Foundation and Embankment Construction in Peat: An Overview

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ABSTRACT

This paper has discussed on the various methods of foundation and embankment construction over peat under two major construction aspects; peat removal and peat left in place. Peat removal means doing away with the peat soil prior to the construction and the methods under this aspect have been categorized as avoidance, peat excavation, peat replacement and peat displacement. On the other hand, peat left in place entails all the constructions that are undertaken directly on peat deposit in order to avoid bulk earthworks and the methods under this aspect have been categorized into methods of accelerating consolidation, ground improvement techniques to reduce deformation, load modification, stabilization and piling methods. All the techniques under these methods have been explained fully. Finally, the paper presented a potential research area of using air pressure and lightweight materials for foundation construction over peat.

KEYWORDS: Peat, floating foundation, embankment, construction.

INTRODUCTION

Peat is a type of soil formed from the accumulation of the remains of vegetation partially decomposed due to inadequate supply of oxygen from within and is characterized with high organic content, high water content, large void ratio, high compressibility and low bearing capacity. This behavior makes it almost inaccessible most often, especially when alternative land is available. In a situation whereby it covers a large area, it poses a greater challenge to the engineers on how it can be put into proper use.
Duraisamy, Huat and Aziz (2007); and Huat, Prasad, Asadi and Kazemian (2014), described peat as a naturally occurring highly organic substance derived primarily from plant material which is formed when organic matter (usually plant) accumulates more quickly than it humidifies (decays). This phenomenon usually occurs when organic matter is preserved below high water table like in swamps or wetlands (Huat et al., 2014). Peat represents an accumulation of disintegrated plant remains which have been preserved under conditions of incomplete aeration and high water content and can give rise to geotechnical problems in the area of sampling, settlement, stability, in situ testing, stabilization and construction (Huat et al., 2014). For a successful design, construction and good performance of structures on such soil, it is paramount to predict its geotechnical behavior in terms of settlement, shear strength and stability, with respect to time (Huat et al., 2014). Engineering constructions on this type of soil has now become inevitable due to land scarcity caused by population growth and land use policies. Different types of construction techniques have been carried out to support embankments over peat deposits without risking bearing failures but settlement of these embankments remains excessively large and continues for many years (Huat et al., 2014).

Design and building of foundation system over peat and organic soils pose a greater challenge to the geotechnical engineers. This might not be unconnected with the challenging characteristic properties of the material which sometimes require some soil improvement prior to the construction. Several soil improvement techniques have been presented by different researchers (Andersson, Johansson & Axelsson, 2002; Black, Sivakumar, Madhav & Hamill, 2007; Deboucha, Hashim & Alwi, 2008; Hashim & Islam, 2008; Kalantari & Huat, 2008; Kalantari & Huat, 2009; Kalantari, Prasad & Huat, 2010; Kazemian & Huat, 2009; Kazemian, Asadi, Huat, Prasad & Rahim, 2009; Murugesan & Rajagopal, 2009; Tastan, Edil, Benson & Aydilek, 2011). Constructions such as road embankments, railway tracks, building structures, etc; have been taking place on peat, and with the application of the soil improvement techniques have been successful (Winter, Johnson & Reid, 2005; Carchedi, Monaghan & Parra, 2006; Wissmann, Fox & Martin, 2000; Fox & Edil, 2001; Allgood, Weppler, Lien & Fox, 2003). In any foundation construction, it is indispensable to consider the bearing capacity and settlement of the underlying soil. Peat is very poor in these respects and therefore, method of construction on peat has to overcome these problems in order to become effective.

There are two major construction aspects including peat removal and peat left in place; peat removal means doing away with the peat soil prior to the construction and the methods under this aspect have been categorized as avoidance, peat excavation, peat replacement and peat displacement. Peat left in place entails all the constructions that are undertaken directly on peat deposit in order to avoid bulk earthworks and the methods under this aspect have been categorized into methods of accelerating consolidation, ground improvement techniques to reduce deformation, load modification, stabilization and piling methods.

This review paper aims to explain different methods of construction in peat. Furthermore, the paper presents a potential research area of using air pressure and lightweight materials for foundation construction over peat.

