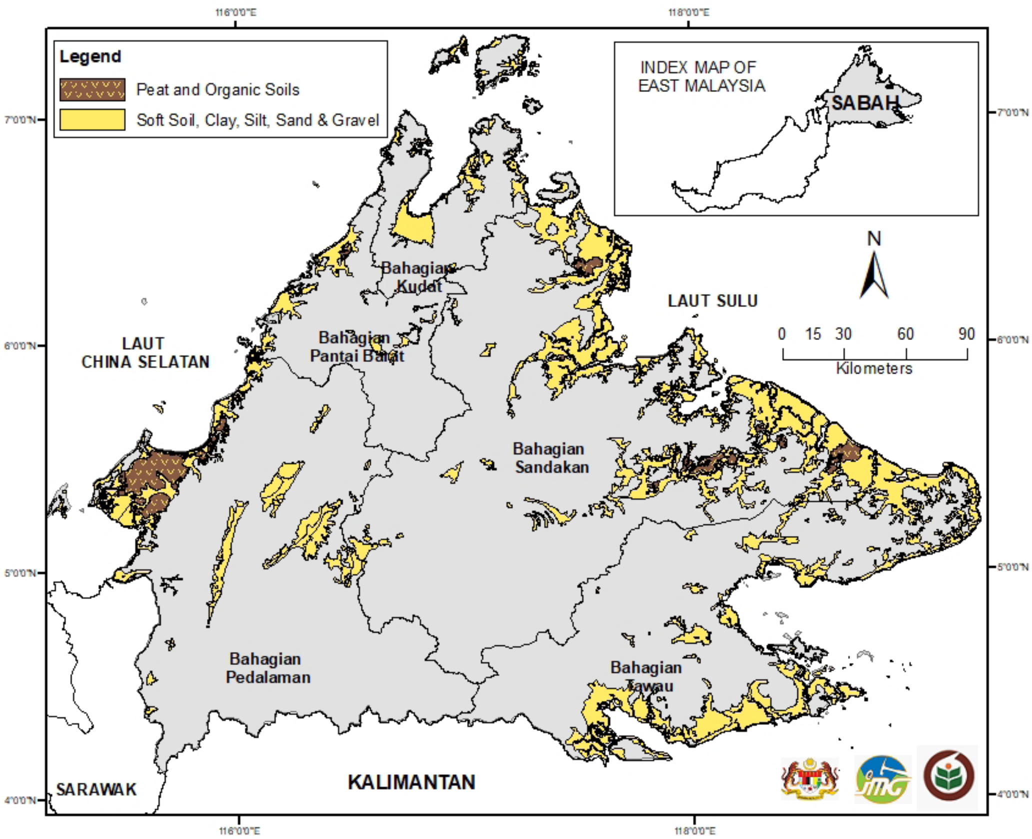


Figure 2 - 13. General Distribution of Peat & Organic Soils and Soft Soils: Clay, Silt, Sand & Gravel in Peninsular Malaysia (Soft Soils : Courtesy of Department of Mineral And Geoscience (JMG) Malaysia Peat And Organic Soils : Courtesy of Department of Agriculture (DOA) Malaysia, 2019)

Chapter 3

Soil Investigation and Peat Testing for Peat and Organic Soil

3.1 INTRODUCTION

Unlike any other ground, an investigation in peat and organics soil area would be an extra challenging task due to its nature and conditions where it exists. However the fundamental purpose of soil investigations would always remain the same which is to gather essential amount of information on the proposed land for development. The investigation in peat shall commence with a literature survey and data collection, followed by a study of geological and topographical map of the project area. Literature survey incorporates all information that is available, whether published or unpublished prior to an investigation. Valuable data can be obtained from various sources including quaternary studies, hydrogeological, engineering or geophysical investigations that have been carried out within the proposed project area.

3.2 DESK STUDY

Site investigations are conducted on water and soil to obtain their in – situ physical, chemical and engineering properties. MS 2038 Site Investigations-Code of Practice (2006) shall be referred for detail of activities in ground investigation.

A common starting point is to use valid documents such as the:

i. Geological maps. In addition to historical maps that allow more information to be obtained such as the former uses of the site; concealed mine workings; infilled ponds; old clay, gravel and sand pits; disused quarries; changes in topography and drainage; changes in stream and river courses; changes in potential landslide areas. Example of map showing distribution of peat in Malaysia is in section 1.3 of Chapter 1.

ii. Ariel Photography is another useful source of information. Such records can be extremely useful in ascertaining historical use of the site, hidden foundations, changes of river course and much more other hidden data. Example of ariels photos can be obtained from Google Earth applications and also incorporating aerial videography and photography with radio controlled drone.

iii. Services records are also an essential part of the desk study, necessary to locate hidden services such as electricity cables, sewers and telephone wires. It is essential when conducting a desk study that as much information as possible is obtained. Work at this stage of the investigation saves much time later and vastly improves the planning and quality of the Investigation. Local Municipal Council and some of the agencies that could provide information relevant to the site.

According to the Board of Engineers Malaysia (BEM) soil investigation shall be planned, carried out and supervised by qualified and experienced personnel based on the MS2038 Code of Practice and MS1056 Method of Test for Soils for Civil Engineering Purposes.

Although major part of this chapter is written in line with the existing guideline for Engineering Geological Mapping in Peat and Soft Soils produced by Minerals and Geoscience Department of Malaysia, there are sections which are valid for others types of soil due to the common function of the testing methodology. In spite of that, a specific tests involving peat and organic soils are also referred to other relevant protocols and standards available such ASTM and European code.

3.3 SITE RECONNAISSANCE

The site reconnaissance is the phase in site investigation which is normally done in the form of walk over survey on the site to recognize any difficult ground conditions such as peat. Here are some of the important tips or evidence to look out for:

i. Hydrogeology: Wet marshy ground, watershed and catchment area, wetland ponds and streams.
ii. Ground subsidence: Signs of ground subsidence at existing platforms include huge cracks at utility facilities and gaps between subsurface and building foundations, and displaced fences or drains.
iii. Plantation: The presence of active agriculture and plantation area is often a good sign of soil fertility. To sustain plant growth and to optimize crop yield, capacity of soil is maintained through enhanced drainage system. Ground water table control using lateral drainage system may disturb the ground stability of nearby settlements.
iv. Access: It is essential that access to the site can be easily obtained. Possible problems include dense mangrove swamp or thick forest and with traces of peatland wild fire. Presence of natural wildlife sanctuary should be protected as geographic landmark for future generations.

Engineering classification and determination of peat decomposition can be divided into field and laboratory method.

3.4 FIELD TESTS

Field tests are mainly conducted through visual inspections and the consideration factors are the quantity and the colour of water as well as the consistence and the structure of tissue (fibers) which remains in the palm after squeezing. It is the least time consuming technique and the cheapest way to classify peat.

i. After Wallgren (1915)
ii. After von Post (1924)
iii. After Maciak and Liwski (1979)

All the above methods undoubtedly give access to direct parameters during sampling in the field. However, with little practice and no modern instrumentation involved, it may result in erroneous conclusion. Therefore, this method should be only used as a preliminary study and in general assessment purpose.

Alternatively there are other state of the art methods which is more reliable and accurate. Generally theses methods involve electricity and seismic waves in identifying the peat location and its properties. The techniques will determine the subsurface materials by measuring some physical property of the material and, through some correlations, using the obtained values for identifications. Most of the methods determine conditions over a sizable distance. The methods do not actually measure engineering properties directly. Several techniques can be utilised, namely:

i. Seismic refraction method

   Based on the seismic waves travelling through the surrounding soil and rock at speeds relating to the density and bonding characteristics of the material. The velocity of the seismic waves passing through subsurface soil or rock materials is determined, and the magnitude of the velocity is then utilised to identify the material. The value of results need to be verify with the borehlog to determine the depth of the peat layer (Zainorabidin and Said, 2015).

ii. Electrical resistivity method

   By this method the apparent resistivity of the ground is determined by measuring the potential different across two electrodes while introducing a current into the ground through two other electrodes. The main factor which contributes to the succesful application of the resistivity method is the existence of contrast in the resistivity of the different rock types. Figure 3-1 shows the example depth of peat layer was determined at the level 3.9 and 3.7 meters for 1 meter and 1.5 meters electrode spacing respectively (West-east and North-South). The resistivity value ranging from 100.8 to 139.5 ohm.m revealed at Parit Nipah, Johor (Kasbi et al., 2019). These data can be verified commensurately with peat sampler method.

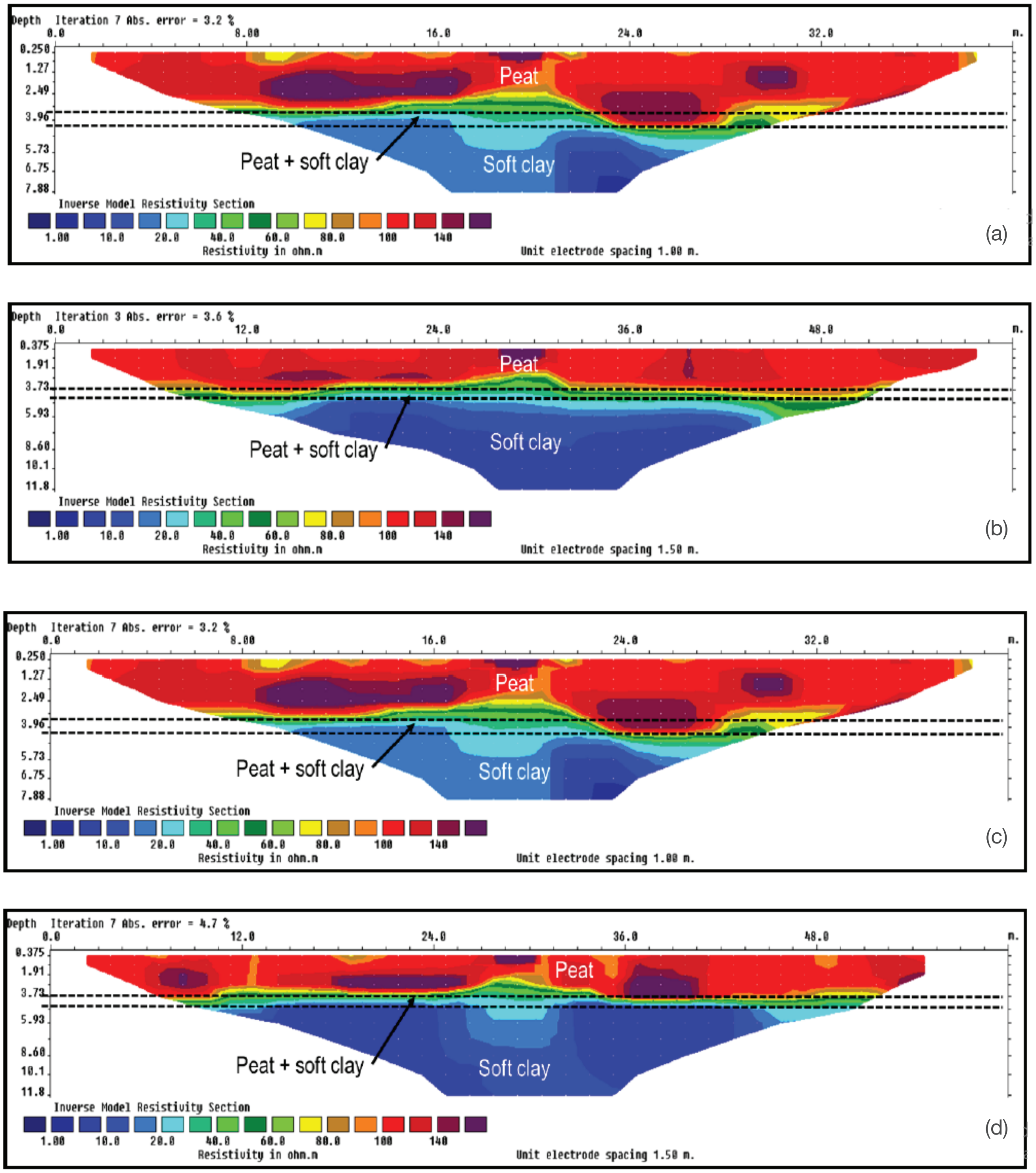


Figure 3 – 1. Peat and organic soil zoning and profiling using electrical resistivity method. 2-D soil stratigraphy using Schlumberger array; (a) 1.0 m at x-axis (West-East), (b) 1.5 m at x-axis (West-East) (c) 1.0 m at y-axis (North-South) and (d) 1.5 m at y-axis (North-South) (Source: Kasbi et al. (2019))

iii. Ground-penetrating radar

Also know as ground-probing radar. Capable of defining the shallow zones of soil and rock materials that underlie an area. The method relies on the penetration and reflection of high frequency radio waves.

3.4.1 Visual Inspection

A visual inspection should be carried out on peat in order to classify the material, the factors that are usually assessed in the field are:

i. Botanic composition – the forms of plants from which the peat is composed is estimated to the nearest 10 percent. In listing the components the dominant species is listed last e.g. a shrubby – *Carex – Sphagnum* peat is predominantly *Sphagnum* with lesser amounts of *Carex* and shrubs (Refer to Andriesse, 2008 for further detail).
ii. Degree of Humification (H) – use the Von Post classification test (Von Post L. & Granlund, E., 1926) and identify the scale based on the description given in Chapter 1 (Table 1-3). Figure 3 - 2 shows Von Post classification technique.

3.4.2 Mackintosh/ JKR Probe

Mackintosh/ JKR probe tests are very useful for making comparative qualitative assessments of ground characteristics. Similar to SPT test, Mackintosh/ JKR probe tests can provide an indication on strength profile of peat and the depth of the underlying stiff layers. However, the strength parameters of peat need to be verified prior using by the design engineers.

Figure 3 - 2. Peat Decomposition Identification In-Situ (courtesy photo : Adnan,2019)

3.4.3 Vane Shear Test

The method of carrying out the test is described in MS 2038 (2006) and BS1377: Part 9 (1990). Vane can take the form of borehole vanes or penetration vanes, the latter being much more reliable. The following recommendations shall be considered for carrying out vane shear test in peat:

i. Resistance values during vane test include the vertical shear stress (τ_v) and horizontal shear stress (τ_h). In clay substrata this is a nearly smooth curve and often has a peak value. In peat the results are jagged line due to resistance by the fibre in the material.

ii. In clay, different vane size has little effect on the result but not in the case of peat. It is recommended that vane size of 55 to 110mm and height to diameter ratio of 2 be used for testing of peat.

iii. In clay, the vane shear strength increases with rotational speed. In peat, with high water content and compressibility, low rotation speed can result in apparent increase in strength due to drainage and compression of peat. High speed will result in increase in strength due to tensile resistance of peat or cohesive and frictional resistance between peat fibres. A speed of 0.1deg/s does not give minimum strength but higher speed results in smaller strength. A speed of 0.5deg/s usually gives a smooth result.

iv. Section 5.2.3.2 of MS 2038 (2006) indicates that the presence of rootlets in organic soil may lead to erroneous reading. Recommended correction/reduction factors are often applied to the measured field value as follows (Long, M., 2005):

- o $(0.43/LL)^{0.45}$ - Sweden (LL is liquid limit)
- o 0.50 – 0.55 - Poland
- o 0.50 - Japan

The average undrained shear strength for tropical peat in Malaysia obtained by field vane test is between 3 and 15 kPa (Huat, 2004) which is much lower than that of the mineral soil. The high-water content and low dry density give peat exceptionally low shear strength. The interpretation of the results of Vane Shear Test must be done carefully because it is not clear whether the value is representative of field condition. A correction factor of 0.5 is suggested for the test results on organic soil with a liquid limit of greater than 200 %. The undrained shear strength is greatly affected by disturbance. The sensitivity of peat soil obtained in Malaysia range from 4 to 12 (Al Raziqi et al. 2003).

According to Edil (2003), large vanes of diameter 55 to 110 mm and height to diameter ratio of 2 are recommended for peat. During the field vane shear test, drainage and uncontrolled consolidation may occur. Hanzawa et al. (1994) states that field vane test do not provide the appropriate shear strength of peaty soil for design use, s_u and it is widely known that the vane shear strength is unsafe. In addition, it is difficult to obtain the strength increment ratio in the normally consolidated state, s_u/σ'_{vc} from field vane shear test.

where:

s_u = Undrained shear stress

σ'_{vc} = Vertical consolidation pressure.

The shear increment ratio is an important design parameter for peaty soil compared with normal clayey soil. Researches showed that the shear strength determined by the test is greater than the actual shear strength of peat (Noto, 1991). Thus, the vane shear strength of peat may be taken as engineering index, and when converted by some factor it gives an indication of the design shear strength.

3.4.4 Static Cone Penetration (CPTs)

The method of carrying out the test is described in BS1377: Part 9 (1990). Reference also can be made to the International Society for Soil Mechanics and Foundation Engineering (ISSMFE, 1977) and the American Standard for Testing Materials (ASTM, 1985).

Cone penetration test only indicates the relative strength of the substrata. The resistance to cone penetration depends on the cone size, shape, penetration rate and anisotropy of the soil. In practice, the strength of peat is often estimated by comparing the vane shear strength and the cone bearing capacity.

Several notes on the test:-

i. Very low tip resistance (q_t) and sleeve friction (f_s), ranging from 0 to 0.3 MN/m^2 and 0 to 0.01 MN/m^2 respectively have been recorded for peat in the Kuching area (Keng, 1998)
ii. Peat is characterized by high friction ratio (R_f) greater than 5% (Lunne et al., 1997)
iii. Also, negative pore pressures can be observed in fibrous zones (Lunne et al., 1997)
iv. Device (cone) is recommended to be as large as possible (Long, M., 2005)
v. Erratic high value might be registered due to presence of undecomposed wood (Lunne et al., 1997)

The accuracy of standard CPT is often insufficient to delineate strength of very soft organic deposits such as peat. Hanzawa et al. (1994), states that CPT is a very useful tool for quality control as well as for determining the danger zone for stability of peat soil. Edil (2003) suggested the use of extra sensitive and large cones for this purpose.

3.4.5 T Bar and Ball Penetrometers

These are the full flow penetrometers which have the advantage of having larger projected area. Soil shall be able to flow around the probes and thus, the overburden stress is equilibrated above and below the probe. Hence, it only requires minimal correction for pore pressure and overburden stress compared to CPT/CPTu.

Values of net resistance are less erratic than the CPTu because of their larger bearing area thus averaging the local effects of wood and large fibres. Work by Boylan et al. (2011) could be referred. Figure 3 - 3 shows the full flow penetrometers.

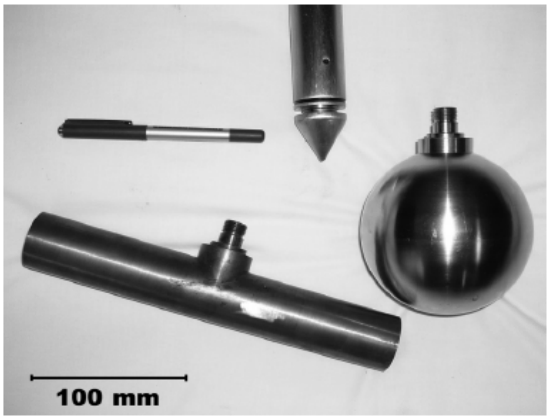


Figure 3 - 3. Full Flow Penetrometers – T Bar and Ball Penetrometers (Boylan, et al., 2011)

3.4.6 Full Scale Loading Test

In view of the importance of the field factors and effects of the sample disturbance, large scale field trials would appear to be essential for large projects. Loading test and measurement of settlement and displacement shall be carried out in the field. Settlement plates and markers are commonly used to measure settlement. Measurement of subsoil settlement sometimes uses inclinometer with spider magnetic or extensometers. Section 5.10 of MS 2038 (2006) details out the necessary activities and intrumentation needed in any full scale test.

3.5 SAMPLING OF PEAT

These practices usually involve test pit excavation and are limited to relatively shallow depths. Except in the case of large diameter (that is, >0.75 m) bored shafts of circular cross-section in unsaturated soils, for depths greater than about 1 to 1.5 meters or depths below the water table, the cost and difficulties of excavating, cribbing, and dewatering generally make block sampling impractical and uneconomical. For these conditions, use of a thin-walled push tube soil sampler (Practice ASTM D1587), a piston-type soil sampler (Practice ASTM D6519), or Hollow-Stem Auger (Practice ASTM D6151), Dennison, or Pitcher-type soil core samplers, or freezing the soil and coring may be required. This practice does not address environmental sampling; consult Guides D 6169 and D 6232 for information on sampling for environmental investigations.

Sampling of deeper peat deposits is usually carried out with a ‘thin-walled piston sampler’ or similar sampler to extract undisturbed samples at depth and the samples obtained used in the determination of the index properties and settlement parameters of the peat. The piston sampler cuts a sample of soil by being pushed in closed mode down through the deposit to the test level at which point a piston slowly pushes a sample tube into the soil to be extracted. The technique aims to minimise edge effects on the sample but some disturbance such as smear is inevitable as the sampler is inserted. Once the cut sample has stabilized the complete assembly is withdrawn and the test sample recovered.

Site sampling of shallow peat areas is generally carried out by means of a screw auger, post hole auger or Hiller auger and the samples obtained (disturbed samples) used to determine the classification and stratigraphy of the peat. The usefulness of the laboratory tests results depends on the quality of the samples at the time they are tested.

3.5.1 Peat Sampler

The peat or Russian – type sampler (Figure 3-3) described in Jowsey (1966), is mainly used for peat sampling. It consists of an anchored fin and a moveable sampling chamber. The latter is a semi – circular cylinder measuring 50cm in length and 5cm diameter, with one end forming the sharp pointed edge that penetrates the peat sequence while the other end is connected to the T – shaped handle. Like the gouge auger, the peat sampler operates quite similarly, the difference being the latter is only rotated through a 180° turn during sampling. Before sampling proceeds, one needs to observe the alignment of the fin with regard to the sampling chamber so that when the sampler is rotated the required samples will be collected. There have been instances when the fin, which is supposed to be stationary, is forced to rotate. This can be due to incorrect fin and sampling chamber orientation when the sampler is rotated, or turning the auger more than 180°. This unnecessarily incur some damage to the sampler whereby the sampling chamber becomes skewed.

Sample collected using the peat sampler is not considered as undisturbed compared to those collected with the guts (gouge) auger. This is because the samples remain enclosed within the sampling chamber of the peat sampler throughout the process of sampling.

Figure 3 - 4. Peat Sampler

3.5.2 Tropical Peat Sampler

In order to improve and overcome the limitations with the existing peat sampler, many unconventional approaches have been used in research field. These include samplers which not only reduce the sample disturbance but also moisture loss at the same time are highly recommended. To serve the current purpose, a sampler with built-in extruder (aka TROPITER) was granted patent (MY-156990-A) in 2010 with features that strictly follows Eurocode 7 Part 3: 2000 Clause 12.3.2.4 (5). The overall performance of this type of sampler is proven to work perfectly in highly fibrously tropical peat. TROPITER has been carefully designed with sharp edges which able to cut through soil fibers easily without much disturbance. This sampler falls into the category of A and B sampling conditions where most of the existing mechanical and hand augers falls under the C category according to ENV 1997-3:1999 (Figure 3 - 5). However, the usage of this sampler is still limited within the engineering laboratory and for research purpose only.

Figure 3 – 5. Tropical peat sampler with built-in extruder

3.5.3 Tube Samplers

Immediately after the tube samples have been taken from the borehole or excavation, the ends of the sample shall be removed to a depth of about 25mm and any obvious disturbed soil in the top of the sampler shall also be removed. Several layers of molten wax, preferably microcrystalline wax, shall then be applied to each end to give a plug about 25mm in thickness. The molten wax shall be as cool as possible. It is essential that the sides of the tube be clean and free from adhering soil. If the sample is very porous, a layer of waxed paper or aluminium foil should be placed over the end of the sample before applying the wax.

Any remaining space between the end of the tube or liner and the wax shall be tightly packed with a material that is less compressible than the sample and not capable of extracting water from it and a close – fitting lid or screw – cap shall then be placed on each end of the tube or liner. The lids should, if necessary, be held in position with adhesive tape.

For soft soil samples, the tube or liner should be held vertically, keeping the sample in the same direction as it left the ground, and extreme care shall be taken during all stages of handling and transportation. However, for peat this method is needed to be done carefully due to present of fibre and high water content to minimise the sample disturbance.

3.5.4 Block Samples

Block sample method is used to collect undisturbed sample of shallow depth of peat. The sampling procedure is accordance to ASTM D7015-04. Intact block samples are obtained from laboratory tests to determine the strength, consolidation, permeability, and other geotechnical engineering or physical properties of the intact soil. The intact block method of sampling is advantageous where the soil to be sampled is near the ground surface. After being excavated, the sample tubes are pushed slowly into the peat soil. Then the top and bottom tubes are covered by paraffin wax and wood plates. Samples that are not retained in a tube should be wholly covered with several layers of molten paraffin wax, immediately after being removed from the sampling tool, and then should be tightly packed with suitable material into a metal and plastic container. However, this method is not recommended for tropical peat due its composition with large trunk, high water content, too soft and difficult to cut the sample.

3.5.5 Other Sampling Techniques

Other peat sampling tools (UPM peat sampler – Duraisamy et al. (2009); UNIMAS Peat Sampler – Kolay et al. (2012); Tropiter – Duraisamy (2010); Sherbrooke Sampler – Boylan et al., 2011) have been utilized to attain undisturbed samples. Figures 3 - 6 and 3 - 7 show the samplers.

(a)

(b)

Figure 3 - 6. (a) Sherbrooke Sampler in Use (b) Waxed Sample (Boylan, et al., 2011)

Figure 3 - 7. UPM Peat Sampler (Duraisamy et al., 2009)

3.5.6 Securing Natural Moisture Content

Natural moisture content of peat is an important parameter (refer to 3.6.2). Hence, maintaining its value is crucial and requires special care. Tube sample's ends shall be plugged with molten wax and any space between the lid and wax should be tightly packed to ensure no moisture loss. Block samples should be wholly covered with layers of molten wax. MS 2038 (2006) indicates that block sampling requires appreciable time which may lead to moisture changes. Hence, during sampling, extraneous water is not allowed to be in contact with samples and samples should be protected from wind and direct rays of sun. Securing the samples further by keeping them in air tight container is highly recommended. Test on moisture content should be performed immediately as to reduce further loss of moisture.

3.6 LABORATORY TESTS

Peat classification process can be carried out using 3 techniques; 1. Methods based on the physical features of peat, 2. Methods based on chemical properties of peat and 3. The microscopic method.

i. Method based on the physical features

The range lies between fresh plant remains and a completely decayed visibly amorphous material with no recognizable plant structure. Where a soft soil/peat lies within this spectrum radically affects its engineering behaviour. In the field it may be assessed by the Von Post Squeeze Test. A sample of the peat is squeezed in the hand. The color and form of fluid that is extrude between the fingers is observed together with the pressed residue remaining in the hand after squeezing (Figure 3 - 8).

Figure 3 – 8. Peat classification using hand squeezing technique (courtesy photo: Adnan.2019)

Table 3 – 1. Peat classification based on von Post system (after Karlsson and Hansbo 1981)

Category	Group	Physical features
Fibrous	H1-H4	Low degree of decomposition. More fibre. Easily recognized plant structure.
Pseudo fibrous	H5-H7	An intermediate degree of decomposition. Recognizable plant structure.
Amorphous	H8-H10	High degree of decomposition. No visible plant structure. Soft or semi-liquid consistency

ii. Method based on chemical properties

The general rules applied in this method after Davydik (1987) is the higher the degree of decomposition, the higher the content of carbon and the lower the oxygen in peat. As peat decomposes the amount of humic acids increases in proportions. However, the changes in humic acids may be due to vegetation changes controlled by hydrology more than changes in humification or decomposition. Hence the pH reading from laboratory testing should be used with extra cautious for classification and more than a method is recommended for confirmation.

Table 3 – 2. Classification of peat using chemical properties (ASTM Standards)

pH	Degree of decomposition
<4.5	Very Highly decomposed
4.5-5.5	Highly decomposed
5.5-7	Moderately decomposed
>7	Less decomposed

iii. The microscopic method

Quantitative approach to classify peat based on degree of decomposition. This is observed under the light microscope to compute ratio between completely humified peat mass over the whole peat mass in water suspension. Generally, peat appears to be fibrous in naked eyes and often recognized as plat tissue with a cellular structure during microscopic study. According to Obidowicz (1990) peat may be divided into 4 categories:

Table 3 - 3. Classification of peat based on mircroscopic test (after Obidowicz, 1990)

Degree of decomposition (%)	Description
0-25	Slightly decomposed. Cellular structure of plant tissues well preserved
30-40	Medium decomposed. Visible changes in the structure of tissues, fairly large quantity of humus
45-60	Highly decomposed. Considerable changes in the structure of tissues, very large quantity of humus.
>65	Humopeat. Tissues changed so much that their identifications is practically impossible

In addition to that, the fiber arrangement of peat can be observed through scanning electron microscope (SEM). The peat fiber visual captured using SEM has a good resolution and its depth of field is about 300 times that of the light microscope. This corresponds to a useful depth of field over 1000 microns at 1000 magnification and about 10 microns at 10,000 magnification. The specimen can be tilted by as much as 60 degrees in either direction and can still be kept in focus. The working distance to the specimen is typically 10–25 mm. Example of SEM visual on different peat fiber is as shown in Figure 1-1. Figure 1-1 (Refer Chapter 1).

The following parameters are mandatory to define the characteristics of peat and organic soil:

i. Water content: The water content is measured using procedures specified in ASTM D2974 or BS 1377.
ii. Organic content: As a percentage of dry weight. The organic content is measured in the laboratory using a Loss on Ignition Test, ASTM D2974 or BS 1377 Part 3(4), or a Chemical Oxidation Test, BS 1377 Part 3(3).
iii. Degree of Humification (Decomposition) of the organic material. The degree of humification represents the degree to which the organic remains have decayed.

The range lies between fresh plant remains and a completely decayed visibly amorphous material with no recognizable plant structure. Where a soft soil/peat lies within this spectrum radically affects its engineering behaviour. In the field it may be assessed by the Von Post Squeeze Test. A sample of the peat is squeezed in the hand. The color and form of fluid that is extrude between the fingers is observed together with the pressed residue remaining in the hand after squeezing.

