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# An overview of the basic engineering properties of Malaysian peats

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A R T I C L E I N F O

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A B S T R A C T

This review addresses key factors influencing the basic engineering properties of Malaysian peats. The fibrous structure and high organic content (OC) of peats are likely to result in large amounts of compression and settlement. High Malaysian rainfall provides water to these fibrous structures, resulting in high natural/field water-contents ranging 500–2000% by dry mass, based on the literature. From an engineering perspective, peats are a unique soil type the behavior of which is influenced mainly by regional geology and environment. Records of peats from various locations across the country showed OCs ranging 0–100%, specifically, 0–90% and 70–100% in eastern and western Malaysia, respectively. This review highlights OC as one of the prime factors influencing the basic engineering properties of Malaysian peats.

## 1. Introduction

Peats are often viewed as problematic soils, mainly because of their inferior engineering properties in comparison to other soft soils. Generally being organic-rich, fibrous, pale-brown to black material (Mesri and Ajlouni, 2007), peats are widely identified due to their agricultural importance primarily owing to their fertile organic deposits, plant residues, and hydrophytic vegetation (Keddy, 2010). Nonetheless, the engineering stability and sustainability of peat soils where they support infrastructure, including transportation facilities for goods and people, water systems, and electric and other power facilities, cannot be neglected. Instability of infrastructure such as local sinking, slip failures, and massive primary and long-term settlements are examples of major catastrophes that can occur. Although planning major construction projects in peat deposits is commonly avoided, construction of essential and basic facilities such as transportation and milling facilities in peat may be unavoidable, which creates a need for a thorough understanding of its engineering behavior. Moreover, depending on the formation of a soil and on the local geology and other factors, the behaviors of soils are most likely to vary from location to location. Peatlands are distributed in patches throughout the world, with deposits spanning approximately 2.4 million hectares in Malaysia, including 1.65 million hectares in Sarawak and smaller areas in Peninsular Malaysia and Sabah (Zainorabidin and Wijeyesekera, 2007). Carbon dating indicates that Malaysian peat was deposited starting approximately 11,000 years ago (Zainorabidin and Wijeyesekera, 2007).

A report by the United Nations Environmental Program (FAO, 2012) regarding the exploitation of peatlands describes their use for construction and agricultural purposes, which has resulted in a gradual decrease in the volume of peat deposits. However, current demands catering to rapid development, particularly in developing countries such as Malaysia, call for sustainable infrastructure and resource management. A sustainable approach is needed because peats not only serve as bearing soils for infrastructure but more importantly play a key role in storing atmospheric carbon. For example, prior to the most recent de-glaciation period, 400–500 Pg of atmospheric carbon was sequestered in peat deposits (Belyea and Clymo, 2001). Release of the sequestered carbon would significantly affect the environmental and the ecologic-geologic balance. Therefore, the exploitation or use of peats requires thorough knowledge of the material in its natural state, i.e., its field condition. The purpose of this paper, therefore, is to address these points by tabulating and comparing the basic geotechnical properties of Malaysian peat deposits based on laboratory and field data obtained from the literature. The discussion mostly elaborates on various factors influencing these properties and their interdependency.

## 2. Formation and development

The behavior of a soil deposit generally depends on various conditions present during its formation and development. Jenny (1994) asserted that *"the estimation of relative age or degree of maturity of soils is universally based on horizon differentiation"*. Fig. 1 shows the process of peat formation by way of a flow chart based on details and other

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*Abbreviations:* $C_c$, compression index; $\rho_b$, bulk density; $\rho_d$, dry density; $w_L$, liquid limit; $w_n$, natural water content; $w_P$, plastic limit; $e$, void ratio; $OC$, organic content; $G_S$, specific gravity

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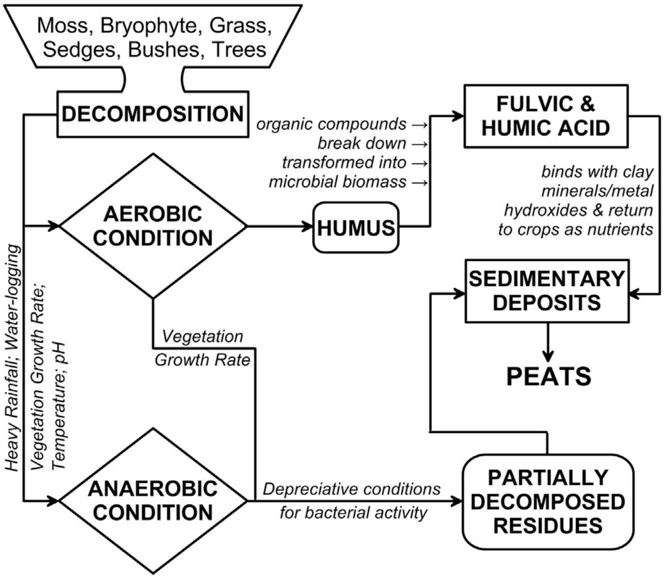

**Fig. 1.** Schematics briefing various processes involved in the formation of peats.

information presented in the literature. Peat forms when the rate of dead organic matter production exceeds the rate of decomposition of local plant constituents. Generally, conditions that inhibit the decomposition of organic matter are present mostly in waterlogged environments such as marshes, bogs and swamps (Silk et al., 1997). Regardless of whether the decomposition process is aerobic or anaerobic, numerous factors influence and contribute to the incomplete or partial decomposition of plant residues. Soil organic matter is decomposed via humification when it is exposed to sufficient concentrations of oxygen, which serves as a catalyst. Humification improves biological soil health by providing energy for soil micro-organisms and other soil organisms (Vreeken-Buijs et al., 1998). Eventually, these organic compounds break down to form simpler molecules that are transformed into microbial biomass and form *fulvic* and *humic* acids (Eyheraguibel et al., 2008). These acids bind with clay minerals and metal hydroxides, are used by crops, and form sedimentary deposits during aerobic (oxygenated) decomposition. The loss of humus from the topsoil promotes further mineralization and is associated with a qualitative decrease in soil fertility (Nebel and Wright, 1993), which perhaps decreases the soil's water-holding, infiltration and aeration capacities. Under these conditions, oxygen is deficient, and the organic components of the soil are only partially decomposed, resulting in favorable conditions for the formation of peats (Boron et al., 1987).