PEAT DEPOSITS, PROPERTIES AND CLASSIFICATION

Peat Deposits

Peat is found in all part of the world except in deserts and the arctic regions (Deboucha et al., 2008). The peat land area in North America is the largest accounting for 43.54% of the total
global peat land area, followed by Asia (28.08%) and Europe (24.02%), and the total global peat land area is estimated to be about \(4 \times 10^6\) km\(^2\) (Zigang & Xintu, n.d.). Canada has more peat land than any other country in the world and Vancouver, in the south-west corner of the Pacific coast main-land, is the major metropolitan centre where extensive peat deposits and booming modern construction come together (Nichol, 1998). Malaysia covers approximately 2.7 million hectares of peat lands and out of that about 1.66 million hectares (i.e. 61%) are located in the deltas and coastal plains of Sarawak. Peat soils of Sarawak occupy 13% of the total land area and most of the year; these areas are waterlogged (Mutalib, Lim, Wong & Koonvai 1991).

Peat deposits exist at different subsoil formation levels. While in some cases the material cover the entire area and within a significant depth, in other conditions it is found within some pocket(s) of soils with different properties entirely. Example is the subsoil condition under the most high rise building tower considered as the tallest building in Australia and the 25th tallest building in the world at Surfers Paradise of the Gold Coast city in Queensland Australia (Al-Ani, Oh, Eslami-Andargoli & Chai 2013). The subsoil condition of the area includes a very dense sand layer with some pockets of peat layer with thickness varying between 0.1 – 7 m, and below which lies an inter-bedded firm to very stiff clay layers about 26.6 m thick (Al-Ani et al., 2013).

Properties of peat

Organic content is an important parameter for peats. In Malaysia the organic content of peat is up to 98 % (Huat et al., 2014).

Water content (also commonly referred to as natural moisture content) is one of the important peat parameters which can be measured in the laboratory over dry weight of peat (BS 1377-2, 1990). There is a fear that standard drying of the peat at 105°C for 24h produces too large figure for water content due to loss of organic matter. In peat, the water is held in the organic matter and cells of the plants remains. Generally, water content decreases with an increase in mineral content. The fibrous peat also tends to have higher water content than humified peat. Natural water content of peat in Malaysia is up to 2207% (Huat et al., 2014).

The relationship between water content and soil consistency can be evaluated by means of Atterberg limits. For peats, the liquid limit depends on the type of plant detritus contained, the degree of decomposition, and clay portion of the peat which ranges between 200 to 1500%. Literature reports that the liquid limit of west Malaysian peat ranges from 190 to 360% (Huat et al., 2014).

The bulk densities of peats are in the range of 0.8-1.2 Mg/m\(^3\) compared with the bulk densities of mineral soils which are in the range of 1.8 to 2 Mg/m\(^3\) (Huat et al., 2014). This is because of the lower specific gravity and the higher water holding capacity in peat compared to the mineral soils.

Shear strength parameters always play an important role in engineering decisions when dealing with any soil including peat. The undrained shear strength of peat is low, with cohesion values in the range of 6 to 17 kPa and angle of internal friction in the range of 3 to 25°. The vane shear strength of peats is in the range of 3 to 17 kPa. The shear strength parameters are generally lower with an increase in degree of humification (Huat et al., 2014). The angle of friction also increases while the fiber content increases. In general, fibric peat has higher shear strength than hemic and sepric peat. The presence of fiber affects the strength behavior of peat.

Primary compression (also commonly known as consolidation) is the process of compression due to extrusion of water from soil voids as a result of increased loading. Peat with high water content, organic and fiber content, however, tends to show a rapid primary compression under the
applied stress. The compression index (C_c) values of tropical peat can be up to 10 compared with that of clay of only 0.2 to 0.8. The C_c of the peat increases as the liquid limit and the organic content increase. The void ratio (e_0) of peat reported even up to 25. Such high void ratios phenomenally increase the potential ability of the peat for water adsorption. The void ratio of fibric peat is higher than amorphous peat. The e_0 generally increases with an increase in liquid limit or natural water content (Huat et al., 2014).