The degree of humification on a 10-point scale, H1 to H10, is obtained by comparing the observations to those described in Table 1-3 (Refer Chapter 1).

Atterberg Limits: The fibres in peat make determination of the Atterberg limits difficult, and results depend strongly on the methods used to prepare the samples.

The definition of having greater than 75% organic content, is most commonly used by engineers in North America, ASTM D4427, Classification of Peat Samples by Laboratory Testing, Peat on the other hand may well appear to be completely organic, contain recognizable plant remains, have a low density and also black or dark brown. Following a Von Post test it could be further categorised as listed in Table 3-5.

Thus, for example, a peat could be described as a Fibrous Peat and given a symbol, Ptf. Organic Soils is more difficult to sub-divide lying, as it does, between the other two categories. There is insufficient information at present to determine whether this group can be meaningfully sub categorised.

Currently, for these materials, an attempt should be made to provide both the Atterberg Limits and the Degree of Humification to allow establishment of a database from which future analyses can be made. In fact, it may be that neither of these tests work for the Organic Soil category. The degree of humification is only meaningful for soils that are predominantly organic. The presence of inorganic material tends to confuse the interpretation of the degree of humification. Similarly, the Atterberg limits are only truly meaningful for soil that are primarily inorganic and the presence of organic material may well interfere with those tests.

Table 3 – 4. Qualifying terms and symbols for peat and organic soil.

Organic Components	Von Post Degree of Humification	Qualifying Terms	Symbol
Peat			Pt
	H1-H3	Fibric or Fibrous (>66%)	f
	H4-H6	Hemic (33-66%)	h
	H7-H10	Amorphous (<33%)	a
Organic Soil			O

3.6.1 Mineral Composition

The major mineral compositions of peat sample are determined. The composition may be quartz, feldspar, clays like kaolin, illite, vermiculite, chlorite or montmorillonite in varying amounts. One of the method to determine the elements and the mineralogy of peat and organics soil is using Energy Dispersive X-ray Spectroscopy (EDX). The contents of mineral elements in peat such as N (Nitrogen), Mg (Magnesium), Na (Sodium), Ca (Calcium), K (Potassium), Al (Aluminium), FeS_2 (Pyrite), C (Carbon), P (Phosphorus), Si (Silicon) and O (Oxygen) can be relatively quantified. In general the cation exchange in peat is Ca^{+}, Mg^{3+}, Fe^{3+}, Al^{3+}, K^{3+}, Na^{3+}, NH^{4+}.

3.6.2 Natural Moisture Content

Measuring moisture content in peat and organic soils requires special attention beyond that usually needed to classify other soils. Typically, Skempton and Petley (1970) and Hobbs (1986) reported that oven drying of peat and organic soil at 105˚C or more generally, at a temperature 100˚C and 110 ˚C is acceptable for routine water content determinations.

Even though the general recommendation to test moisture content is 16 hours to 24 hour or until no further change in mass after drying in excess of 1 hour, quite often there is no specific time when it comes to peat. Peat with high natural moisture content may requires 2 days of drying in oven with constant monitoring. However fibrous peat sample on the other hand may experience particle burning even at temperature well below 110 ˚C.

According to Brendon (2005) oven drying of peat and other highly organic soils over a period 24 hours at 80 ˚C produced similar levels of accuracy in the moisture content measurement as that for inorganic soil using the standard oven drying temperature at 105 ˚C or 110 ˚C.

Considering the effects of over burning fibrous peat while testing and changing the properties of organic content may occur, it is recommended to do periodical drying of peat at temperature no more than 80 ˚C for at least 2 days for high accuracy.

The natural moisture content serves as one of the most useful index properties of peat since it influences the strength and consolidation. It also gives an indication of the need for special drainage during construction. Values of moisture content have been correlated to design parameters such as bulk and dry densities (Den Haan & Kruse, 2007) and compressibility index C_c (Mesri & Aljouni, 2007). Peat deposits are usually waterlogged and very high in moisture content. The moisture content, expressed as a percentage of dry weight, may range from 100% to 1600% compared to 40% to 95% for estuarine sediments.

3.6.3 Density

Peat has low bulk density, typically between 950 and 1150 kg/m^3. Bulk density and void ratio may be influenced by the presence of internal gases generated by the decomposition process, occurring either as free gas in the macropores or entrapped gas in micropores. Bulk density generally increase with depth due to compaction and presence of mineral soils.

3.6.4 Atterberg Limit

Special care should be taken when performing the tests as it is widely agreed that fibrous peat is not suitable for the test. Based on Von Post's scale, peat of scale H3 and above (high degree of decomposition) is more suitable for the test (Skempton and Petley, 1970).

Due to the presence of fibres and negligible mineral content, it is difficult to perform the liquid limit and plastic limit tests on peat. However, these limits could be determined by first removing coarse fibres using tweezers (as allowed by the British Standard) and then mixing the remaining material using a broad-bladed knife to produce a homogeneous paste. It is reported that most of the peat are lack in the plastic limit. Moreover, Atterberg's limits are inappropriate due to the presence of reinforcement (i.e fibres and roots) and scaling (size of thread) effect. Therefore, based on supporting documentation it is clear that Atterberg limits are not appropriate to classify peat (Huat,2004, Adnan et al, 2016)

3.6.5 Specific Gravity

As peat is of plant pieces which are lighter than water, the use of kerosene is recommended. Pulverized peat sample is placed in a flask or bottle filled with de-aired and filtered kerosene (Akroyd, 1964). High vacuum is applied until no air bubbles emitted. The same flask is again filled with kerosene and let to reach a constant temperature. From Akroyd, the calculation of specific gravity (G_s) is:

$$G_s \text{ of Peat} = \left(\frac{\text{(Mass of dry peat)}}{\text{(Mass of kerosene displaced)}}\right) \times G_s \text{ of kerosene;} \qquad \text{Eq. 3-1}$$

Peat has very low specific gravity of solids, mainly attributable to the presence of cellulose and lignin which are the principal constituents of the organic matter. According to Mesri & Ajlouni (2007), fibrous peat with an organic content of greater than 90% typically has specific gravity of the solid particle in the range of 1.4 to 1.6.

Specific gravity can be affected by the proportion of inorganic material, which can be related to the mineral content and degree of decomposition. Higher values of specific gravity generally indicate higher mineral content and (or) higher states of decomposition.

3.6.6 Organic Content

The organic content in peat could be determined through loss on ignition test by igniting specimens of the powdered materials in a muffle furnace (Figure 3 - 9) at 440ºC, over an 18-h period. This test is only suitable for measuring organic matter for soil with more than 10% organic matter (MS 1056 Part 3 (2005), BS5930:2015). Loss in ignition test shall be performed in accordance with MS 1056 Part 3(2005) or BS1377: Part 2 (1990).

Organic Content is calculated according to an equation proposed by Skempton and Petley (1970)

Figure 3 - 9. A Muffle Furnace

Organic Content, OC (%) = 100 – C (100-(LOI)) Eq. 3-2

where correction factor C = 1 for temperature of 440 °C; C=1.04 for temperature of 550 °C; Edil, 2003) and LOI = Loss on Ignition (%) = 100.0 – Ash Content (N)

Ash content, N(%) = $[(m_2-m_c)/(m_1- m_c)] \times 100$

Where m_c = Mass of empty crucible

m_1 = Mass of crucible + oven dried sample

m_2 = Mass of crucible + remaining sample after ignition

The amount of organic content in peat has a strong influence on its index properties such as moisture content, density, plasticity and others. Hence it affects the engineering behavior of peat and therefore, accurate determination of this property is useful for engineering works.

3.6.7 Fibre Content

Parameter to obtain is the dry mass of fibres as a proportion by initial oven dried mass of peat (in %). The method has been described in ASTM D 1997-91. Fiber is defined as piece of plant tissue that retains on a 100 mesh sieve (opening of 150 μm). Piece of plant with 20 mm in smallest dimension is not considered fibers.

$$\text{Fibres content, FC (\%)} = \frac{\textit{(Mass of dry fiber in sieve\#100)}}{\textit{(Mass of dry soil on pan)}} \chi \ 100 \qquad \text{E.q 3.3}$$

i. pH Value Test

The pH value has to be measured for peat and water samples obtained from the field. Natural water in peat is made acidic by organic acids produced by decaying vegetation. This is a crucial test as acidic water attacks concrete causing disintegration of concrete cover and exposing aggregates (Keng, 1998). MS 1056 Part 3(2005), BS 1377: Part 3 (1990) and ASTM D2976-71 discuss the technique. A common method of measuring peat sample pH is performed by placing a glass electrode in a mixture of peat and deionized water. The test shall be performed in accordance with ASTM D4974 - 13: Standard Test Method for pH of Soils.

3.6.8 Hydraulic Conductivity

Permeability of peat controls the rate of consolidation and increases its shear strength of soil. Constant head permeability and Rowe consolidation cells have been used to determine the vertical and horizontal coefficients of permeability of fibrous peat.

In *ASTM D 4511-00 Standard Test Method for Hydraulic Conductivity of Essentially Saturated*

Peat, sample is saturated and in cylindrical sections retained in the sampling tube. Specimen shall have a minimum diameter of 73 mm and height to diameter ratio between 1 and 2. Sample needs to be soaked prior to testing for 72 h. Permeability is a measured constant flow rate of water passing through the sample under constant head. Figure 3 - 10 shows the set up of the experiment.

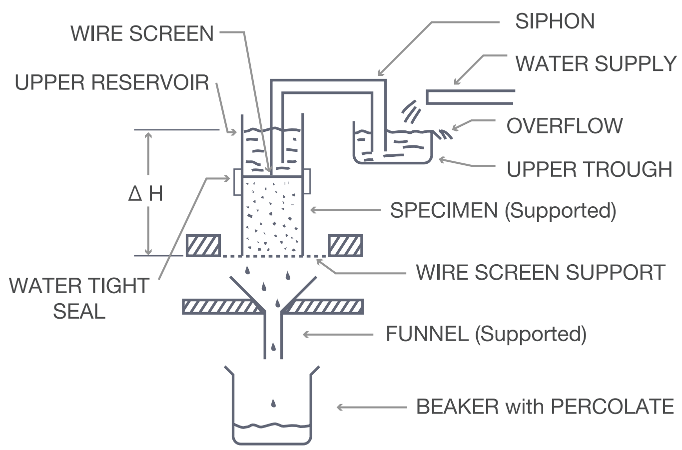


Figure 3 - 10. Set up of Hydraulic Conductivity Test for Peat (ASTM D4511-00, 2006)

In addition, crude information can be obtained relatively easy by installing a drain and measuring the water-table at increasing distances.

3.6.9 Consolidation

Important parameters to be obtained are the Coefficient of Consolidation (c_v; unit m^2/year), Primary Compression Index (C_c) and Secondary Compression Index (C_α). The compressibility characteristics of peat are usually determined from consolidation tests. General laboratory tests for measurement of compression and consolidation characteristics of peat are: Oedometer consolidation test, Constant Rate of Strain (CRS) test, and Rowe Cell test. The procedures for these tests are fully described in MS 1056 Parts 5&6 (2005), BS 1377: Part 6 (1990) and Head (1982, 1986).

Mold sizing is important in performing the test. As mentioned in MS 1056 Part 5 (2005) and BS 1377: Part 5 (1990), for peat sample which breaks and deforms badly upon extraction from sampling tube, the size of the mold's inner diameter is best to be of sampling tube diameter due to difficulty in trimming the sample. Several suggestions on equipments to use are:-

i. Conventional Oedometer – size up to accommodate larger size particles
ii. Larger hydraulic consolidation cell with drainage and control loading conditions – Rowe Cell

iii. Isotropic Consolidation in Triaxial

Although more sophisticated consolidation tests are now available, the oedometer test is still recognized as the standard test for determining the consolidation characteristics. Oedometer cell can accommodate 50-75 mm diameter and 14-20 mm thick samples (Figure 3 - 11). Due to the relatively small specimen thickness, testing time is not excessively long and the test can be extended to a long-term test if secondary characteristics are required.

However, the rate of settlement measured in oedometer test is often underestimated, that is, the total settlement is reached in a shorter time than that predicted from the test data. This is largely due to the size of sample which does not represent soil fabric and its profound effect on drainage conditions. Besides the natural condition of the sample, sampling disturbance will have a more pronounced effect on the results of the test done on small samples. Furthermore, the boundary effect from the ring enhances the friction of the sample. Friction reduces the stress acted on the soil during loading and reduces swelling during unloading. In addition, excessive disturbance upon applying load i.e. sudden shock also reduces the effect of secondary compression which is a very important characteristic of fibrous peat.

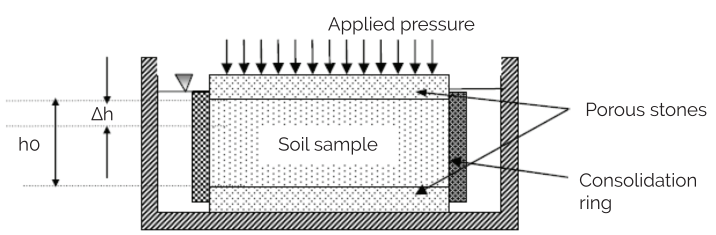


Figure 3 - 11. Schematic diagram of Oedometer Cell

The large strain test using Rowe consolidation cell (Figure 3 - 12) was introduced by Rowe and Barden in 1966 to overcome the disadvantages of the conventional Oedometer apparatus when performing consolidation tests on non-uniform deposits such as fibrous peat. Rowe cell has many advantages over the conventional Oedometer consolidation apparatus.

It is stated here that decision on the suitable type of cell (oedometer/Rowe) to utilise depends largely on the type of peat being handled. Amorphous or highly decomposed peat and organic soil (for example peaty clay) would suit well with the smaller diameter oedometer compared to fibrous peat in which larger particle size within the peat matrix requires larger diameter cell in order to have a more representative soil fabric.

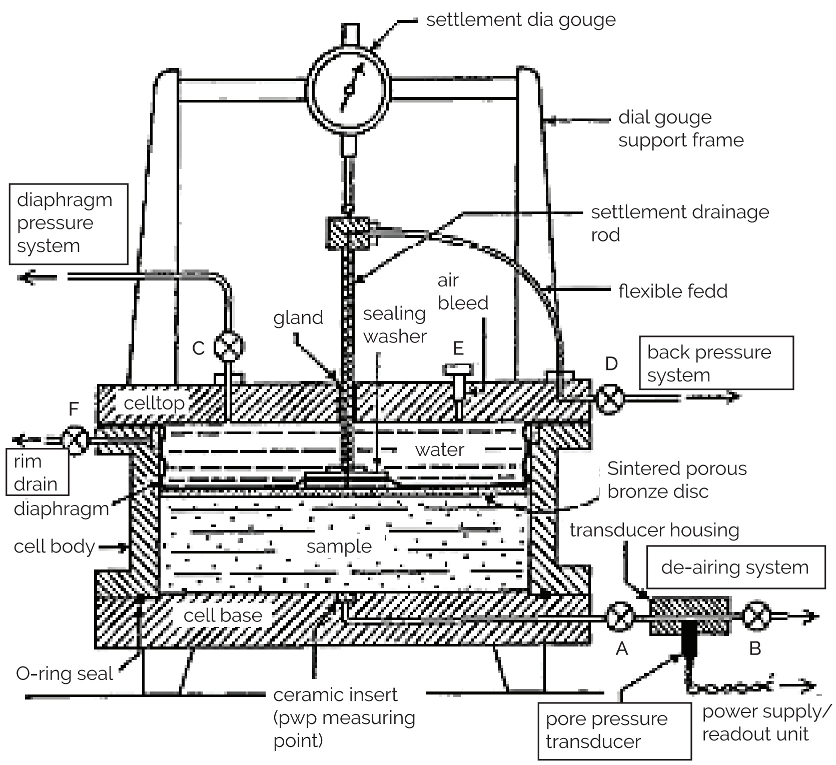


Figure 3 - 12. Schematic diagram of Rowe Consolidation cell

3.6.10 Shear Strength Test

Shear strength parameters always play a vital role in engineering decisions when dealing with any soil including peat. Accuracy in determining the shear strength of peat is associated with several variables namely; its origin, water content, organic content and degree of decomposition. In addition, the evaluation of shear strength of peat is greatly affected by sample disturbance.

Considering the presence of peat is usually below ground water level, it is common practice to use undrained shear strength and total stress analysis in assessing the end of construction stability of embankments. The undrained shear strength may be obtained by field tests where there is no need of sampling. The undrained strength of peat is typically determined by vane shear in the field. Other method includes the plate load test, the screw plate test, and the cone penetration test (Edil, 2003).

Drained and undrained shear strength parameters of peat may be determined through several methods such as triaxial test, shear box test, ring shear or direct shear, and vane shear tests.

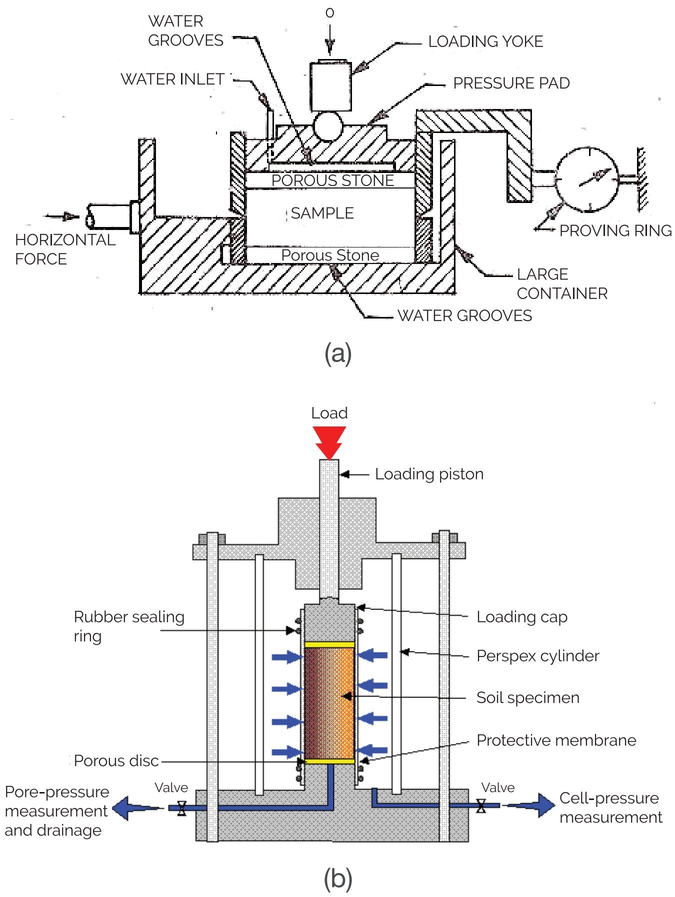


Figure 3 - 13. (a) Shear Box; (b) Triaxial Apparatus

Unlike mineral soils, the presence of fibres in peat and their varying interaction within the shearing mode imposed by particular testing procedure creates difficulties in assessing the true operating strength value of the material.

Drained strength obtained using triaxial test is commonly used in stability analysis. However, the results obtained may not be reliable due to samples disturbance during preparation and squeezed out of pore water during compression. Stress – strain curve without any apparent peak is usually observed.

Effective friction angle of peat is typically determined in consolidated undrained (CU) triaxial compression tests with pore water pressure measurement and occasionally in drained direct simple or ring shear tests. Drained triaxial tests (CD) are seldom performed due to gross changes in specimen dimensions and shape during the test. Normally consolidated peat exhibits zero or small effective cohesion and generally high effective friction angles in average of 53° (Edil and Wang, 2000). Undrained shear strength parameters of peat may be determined using shear box test. The cohesion (c) value in the range of 6 to 17 kPa and angle of internal friction (ϕ) in the range of 3 to 20° have been reported from tests carried out on various tropical peats (Huat, 2006).

Another aspect to consider is the effect of fibre and other characteristics of peat on these tests' results. It has been summarized by Long (2005) that results from various laboratory tests on peat indicate;

ϕ' (Triaxial) > ϕ' (Direct Shear) > ϕ' (Direct Simple Shear)> ϕ' (Ring Shear)

This again requires the designer's further judgment on suitable parameters to be used in design. It is highly suggested that representative samples are prepared for the tests and multiple types of test performed to estimate these values.

Several suggestions on performing strength tests on peat are summarized below:

i. Triaxial Test

Strength of peat in compression and extension can be obtained. According to Long (2005), extension strength is crucial in analyzing landslides in peat. Also, it is recommended (1) to use special smooth end platens / silicon membrane inserts (2) perform accurate correction on membrane stiffness, use of thin membrane – 0.2 mm (3) to use a differential pressure controller to ensure that the differential pressure between the cell and back pressure controlling devices is constant. On obtaining the effective strength parameters, undrained test with pore pressure measurement is suitable for highly organic peat (Anggraini, 2006) while for relatively low organic content, drained test could be considered.

ii. Direct Shear Test

As in other tests, fibre orientation provides a significant effect due to its predetermined failure surface. Careful sample preparation is required.

iii. Direct Simple Shear Test

Results from this test have been reported to be smaller (underestimate) than that of triaxial test. However, the mode of failure from this test is suitable for analyzing landslides in peat.

iv. Ring Shear Test

This is a reliable laboratory test for determining effective strength parameters of peat (Landva and La Rochelle, 1983). The effect of fibres is eliminated due to the large strains imposed during the test.

This chapter has described comprehensively the laboratory and field tests that may be performed on peat. Information pertinent to the described tests have been highlighted especially on experiences and findings of other researchers and practitioners from performing tests on peat. Ultimately, good quality peat samples needed in a number of tests should be attained in order to produce reliable results and this crucial factor is emphasized in this chapter. Importance of parameters such as physical and strength properties mentioned here shall be further described in subsequent chapters. In Chapter 5 for example, various representations of these parameters in the form of correlation graphs which are useful for preliminary design are presented.

In conclusion, investigation on peat's physical and strength properties by performing various laboratory and field tests which outcomes are further analysed against published data from literature are strongly advised and should be the practice of those involved in designing structures on peat (Edil (2003)., Al-Raziqi et al (2003)., Huat (2004)., Gofar and Sutejo (2006)., Anggraini (2006), Adnan and Mansor (2016), Z. Adnan et al (2016) and Adnan and Habib (2017).

The most distinctive characteristic of a virgin peat deposit is probably its high water content and many of the characteristics of peat of interest to the engineer as a foundation material result from this basic property. Water contents of tropical peat is generally in the range from 100% to 2000% but can reach as high as 2,500% for some coarse fibrous peats. Water content values of less than 500% are usually an indicator of high mineral fractions within the peat sample.

The **ash content** (**or non organic content**) of a peat sample is the percentage of dry material that remains as ash after controlled combustion. A virgin tropical peat normally has an ash content of somewhere between 2% and 20% of its insitu volume and this range of ash contents can be an indicator of this type of peat.

The **insitu bulk density** of a peat depends predominantly on its moisture content. Amorphous granular peats can have insitu undrained bulk densities of up to 1200 kg/m³ whilst at the other end of the scale very woody fibrous peats can have insitu densties of as low as 600 kg/m³.

The **dry density** of peat is also dependent on the natural moisture content and mineral content of the particular deposit. This density is an important characteristic for the engineer concerned with road construction over peat as it influences the behaviour of the peat under load. Dry densities of peat can typically vary between 60 kg/m^3 to 120 kg/m^3. Higher values are possible however where the deposit has a high mineral content.

The **specific gravity** of peat typically varies from 1.5 to 1.8 with the higher ranges again reflecting a higher mineral content.

The **void ratio** of peat varies with the type of peat and moisture content. As an example a peat with a moisture content of 1,000% is likely to have a void ratio of approximately 18. Void ratios as high as 25 can be found in fibrous peats and void ratios as low as 9 are possible for the denser amorphous granular peats. The void ratio of a particular peat bog normally tends to decrease with depth but as always there can be exceptions to this general rule.

The **hydraulic conductivity** of peat in the field is highly variable depending on its morphology and reduces dramatically when subjected to loading. The permeability of virgin peat usually ranges from 10^{-2} to 10^{-4} cm/sec but when loaded with a low embankment it can quickly reduce to 10^{-6} cm/sec and with a higher embankment construction to as low as 10^{-8} to 10^{-9} cm/sec.

The **shear strength** of peat soil in Malaysia is indicated by cohesion (c) in the range of 6 to 17 kPa and angle of internal friction (ϕ) in the range of 3° to 25°. It was reported that the drained strength of peat is useful in slope stability analysis because drained parameters are considered to be more fundamental and less variable than undrained strength parameters and it is widely practiced in country like Europe where temperate peat is common. Angle of friction of 50° for amorphous peat and 53°-57° and for fibrous peat ranged from 27°-32°under a normal pressure of 3 to 50 kPa.

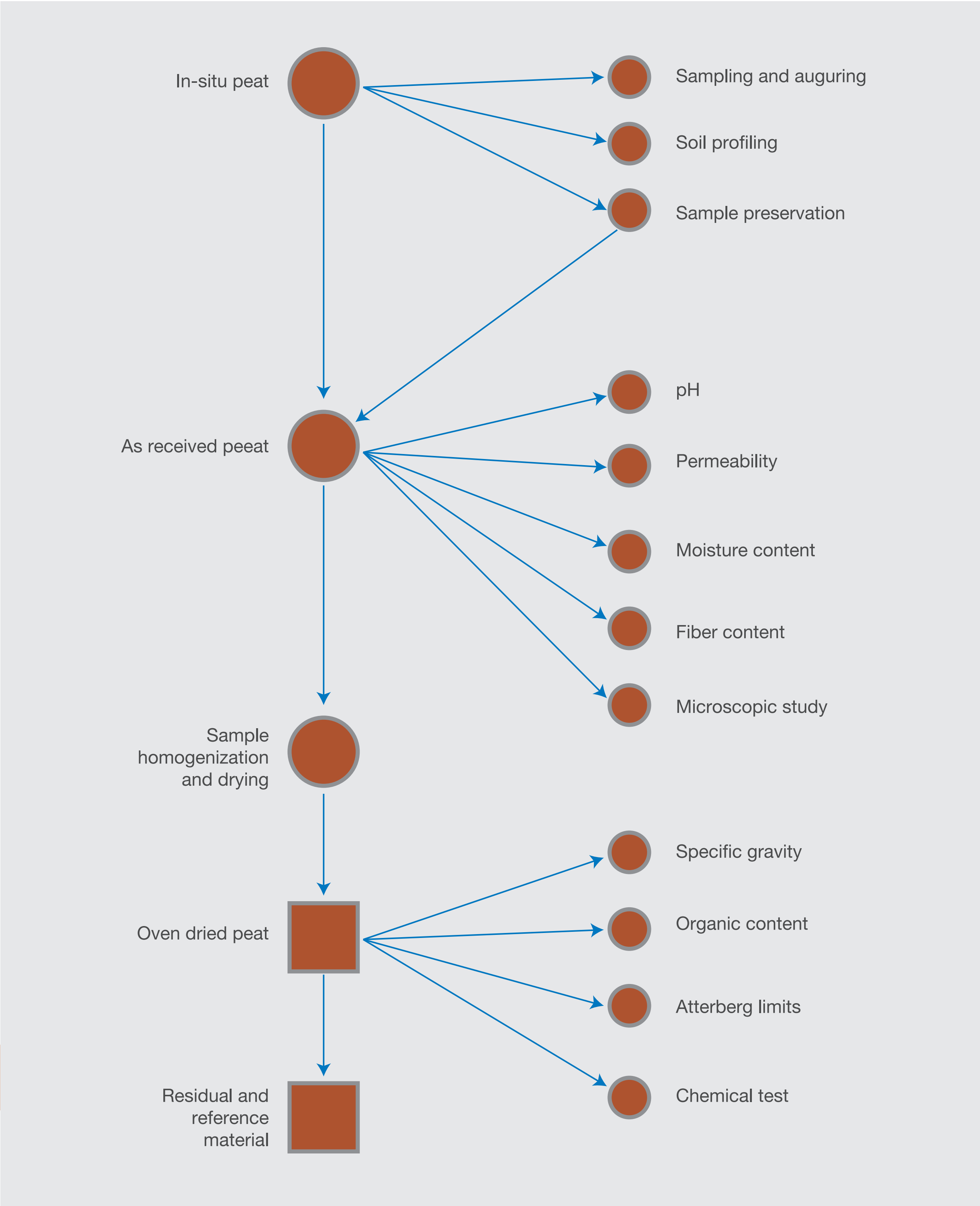


Figure 3 – 14. General field and laboratory handing/testing of peat and organic soil sample

Chapter 4

Methodology and Criteria for Design

4.1 INTRODUCTION

Design of embankments and fills on peat largely involves stability and settlement analyses. These two essential aspects of the design are addressed in this chapter and an example included.

An often neglected consideration is the effect due to deep drains causing lowering of ground water resulting in decomposition of peat. The lowering of the peat levels from decomposition can have a serious effect on the long term performance of embankments and the proper functioning of highway drainage structures. Nearby properties and agricultural activities can also be affected.

4.2 METHODS FOR STABILITY AND SETTLEMENT ANALYSIS

4.2.1 Stability analysis

4.2.1.1 Peat over stiff or dense soils

Total stress stability analysis of embankments on peat is inappropriate because of :

i. Difficulties in obtaining an appropriate S_u value due to problems in carrying out vane shear tests and recovery of undisturbed samples for laboratory tests;
ii. The fairly high coefficient of permeability k and coefficient of consolidation c_v especially at the early stages of loading can result in appreciable consolidation during embankment construction;
iii. The appreciably high Φ' and S_u / σ_{vo}' values will result in appreciable gain in strength.

It is considered more appropriate to adopt effective stress parameters for the peat with estimates of pore pressures from consolidation analysis when assessing the stability of embankments on peat.

4.2.1.2 Peat over soft clay

For the common case of peat over soft clay, embankment stability analysis can be by use of a mixed effective stress and total stress approach (Figure 4 - 1) where:

i. Effective stress parameters with estimated pore pressures are adopted for the peat layer;
ii. Total stress parameters with S_u values from vane shear strengths (S_{uv}) for the underlying soft clay.