Under anaerobic conditions, peat is formed from layers of compressed plant materials due to the inadequate supply of oxygen. Soils with poor drainage, such as those with clay or silty clay textures, significantly influence the formation of peats, particularly under waterlogged conditions. This influence results from the restricted circulation of air and from the depletion of oxygen in the strata (Pearsall and Mortimer, 1939). Plants, for example mosses, bryophytes, grasses, sedges, bushes and trees, commonly grow well under acidic and waterlogged conditions and/or cool climates (Clymo, 1984). One major constituent of Malaysian peat is *Sphagnum* moss, which grows in clusters in damp or shady locations (Huat et al., 2014; Kazemian et al., 2011). The cell structures of *Sphagnum* mosses allow them to absorb and hold water (Moore, 1989). The main solid component in peat is organic matter, with minor contributions from inorganic materials. The organic fraction of peat commonly includes lignin (36–59%) and glucose and bitumen (30–70%); bitumen is a mixture of asphalt, resins and waxes whose fraction of peat increases with the degree of decomposition (Fuchsman, 2012). Most of these components are decomposed in the upper (*acrotelm*) and unsaturated layer of peat, and only 10–20% of the components reach the underlying saturated peat layer (*catotelm*) (Broder et al., 2012). This unbalanced zonation of the water table further impedes decomposition, thereby creating dome-shaped peatlands (Dommain et al., 2010). Evidence has indicated that Malaysian peats formed from 1 to 20 m of deposits, and approximately 90% of the peat soils extend to depths of $>$ 1 m (Huat, 2006; Mutalib et al., 1991).

Over time, continued formation processes result in new peat layers forming over the existing soil layer, which generally includes sediments/deposits such as clays, silts and sands or older peat layers. In extremely wet climates, peats may develop on gentle slopes and on soils that were not originally saturated (Barry, 1954; Granlund, 1932). Frequently, peat spreads outward from its favorable environment of deposition and across adjacent areas (Anderson et al., 2003; Fenton et al., 2005). The dynamic movement of the water table results from sudden wetting during rainfall events and gradual drying during the dry season. Malaysia, located near the Equator, receives high rainfall of 2000 to 4000 mm per year, which results in extremely soft and wet peat deposits (Aminur et al., 2009; Zainorabidin and Wijeyesekera, 2007). Nevertheless, the altitude frequently influences the water table depth in Malaysia and impacts the drying-wetting cycles of the peat (Azlan et al., 2013). Dry conditions are accompanied by higher evapotranspiration, which results in further drying of the peat deposits (Ise et al., 2008). The decomposition of peat in a humic layer increases when the layer is exposed to oxygen as the water table drops (Wösten et al., 2008). Consequently, the decomposition of peat is controlled by climate variations. The responses of plants to the natural moisture content, temperature, nutrient content, atmospheric $CO_2$ content, peat texture, and wetland litter quality influence the decomposition and accumulation of peat (Belyea and Malmer, 2004; Lucchese et al., 2010; Mack et al., 2004; Suzuki et al., 2007). Other studies indicated that the rate of decay is greatest in the zone of water table fluctuation, with average decay rates above the water table and minimum decay rates in the waterlogged zones (Belyea and Baird, 2006). Peatlands near the sea are generally exposed to sea spray, which influences vegetation in the form of a fertilizing effect (Kleinebecker et al., 2008; Zainorabidin and Wijeyesekera, 2007; Zainorabidin and Wijeyesekera, 2008). One possible explanation for this phenomenon is that the sulfate in the sea spray is used as an electron acceptor for anaerobic respiration and stimulates decomposition (Segers and Kengen, 1998). Therefore, the decomposition or humification of peat, which results in the loss of organic matter, ultimately changes the physical and chemical structure of the peat (Huat et al., 2009). As a special case, the formation of acidic peat on upland soils has also been reported in the literature (Webb, 1947).

## 3. Engineering properties of peat

Soils with high organic contents are generally highly compressible, with high rates of creep and, occasionally, unsatisfactory strength characteristics that increase the threat of unacceptable settlement and eventual failure as a foundation bearing material. As mentioned earlier, peat swamps in Malaysia are distributed in three regions of Malaysia: Sarawak, Peninsular Malaysia and Sabah (in decreasing order of size). Due to the limited literature describing the peats in Sabah, in this paper, the properties of these peats are assumed to be similar to those of the peat in Sarawak. Table 1 summarises the basic engineering properties of peats from various locations across the Malaysia. The organic content (OC) values of the peats range from 35 to 79%, with no apparent trend in these values from one location to the next (Zainorabidin and Wijeyesekera, 2007). The reasons for this lack of a trend, perhaps, is the influence of various factors such as historical agricultural activities, the water table depth, rainfall intensity, and other regional factors on the OC of peat deposits at a particular location. Fig. 2 presents a visual comparison of the variation in the OC across various locations in Malaysia. The OC contributes to free water movement and increases soil water retention, resulting in greater water contents in peat soils (Zainorabidin and Wijeyesekera, 2008). The shaded region in Fig. 2