**Classification of peat**

MacFarlane (1969) considered peat to fall into three basic groups. These are ‘amorphous-granular peat’, ‘coarse fibrous peat’ and ‘fine fibrous peat’. He further listed 17 sub-groups within these basic groups. The ‘amorphous-granular’ peat is that with high colloidal mineral components which tend to hold the contained water in an adsorbed state around the grain structure. The other two are woodier and hold most of their water within the peat mass as free water (MacFarlane, 1969).

Von Post and Granlund (as cited by Munro et al., 2007) classified peat into 10 categories (H1 to H10) according to their degree of humification. H1 being completely unconverted and mud-free peat which when pressed in the hand gives off clear water and plant remains can easily be identified, while H10 is completely decomposed or mud peat where no plant remains can be seen and the entire peat substance passes through the fingers when pressed.

The system of organic soil classification presented by Huang, Patel, Santagata, and Bobet (2009) is now among the latest. They reviewed the previous classifications and consider them in consistent because they are mostly based on “loss of ignition”, which may lead to improper and exaggerated conclusions on the class of soil especially if the organic content in the soil is little. They proposed a system of classification based on the percentage of organic matter present in the soil as; *mineral soils* (organic content <3%), *mineral soils with organics* (organic content >3% and < 15%), *organic soil* (organic content >15% but <30%) and *highly organic soils or peats* (organic content > 30%).

**CONSTRUCTION METHODS OVER PEAT**

Numerous constructions with different methods have been carried out on peat some of which are road constructions while others are building constructions (Munro et al., 2007; Fox & Edil, 2001.). Different construction criteria have to be considered in construction over peat depending on the construction intended to embark upon. Construction methods over peat may be categorized into two aspects. One aspect is the construction in which peat deposit is totally removed from the construction site before the construction commences, while the other is the one in which peat is left in place but with certain modifications, the material becomes more sustainable to support the intended construction. The first aspect has been divided into four basic sub-headings as presented by Munro (2004) and Munro et al. (2007) which include; avoidance, peat excavation, peat replacement and peat displacement. Although the researchers considered avoidance as a construction method, in reality it may only be considered as managerial decision that could be taken based on the various scenarios on ground because there is no any gain in the geotechnical properties of the peat soils that will allow structures to be erected on them.
Peat Removal

Avoidance

Avoidance simply means finding alternative land devoid of any construction problems if such option is available and all the necessary economic, environmental and technical conditions are considered. In a situation where by peat soil covers a large area and coupled with the inherent demand for accommodations due to growth in population and other safe land areas are not always readily available, this option might not be always feasible. Thus, it becomes imperative upon the engineers to find alternative solutions that will allow engineering structures to be sited on it.

Peat Excavation

This involves removal of peat soil in order to expose a firm layer of sufficient bearing capacity to accommodate new construction with a minimum threat of settlement or shear failure. This method is only economically viable for shallower depth (between 3 and 4 meters) of peat lands with clear consideration to the type of peat, the volume of excavation, availability of spoil areas, etc (Munro, 2004). As the depth of excavation increases beyond 4 meters, it will be more difficult to keep the excavation sides stable. Another problem that may be encountered with this method is local pockets of peat left-over that can result in bearing capacity failure and settlement of the finished structure if left uncorrected (Munro, 2004).

Peat Replacement

This method is almost similar to excavation method the only difference is that in this method the removed peat material has to be replaced with imported suitable fill material to form the foundation for new construction (e.g. road embankment) and the grade line of the new construction will be at the same level or even above the adjacent peat land (Munro, 2004).

Peat Displacement

The concept involves pushing away the peat deposits from within the alignment of the new construction site. This method is normally employed where the depth of peat is beyond economic limits of excavation or replacement (Munro, 2004). In road construction, the weight of intended road embankment will be used to sufficiently cause shear failure of peat underneath and this will result in displacement of peat laterally below the embankment (Munro, 2004). There are a number of related methods within this category such as progressive displacement, partial excavation and assisted displacement (Munro, 2004). Care has to be taken in order to avoid trapping pockets of peat below the embankment. It is highly recommended to take proving cores underneath the completed structure after displacement and where peat pockets are encountered the alternative solution is to allow the trapped peat consolidate under an applied surcharge or blast the material out from below the embankment by using explosives (Munro, 2004).