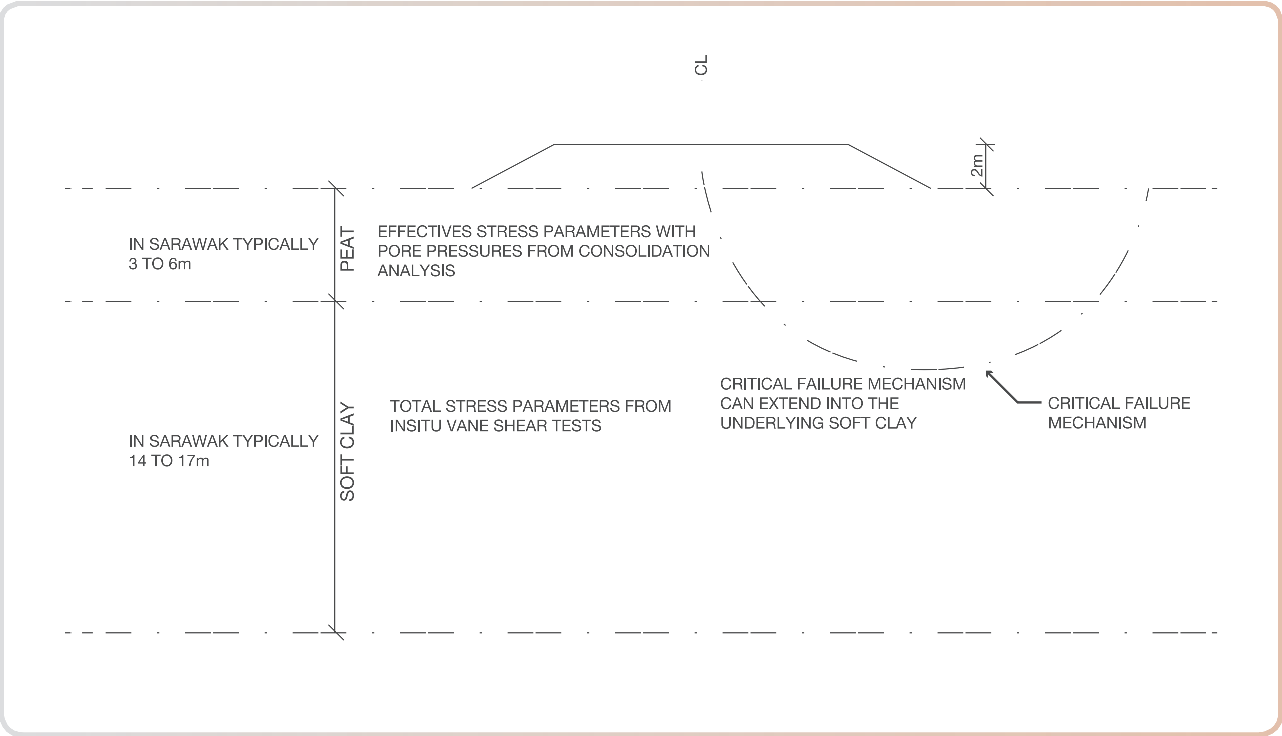


Figure 4 - 1. Method for stability analysis

The critical mechanism of instability can extend below the peat into the underlying soft clay. If the peat is thin or when consolidation of the peat occurs quickly, the strength properties of the soft clay may in fact be the more important.

4.2.2 Settlement

The following method for estimating total primary and secondary settlement is commonly in use:

$$\text{Total primary consolidation settlement} = \left(\frac{Cc}{1 + e0}\right) H \log \left(1 + \Delta\sigma v/\sigma vo'\right) \qquad \text{Eq. 4-1}$$

$$\text{Secondary consolidation settlement} = \left(\frac{Cc}{1 + e0}\right)\left(\frac{C\alpha}{Cc}\right) H \log \left(\frac{t}{tp}\right) \qquad \text{Eq. 4-2}$$

The method for estimating primary consolidation settlement and excess pore pressures over time should be by use of finite difference (CONSOL) or finite element (SAGE CRISP, PLAXIS, MIDAS-GTS) algorithms.

Due to the significant settlement during embankment construction, it is essential to adopt a time stepping analysis and closely approximate the actual rate of embankment build up and at all stages account for the changing fill thickness.

4.3 DESIGN CRITERIA

4.3.1 Embankment Factor of Safety

Following the methodology described in Section 4.2.1, a minimum factor of safety of 1.3 is considered appropriate for all road embankments and fills where:

i. instability can be readily rectified and economic loss is small;
ii. movements and instability will not have an effect on structures like culverts, bridge structures and buildings.

Otherwise the minimum Factor of Safety should be 1.5.

The minimum factors of safety are conditional on the following in stability analyses:

i. Φ' of peat not exceeding 40 degrees;
ii. Pore pressures in peat from consolidation analysis to be taken into account;
iii. Undrained shear strengths of the underlying soft clay:

$Su = \mu\ Suv$	Eq. 4 - 3

where:

a) μ can take the value of 1.0 if lower bound vane shear strengths are adopted;

b) μ should follow the correlations by Bjerrum (1972); Ladd et al. (1977) and Larsson (1980) if average vane shear strengths are adopted; subject that sufficient vane shear tests have been carried out to capture the upper and lower bounds within the site.

4.3.2 Settlement

4.3.2.1 Commonly adopted criteria for post construction settlement

There are several commonly adopted design criteria for post construction settlement required by Malaysian authorities :

i. 10% of the total consolidation settlement;
i. 400 mm over the first 7 post construction years;
ii. 250mm over the first 5 post construction years;
iii. 200mm over the first 3 post construction years.
iv. Differential settlement of 1 in 500.

The stricter criteria such as in (i) would result in higher construction costs and may in many circumstances may not be necessary.

4.3.2.2 Proposed criteria for post construction settlement

A sensible criterion for post-construction settlement should be based on:

i. An appropriate balance between capital costs and pavement maintenance costs;
ii. The ability to maintain an acceptable riding quality by overlaying and pavement regulation with minimal disruption to traffic flow;

Commonly, JKR's frequency of pavement overlaying is once in seven years corresponding to the design life of the road pavement. It is convenient to use this frequency of pavement overlaying as the basis for deciding on a post construction settlement criterion. Since commonly the thickness of a pavement overlay is between 300 and 500mm, the criteria for post construction settlement should also be of the order of 300 to 500mm over the first 7 post construction years.

The often specified differential settlement of 1 in 500 cannot be designed for, is unachievable and should not be adopted. Differential settlement arises not just due to height of embankment and fill thickness but more so the variation in properties of peat and soft clay that cannot be so comprehensively captured in investigations. It has to be accepted that there will always be some discomfort in riding quality at the interface of piled structure and embankments not on piles. A differential settlement at the transition from embankments undergoing settlement to pile supported structures of 1: 50 is considered adequate to ensure a reasonably comfortable riding quality for vehicular speed of less than 90 km per hour. The surest method to minimize riding discomfort is regular maintenance.

In peat and soft clays, ample time should always be allowed to maximize consolidation before pavement construction. Time is the essence to minimize construction costs and as well minimize post construction settlement.

4.4 EARTH FILLING TO FORM A PLATFORM FOR DEVELOPMENT

Design of platform levels of fills for building development are commonly based on anticipated flood levels and the required gradients for the proper performance of infrastructures such as surface drains, water supply lines and sewerage systems. Figures 4 - 2, 4 - 3, 4 - 4 illustrate problems associated with excessive post construction settlement around structures on piles. Figure 4-5 illustrates excessive settlement resulting in flooding over an access road.

Figure 4 - 2. Ground settlement around a building founded on piles

Figure 4 – 3. Settlement of road adjacent to culvert founded on piles

Figure 4 - 4. Settlement next to concrete drains supported on piles

Figure 4 – 5. Excessive settlement and flooding of access road

To keep maintenance costs to acceptable levels, Town, Municipality and City Councils should stipulate a realistic post construction settlement criterion that is a good balance between capital costs (often borne by developers and eventually the consumers) and maintenance costs (often borne by Councils) Early commencement of earthworks and ample time for fill placement and consolidation settlement before building works is highly encouraged. Preloading or surcharge should be carried out for as long as possible.

A post construction settlement criterion of 200mm in the first 3 years is considered reasonable for the proper functioning of infra-structures, albeit with some level of maintenance. The following are also recommended:

i. Buildings, sewers and main water pipe lines should be supported on pile foundations. Water, sewer lines, and other services within the building footprint shall be attached to the structure.
ii. Flexible water pipes and pipe joints which can accommodate larger distortions are recommended particularly at the connections to buildings. Connections to the buildings should be at locations that can readily be accessed for maintenance.
iii. Piles shall be designed for drag down force.
iv. Buildings shall have suspended ground floor slabs.
v. The external ground beam of the building should be deepened to ensure that settlement of the external ground will not reveal the inevitable gap beneath the building or result in

soil washed into the gap. Aprons skirting the building should be either constructed independent of the building and allowed to settle with the ground or be designed with fixity to the perimeter ground beam. In the case of the latter the outside edge of the apron should be turned down and buried by an amount similar to the expected long term ground settlement.

vi. Drains on the fill platform should not be supported on piles and should be designed with maximum gradients to reduce the problems associated with differential settlement. Surface drains will have to be maintained and if necessary reconstructed at some stage.

4.5 OTHER IMPORTANT CONSIDERATIONS

4.5.1 Effects of agriculture

Agriculture involves surface drainage and lowering of the ground water. This in turn causes lowering of the peat surface because of:

i. Absence of farther accumulation and deposition of organic material;
ii. Progressive decomposition of peat exposed to the atmosphere

Lowering of the peat ground in turn necessitates, for the purpose of agriculture, farther lowering of surface drains and consequently farther lowering of the ground water and greater decomposition of exposed peat. The progressive lowering of ground water will mean progressive decomposition of the peat until eventually there is no more peat. Ground water level management is therefore of critical importance in the preservation of peat land.

Environment Waikato Regional Council (2006) contains guidelines for maintaining surface drains to minimize decomposition of peat and includes estimates of ground settlement for different depths of drains. Table 4 - 1 extracted from Environment Waikato Regional Council (2006) gives the estimated ground settlement for different drain depths and at different distances.

Table 4 - 1. Predicted peat subsidence (m) away from drains of different depths

	Distance from drain (m)							
Drain depth (m)	25	50	100	150	200	300	400	500
1	0.07	0	-	-	-	-	-	-
1.5	0.28	0.17	0.05	-	-	-	-	-
2	0.49	0.34	0.18	0.09	0.02	-	-	-
2.5	0.70	0.51	0.31	0.19	0.11	0	-	-

Environment Waikato Technical Report (2004) reported settlement rates of on average 33 mm per year since 1925. Their settlement monitoring data is reproduced in Figure 4 - 6

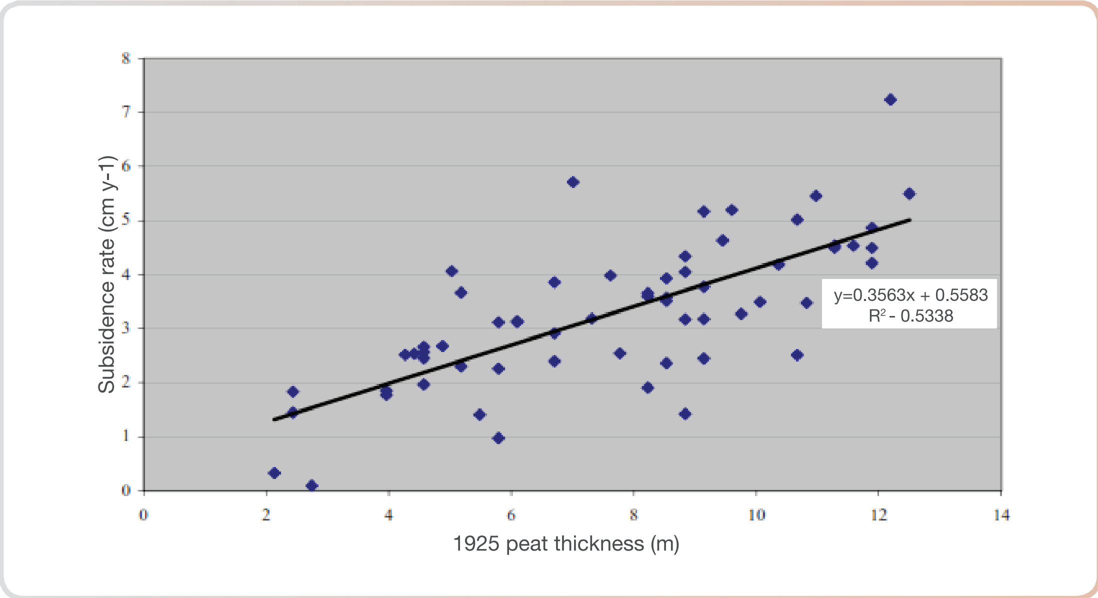


Figure 4-6. Settlement at moantuatua swamp area – extracted from environmental waikato technical Report 2004 / 17

It is therefore necessary in the design of roads passing through agricultural areas to take into account lowering of the peat ground due to agriculture. The roads should be kept at such distances from agricultural drains as to minimize ground settlement due to peat decomposition. Ground settlement close to the embankments can cause:

i. Invert levels of culverts to be higher than the surrounding ground levels;

ii. Increased embankment settlement.

4.5.2 Examples of the effect of agriculture on an existing road

Figures 4 - 7, 4 - 8 and 4 - 9, Illustrate clearance of peat swamp and lowering of ground water for cultivating oil palm close to an existing road that had been stabilized by total replacement of peat with sand.

Figure 4 - 7. Clearance of peat swamp and lowering of ground water for agriculture close to an existing road

Figure 4 – 8. Lowering of ground water next to an existing road

Figure 4 - 9. Lowered ground water and planting oil palms

Figure 4 - 10 shows the damage to the road that was subject to treatment by total replacement of peat with sand : this road had performed satisfactorily until lowering of the ground water for planting palm oil. Figure 4 - 11 illustrates the lowered ground due to peat decomposition from ground water lowering. The original ground level was at the invert level of the culvert.

Plantation owners should be reminded that Malaysia law requires that parties carrying out ground water lowering take all necessary measures to prevent damage to adjacent properties including public assets.

Figure 4 - 10. Damage to the road pavement due to agriculture with ground water lowering

Figure 4 - 11. Lowered Ground water and ground next to pipe culvert

4.5.3 Embankment toe drains and its effect on peat decomposition

It is not uncommon for permanent drains to be constructed at the toe of embankment to discharge rain water falling onto the carriageway. Deep embankment toe drains of a permanent nature are discouraged because of the potential for lowering ground water causing peat decomposition and with it peat ground settlement. Lowering of the ground water will also degrade rich agricultural land.

4.6 AN EXAMPLE OF STABILITY AND SETTLEMENT ANALYSES OF AN EMBANKMENT

The stability and settlement analyses of a 1.5m high road embankment on a fairly typical condition in Sarawak with 4m peat over 21m soft clay are presented herein. The intention is to ensure a minimum Factor of safety of 1.3 and a post construction settlement of 200mm over the first three years.

The embankment configuration and parameters are illustrated in Figure 4-12. The intention is to build the embankment to a surcharge level 1.0m higher than the final road level at a rate of 300mm per week and allow to it to settle for 9 months before excavating away the remainder surcharge down to subgrade level to construct the road pavement.

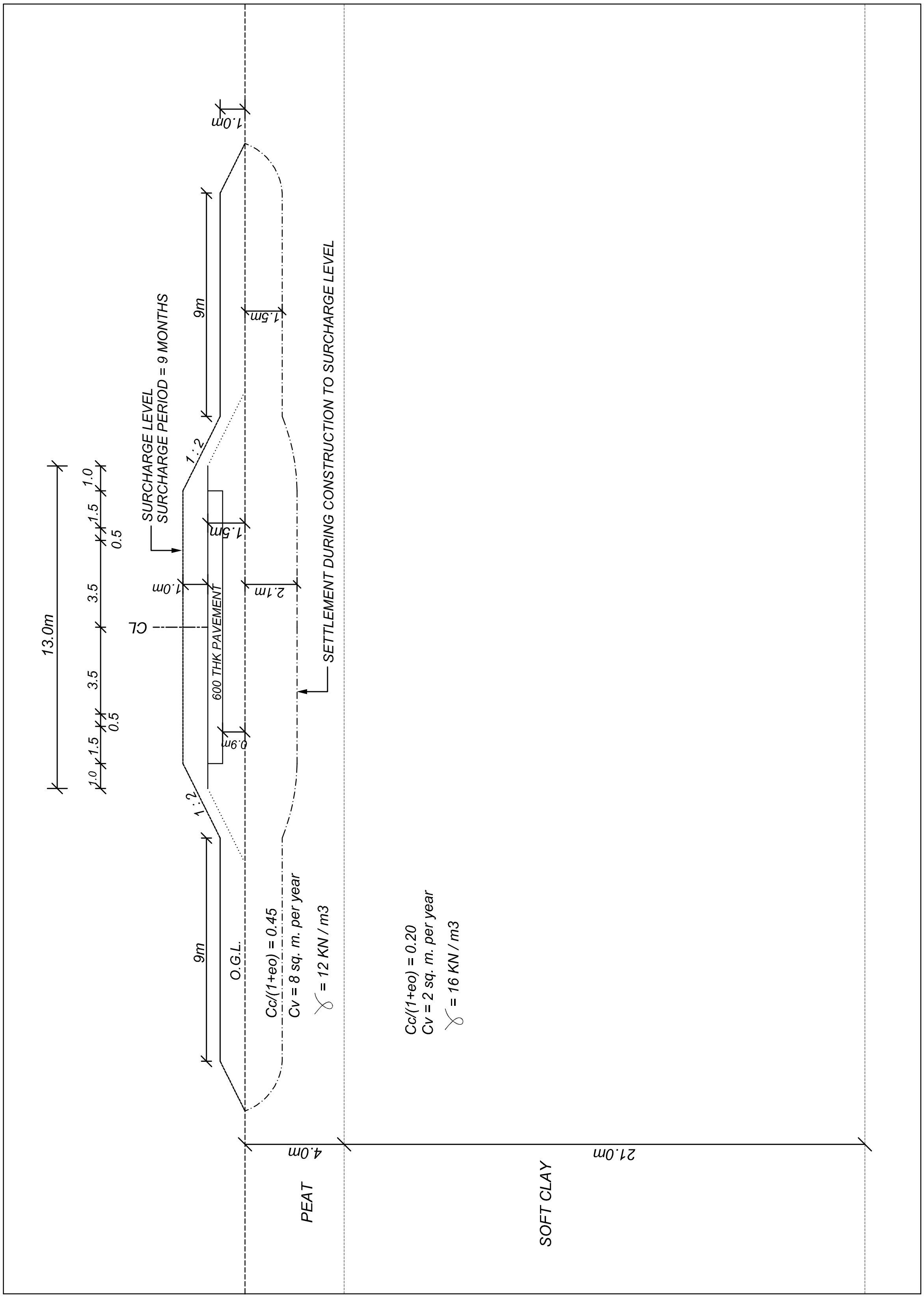


Figure 4 – 12. Typical road embankment on peat & soft clay

Table 4 – 2. is a summary of the salient features of the analyses.

<table>
<tr><td>Final road level</td><td>1.5m above original ground level</td></tr>
<tr><td>Peat thickness</td><td>4.0m</td></tr>
<tr><td>Soft clay thickness</td><td>21.0m</td></tr>
<tr><td>Embankment surcharge level</td><td>1.0m above the final road level or 2.5m above the original ground level</td></tr>
<tr><td>Rate of embankment filling</td><td>300mm per week</td></tr>
<tr><td>Time to complete filling to surcharge level</td><td>4 months</td></tr>
<tr><td>Preload period</td><td>9 months</td></tr>
<tr><td>Excess pore pressures below embankment centre in peat layer at end of filling</td><td><table>
<tr><th>Depth below OGL (m)</th><th>Excess pore pressure (kPa)</th></tr>
<tr><td>2.18</td><td>3.2</td></tr>
<tr><td>2.48</td><td>16.4</td></tr>
<tr><td>3.01</td><td>35.7</td></tr>
<tr><td>3.71</td><td>49.5</td></tr>
</table></td></tr>
<tr><td>Excess pore pressures below stability berm in peat layer at end of filling</td><td><table>
<tr><th>Depth below OGL (m)</th><th>Excess pore pressure (kPa)</th></tr>
<tr><td>1.67</td><td>2.8</td></tr>
<tr><td>2.11</td><td>11.0</td></tr>
<tr><td>2.78</td><td>20.7</td></tr>
<tr><td>3.60</td><td>26.7</td></tr>
</table></td></tr>
<tr><td>Time for end of consolidation of peat layer</td><td>12 months</td></tr>
<tr><td>Settlement during filling</td><td>2100m</td></tr>
<tr><td>Settlement over surcharge period</td><td>570mm</td></tr>
<tr><td>Amount of earth to be removed to subgrade level for pavement construction at end of surcharge</td><td>1000mm (pavement thickness = 600mm)</td></tr>
<tr><td>Factor of safety on reaching surcharge level</td><td>1.30</td></tr>
<tr><td>Post construction settlement 3 years after completion of road</td><td>200mm</td></tr>
<tr><td>Post construction settlement 7 years after completion of road</td><td>380mm</td></tr>
</table>

Figure 4 - 13 illustrates the estimated settlement versus time. Figure 4 - 14 is a plot of the estimated fill level over time. The settlement during fill placement is about 50% of the fill thickness. The analyses show that the post construction settlement criteria of 200mm in 3 years and 400mm in 7 years can be achieved without the use prefabricated vertical drains.

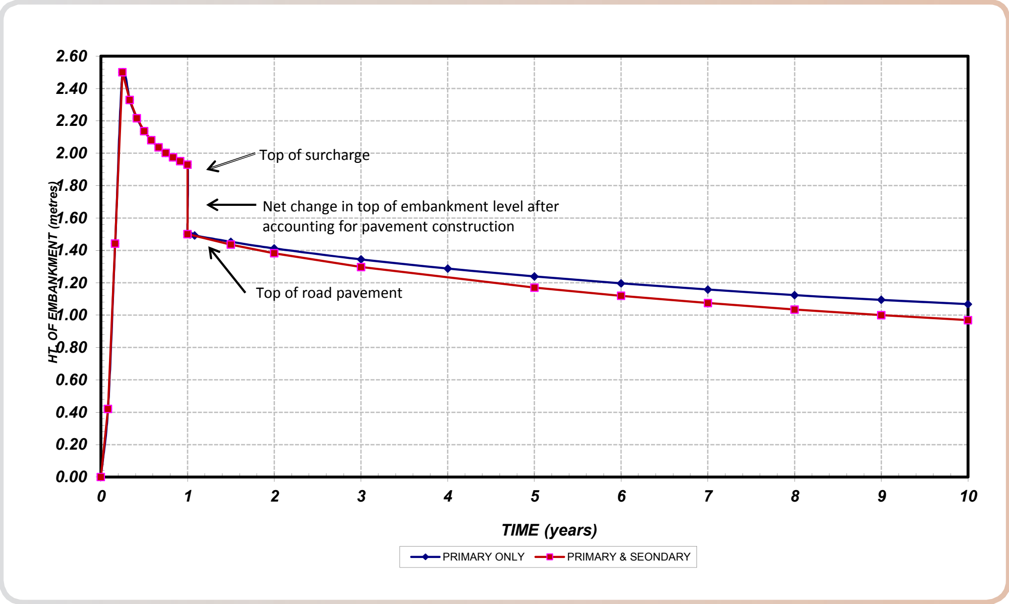


Figure 4 - 13. Estimated settlement for typical road embankment, HT = 1.5m & Surcharge = 1.0m

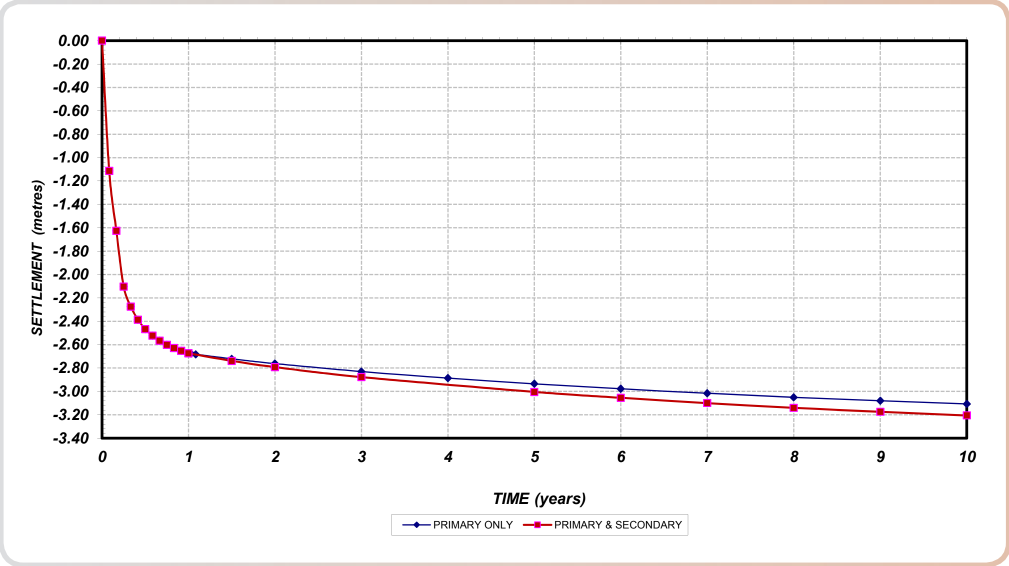


Figure 4 - 14. Estimated fill level for typical road embankment, HT = 1.5m & Surcharge = 1.0m

In this example, the 9m wide stability berm is required to ensure a Factor of safety of 1.3 at the most critical stage viz. end of filling. The critical failure mechanism is within the peat layer (see Figure 4 - 15). The width of the stability berm can be reduced if the excess pore pressures in the peat at end of filling are lower; a reduction in excess pore pressures can be achieved by a slower rate of filling possibly 300mm in two weeks or else by stage construction.

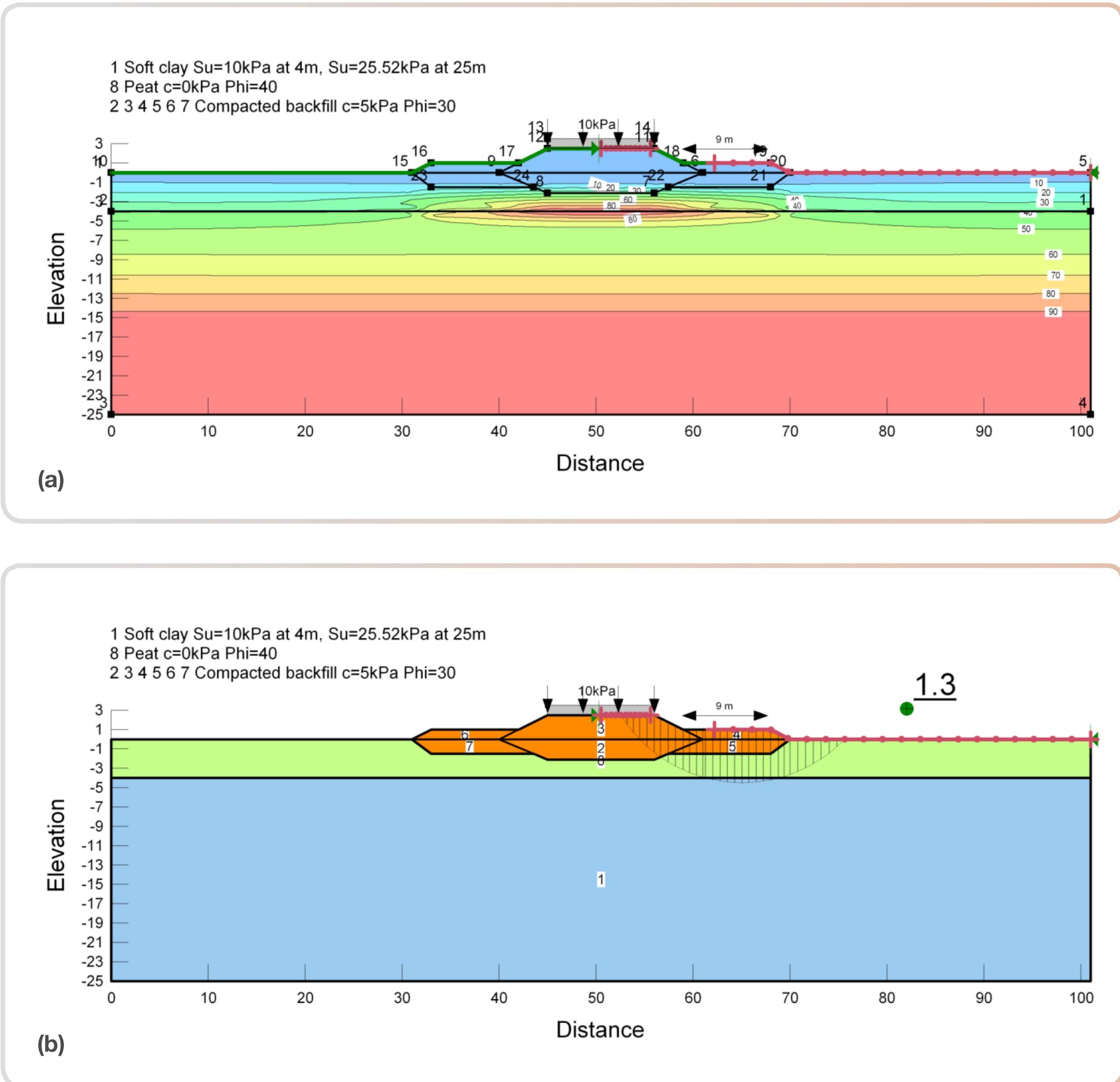


Figure 4 - 15. (a) Pore pressure at end of filling to surcharge level (b) Stability analysis

4.7 PREFABRICATED VERTICAL DRAINS

The above example of a typical road embankment over a typical Sarawak subsurface condition with peat over thick soft clay shows that prefabricated vertical drains need not be adopted. Indeed it is not uncommon for JKR roads in Sarawak on similar ground not to be treated with prefabricated vertical drains. Prefabricated vertical drains will however be required if the stricter criterion of limiting post construction settlement to 10% of the total primary settlement is specified.

The large settlements associated with peats can cause prefabricated vertical drains installed through peat and underlying soft clay to "crimp" rendering the vertical drains ineffective. If prefabricated vertical drains are to be used, then the vertical drains should be installed only after:

i. removal of the peat as shown in two of the case histories presented in Chapter 6.
ii. the embankment has been significantly raised and only after a significant proportion of peat compression has taken place.