Peat Left in Place

Methods that leave the peat in place and avoid bulk earthworks are now becoming increasingly more attractive to engineers as construction budgets reduce and more cost effective solutions are sought through waste minimization and environmental considerations (Munro, 2004). These methods have been discussed under different sub-headings (Munro, 2004; Munro et al., 2007; Huat et al., 2014) and are further presented in this review with some modifications.
They include: Methods of accelerating consolidation, ground improvement techniques to reduce deformation, stabilization, load modification, and piling methods.

**Methods of Accelerating Consolidation**

These include preloading, stage construction and vertical drains.

**Preloading:** In this method, a temporary fill is placed over the construction site in excess of the final design fill. This causes settlement to occur more rapidly than would have occurred under the final fill design height alone until it reaches the predicted in-service settlement for the intended load. Once this settlement has been reached any excess load (surcharge) is removed and the service load left on the strengthened foundation at its final in-service settlement (Munro, 2004; Munro et al., 2007; Huat et al., 2014). Peat is well suited to the preloading method as it has a very high permeability naturally and compresses in a relatively short time under load when compared to other engineering soils. The peat matrix deforms under load which decreases its permeability and compressibility with resultant increase in its shear strength (Munro, 2004). One of the disadvantages of this method is that it can extend the construction time and the preloading materials have to be imported in excess which may lead to double handling after design settlement is achieved. Comprehensive preliminary site investigation, laboratory testing and site monitoring are very essential for a good performance (Munro, 2004).

**Stage construction:** As the name implies, in this method the construction is carried out in stages in order to guard against shear failure of the underlying peat during preloading due to the high surcharge fill material. As such, fill materials are applied in stages and that additional load is only applied when a suitable gain in strength of the underlying peat has been achieved (Munro, 2004). The rate of loading peat by stages is normally determined by the rate of elimination of pore-water from the underlying peat especially in fibrous peats which have excellent initial properties of high compressibility and permeability that make them suitable for stage loading (Munro, 2004).

**Vertical drains:** They are used in order to shorten drainage paths in soil thereby accelerating the rate of pore water dissipation which speed up settlement process with resultant primary consolidation and gain in strength earlier (Munro, 2004). There are two basic reasons for the need in quick dissipation of pore water from peat: Gain in strength of the subsoil at each stage which will ensure the stability of the next stage loading. It also allows faster construction and reduces the time necessary for preloading (Munro, 2004; Huat et al., 2014).

**Ground Improvement Techniques**

These refer to the various methods or techniques that influence the engineering properties of peat soil, such as shear strength, compressibility, stiffness or permeability in order to improve its good performance (Huat et al., 2014). It involves mainly the various reinforcement techniques such as stone columns, cement columns, soil columns, geopiers and surface reinforcement.

**Stone Columns:** These are vertical columnar elements formed below the ground level with compacted and uncemented stone fragments (gravels) or sand which serves as load bearing columns and usually penetrate through the weak strata (Murugesan & Rajagopal, 2009). With proper installation equipments and more rigorous control methods, stone columns can be formed to greater depths of up to 30 m which makes vibrated stone columns to be used as a practical alternative to traditional treatment methods such as a piling for low-rise structures (Black et al., 2007). The overall performance of stone columns is controlled by the lateral support from the lateral confining pressure provided by the surrounding soil, which typically increases with depth.
In weak deposits such as peat the lateral support is very low and has consequences on column integrity that cause the column to fail by “bulging” (Murugesan & Rajagopal, 2009; Black et al., 2007).

There have been a lot of researches on stone column available in the literature. Black, et al. (2007), made investigation on the performance of stone columns in a weak deposit such as peat and evaluated the effects of reinforcing stone columns by jacketing; Alexiew, Brokemper and Lothspeich (2005), made their investigations on encased stone columns based on load capacity and geotextile selection; Murugesan and Rajagopal (2009); Ambily and Gandhi (2007), made their investigations on the behavior of single and group encased columns; Zhang and Zhao (2014), made their investigations on deformation analysis of stone columns.

The construction of stone column involves partial replacement and/or lateral compaction of loose subsurface soils with a compacted vertical column of stone aggregate. The presence of the columns creates a composite material which is stiffer and stronger than the original unsuitable soil (Murugesan & Rajagopal, 2009). When used in sensitive clays, stone columns have certain limitations such as increase in the settlement of the bed because of the absence of the lateral restraint, and clay particles get clogged around the stone column thereby reducing radial drainage. In order to overcome these limitations, and to improve the efficiency of the stone columns with respect to the strength and the compressibility, stone columns are encased (reinforced) using geogrids/geocomposites (Mokhtari & Kalantari, 2012).

Peat lenses are usually encountered in soft compressible deposits. Thickness and structure of the peat layers are the important parameters affecting the use of stone columns. A fibrous peat is considered more suitable to non-fibrous peat due to the reinforcement provided by the fibers (Barksdale & Bachus, 1983). Barksdale and Bachus (1983) further suggested that, in order to prevent problems with excessive settlement and stability of the stone column, the ratio of the peat layer thickness to the stone column diameter must always be kept less than two or even less than one.

Cement Columns: They are almost similar to the stone column in geometry and performance, the significant difference is that, while the materials for the construction of stone column are imported from elsewhere, cement columns are normally constructed by mixing cement with peat soil either in-situ or make precast columns and installed thereafter in the soft material (Kazemian & Huat, 2009; Kazemian et al., 2009; Banadaki, Ahmad & Ali, 2012). They could be produced also by adding more binder or reinforcing elements together with the cement (Kalantari & Huat, 2009). Kalantari and Huat (2009) conducted a laboratory experiment on “precast stabilized peat columns” made up of peat soil and ordinary Portland cement with and without polypropylene fiber reinforcement. The results of their study obtained from shear strength parameters, stress-strain curves and undrained modulus proved that precast stabilized peat columns could be used to reinforce and strengthen weak deposits of peat soil and their production requires relatively small amounts of cement with higher strength values compared to the usual in situ columns.

Soil Columns: The major difference between soil columns and cement column is that imported filler material (usually fine aggregates) is involved in constructing soil column other than the use of insitu material as in the case of cement column. Both of them require some binder materials (e. g. cement) in their manufacture. A field model study was undertaken by Hashim and Islam (2008) using soil cement column in order to stabilize peat soil using various types of binder materials and from their test results it was observed that the engineering properties of peat soil can be improved by stabilization using additives. Islam and Hashim (2010), carried out a field model study in order to observe the settlement of stabilized group peat columns by constructing two sets of test group columns (in-situ soil column and pre-bored-premixed columns) using Palm
oil Fuel Ash (PFA), cement, calcium chloride and siliceous sand as binder materials. From their findings, group columns give higher efficiency than the single column such that group columns act as a block and its failure depends on the skin friction provided by the group columns.

Geopier: This is an intermediary foundation system which incorporates very stiff aggregate piers to reinforce weak and compressible peat and highly organic soils with a basic requirement that the peat and highly organic soil layer has to be penetrated completely (Allgood et al., 2003; Fox & Edil, 2001). Two reasons for the unique success of the geopier system in reinforcing peat and highly organic soils are: The construction method prevents significant mixing and contamination of the organic soils and peat with the aggregate materials, unlike soil column or stone column methods; and the prestressing and prestraining of the poor matrix soils during installation of the aggregate piers stiffens these soils and increases perimeter shear resistance of the constructed piers (Allgood et al., 2003).

Although the geopier method requires complete penetration of the peat and highly organic soil layer, the pier cavity usually lies within soft and compressible inorganic soils and does not have to extend to a good soil layer (Allgood et al., 2003). Research on the feasibility and design approaches including some case histories regarding the use of the geopier system to support structures constructed over peat and highly organic soil was as presented in (Allgood et al., 2003). It shows that geopier are technically feasible and are usually highly cost effective compared to massive excavation and replacement methods, deep foundation systems, or other soil improvement techniques. Fox and Edil (2001) presented the methods for analyzing and estimating settlements of footings supported by geopier and verified their design by full-scale modulus load test. They also presented some discussions on projects regarding their modulus test data and subsurface information. Research on load–settlement and load–transfer behaviors of rammed aggregate piers were as presented by Suleiman and White (2006) with clear focus on floating rammed aggregate piers. They also presented some charts and equations for estimating vertical stress at the base and settlement at the top of floating geopier.