Chapter 5

Design Parameters From Basic Properties

5.1 INTRODUCTION

Undisturbed samples of peat cannot be readily obtained unless the clay content is appreciable. Therefore and in recognition of the current best soil investigation practice in Malaysia, selection of design parameters often has to be based on correlations with properties that can be readily obtained from disturbed samples such as natural moisture contents, organic contents and ash contents.

Correlations relating basic properties to parameters must necessarily be based on a large number of high quality tests. Since the first publication of the Guidelines in 2015, there has been appreciable increase in the amount of data for tropical peat in Malaysia. The correlations given in this Chapter are to a large extent published data on peat from all over the world but with data from Malaysian Institutions added on. There is therefore a need for local institutions to continue with research on the properties of tropical peat to add on to the correlations in this Chapter. As shall be shown in Chapter 6, parameters obtained from basic properties using internationally established correlations do give reasonable estimates of settlement.

5.2 BASIC PEAT PROPERTIES THAT ARE CORRELATED TO DESIGN PARAMETERS

Disturbed samples of peat are readily obtained using peat samplers. The following tests can be readily carried out on disturbed samples and form the mainstay of correlations:

i. Natural moisture content.

ii. Organic content/ Ash content / Ignition Loss where:

   a. Ash content (%) = 100 – Organic content (%)

   b. Ignition loss (%) Organic content (%)

5.3 CORRELATIONS WITH PARAMETERS FOR ESTIMATING SETTLEMENT

The basic equations for estimating total primary and secondary settlement are given in Chapter 4 and repeated herein below:

$$\text{Total primary consolidation settlement} = \left(\frac{Cc}{1+e0}\right) H \log\left(1 + \Delta\sigma v/\sigma vo'\right) \qquad \text{Eq. 4-1}$$

$$\text{Secondary consolidation settlement} = \left(\frac{Cc}{1+e0}\right)\left(\frac{C\alpha}{Cc}\right) H \log\left(\frac{t}{tp}\right) \qquad \text{Eq. 4-2}$$

Table 5 -1 summarizes the different experimentally determined relationships between basic properties and parameters for estimating consolidation settlement. Estimates of primary and secondary consolidation can therefore be made from the basic properties.

Table 5 – 1. Relationships between basic properties and parameters for estimating consolidation settlement

Basic property	Figures relating basic property to parameter for estimating settlement	Parameters related to basic properties	Parameters for use in settlement analysis
Natural moisture content	Figure 5.1 from den Haan & Kruse (2007) with added data on tropical peat	Dry density γ_d and Bulk density γ_b	in situ effective stress σ_{vo}'
Ignition Loss	Figure 5.2 from den Haan & Kruse (2007) with added data on tropical peat	Specific gravity G_s	Void ratio e
Natural moisture content	Figure 5.3 from den Haan & Kruse (2007) with added data on tropical peat	Initial void ratio e_o	Initial void ratio e_o
-	Figure 5.4 from Mesri & Ajlouni (2007)	Coefficient of permeability k versus void ratio	Coefficient of consolidation Cv
Natural moisture content	Figure 5.5 from Mesri & Ajlouni (2007) with added data on tropical peat Figure 5.6 Siti Taib et al (2014)	Compression Index Cc	Cc
-	Figure 5.7 from Mesri & Ajlouni (2007) with added data on tropical peat	Secondary consolidation index,Cα versus Cc	Cα

The results for Sarawak tropical peat by Siti Taib et al (2014) fall within the general trend by Mesri & Ajlouni (2007).

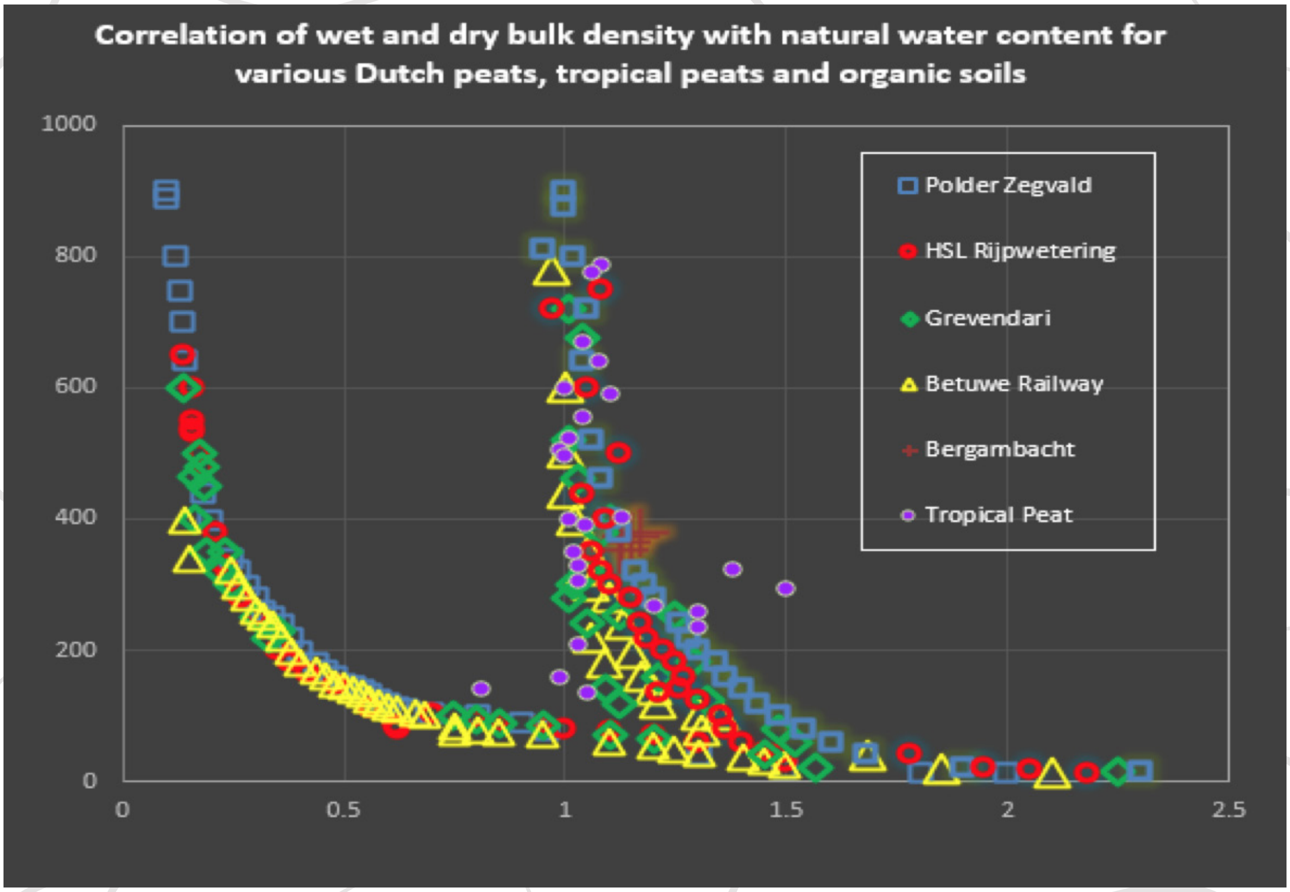


Figure 5 - 1. Correlation of bulk density ρ and dry density ρd with natural moisture content wo (revised Den Haan & Kruse, 2007-reproduced by Youventharan Duraisamy)

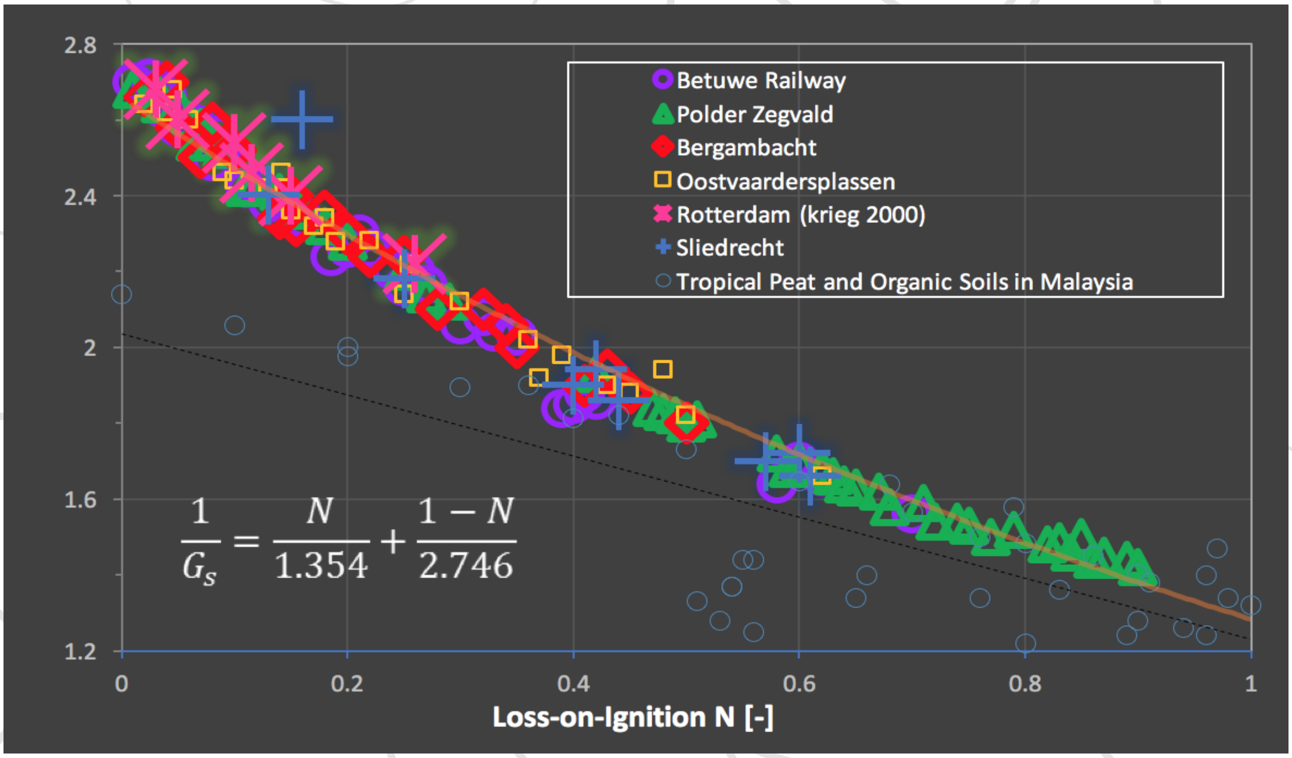


Figure 5 - 2. Correlation of specific gravity ρs with Ignition Loss N (revised Den Haan & Kruse, 2007- reproduced by Youventharan Duraisamy)

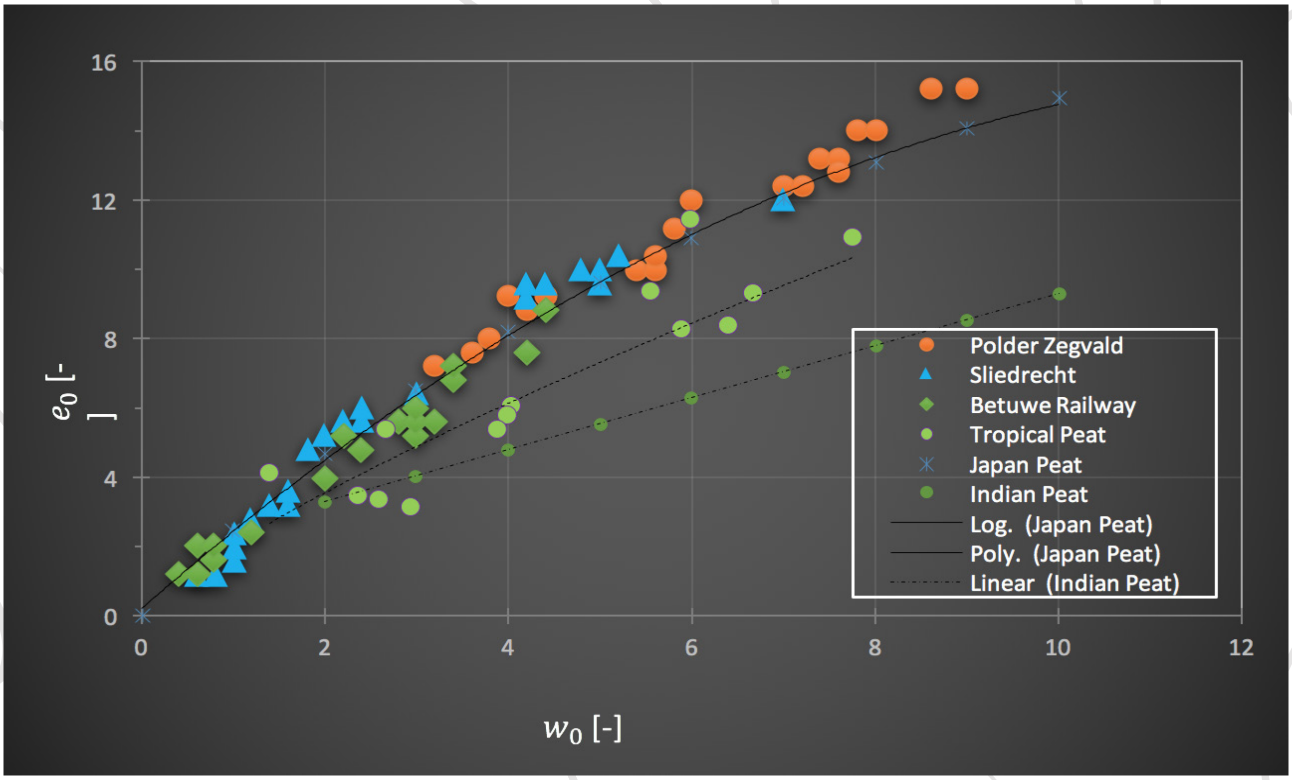


Figure 5 - 3. Correlation of initial void ratio e_o with natural moisture content, w_o (revised Den Haan & Kruse, 2007- reproduced by Youventharan Duraisamy).

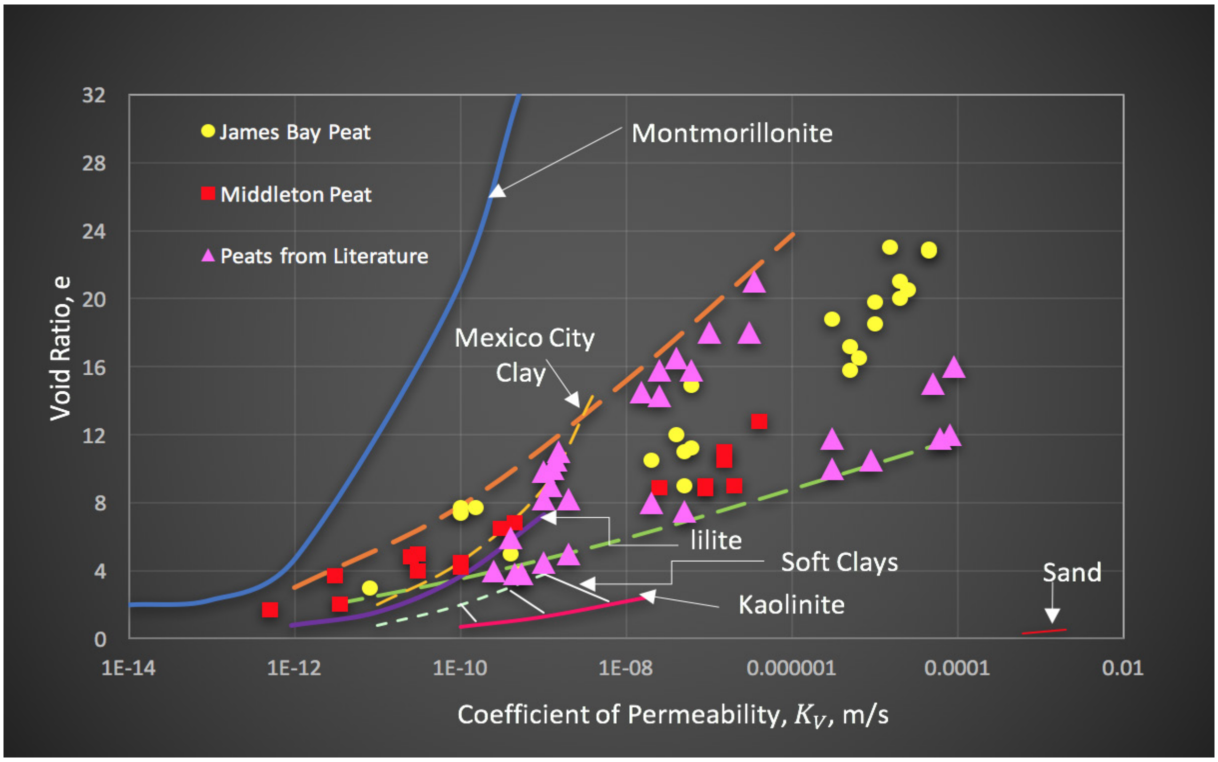


Figure 5 - 4. Correlation of void ratio with coefficient of permability (extracted from Mesri & Ajlouni (2007)-reproduced by Youventharan Duraisamy)

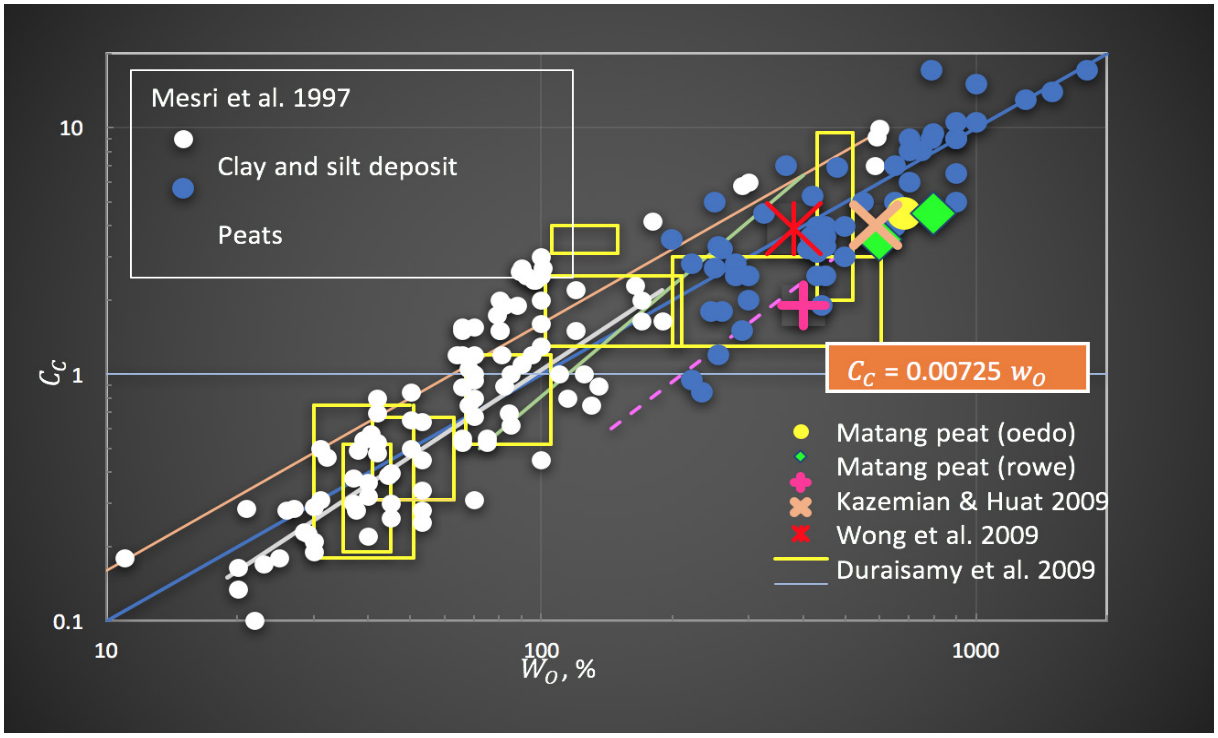


Figure 5 - 5. Correlation of compressibility Index C_c with natural moisture content w_o , for peats and soft clay (revised Mesri & Aljouni, 2007 - reproduced by Youventharan Duraisamy)

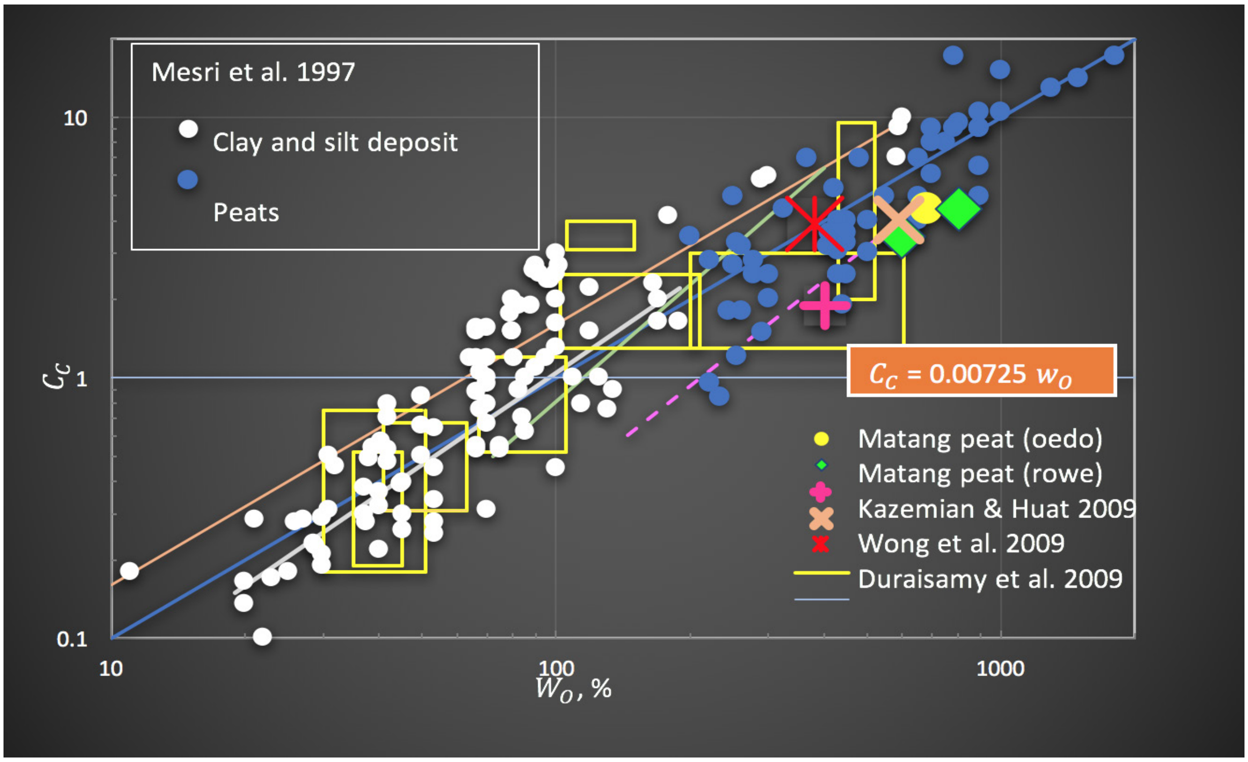


Figure 5 - 6. Compressibility of sarawak tropical peat plotted against correlation by Mesri And Ajlouni (2007) and Taib ***et al*****., (2014) - reproduced by Youventharan Duraisamy**

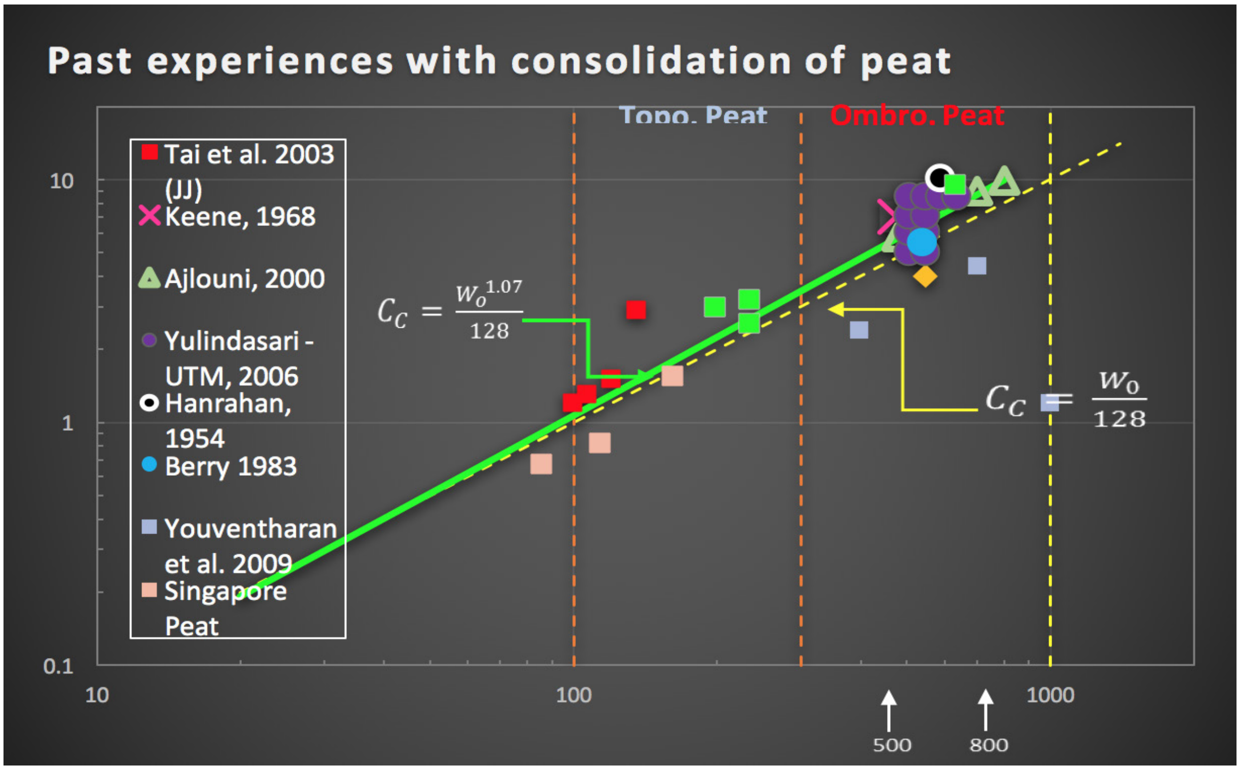


Figure 5 - 7. Compressibility of tropical peat from Tai & Lee (2003), Yusindasari (2006) and Youventharan et. al (2009) plotted against correlation by Kogure & Ohira (1997) - reproduced by Youventharan Duraisamy

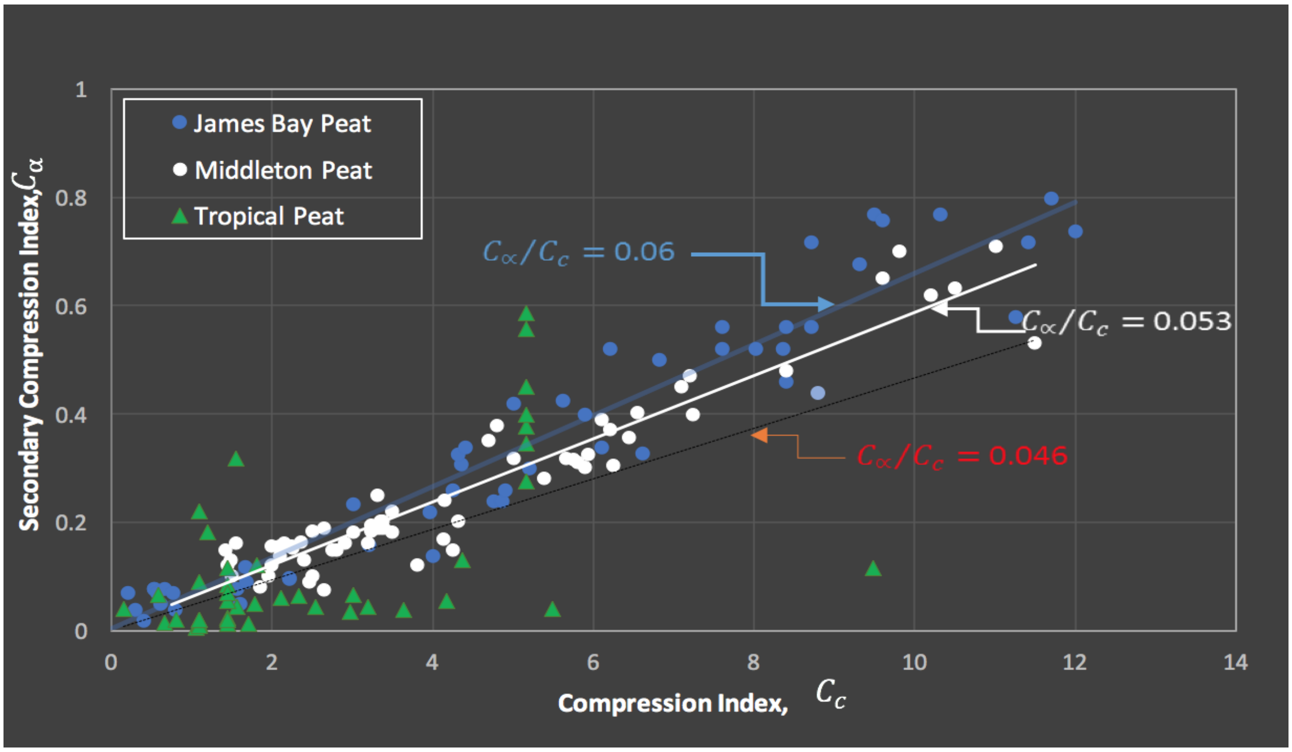


Figure 5 - 8. Correlation of compressibility Index Cc with secondary compression index Cα (revised Mesri & Aljouni, 2007)

5.4 CORRELATIONS WITH STRENGTH PARAMETERS

5.4.1 Effective stress parameters

Table 5 - 2 from Mesri & Ajlouni (2007) is a summary of Φ' values from triaxaial compression tests and show Φ' values that are higher than sand. Figure 5 - 8 from Den Haan & Fedema (2009) show Φ' values close to 80 degrees for fibrous peats (low bulk density). The Φ' values decrease as bulk density increases. The same trend is shown in Figure 5 - 9 also from Den Haan & Fedema (2009) where the Φ' is also expressed as M, the critical state strength parameter (M = 6sinΦ'/(3-sinΦ'). Bulk and dry densities can be estimated from natural moisture contents following Figure 5 - 1 from den Haan & Kruse (2007).

Peat is a mass of entangled fibres and cellular connections. The fibres have tensile stiffness and strength. They are likely to be horizontally lined due to the depositional sequence resulting in cross anisotropic properties. The high Φ' from triaxial compression is attributed to the reinforcing effects of fibres. During triaxial compression, the fibres extend and reinforce the matrix of granular organic material.

Table 5 - 2. Fiction Angle of Fibrous Peats from Triaxial Compression Test on Vertical

Source	Peat	w_o	ϕ’
Habib M. M. et al. (2019)	Beaufort, Sabah	713.35	18.45
	Parit Sulong, Johor	637.00	15
	Parit Nipah, Johor	676.30	24.4
Ajlouni (2000)	Middleton	510-850	60
Yamaguchi et al. (1985a,c,d)	Ohmiya	960-1,190	51-55
Yamaguchi et al. (1983)	San Joaquin	200-500	44
Marachi et al. (1983)	San Joaquin	200-500	44
Landva and LaRochelle (1983)	Escuminac	1,240-1.380	40-50
Edil and Dhowian (1981) and Edil and Wang (2000)	Middleton	500-600	57
Tsushima et al. (1982)	Muck	-	51
Yasuhara and Takenaka (1977)	Omono	-	50-60
Tsushima et al. (1977)	Muck	-	52-60
Ozden et al. (1970)	Muskeg	800	46
Adams (1965)	Moose River	330-600	48
Adams (1961)	Muskeg	375-430	50-60

O’Kelly and Orr (2014) expressed concern over the high Φ’ values from triaxial compression tests as *“this can lead to unrealistically high factors of safety and the question arises as to how much of these high measured Φ’ values, if used in an effective-stress stability analysis, can be counted on to operate in the field? The un-conservative nature of these high Φ values is recognised in practice”.*

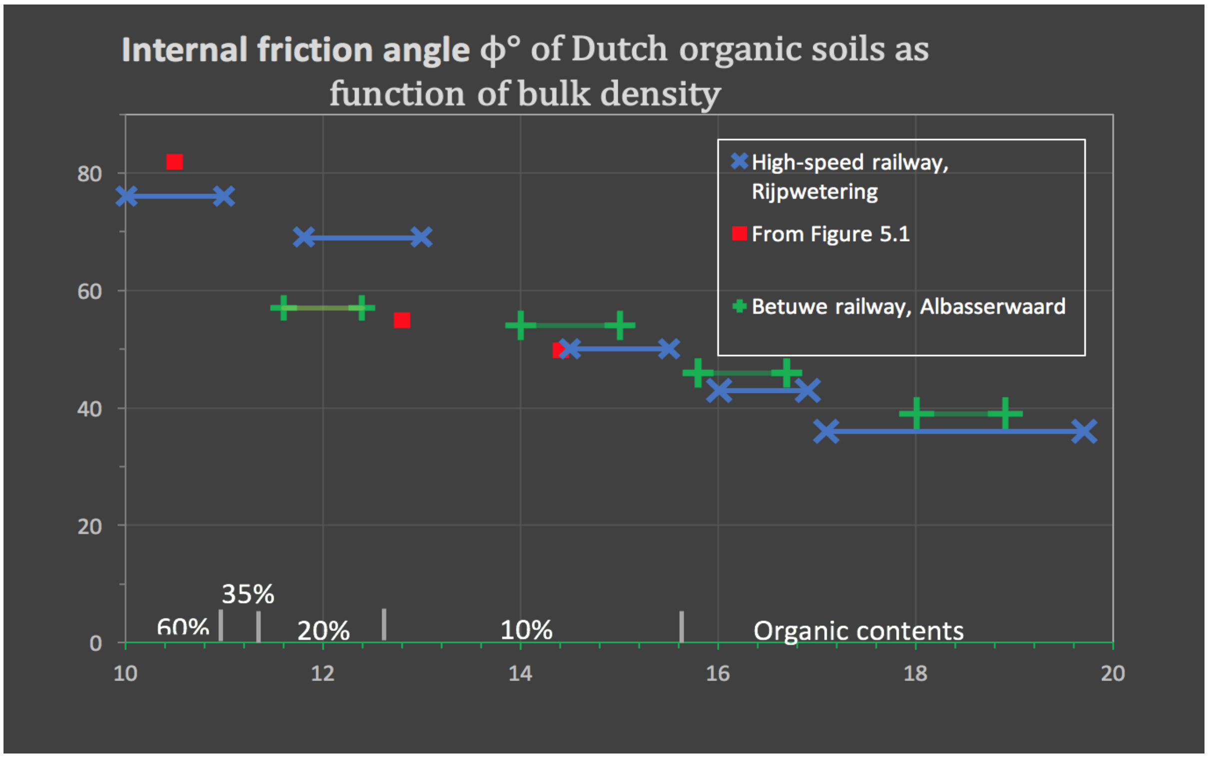


Figure 5 - 9. Fiction angle φ’ as a function of bulk density. (Den Haan & Fedema, 2009)

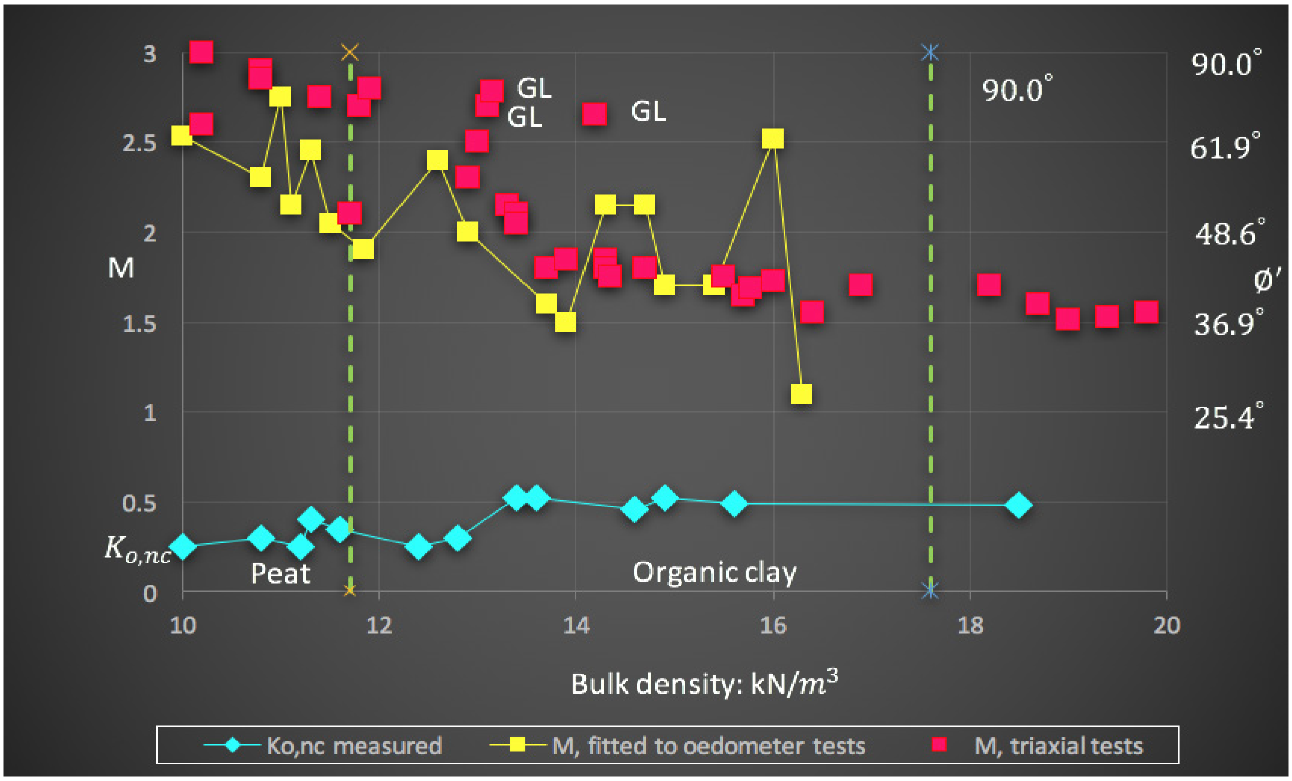


Figure 5 - 10. Critical state strength parameter m or φ' as a function of bulk density. (Den Haan & Fedema, 2009)

Landva and La Rochelle (1983) have suggested that shearing parallel to fibre orientations may lead to reduced particle interlocking and frictional resistance. Table 5 - 3 is a summary of Φ' values from direct shear, direct simple shear tests and ring shear test. Given the uncertainties with the high Φ' values from triaxial compression tests on peat and unless sufficient direct shear tests on undisturbed samples are carried out, it is considered prudent to limit the Φ' values for design to 40 degrees; this value being closed.

Table 5 – 3. Summary of φ'values from direct shear, direct simple shear test and ring shear tests

Source	Test type	Range of Φ'	Effective normal stress
Bujang B. K. H. (2004)	Shear box test	6 - 25	17 kPa
A. Zainorabidin and S. H. Mansor (2016)	Direct shear box test	37.1 – 37.2	12.5 – 100 kPa
Landva & La Rochelle (1983)	Ring shear tests	32 to 40	10 to 50 kPa
Aljourni (2000) Middleton peat	Direct shear tests	54 (peak) 40 (post peak)	Low normal stress range
		37 (peak) 26 (post peak)	60 kPa
Yamaguchi et al (1987)	Direct simple shear tests	40 to 41	-

5.4.2 Total Stress Parameters

Total stress strength parameters cannot be reliably obtained using vane shear tests or piezocones. Figure 5 - 11 from Mesri & Ajlourni (2007) shows the wide scatter in vane shear strengths when plotted against void ratios.

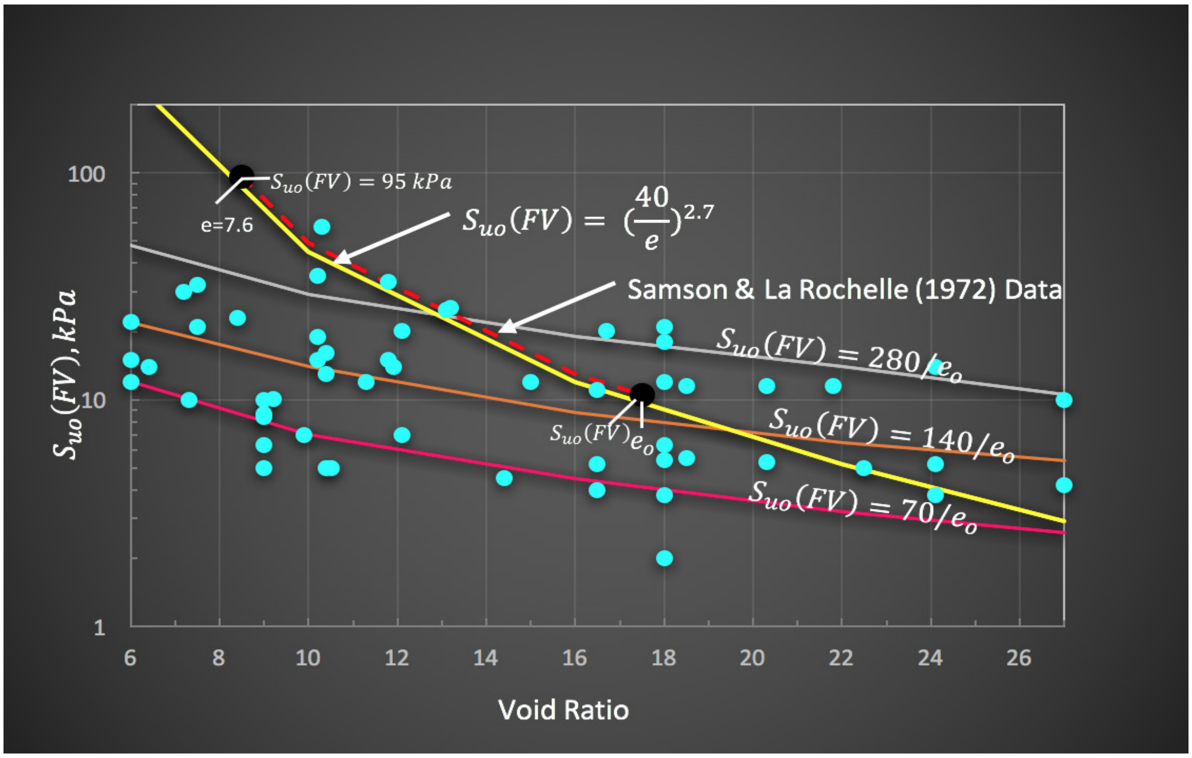


Figure 5 - 11. Vane shear strength versus void ratio (Mesri, 2009)

Table 5 - 4 from Mesri & Ajlouni (2007) lists su/σv' values for peat. The su/σv' values for peat are all higher than 0.47. The Su/σv' for soft clays are lower and typically of the order of 0.25. The higher su/σv' values are consistent with the high Φ' values attributed to the effects of fibres.

Table 5 – 4. List the Su / σv' Mesri and Ajlourni (2007)

Source	Peat	Wo (%)	S_u(TC)/σ'$_{vc}$
Moran et al. (1958)	Antioch, Algiers	230-1.000	0.48-0.60
Lea and Brawner (1959)	Burnaby	400-1.200	0.47-0.58
Adams (1965)	Moose River	330-600	0.68
Forrest and MacFarlane (1969)	Ottawa	900-1.200	0.50
Yasuhara and Takenaka (1977)	Omono	-	0.54
Tsushima et al. (1977)	-	-	0.52-0.54
Dhowian (1978) and Edil and Wang (2000)	Middleton	500-600	0.55-0.75
	Portage	600	0.70
Yamaguchi et al. (1985a.c.d)	Ohmiya	960-1.190	0.55
	Urawa	960-1.260	0.52
Den Haan (1997)	-	-	0.54-0.78
Ajlouni (2000)	Middleton	510-850	0.53[a]

[a]Defined at phase transformation yield point.

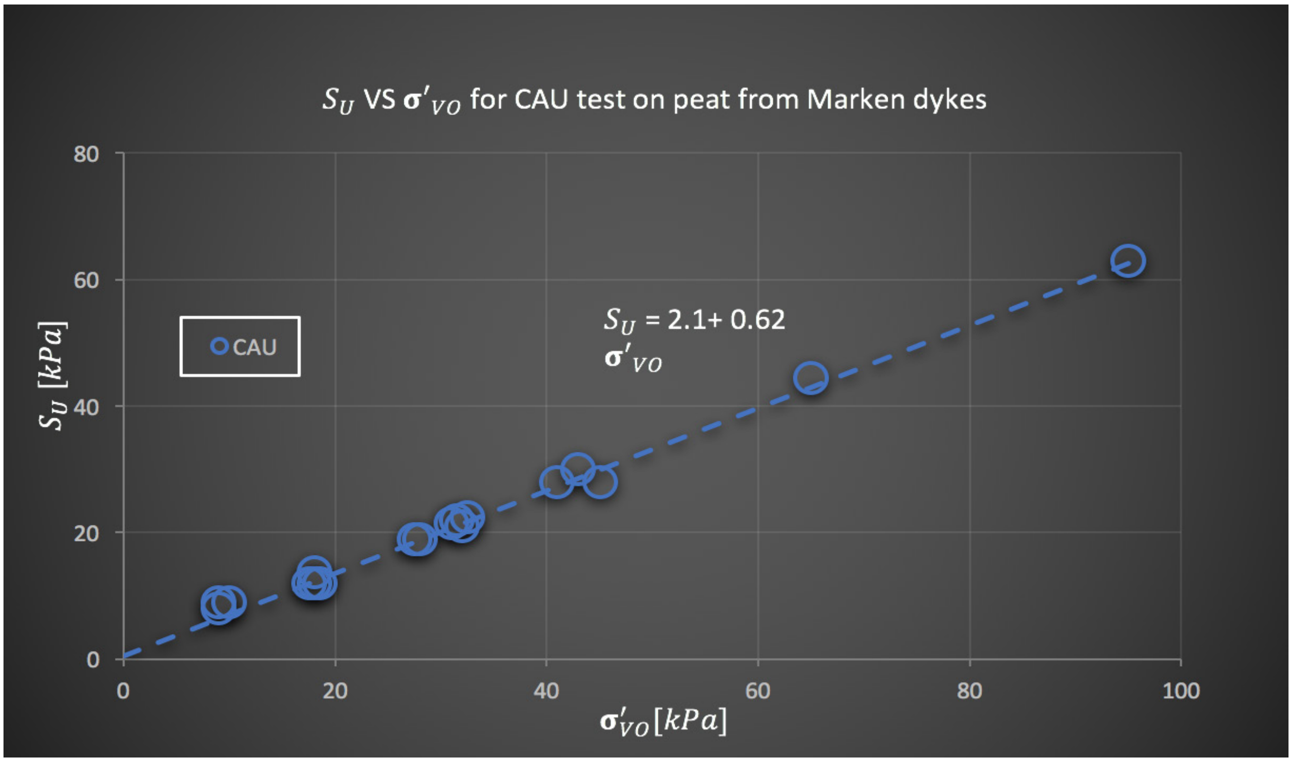


Figure 5 - 12. S_u versus effective vertical stress (Den Haan & Kruse, 2007)

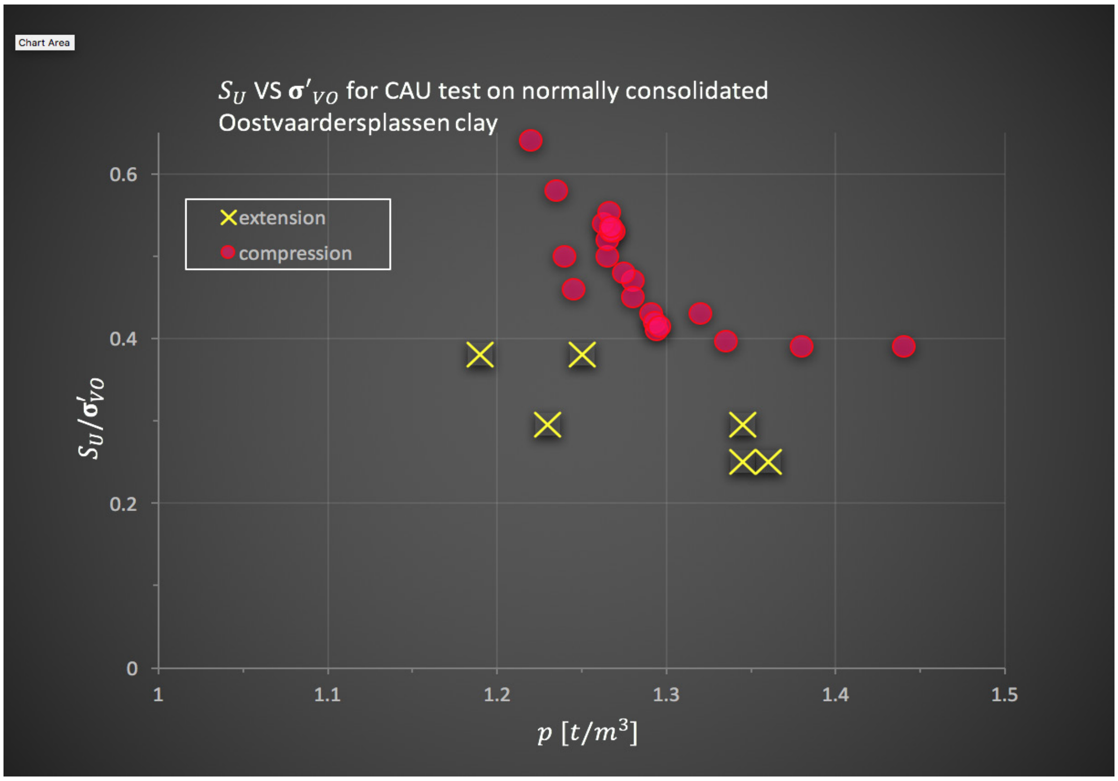


Figure 5 -13. S_u / σ_{vo}' versus bulk density. (Den Haan & Kruse, 2007)

5.5 SLOW RATE OF EMBANKMENT CONSTRUCTION

Embankments on peat should be constructed slowly (not faster than 300mm per week) or in stages with rest periods. Several case histories on embankment construction are presented in Chapter 6.

The reason for adopting slow rates of construction is because:

i. Higher coefficient of consolidation, c_v and permeability, k results in a substantial degree of consolidation during the filling stage; if the rate of filling is kept low. A high degree of consolidation also reduces significantly the lateral movements.

ii. Higher s_u/σ_v' and Φ' results in larger gain in strength on consolidation resulting in higher Factors of safety.

Chapter 6

Case Histories of Construction on Peat

6.1 INTRODUCTION

The case histories pertain to both design as well as construction of embankments and fills. The basic principal of controlled earthworks with minimal mud waves is emphasized and the construction techniques to achieve this illustrated by examples. Back analysis which is never definitive but always subject to assumptions is carried out for a few cases to check on the correctness of parameters estimated from correlations with basic properties discussed in Chapter 5.

6.2 COVERAGE

The case histories illustrate methods currently in use for construction of embankments and fills on peat and are reflective of good practice. Table 6 - 1 summarizes the type of problems encountered when constructing embankments on peat and the methods adopted for overcoming them.

Table 6 – 1. Type of problems encountered when constructing embankments on peat

	Engineering Problems	Effects, Methods And Techniques Discussed In Chapter 6
Earth fill	preparation for access on peat ground	(i) Surface drainage of peat ground and lowering of ground water by about 1 m. (ii) Geotextile fascine mattress
	Fill materials and method of fill placement	(i) Controlled layered placement compared to displacement (ii) Use of sand fill and soil fill
	Settlement	Pre-loading
Excavation and replacement	Ground water drawdown	Excavation in wet compared with excavation in dry
Other methods	Pile embankments	(i) Suspended formwork (ii) High density concrete to overcome acidic conditions

6.3 LESSONS FROM HISTORY

Until the onset of earthworks equipment, ancient man crossed peat swamps by use of timber platforms. Coles (1989) reported an 1800m long timber track built in 3,807 BCE in a peat swamp called Somerset Levels near the town of Glastonbury, UK (see Figure 6 - 1 from Coles 1989).

Figure 6 – 1. Ancient man crossing peat swamp 3,807 BCE. (J. M. Coles (1989))

Corduroy roads made from timber have been in use since Roman times (see Figures 6 - 2, 6 - 3, 6 - 4, 6 - 5 and 6 - 6) and until presently.

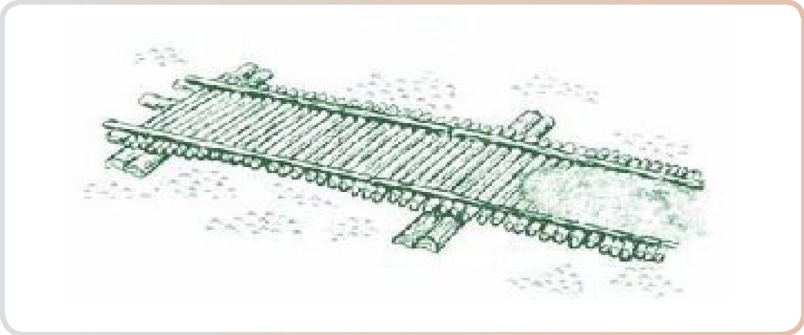


Figure 6 – 2. Corduroy road (from Google Images. 5th October 2015)

Figure 6 – 3. Conserved timber track, Ireland 148 BC (from Google Images. 5th October 2015)

Figure 6 – 4. Corduroy road construction. American Civil War (from Google Images. 5th October 2015)

Figure 6 – 5. Corduroy road construction. American Civil war (from Google Images. 5th October 2015)

Figure 6 – 6. German tank on corduroy road crossing peat. World War II (from Google Images. 5th October 2015)

6.4 EARTH FILLS

6.4.1 General

Peat surface is often water logged and development always requires the ground levels to be raised above the flood levels. Forming a stable platform constitutes a critical engineering activity on peat ground. Failure to form a stable platform properly will result in severe total and differential settlements due to variable fill thickness and consumption of large quantities of fill materials.

During the wet season the ground water is at or near to the surface. The peat is soft and cannot support the weight of person. Timber matting is often used to support light equipment such as soil investigation equipment (see Figure 6 - 7 from Toh et. al 1990).

Timber matting required for drilling rig access during site investigation

Figure 6 – 7. Timber track for soil investigation, Machap, Johor. (Toh *et. al.,* 1990)

In dry season peat fires often occur burning the organic materials above the lowered water table (see Figure 6 - 8 from Ricon 1985) making it dangerous to venture across a dry peat swamp.

Figure 6 – 8. Peat fires from P. Rincon (1985)

6.4.2 Method Of Fill Placement

6.4.2.1 End Tipping

Prior to the 1980s placement of fill involved largely end tipping. This is an uncontrolled process and results in consumption of large quantities of earth-fill, mud waves with heave of surrounding ground often rising above the natural ground levels (see Figure 6 - 9 from Toh et al 1994). An old picture of the effects of end tipping to form the Air Baloi road in Johor is reproduced from Toh & Chee (2008) in Figure 6 - 10. Post construction differential settlements are usually severe given the large variation in fill thickness. Measurement of the fill volume becomes extremely difficult.

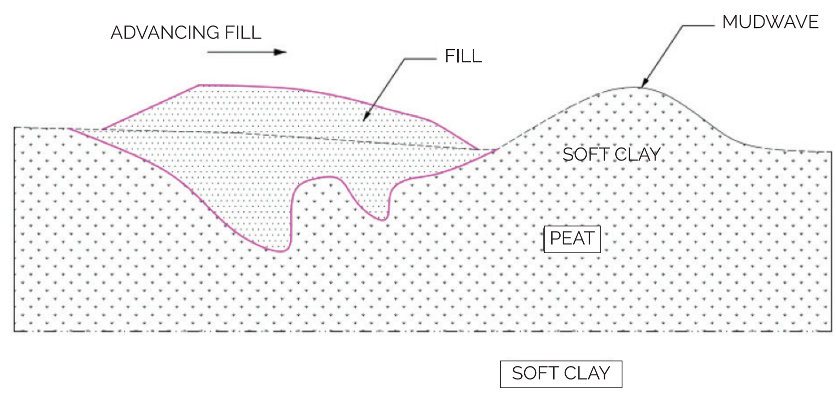


Figure 6 – 9. Uncontrolled filling by end tipping into peat. (Toh & Chee 2008)

Figure 6 – 10. Heave during construction of the Air Baloi road, Johor.(Toh & Chee (2008))

End tipping is often thought as a means of displacing peat. End tipping can only displace a thin peat layer. Inevitably some peat will be trapped. It is better to excavate thin peat than to try to displace it.

Another case of end tipping is the construction of the Sibu to airport road in the 1980s where rock fill was used as the fill material. Post construction settlements have been severe and highly variable.

End tipping must not be permitted as it is an uncontrolled process with severe long term consequences in the form of large settlements and differential settlements.

6.4.2.2 Forming A Stable Earth Platform

Forming a stable platform in a uncontrolled manner with minimal displacement is essential. Figure 6 - 11 courtesy of K S Low shows the problems of accessing peat ground in the absence of a stable platform.

Figure 6 – 11. Excavator sinking into saturated peat (Low, 2015)

There are two methods of forming a stable platform:

i. Dry method where earth is placed and compacted in layers is the most commonly adopted method for forming a stable earth platform.
ii. Wet method where sand is pumped over the peat is sometimes adopted in Sarawak where sea or river sand is plentiful and the site close to rivers where sand can be delivered by barges.

a) Dry Method

This is a controlled process where earth is placed in layers with minimal displacement of peat resulting in uniform thickness of fill and peat and consequently more uniform post construction settlements that are due mainly to consolidation and not lateral movements. The process described herein has been commonly adopted for road construction in Sarawak since around early 1990 and is well proven. The method involves the following important steps:

i. Preparation of the site by surface drainage of the peat to lower the ground water by about 1.0m (see Figure 6 - 12 from Toh & Chee (2008)) and allow approximately 0.5m to 1.0m peat to dry. Figures 6 - 13 and 6 - 14 from Toh & Chee (2008) illustrate the surface conditions of a peat swamp in Johor after surface drainage.

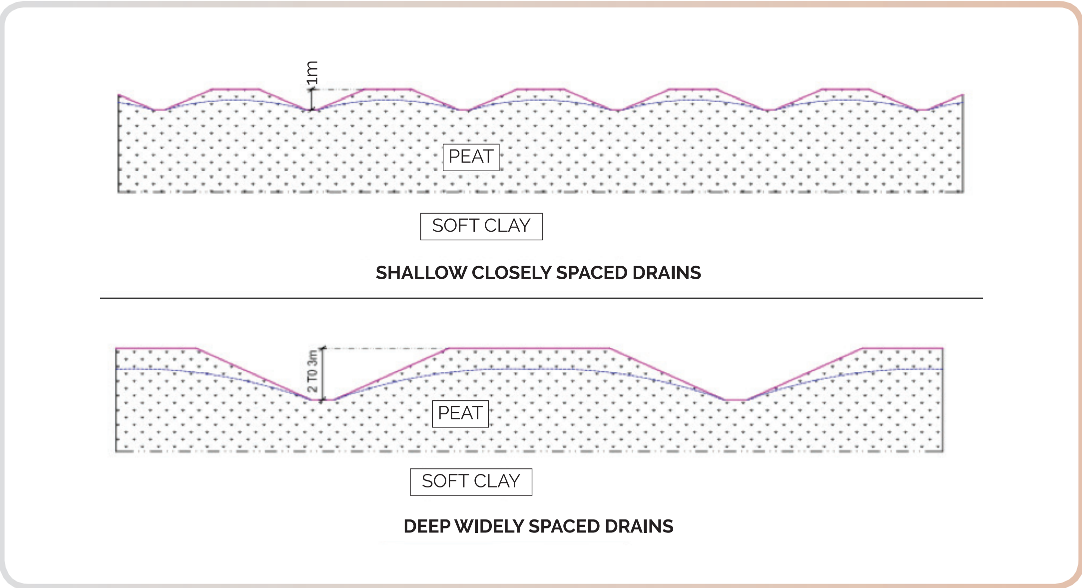


Figure 6 – 12. Surface drainage to lower ground water to form access to pet swamp for filling. Toh & Chee (2008)

Figure 6 – 13. Peat swamp in Johor after drainage by JPS. (Toh & Chee, 2008)

Figure 6 – 14. Peat swamp in Johor after drainage by JPS (Toh & Chee, 2008)

ii. A dried 1.0 to 1.5m peat layer can support light vehicles (see Figure 6 - 15 from Toh & Chee (2008)) thereby allowing controlled placement of the initial fill layer. Once the first 1.0m of earth fill has been placed, heavier earthworks equipment can traverse over the fill. The first 3 layers of fill cannot be compacted to 90% of the maximum dry density (R. R. Hudson (1990)) due to the soft underlying soil. Sand should be used for the first 1.0m.