Surface reinforcement: Surface reinforcement using geotextile; geogrid; timber or bamboo mattresses, concrete raft, etc, is another form of ground improvement techniques as presented by (Munro, 2004; and Huat, et al., 2014). Geotextile or geogrid may be used as a separator to prevent the fill material from contamination by the weak sub soil. As the fill becomes thicker, the material becomes tensile and will play a true reinforcement role (Munro, 2004; and Huat, et al., 2014). The geotextile may also be an aid to construction especially on a wet site in which it helps with the establishment of an initial working platform, and in more fibrous peat it helps to preserve the natural surface mat from the destructive activity of the construction traffic. More so, the natural fibers of peat are helpful in maintaining the stability of the fill (Huat, et al., 2014). Geotextile or geogrid can reduce differential settlements and lateral stresses on the peatland. It can also minimize the need for embankment fill material or any cost of excavation, disposal or need for additional land for storage of spoil (Munro, 2004).

Timber or bamboo mattress (raft) construction using local vegetation is an old method of strengthening embankments over peat. The technology which has been practiced for many years involves laying an interlocking platform of reinforcing materials on the peat land surface to support and distribute the loads of the new embankment until such time as the underlying peat gains sufficient strength to support the embankment on its own (Munro, 2004). Different types of timber reinforcement exist in history, from simple brushwood mattresses and fascines through to the substantial designed steel pinned grillages fabricated with selected timber logs; all have the same aim of preventing local punching shear of the fill material into the peat land and distributing the embankment load across its surface (Munro, 2004). Corduroy construction involves placing cut trees or planks, often obtained from site clearing, at the soil-to-fill interface as a mean of
distributing the load and bridging the soft spots in organic subsoil (Huat et al., 2014). In practice, all of the mattresses explained above and grillages must be pushed down into the water table by the embankment within 6 months of installation otherwise it is likely that the timber elements will rot and the platform decompose (Munro, 2004).

**Stabilization**

Mass stabilization is a well practiced technology in road construction over peat in Finland and Sweden (Munro, 2004). The philosophy in mass stabilization is relatively simple. The weak peat is mixed together with a binding agent, usually cementitious material, by a mechanical mixing tool to produce a stronger and stiffer stabilized block (Munro, 2004). In this process, a dry binder is fed into the mixing head with compressed air and the mixing head is rotated vertically and horizontally through the peat mass. The binder thereby reacts chemically with the pore water in the peat and cures to a cementitious mass (Munro, 2004).

Stabilization of clay soils with slaked limes and cement lime mixture was a common tradition. Binder mixes such as limes, cements, blast furnace slag, fly ash and gypsum are now widely used as the most important components. The choice of binder is dependent on the characteristics of the soil to be improved and in the case of peat this means its geomorphology, geotechnical and chemical properties (Munro, 2004). Cement is found to be more effective in peat stabilization than cement/lime mixtures, and certain additives, such as gypsum, improve the cement’s reactivity. The strength gain is mainly due to hydration products formed by cementitious reactions. It depends on the type of soil, dosage of binder, water content and curing conditions (Huat et al., 2014).

Kalantari et al. (2010), used cement as binders and silica fume as additive in order to stabilize soft, wet and unconsolidated peat soil. This method is cost-effective compared with other ground improvement methods. In their study, 5–50% (by weight) of cement to peat soil, and rate of 5–10% (by weight) of cement to silica fume was added. With air curing technique on the samples (which causes the stabilized peat soils to lose their excess moisture content gradually), it was observed that the UCS and CBR increased by a factor as high as 11 and 25 respectively as compared with untreated peat soil. They were able to evaluate the optimum dose of cement and silica fume and also observed that the upper layer of in situ peat soil can be stabilized with cement and silica fume to increase the strength of sub-base for pavements. In their conclusion they were able to establish that the use of silica fume reduces the requirement for cement which implies that part of the cement can be replaced with silica fume, and making it more economical.

**Load Modification**

Load modification is concerned with altering the load distribution of the proposed structure to better suit the existing strength of the peat. In embankment construction, the process includes Profile lowering, Pressure berms, Slope reduction, Lightweight fill and Offloading (Munro, 2004). Floating foundation can also be considered as another method of load modification.