Figure 6 – 15. Drained peat surface after dewatering from nearby excavation (Toh & Chee, 2000a)

b) Wet Method

In cases where the peat swamp is close to rivers that are large enough for barges to transport sand to the site and where surface drainage is too difficult to execute, placement of the initial fill layer can be by pumping sand but always ensuring that the sand is spread in thin layers with gentle slopes of the order of 1v : 10h (see Figures 6 - 16 and 6 - 17 from Toh & Chee (2000)). Once the sand fill is above water, earth or sand fill can be placed in the dry and compacted in layers to form an embankment.

Figure 6 – 16. Hydraulic sand filling over peat swamp for Matang Expressway, Kuching. (Toh & Chee, 2000a)

Figure 6 – 17. Hydraulic sand filling for Matang Highway, Kuching (Toh & Chee, 2000a)

6.4.3 What if there are localized areas where surface drainage cannot be achieved

Geotextile bamboo fascine mattresses (Toh et al (1994)) have been used to enable filling over wet peat where drainage cannot be carried out. Figures 6 - 18, 6 - 19 and 6 - 20 from Toh et al (1994) illustrate the use of a bamboo geotextile fascine mattress for filling over very soft soils. This technique was first used for reclamation of slime ponds in Kuala Lumpur.

Figure 6 – 18. Bamboo frame for geotextile bamboo fascine mattress. (Toh & Chee, 2000b)

Figure 6 – 19. Filling over geotextile bamboo fascine mattress. (Toh et al 1994)

Figure 6 – 20. Mud wave ahead of filling contained by geotextile bamboo fascine mattress. (Toh et al 1994)

Essentially the bamboo which is laid on a grid pattern (see Figure 6 - 18) enables workers to walk onto the pond. When the bamboo pieces are tied together a frame that increases bearing capacity is formed. The geotextile which must be of high extensibility (at least 70% extensibility) serves to contain mud waves (see Figure 6 - 20). The required geotextile properties for this usage are :

i. High puncture resistance. This is because loose bamboo pieces can puncture the geotextile;
ii. High percentage elongation at break and high resistance against bursting to overcome the upward pressure on the geotextiles due to the mudwaves;
iii. High permeability to enable rapid dissipation of pore pressures;
iv. Strength isotropy to ensure against weakness in any particular direction.

Figures 6 - 21 and 6 - 22 show the use of geotextile bamboo mattress over peat ground.

Figure 6 – 21. Placing geotextile over a bamboo frame on peat (photo courtesy of K S Low)

Figure 6 – 22. Placing fill over geotextile bamboo fascine mattress (photo courtesy of K S Low)

6.5 CONSTRUCTION OF EMBANKMENT ON DEEP PEAT IN BALINGIAN, SARAWAK

6.5.1 Sub-surface conditions and filling

The Balingian road embankment was built on peat of thickness ranging from 4m to 8m with soft clay beneath extending to 30m depth. The final road level is between 0.5m to 1.0m above the original ground surface. Recorded settlements were in the range of 1.0m to 4.0m; the latter occurred where the peat is about 8m thick. The moisture content of the peat was about 500%. The filling was controlled in the manner described in Section 6.4.2.2 (a)

6.5.1 Measured performance and back analysis

Figure 6 - 23 to figure 6 - 28 are reproduced from Chee & Toh (2013). In the deep areas were the peat depth is 7.5m, settlements were of the order of 2.5m to 3.5m. Figure 6 - 24 illustrates the model for back-analysis to check the parameters earlier assumed in the design.

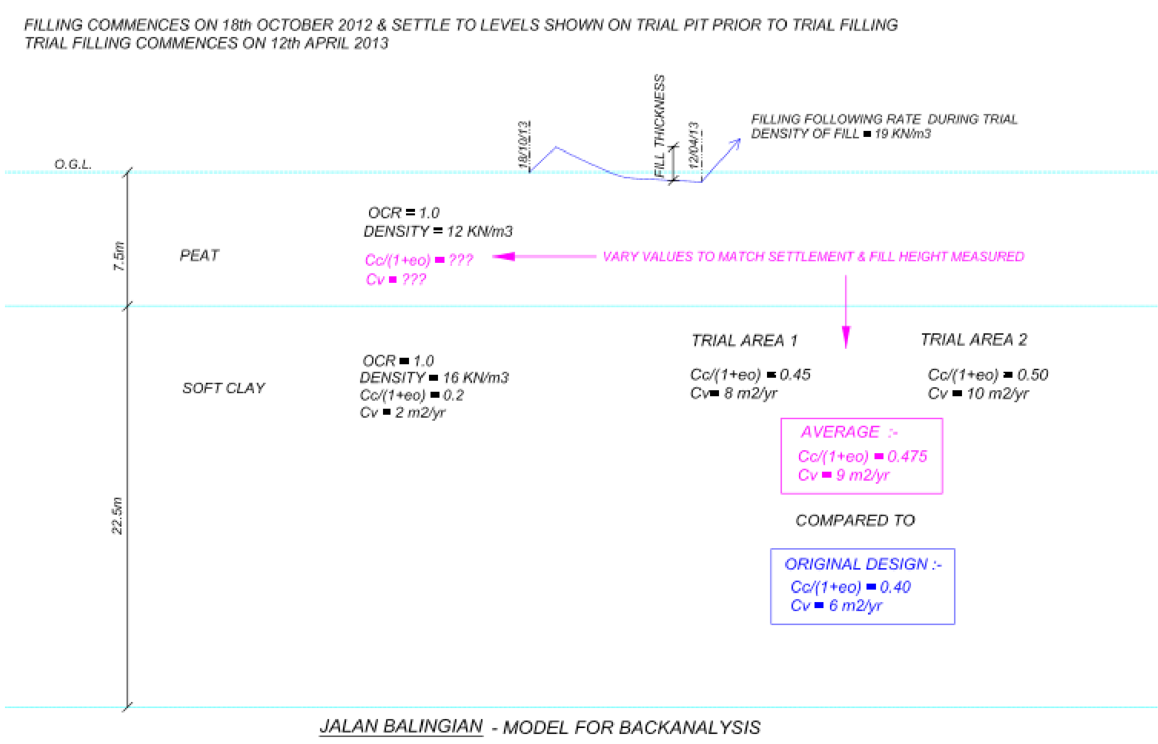


Figure 6 – 23. Model for back analysis Balingian road, Sarawak. (Toh & Chee, 2013)

Figure 6 - 24 shows the final embankment configuration, the peat and soft clay thickness and magnitude of measured settlement. The depth of fill below original ground level is more than twice the height of the embankment. Two trial areas were selected for detailed monitoring of embankment construction. These are referred to as Trial Areas 1 and 2.

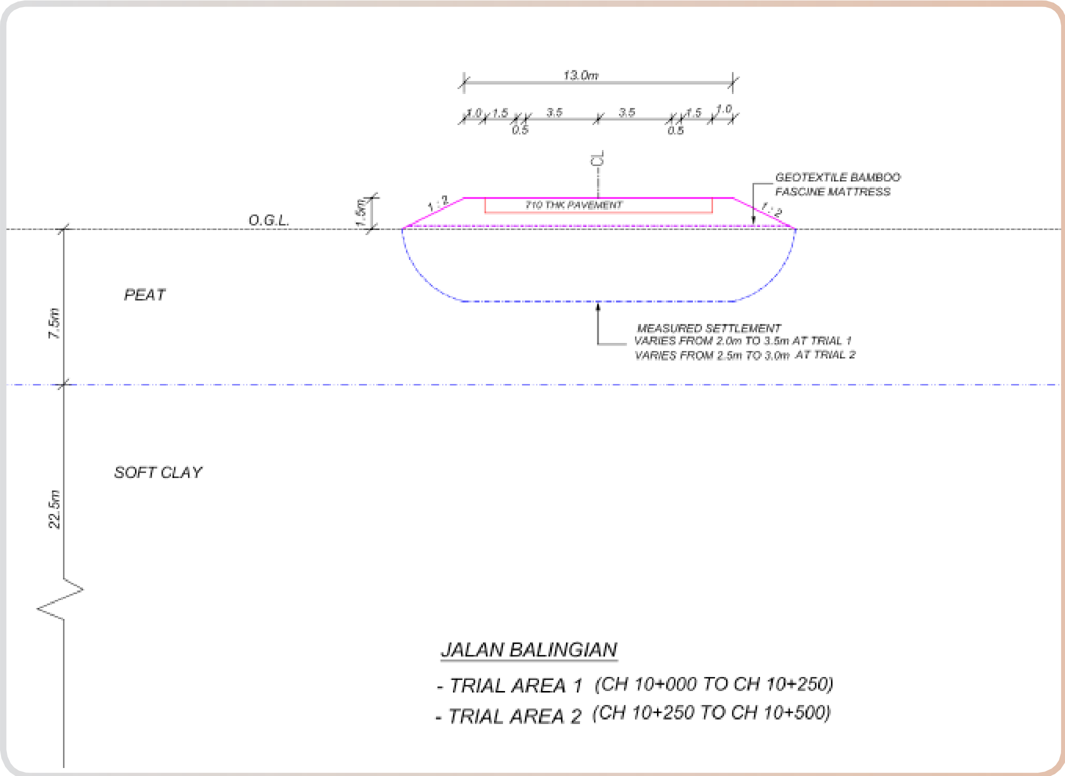


Figure 6 – 24. Road embankment on deep peat. Trial Areas 1 & 2. Balingian road, Sarawak (Toh & Chee, 2013)

Figure 6 - 25 and figure 6 - 26 illustrate the history of filling and the measured settlement together with the back-calculated results for Trial Area 1. There are appreciable differences in the monitoring results over relatively short distances and this is reflective of the heterogeneity of the peat; the measured settlements were between 2.0 and 3.5m. Over the first 6 months of filling at a rate of 300mm over 2 weeks, the top of fill remained below the original ground level. The fill only emerged above the original ground after 6 months of fill placement. At the end of filling the fill thickness was about 2.8m below the original ground level and 0.4m above the original ground.

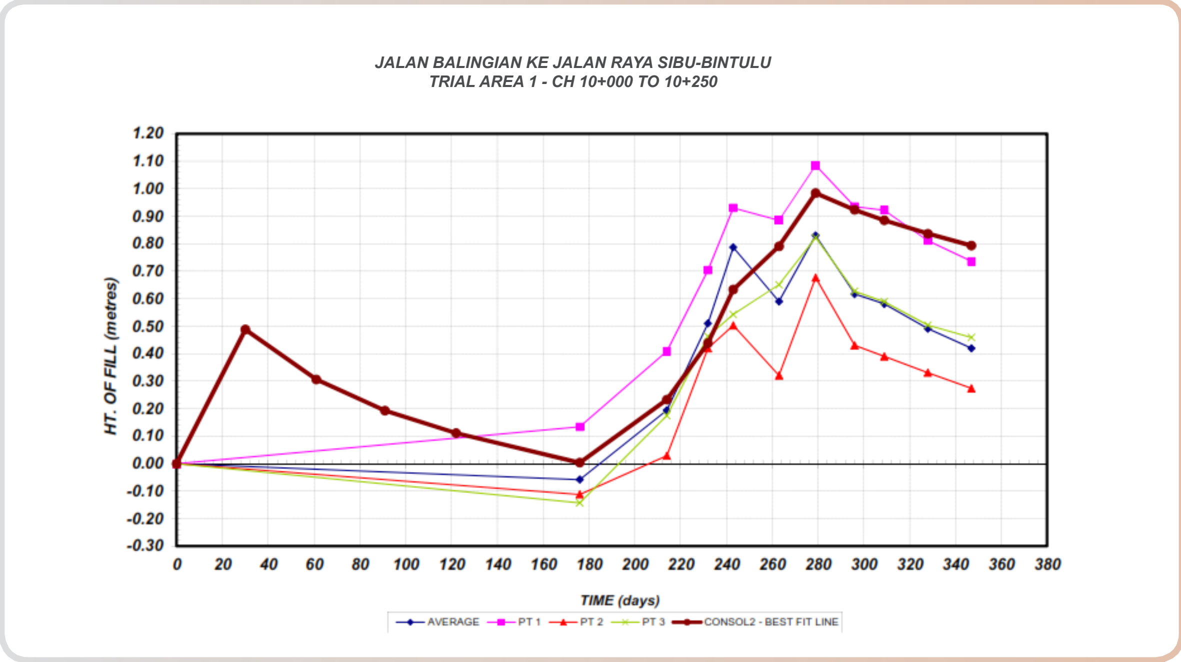


Figure 6 – 25. Back analysis versus measured RL top of embankment versus time. Trial Area 1. (Toh & Chee, 2013)

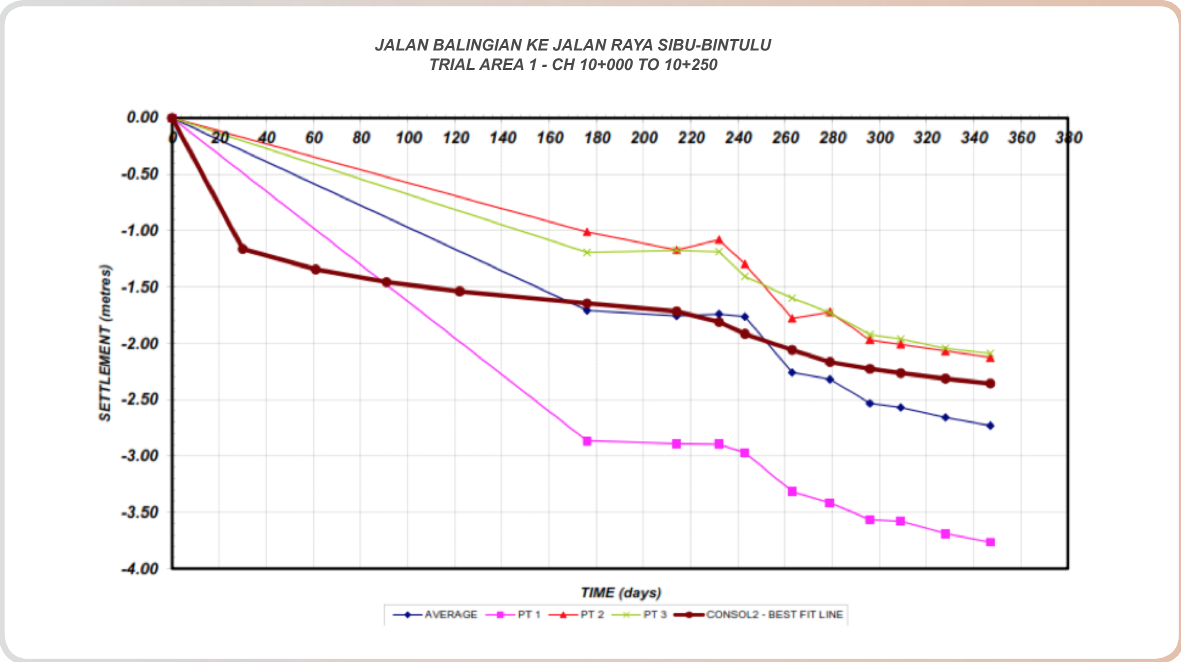


Figure 6 – 26. Back analysis versus measured settlement versus time. Trial Area 1. (Toh & Chee, 2013)

Figure 6 - 27 and figure 6 - 28 illustrate the same for Trial Area 2. The measured settlement was of the order of 3.0m. Again the surface of the fill remained below the original ground for the first 7 to 8 months despite continuous placement of fill at a rate of 300mm every 2 weeks. The fill surface emerged above the original ground only after 6 months.

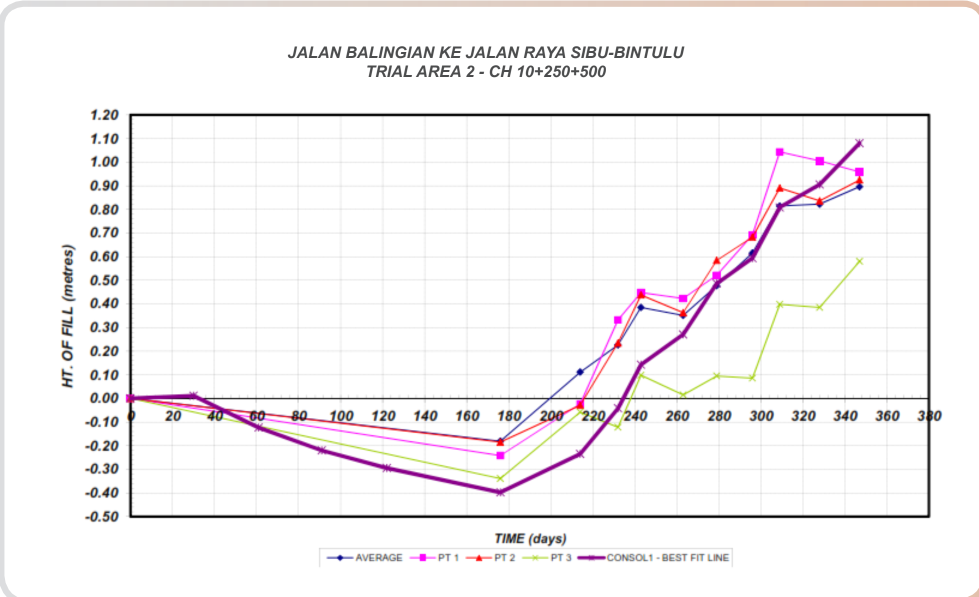


Figure 6 – 27. Back analysis versus measured RL top embankment versus time. Trial Area 2. (Toh & Chee, 2013)

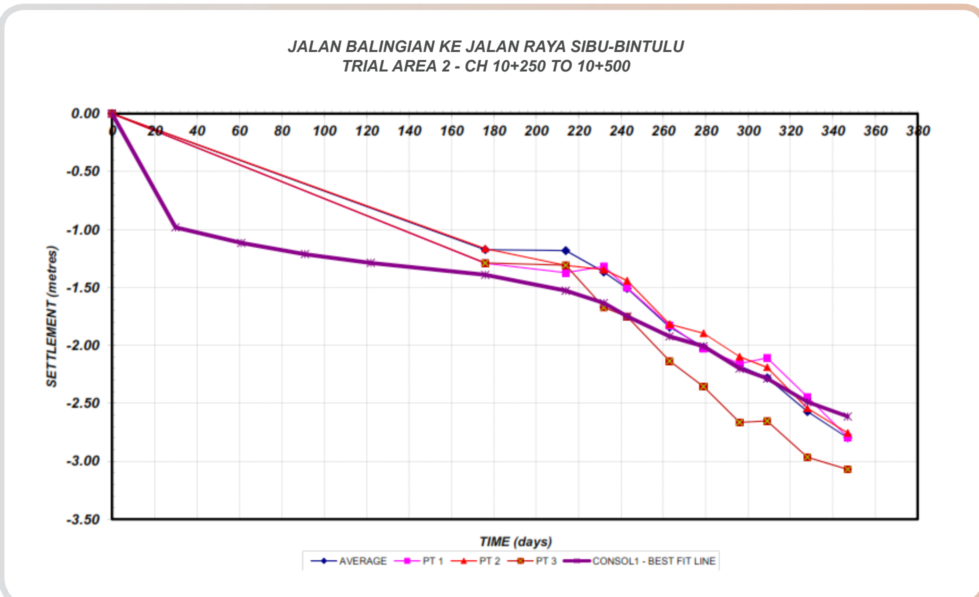


Figure 6 – 28. Back analysis versus measured settlement versus time. Trial Area 2 (Toh & Chee, 2013)

Back- calculation was by use of the finite difference consolidation program CONSOL. The back calculated parameters are given in Table 6 - 2. The back calculated parameters
compare reasonably well with the design parameters derived from the principals set out in Chapter 5.

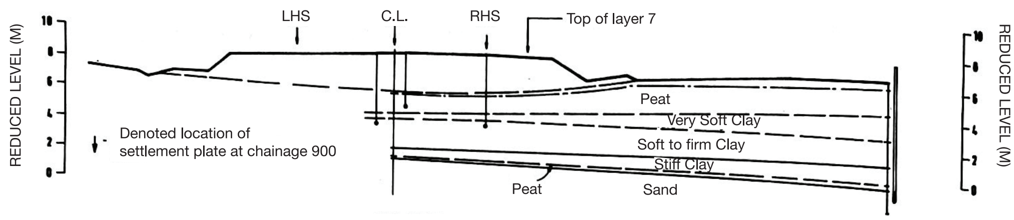
Table 6 – 2. Back calculated parameters

Parameter	Design parameters based on correlation with basic properties MC = 500%	Back calculated values from Trial Area 1	Back calculated values from Trial Area 2	Average back calculated values from back-calculation of Trial Areas 1 and 2
$C_c/(1+e_0)$	0.40	0.45	0.40	0.43
Average C_v over the entire filling period (sq.m. per year)	6.0	8.0	6.0	6.0

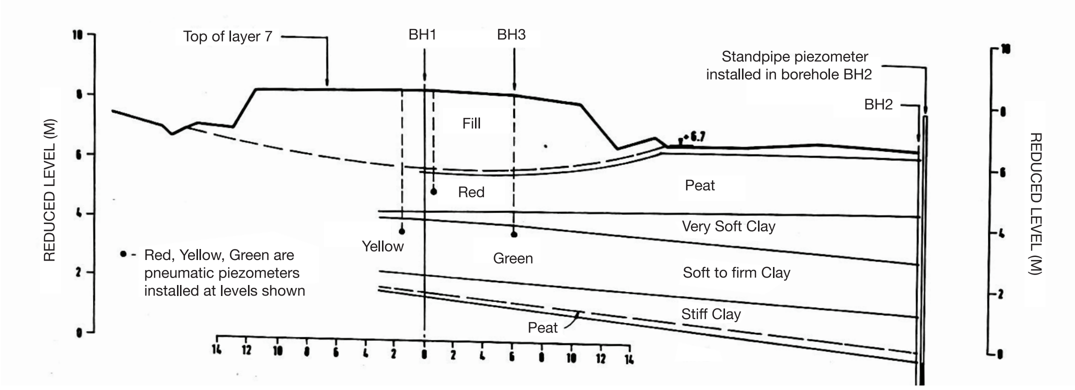
The back- analysis indicates that the method of determining consolidation parameters from basic peat properties gives reasonably correct parameters for assessing consolidation settlements.

6.6 STAGE CONSTRUCTION OF A HIGH EMBANKMENT ON THIN PEAT AND SOFT CLAY IN PAGOH, JOHOR

This case history is extracted from the paper by Khoo and Yam (1990). It involves the staged construction of a 5m high embankment. Figures 6 - 29, 6 - 30, 6 - 31 and 6 - 32 are reproduced from the paper. The sub surface conditions are summarized in Table 6 - 3. Figure 6 - 29 illustrates the embankment configuration and soil layers. Figure 6 - 30 is the plot of natural moisture contents with depth; the peat moisture is of the order of 500%.



CROSS SECTION AT CHAINAGE 910 (NATURAL SCALE)



CROSS SECTION AT CHAINAGE 910 (EXAGGERATED SCALE)

Figure 6 – 29. Stage construction of embankment on peat at Pagoh, Johor. (Koo & Yam, 1990)

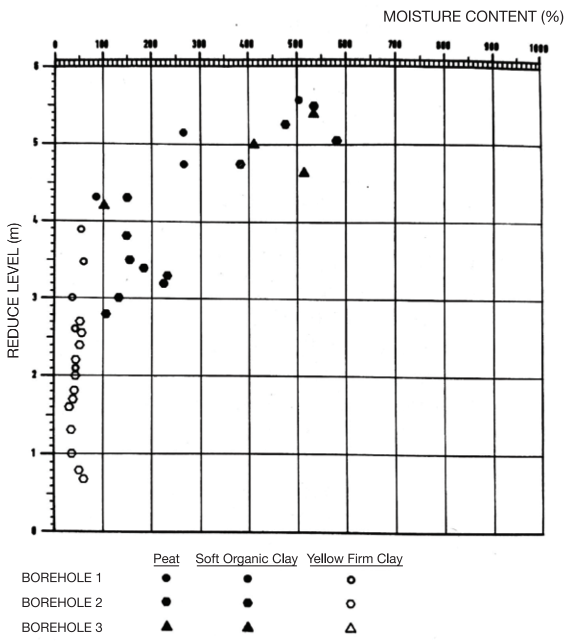


Figure 6 – 30. Natural moisture content with depth. (Koo & Yam, 1990)

Table 6 – 3. Summary of sub surface conditions (Pagoh, Johor)

Depth	Soil description	Natural moisture content
0 to 1.2m	peat	400 to 600%
1.2 to 3.0m	Soft organic clay	150 to 200%
3 to 5.5m	Firm clay	50%

Filling was carried out in stages over a year as shown in Figure 6 - 31. Settlement (see Figure 6 - 31) was of the order of 1.1m. The time required for completion of the embankment was about a year. Pore pressures in the peat layer responded immediately to fill placement and dissipated rapidly after completion of each stage of filling (see Figure 6 - 32).

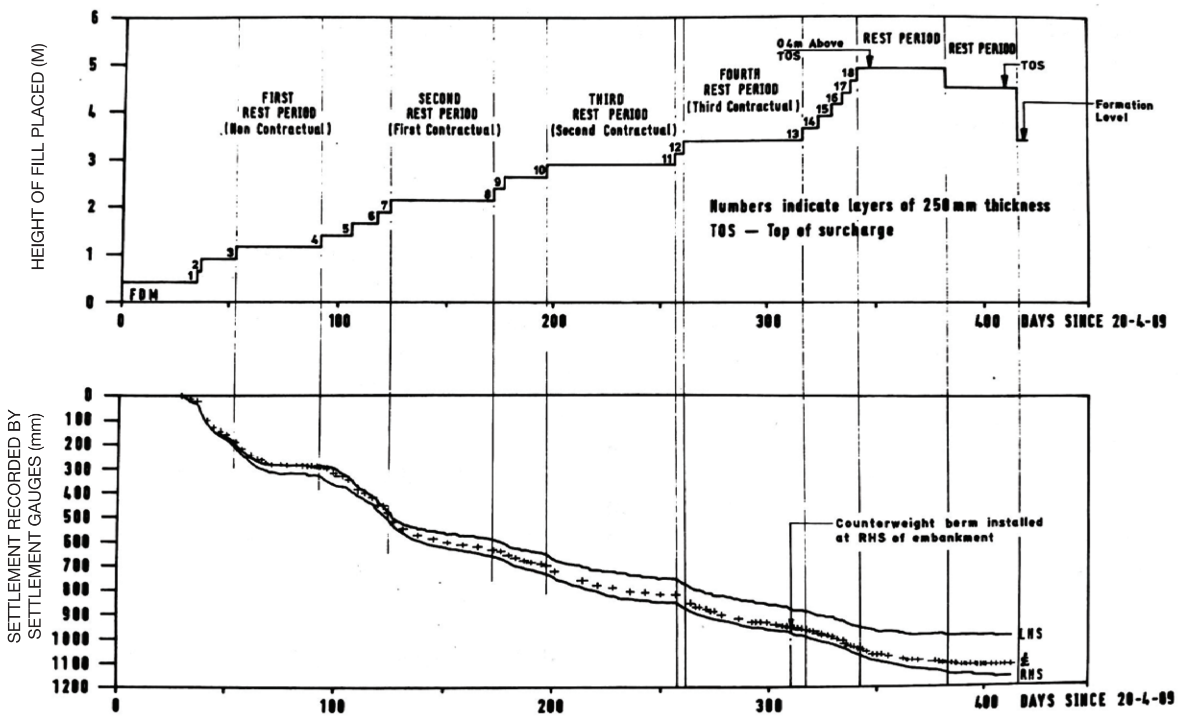


Figure 6 – 31. Embankment construction and measured settlement. (Koo & Yam, 1990)

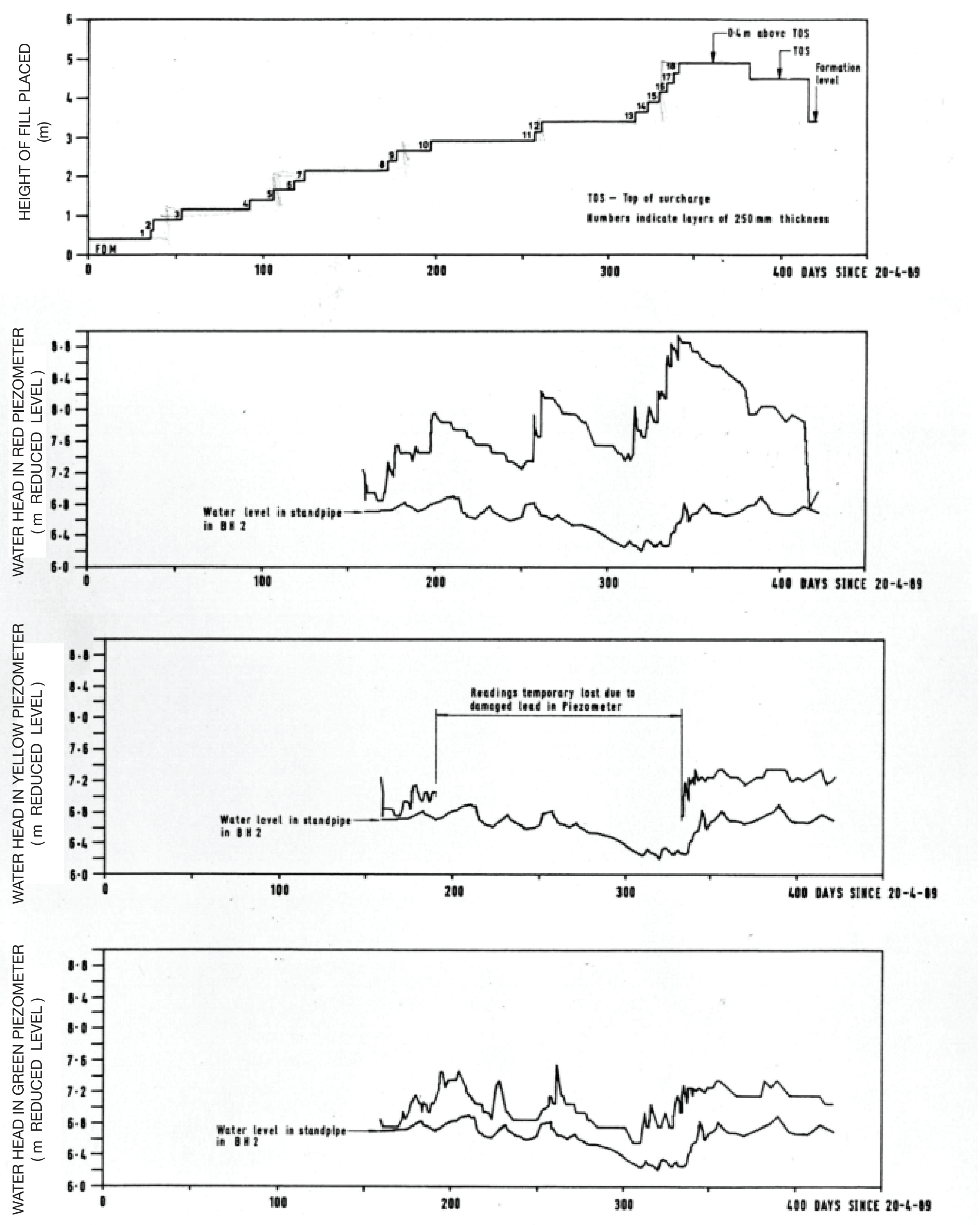


Figure 6 – 32. Measured pore pressures (Koo & Yam, 1990)

6.7 STAGE CONSTRUCTION OF A HIGH GEOTEXTILE REINFORCED EMBANKMENT IN SYLHET, BANGLADESH

This case history is about the construction of a geotextile reinforced road embankment in Sylhet, Bangladesh. Figures 6 - 33 to 6 - 41 are from Toh & Chee (2000). The sub surface conditions are summarized in Table 6 - 4.

Table 6 – 4. Summary of sub surface condition, Sylhet, Bangladesh

Depth (m)	Soil description
0 to 1.0m	Crust
1 to 3.5m	Fibrous peat with natural moisture content of 500 to 600%
3.5 to 8m	Soft clay

Figure 6 – 33. Rice fields over peat. Sylhet, Bangladesh. (Toh & Chee, 2000b)

Figure 6 – 34. Samples of peat, Sylhet, Bangladesh. (Toh & Chee, 2000b)

Figure 6 - 34 illustrates the fibrous peat near to the surface. Figures 6 - 35, figure 6 - 36, figure 6 - 37 and figure 6 - 38 illustrate the bamboo mattress, the laying of the reinforcement geotextile and the completed embankment right up to the bridge abutment.

Figure 6 – 35. Geotextile bamboo fascine mattress for Sylhet road, Bangladesh. (Toh & Chee, 2000b)

Figure 6 – 36. Reinforcement geotextile places over bamboo mattress for Sylhet road, Bangladesh. (Toh & Chee, 2000b)

Figure 6 – 37. Manual placement of sand fill over reinforcement geotextile. Sylhet road, Bangladesh. (Toh & Chee, 2000b)

Figure 6 – 38. Completed geotextile reinforced embankment at bridge abutment. Sylhet road Bangladesh. (Toh & Chee, 2000b)

Figure 6 - 39 illustrates the instrumented section over peat, the the configuration of the embankment and the measured settlements. The height of the embankment up to surcharge level is 3.74m and the settlement ranged from 1.15m to 2.36m. The differential settlement is due to the heterogeneity of the peat. The embankment was built in 2 stages and completed in about 1 year with a rest period of 6 months due to the monsoon season.

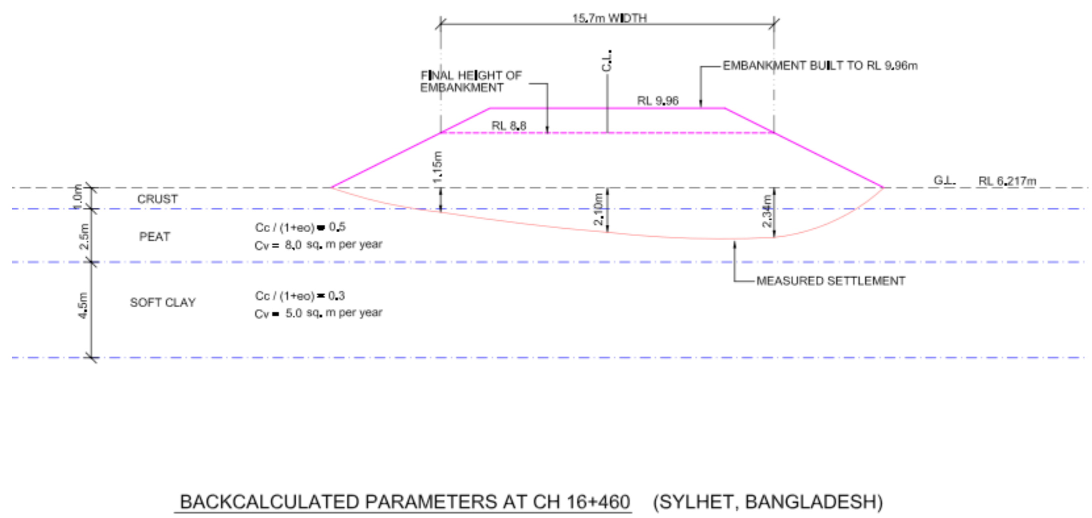


Figure 6 – 39. Embankment configuration with measured settlement and parameters from back analysis. (Toh & Chee, 2000b)

The measured and back calculated settlement – time plots are given in Figure 6.40. Plots of measured and calculated pore pressures are shown in Figure 6 - 41. Back- calculations were carried out using the finite difference algorithm CONSOL.

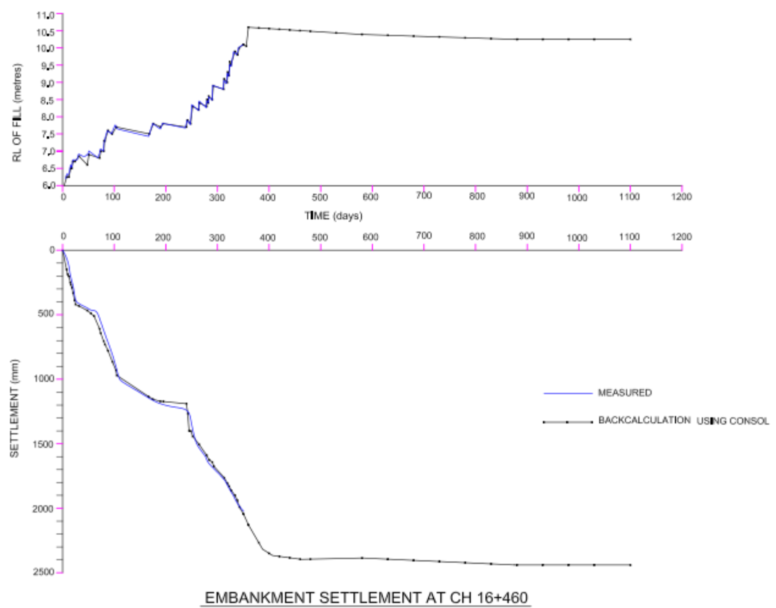


Figure 6 – 40. Measured and back-calculated embankment settlement for Sylhet road, Bangladesh from (Toh & Chee, 2000b)

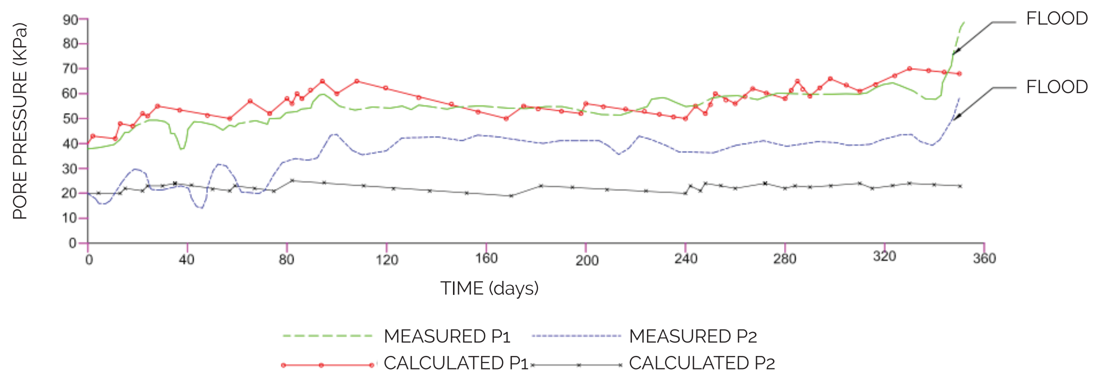


Figure 6 – 41. Measured and back-calculated pore pressures for Sylhet road, Bangladesh. (Toh & Chee, 2000b)

Bangladesh from (Toh & Chee, 2000b)The use of the parameters given in Table 6.5 gave a near perfect match with the observed settlements and a reasonable match with the pore pressures. The Cc/(1+e0) value of 0.5 for peat is the same as that derived from the basic peat properties corresponding to a natural moisture content of about 500 to 600%.

Table 6 – 5. Parameter

Soil description	Cc/(1+eo)	Cv (sq m per year)
Peat	0.5	8.0
Soft clay	0.3	5.0

6.8 EXCAVATION OF PEAT AND REPLACEMENT WITH SAND OR SUITABLE SOIL

6.8.1 Methods

There are two methods that have been adopted in different places:

i. Excavation with dewatering so that filling can be carried out using residual soils placed and compacted in layers;
ii. Excavation without dewatering and replacement with hydraulically deposited sand.

The advantages and disadvantages of the two methods are:

i. Excavation with dewatering permits the use of soil fill. Complete removal of fill is assured. Dewatering dries the peat and stabilizes the side slopes. However lowering of the ground water is significant and can extend over large distances causing significant settlement of the surrounding ground. Hence this method cannot be used near built up areas. In the stretch of the North South highway between Machap and Simpang Renggam in Johor, removal of peat was extended to 13m depth. Excavated peat can be hauled to designated disposal area.
ii. In the case of excavation without dewatering, there is lesser assurance that all the peat will be removed. The depth of peat that can be removed is limited by the reach of a long arm excavator or drag-line. There is no drawdown since the excavation will be full of water. Disposal of excavated saturated peat is usually by spreading on the ground next to the excavation. Sand will have to be used as fill. Sand fill is generally more expensive than soil fill unless near to rivers and the sea where there are no nearby hills.

6.8.2 Excavation and replacement for north south highway between Machap and Simpang Renggam, Johor

Excavation of peat with dewatering was carried out over a sum distance of about 30 kilometres for the construction of the North South expressway between Machap and Simpang Renggam in Johor. The average depth of removal was generally about 7m but in localized areas extended to close to 13m. A trial was carried out before commencement of the main works and the results reported by Toh et al (1990). Figures 6 - 42 to 6 - 49 are obtained from that paper.

Figures 6 - 42 and 6 - 43 illustrate the sub surface conditions at the trial excavation area. The technique of dewatering and lowering the ground water in the peat ahead of the excavation front is shown in Figures 6 - 44. Initial dewatering in the area where excavation starts causes the groundwater to lower sufficiently for access by plant and equipment. Subsequent dewatering of the excavation leads to lowering of the groundwater levels all round resulting in improved working conditions and accessibility all around the excavation; this makes the excavation of unsaturated peat easy to carry out.

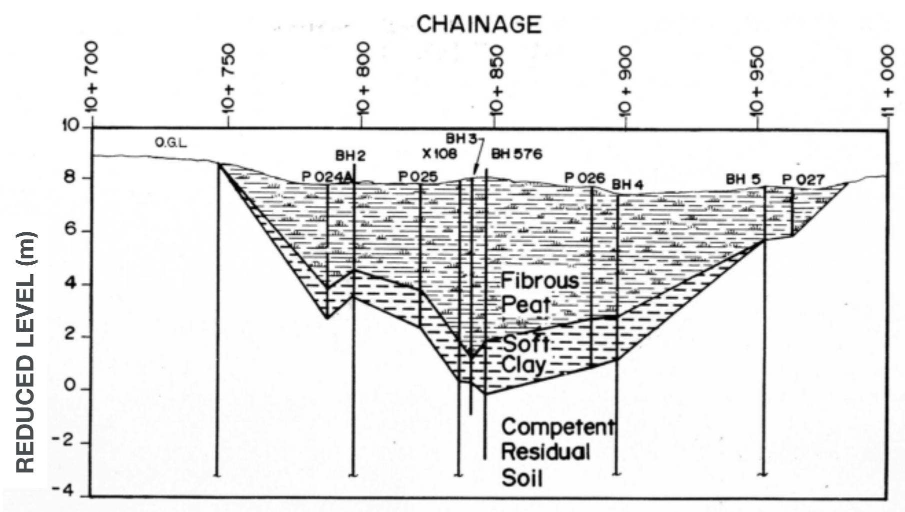


Figure 6 – 42. Soil profile at trial excavation area, Machap, Johor. (Toh et al.,1990)

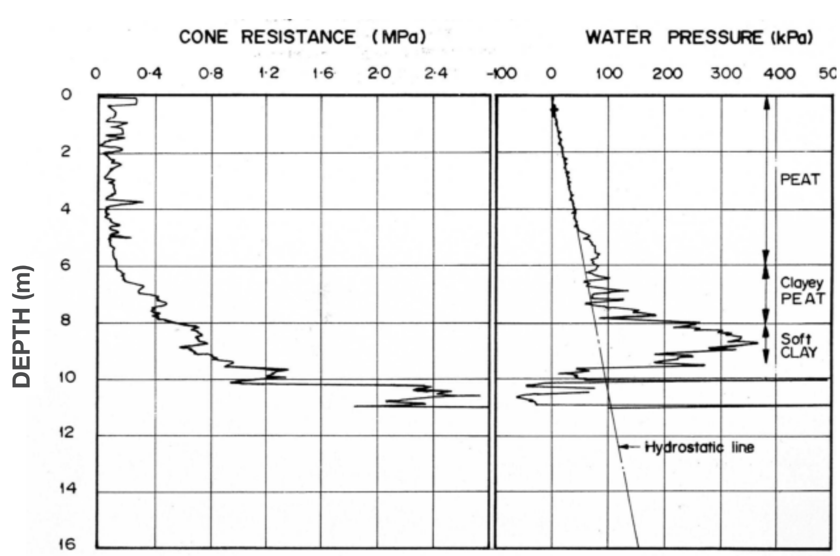


Figure 6 – 43. Piezocone profile at trial excavation area, Machap, Johor. (Toh et al., 1990)

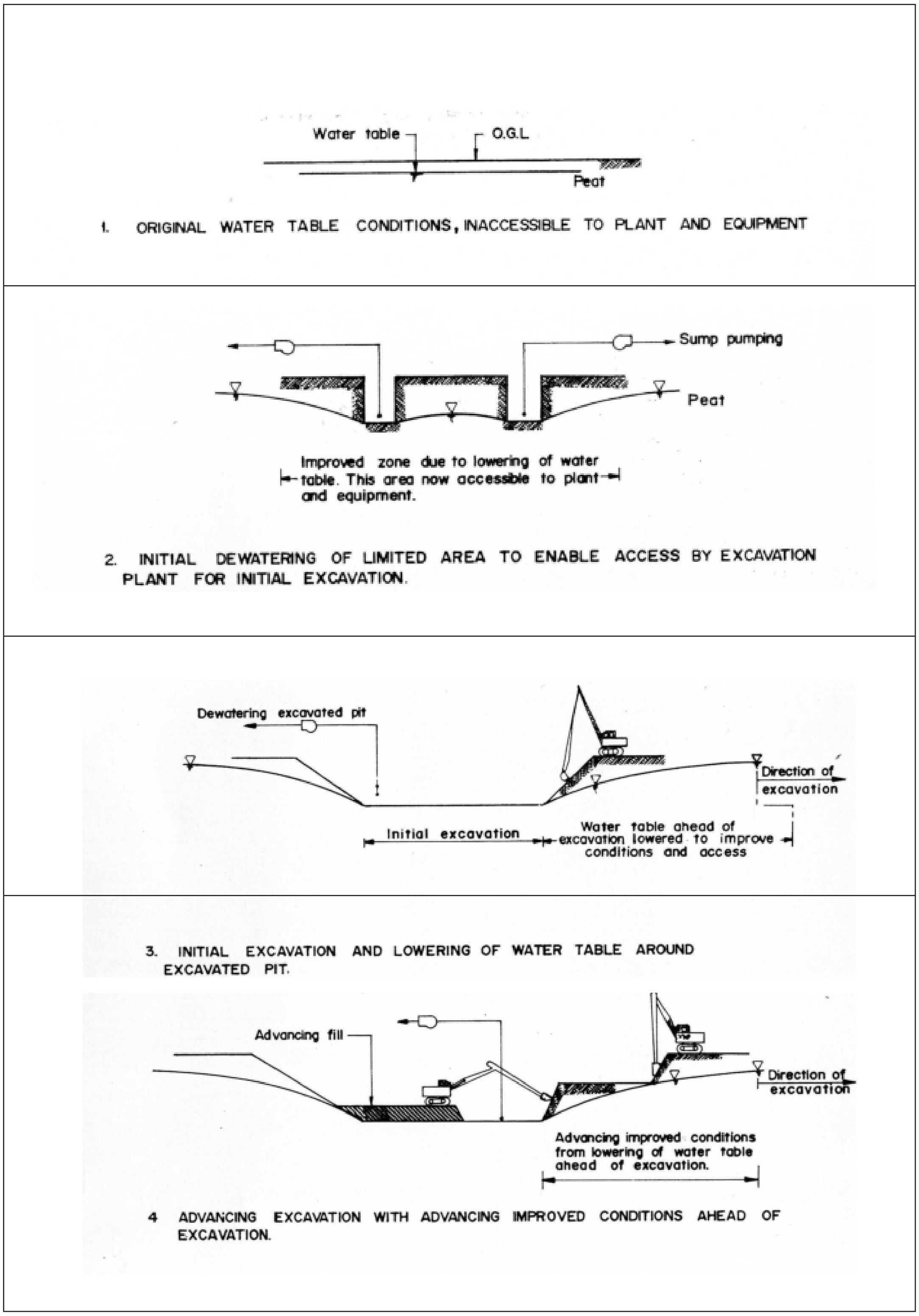


Figure 6 – 44. Ground water lowering facilitates peat excavation. (Toh at al.,1990)

Figure 6 - 45 illustrates the groundwater drawdown with distance from the excavation. Draw-down extends to more than 90m from the excavation.

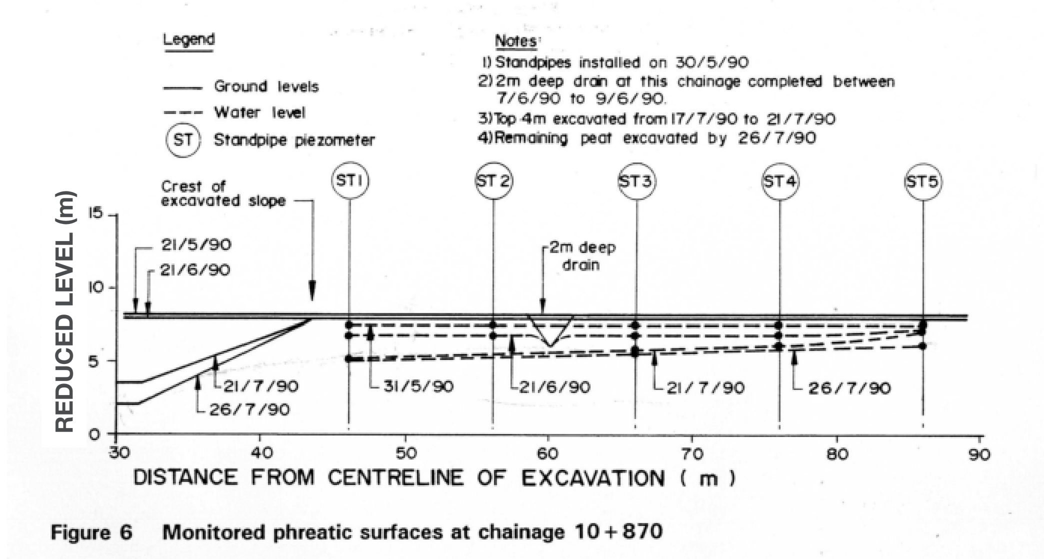


Figure 6 – 45. Drawdown of ground water during excavation with dewatering at Machap, Johor (Toh et al., 1990)

Figures 6 - 46 to 6 - 49 illustrate dry peat conditions from lowering of the ground water and the ease in which dry peat is excavated and backfilling in the dry carried out.

Figure 6 – 46. Excavation of peat and lowering of ground water at Machap, Johor. (Toh et al,.1990)

Figure 6 – 47. Excavation of peat with dewatering and backfill with residual soil in dry at Machap, Johor with compaction from (Toh et al,.1990)

Figure 6 – 48. Excavation of dry peat at Machap, Johor. (Toh et al,.1990)

Figure 6 – 49. Excavation in dry and backfilling at Machap, Johor. (Toh et al,.1990)

6.8.3 Excavation of peat without dewatering for the Sungei Bidut Road, Sibu, Sarawak

Figures 6 - 50 to 6 - 59 are extracted from Ong et al (2009) and Sarawak Construction Sdn Bhd & Jurutera Jasa (2007). The length of the road is approximately 13 km. Figure 6 - 50 illustrates the design embankment configurations. The design called for peat to be excavated without dewatering and replaced with hydraulically deposited sand. The embankment is to be formed using sand with clay and residual soil bunds at the sides to confine the sand.

The depth of peat extends to mostly about 8m with soft clay beneath extending to a depth of 30m. As shown in Figure 6 - 51, the natural moisture content of the peat ranges from 600% to 1200%. The depth of excavation is limited by the reach of a long arm excavator viz. about 8m. After completion of sand filling, prefabricated vertical drains are installed through the sand fill and soft clay to accelerate consolidation.

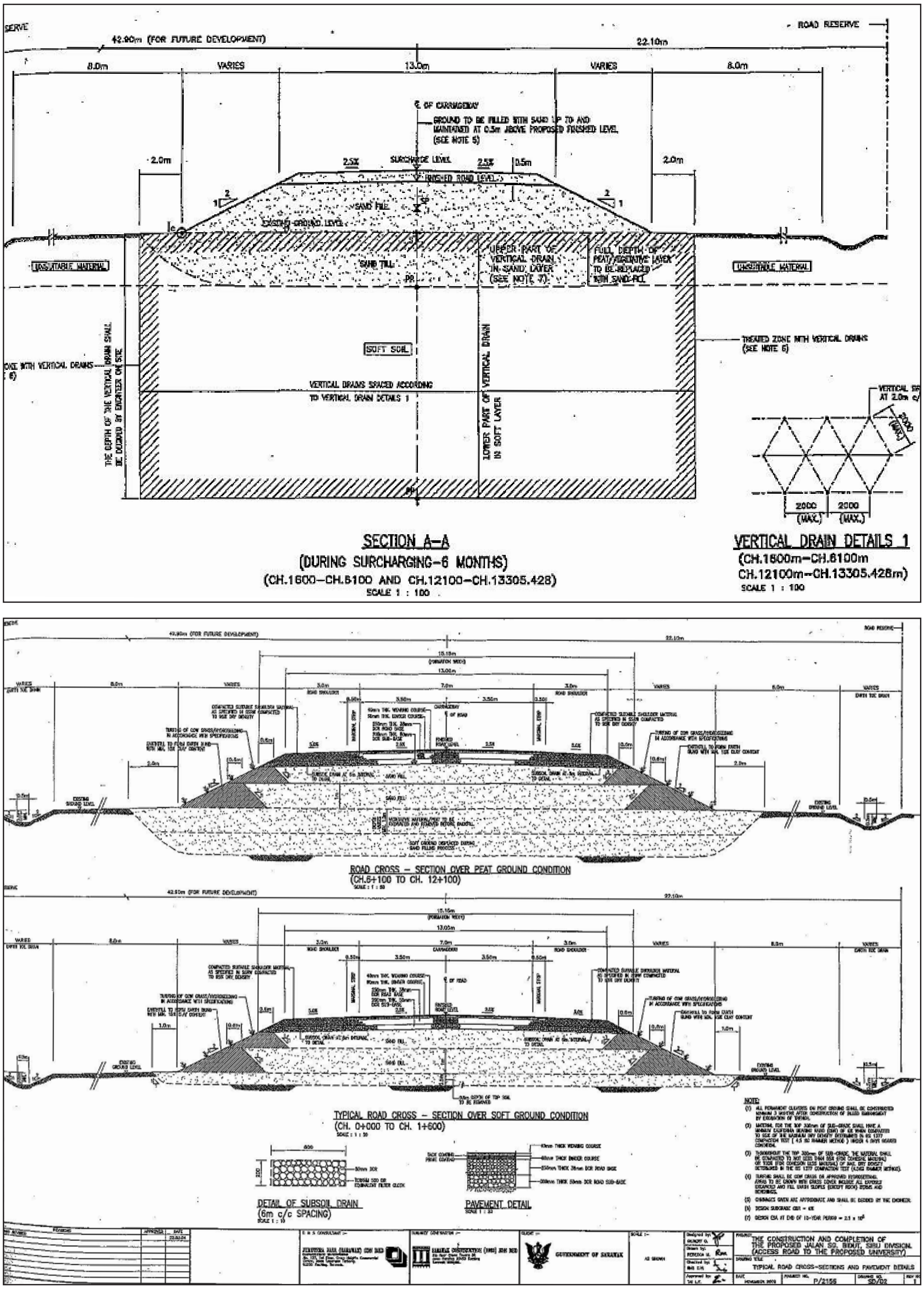
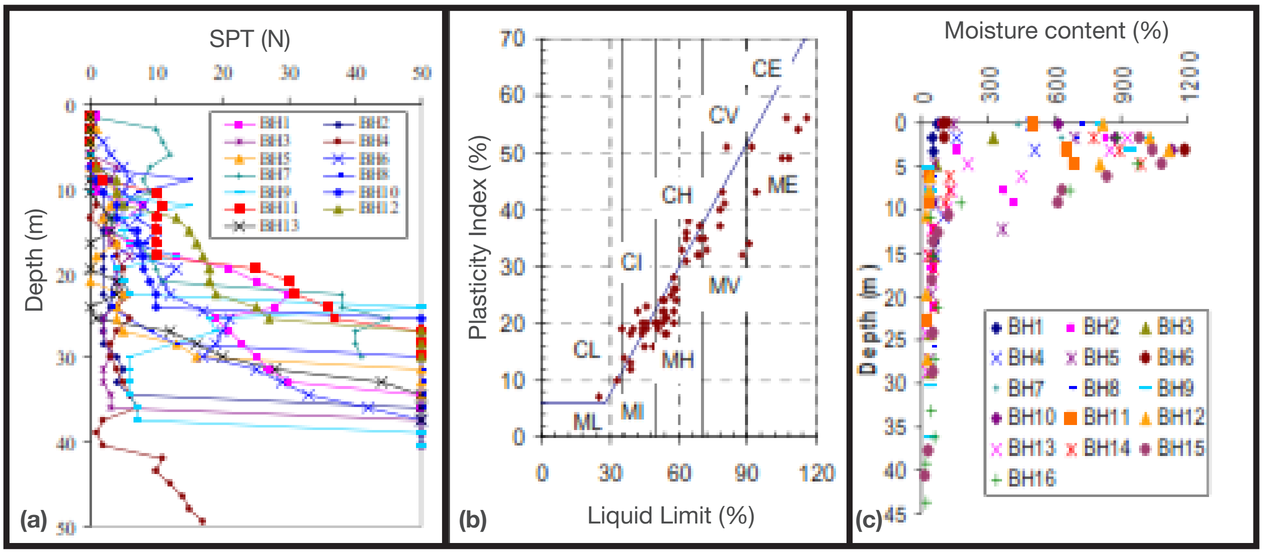


Figure 6 – 50. Details of embankment with peat excavation for Sungei Bidut road, Sarawak. (Sarawak Construction & Jurutera Jasa, 2007)



a) (left) Distribution of SPT N value with depth, b) (middle) plasticity chart for soft soil samples tested and c) (right) distribution of sample moisture content with depth.

Figure 6 – 51. Subsurface conditions for Sungei Bidut Road from (Ong et al,.2009)

Figure 6 - 52 shows the original conditions of the peat swamp. Figures 6 - 53 and 6 - 54 illustrate the excavation of the peat.

Figure 6 – 52. Peat swamp at Sungei Bidut road, Sarawak. (Sarawak Construction & Jurutera Jasa, 2007)

Figure 6 – 53. Peat excavation without dewatering for Sungei Bidut road, Sarawak.(Sarawak Construction & Jurutera Jasa, 2007)

Figure 6 – 54. Peat excavation without dewatering for Sungei Bidut road, Sarawak. (Sarawak Construction & Jurutera Jasa, 2007)

Figures 6 - 55, 6 - 56 and 6 - 57 illustrate the hydraulic filling. Figure 6 - 58 illustrates the forming of the side bunds using excavated peat to form the clay bunds to confine the embankment sand fill. The peat will decompose over time and residual soils were placed over the peat to contain the sand fill.

Figure 6 – 55. Pumping sand after excavation of peat for Sungei Bidut road, Sarawak.. Sarawak Construction & Jurutera Jasa, 2007)

Figure 6 – 56. Pumping sand after excavation of peat for Sungei Bidut road, Sarawak. (Sarawak Construction & Jurutera Jasa, 2007)

Figure 6 – 57. Pumping sand after excavation of peat for Sungei Bidut road, Sarawak. (Sarawak Construction & Jurutera Jasa, 2007)

Figure 6 – 58. Excavated peat to form bunds to contain sand fill in embankment for Sungei Bidut road, Sarawak (Sarawak Construction & Jurutera Jasa, 2007)

Figure 6 - 59 illustrates the measured settlements due to consolidation of soft clays accelerated by prefabricated vertical drains. Settlements of 1.2m were recorded over a period of about 500 days.