*Profile lowering:* This means amending the route vertical alignment to suit the weak soil conditions and lowers the intended embankment height across the peatland to an acceptable level for the strength of the underlying peat (Munro, 2004).

*Pressure berms:* Are used to widen the base of an embankment, distribute the imposed embankment load over a greater surface area and increase the factor of safety of the embankment against slip circle failure (Munro, 2004).
**Slope reduction:** This method is similar to the addition of pressure berms and is again intended to produce a wider embankment, a greater distribution of load over the foundation area and a longer more deep seated potential failure slip circle in the underlying peat. In this method the side slopes of the intended embankment are flattened to a shallower gradient to widen the overall width of the embankment across the peatland (Munro, 2004).

**Lightweight fill:** Lightweight fill is primarily used to reduce the overall weight of an in-service embankment and thereby reduce the permanent stresses on the foundation. Embankments constructed with a lightweight fill core are usually installed in conjunction with a surcharge load to accelerate consolidation and settlement and once the designed settlement has been reached the surcharge is removed leaving the finished in-service embankment on a strengthened sub-grade (Munro, 2004). Lightweight fills are normally only used for partial replacements of embankments due to their high cost and are generally restricted to those sections that cannot be economically addressed by other means. Lightweight fill material should also be durable, resistant to decay, easy to place and compact, have a good compressive strength with low compressibility and be environmentally friendly in addition to being light (Munro, 2004).

Lightweight materials are alternative materials in coping up with extreme soils such as peat. Because of their light weight nature, very little pressure is actually exerted on the existing ground, hence minimizing the stability and settlement problem. Material such as polystyrene blocks with a typical density of about 20 kgm$^{-3}$ (may possibly increase to 100 kgm$^{-3}$ as the material absorbs water from the ground) has a good potential in that it is about 20 times lighter than conventional fill such as clay and sand (Munro, 2004; and Huat et al., 2014).

Lightweight forestry by-products such as bark, woodchip and sawdust wastes from the timber industry have regularly been used as lightweight fills (Munro, 2004). Huat et al. (2014) added shredded waste tires or bales as other materials that could be considered for the lightweight credit construction technique on peat. The most popular lightweight materials today are the specifically manufactured lightweight products such as EPS.

**Offloading:** This basically involves the removal of heavyweight material from an existing road construction and its replacement with something lighter. The aim of offloading is to produce a reduction in load on the underlying peat preferably to a level within its existing bearing capacity (Munro, 2004).

**Floating foundation:** Floating foundations may be considered as a technique of reducing the total and differential settlement of a foundation by decreasing the net applied load through excavation (Mohsenian, Eslami & Kasaei, 2011). Floating foundations are usually considered when foundations must be placed over deposits of compressible soil and when deep foundations are expensive. If the soil is so weak that for a given load there is a risk of shear failure below the foundation, then the loads must be reduced or carried to a stronger underlining layer by piles (Mohsenian et al., 2011). When the weight of a structure is partly compensated by excavation, the building is said to be partially floating; when it is entirely compensated the building is fully floating. As such, the principle of a floating foundation involves balance of weights only, and the foundation itself can consist of spread footings, a raft, a box, piles, or cylinders, or in some cases a combination of these (Mohsenian et al., 2011). Some of the design and construction problems associated with floating foundation consist of excavation, water lowering, bottom heave, settlement, and structure problems (Mohsenian et al., 2011).

Floatation in soft soil (e.g. clay soil) can also be achieved by pile skin friction. In order to overcome the problems of excessive differential settlement, negative skin friction and bearing capacity failure, Tan, Chow and Clue (2005) designed a ‘floating’ piled raft foundation system for a housing development on soft clay. The ‘floating’ piled raft foundation was designed to limit
differential settlement and it consists of short piles strategically located at areas of concentrated loadings and interconnected with a rigid system of strip-raft to control differential settlement. Temporary surcharging of the earth platform prior to the construction has shown to be very effective as demonstrated by monitoring results on the completed structures (Tan et al., 2005).

Another aspect of floatation in soft soil as well as waste management is the use of tire bales and aggregates for floating embankment construction (Humphrey, 2005; Winter et al., 2005).