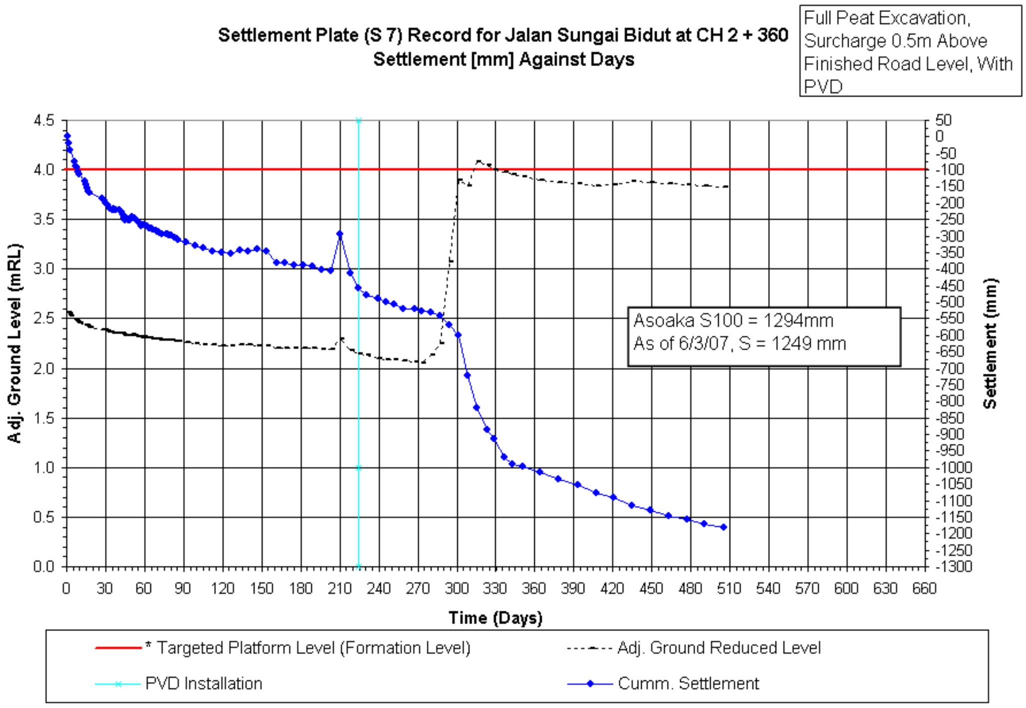


Figure 6 – 59. Measured settlement at Sungei Bidut road. (Ong et al,. 2009)

6.8.4 Excavation of peat without dewatering for Jalan Nang Sang / Teku Link Road, Sibu, Sarawak

Figures 6 - 60 to 6 - 65 are from from JKR Sarawak and Hock Peng Furniture General Contractor (2006). The depth of peat ranges generally from 4m to 8m. The natural moisture content is in the range of 1000 to 2200 %. Excavation of peat was carried out without dewatering and replaced with hydraulically deposited sand. Figure 6 - 60 shows the presence of buildings relatively near to the excavation. Figures 6 - 61 to 6 - 65 illustrate the excavation, backfilling with sand placed in water and the forming of bunds using the excavated peat to confine the embankment sand fill.

Figure 6 – 60. Jalan Nang Sang / Teku Link Road Sibu Sarawak close to existing houses. (JKR Sarawak and Hock Peng Furniture General Contractor) (2006)

Figure 6 – 61. Excavation of peat without dewatering and backfilling with sand Jalan Nang Sang / Teku Link Road Sibu Sarawak. (JKR Sarawak and Hock Peng Furniture General Contractor (2006).

Figure 6 – 62. Excavation of peat without dewatering and use of peat as bunds for containing sand fill. Jalan Nang Sang / Teku Link Road Sibu Sarawak. (JKR Sarawak and Hock Peng Furniture General Contractor, 2006)

Figure 6 – 63. Sand fill contained by bunds formed using excavated peat. Jalan Nang Sang / Teku Link Road Sibu Sarawak. (JKR Sarawak and Hock Peng Furniture General Contractor, 2006)

Figure 6 – 64. Sand fill embankment contained by peat bunds formed from excavation. Jalan Nang Sang / Teku Link Road Sibu Sarawak. (JKR Sarawak and Hock Peng Furniture General Contractor, 2006)

Figure 6 – 65. Completed sand embankment. Jalan Nang Sang / Teku Link Road Sibu Sarawak close to existing houses. (JKR Sarawak and Hock Peng Furniture General Contractor, 2006) General Contractor, 2006)

6.9 PILE EMBANKMENTS

Pile embankments will be required when high embankments are constructed over deep peat. Construction of a piled embankment requires firstly a stable fill platform that can support pile driving rigs, cranes and other construction equipment.

The platform will continue to settle over the duration of pile driving and casting of the reinforced concrete plie slab. Suspended formwork must be adopted to enable the reinforced concrete deck to be constructed without distress. The ground water in peat is usually acidic. Higher density concrete will be required to mitigate acid affecting the piles.

6.10 COMPARISON OF COSTS OF DIFFERENT METHODS

Cost estimates were made for 4 different types of treatment for a typical height of road embankment of 2.0m built over 4m peat over 16m of soft clay as is common in Sarawak.

The four different treatment types are:

i. Surcharge without prefabricated drains (see Figure 6.66 for CASE 1);
ii. Complete excavation of peat with dewatering and replacement with residual soil fill compacted in layers to 90% maximum dry density (See Figure 6.67 for CASE 2A);
iii. Complete excavation of peat without lowering the ground water and replacement with sand (see Figure 6.68 for CASE 2B);
iv. Surcharge with pre-fabricated vertical drains (see Figure 6.69 for CASE 3);
v. Pile embankment with a continuous concrete deck (see Figure 6.70 for CASE 4).

The cost estimates were carried out using 2019 contract rates for Sarawak and the cost per metre of road is given in Table 6 - 6.

Table 6 – 6. The cost estimates were carried out using 2019 contract rates for Sarawak and the cost per metre of road

Item	Description	Unit	Rate (RM)	Case 1		Case 2A		Case 2B		Case 3		Case 4	
				Qty	Amount (RM)	Qty	Amount (RM)	Qty	Amount (RM)	Qty	Amount (RM)	Qty	Amount (RM)
	Earthwork												
1.	Excavation	m^3	10.20	36	367.20	143	1,458.60	104	1,060.80	18	183.60	-	0.00
2.	Approved imported suitable fill material	m^3	20.40	96	1,958.40	177	3,610.80	73	1,489.20	93	1,897.20	53	1,081.20
3.	Approved imported sandfill material	m^3	35.00	-	0.00	-	0.00	104	3,640.00	-	0.00	-	0.00
	Drainage Works												
4.	500mm thick drainage layer wrapped with geotextile	m^2	110.00	18	1,980.00	36	3,960.00	-	0.00	14	1,540.00	-	0.00
5.	100mm diameter perforated UPVC pipe wrapped in geotextile	m	22.00	2	44.00	-	0.00	-	0.00	2	44.00	-	0.00
6.	Prefabricated vertical drain, 21m/no	No	126.00	-	0.00	-	0.00	-	0.00	10	1,260.00	-	0.00
	Piled Embankment												
7.	200 x 200 mm RC pile, 18m/no	No	1,480.00	-	0.00	-	0.00	-	0.00	-	0.00	5	7,400.00
8.	250mm thick embankment slab	m^2	240.00	-	0.00	-	0.00	-	0.00	-	0.00	16	3,840.00
	Cost per metre run (RM):				**4,349.60**		**9,029.40**		**6,190.00**		**4,924.80**		**12,321.20**

Treatment by surcharging is the most economical method of peat treatment. Pile embankment is the most costly at about three times the cost of treatment by surcharge.

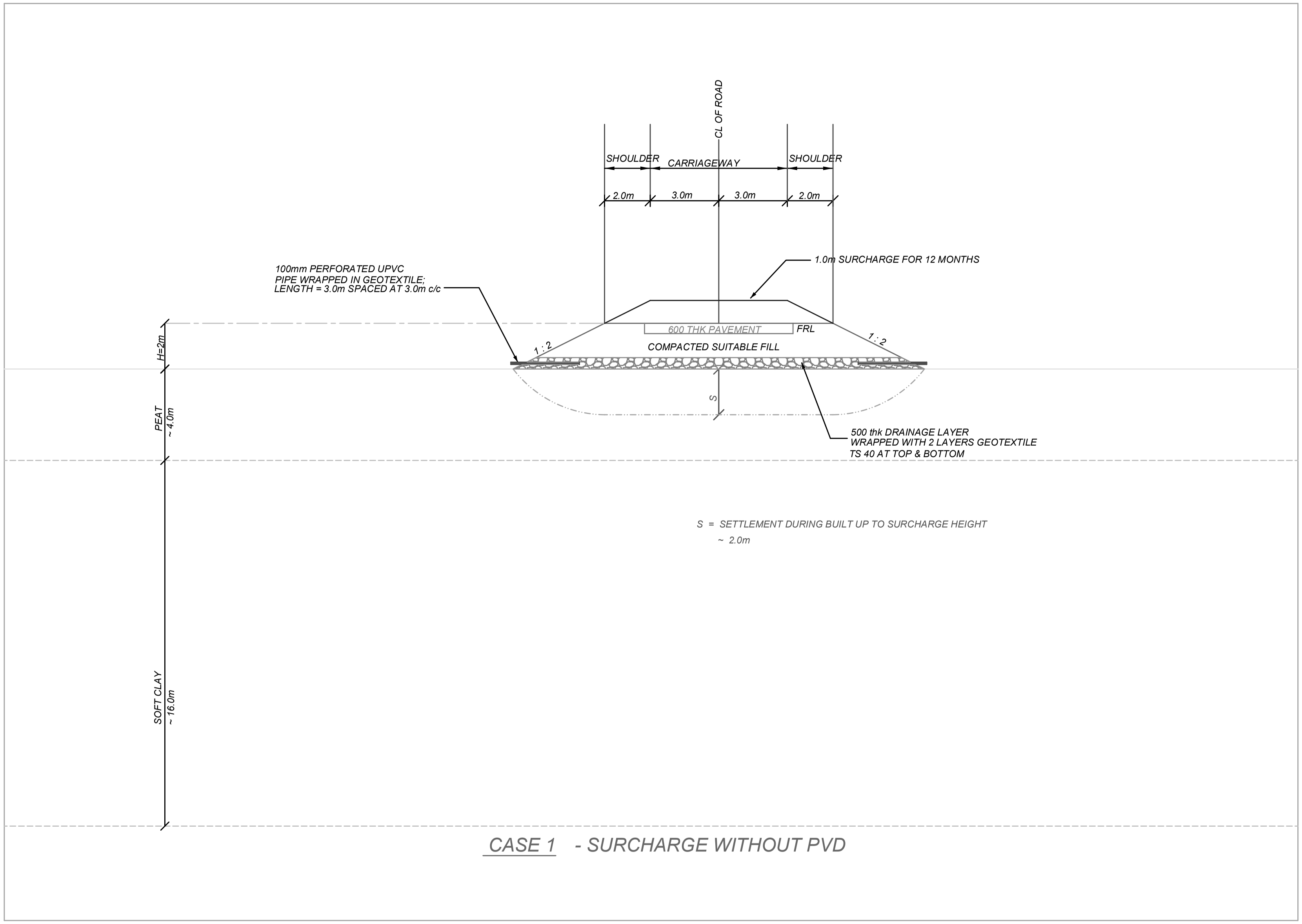


Figure 6 – 66. Surcharge without prefabricated drains

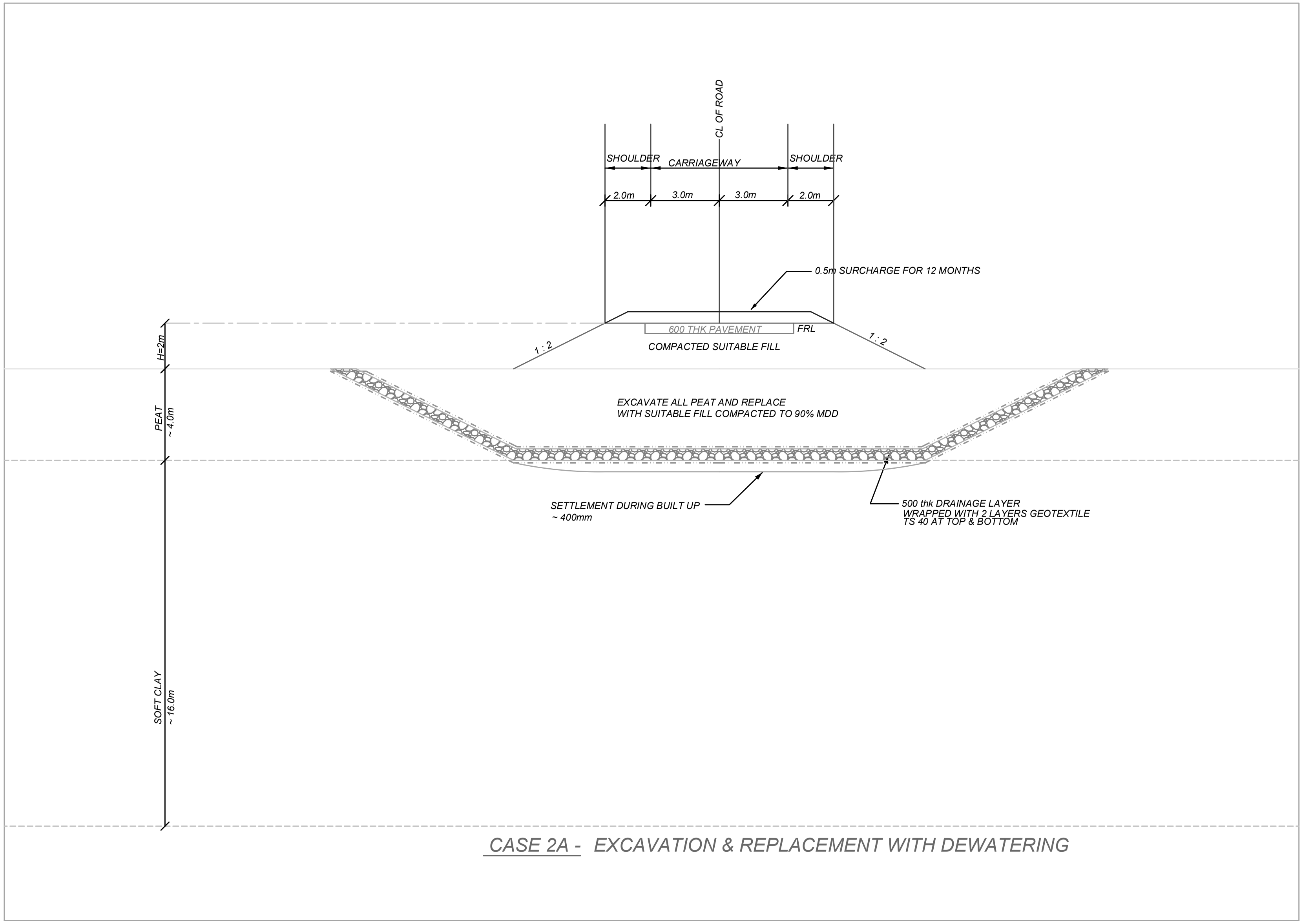


Figure 6 – 67. Complete excavation of peat with dewatering and replacement with residual soil fill compacted in layers to 90% maximum dry density

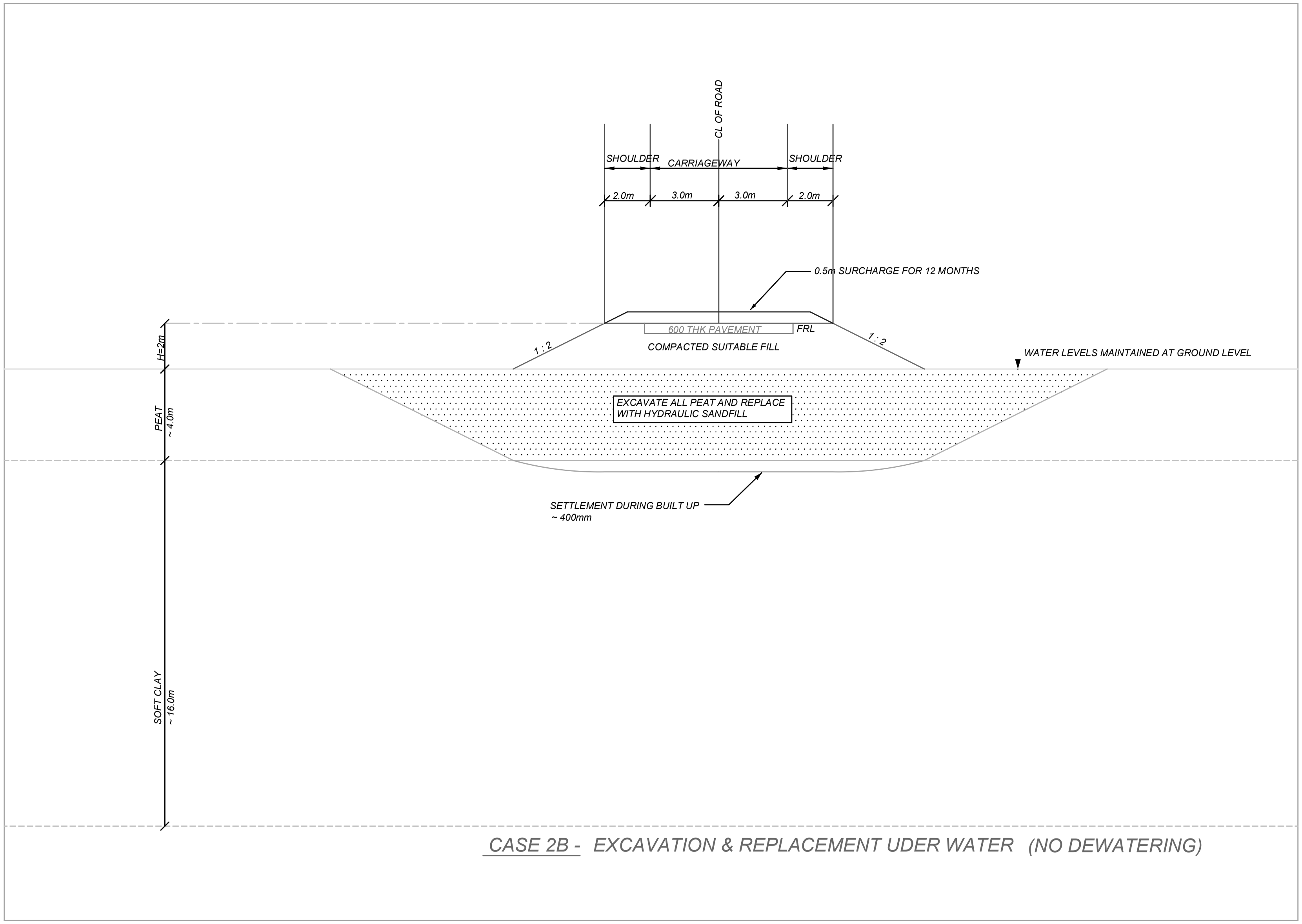


Figure 6 – 68. Complete excavation of peat without lowering the ground water and replacement with sand

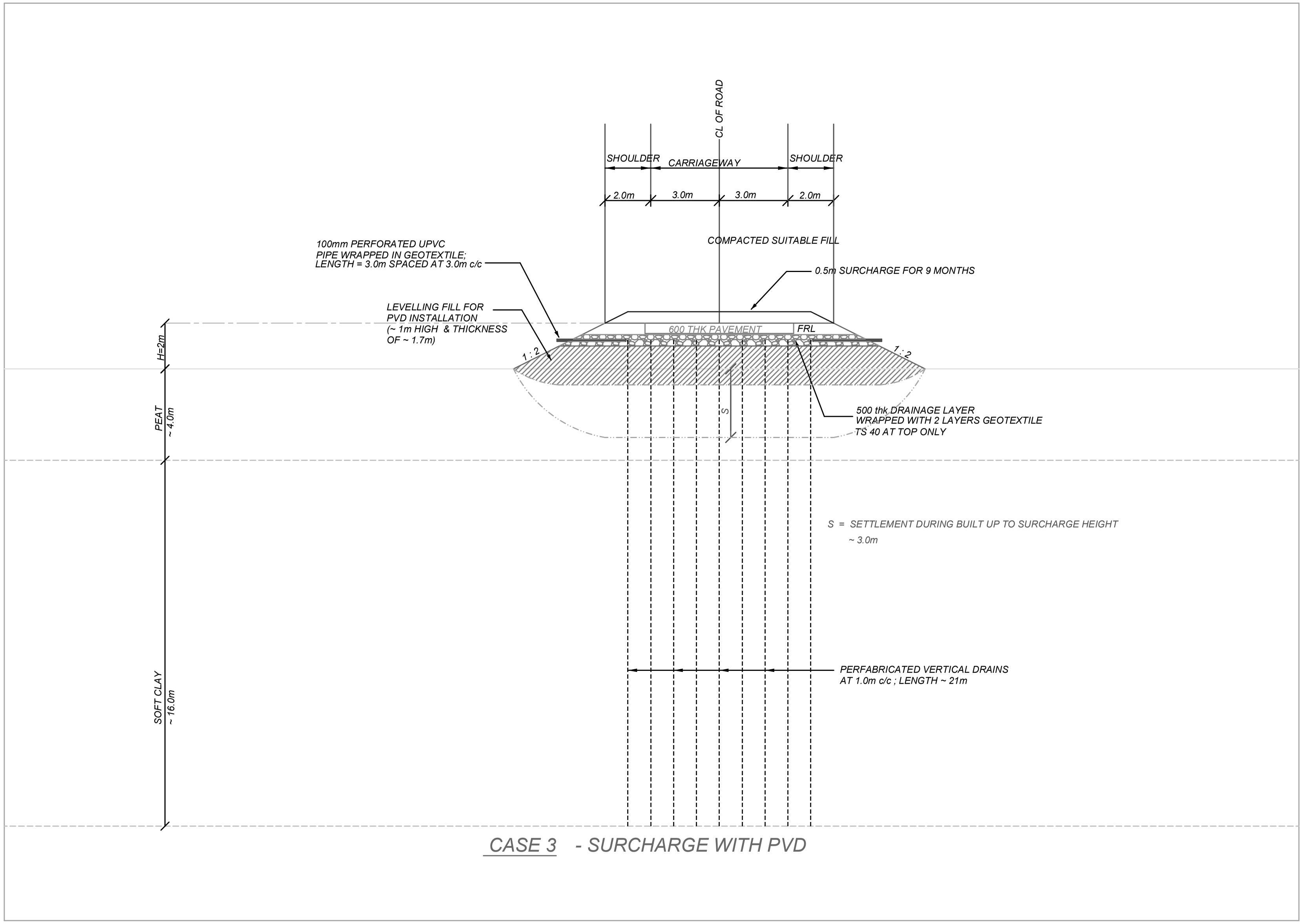


Figure 6 – 69. Surcharge with pre-fabricated vertical drains

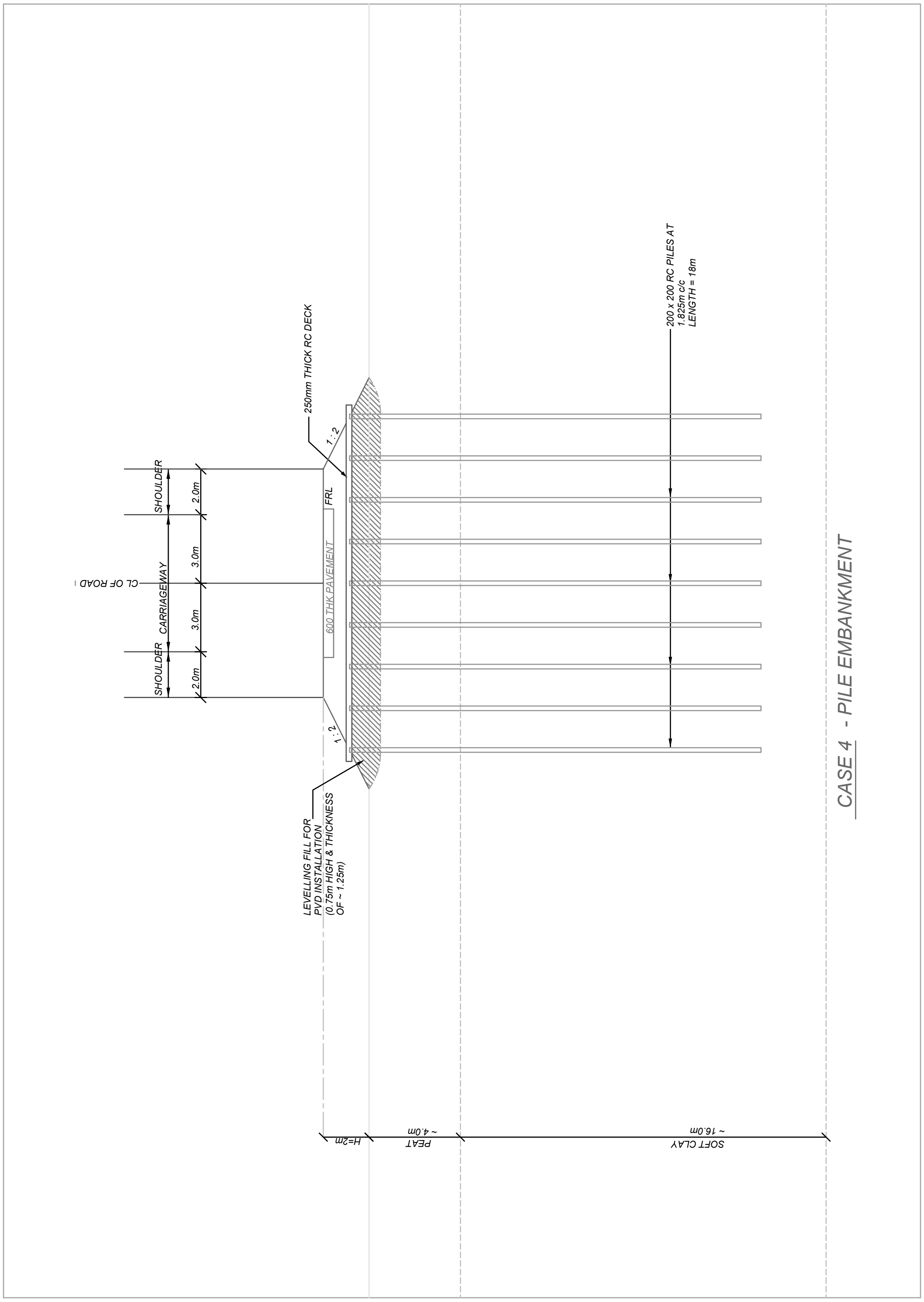


Figure 6 – 70. Pile embankment with a continuous concrete deck

End tipping of fill and the displacement method is not recommended. Before start of earthworks the site should be drained to dry the top 1.0m of the peat. This enables fill to be placed in a controlled manner in layers. Embankment construction should be at slow rates not faster than 300 mm per week. Stage construction should also be considered if high embankments are to be constructed. In areas where drainage is not possible, geotextile bamboo fascine mattresses can be adopted to enable layered fill placement.

Several case histories on embankment construction were presented. Back calculation showed that settlement analysis using compressibility parameters obtained from correlations with basic peat properties gave results that matched reasonably well with measured settlements and pore pressures. Unfortunately long term settlement records are not available.

Case histories were also presented to illustrate peat excavation with dewatering and without dewatering. Excavation with dewatering enables excavations to greater depths but results in drawdown over larger distances and therefore cannot be adopted for urban areas. Residual soils can be used as backfill. Excavation without dewatering does not cause as much disturbance to the surroundings since there is no drawdown. The depth is limited by the reach of the excavator which is about 8m. Sand must be used as backfill.

Soft clays are often found beneath the peat. The soft clay can have an effect on stability and long term settlement and will have to be taken into consideration.

The first consideration when constructing roads on peat is to build slowly and allow ample time for preloading. It is however likely that construction of high embankments (higher than 3m) over deeper peat (more than 6m) will require a very long construction period. Under such circumstances excavation and replacement (either with or without dewatering depending on the surrounding land use and availability of sand) with pre-loading should be considered. The process of excavation and replacement followed by pre-loading also requires a lengthy construction period.

If time is not available then piled embankments or bridge structures will have to be adopted but this will be at about three times the cost.

Summary

This 2nd edition of the Guidelines contains much improvements and enhancements to the 1st Edition that was published 5 years ago. The improvement include:

i. Comprehensive compilation of maps of peat areas throughout Malaysia. This is in large part due to the contribution of Department of Mineral and Geoscience Malaysia (JMG);
ii. The chapter on soil investigations in peat has been improved appreciably to concentrate on peat;
iii. Increased amount of laboratory test data correlating design parameters to basic peat properties and also strength parameter. These tests were carried out notably at Universiti Putra Malaysia, Universiti Teknologi Malaysia, Universiti Tun Hussein Onn Malaysia, Universiti Malaysia Sarawak, Universiti Malaysia Pahang and Universiti Malaysia Sabah.
iv. Records of the effects of agriculture induced groundwater lowering causing oxidation of exposed peat and resulting damage to existing roads constructed with ground improvement and which had performed satisfactorily;
v. Estimates of the costs of different methods of treatment for construction of a two lane road are included.
vi. The case histories in the 1st edition and in this 2nd edition remains the same. The methods of construction described were developed from Malaysian experience over the last 35 years. Construction on peat since the 1st Edition had largely adopted the techniques described therein.

There few shortcomings given in the 1st Edition largely remains:

i. Although there is an increased amount of data on the properties of tropical peat, much more data is required. Though lesser so than the first edition, correlations of basic properties and parameters still have to rely on published data that is largely from the Western world. Locally based research institutes are encouraged to continue carrying out the large number of high quality but mundane tests.
ii. Absence of long term monitoring of settlement. Government agencies or research institutes must take on this task if significant improvements to our ability at engineering to be realized. There has been no improvement on this over the last 5 years.

This 2nd Edition of the Guidelines constitutes an important improvement to the 1st Edition. All guidelines should be updated every few years to capture latest developments. Only by so doing can a document of this nature remain relevant.

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