The concept of floatation is varied in nature depending on the floating medium. In an open body of water, floatation can normally be achieved by pontoon action and/or buoyancy effects (United States Patent No. US 4,988,317, 1991; United States Patent No. US 5,743,205, 1998; United States Patent No. US 5,775,248, 1998; Sirlin, Paliou, Longman, Shinozuka & Samaras, 1986). In clay soils, floatation can be through skin friction offered by piles (Tan et al., 2005) or by compensation activities (Mohsenian et al., 2011). Although there are a number of researches conducted on floating foundation in peat (Abdullah, Huat, Kamaruddin, Ali & Duraisamy, 2007), the area still needs to be explored because floatation in peat is quite different due to a number of reasons: (1) There is no significant friction in peat soil which will allow pile floatation. (2) With zero SPT-N value, it is not likely to construct a compensated foundation in peat. (3) Although peat soil has a very high water content, pontoon action and/or buoyancy effect may not be fully achieved due to the presence of fiber contents in the pool of water. Hence, the concept of floatation in peat need to be investigated more.

**Piling Method**

Piles may be described as long, slender concrete, steel or timber members that can be used in transferring loads through weak/unstable soil to ground of higher load-bearing capacity (Huat et al., 2014). Huat et al (2014) categorized piles into six different types; End bearing piles, Friction piles, Settlement reducing piles, Tension piles, Laterally loaded piles and Piles in fills. End bearing piles terminate in hard and relatively impenetrable material such as rock or very dense sand or gravel; and derive most of their carrying capacity from the resistance of the stratum at the toe of the pile. On the other hand, Friction piles obtain a greater part of their carrying capacity by skin friction or adhesion. This tends to occur when piles do not reach an impenetrable stratum but are driven for some distance into a penetrable soil. Their carrying capacity is derived partly from end bearing and partly from skin friction between the embedded surface of the soil and the surrounding soil (Huat et al., 2014).

Zhang, Zhai and Wang (2014) used Bamboo pile-mattress as a system that combines both bamboo piles and bamboo mattress for embankment reinforcement on soft clay, in which bamboo piles act as friction piles and bamboo mattress was to distribute embankment load uniformly, to alter critical failure surface, and to provide upward buoyancy pressure. This brings about the issue of piled raft foundation.

A piled raft foundation may be described as a composite structure made up of piles connected to the raft from underneath, exercising a variety of responsibilities jointly and independently in providing safe transfer of bearing pressure to the underlying subsurface or sub-base structure (Huat et al., 2014). Poulus (2002) emphasized that, different pile sizes can be used below the raft, depending on the design requirements, and that all piles need not to be of a similar size and length, or that they should extend to a strong bearing stratum. His argument was fully and successfully implemented by Tan et al. (2005).

In designing piled raft foundation, several external variables that influence the design need to be considered. The most important ones are those related to the pile characteristics (number, length, and disposition), raft characteristics (thickness), and the foundation’s overall cost as
presented by Cunha, Poulos and Small (2001). Cunha et al. (2001) also considered the loads acting on the piled raft from column loads perspective which is commonly found in practice rather than the evenly distributed superstructure load that is being considered as acting on piled raft by the majority of researchers.

Rahardjo (2005) gave an insight on the conventional system of embankment construction on peats and soft soils conducted in practice by Indonesian engineers in the use of bamboo pile raft system (known as “cerucuk”), Bakau piles, Ulin and Gelam timber. In his own opinion, no method of design and analysis has been established, despite the more popular application of the system and approach for calculation are only based on experiences or simplification. He further opined that the system has been proven to have some advantages in the increase of the bearing capacity of the soft foundation soils and reducing the settlement of the embankment considering its successful application in many projects, and recommends further investigations on proper method of design and analysis to that effect.

Piling method has high mobilizing costs, setting up and driving costs and is not normally used for road construction over peat unless settlement control is particularly critical such as in bridge approaches and the like where settlement criteria are normally more onerous (Munro, 2004).

**POTENTIAL INNOVATIVE RESEARCH AREAS FOR CONSTRUCTION OVER PEAT**

Peat soil is a very weak material that for any given load there is the risk of bearing capacity failure and high settlement below the foundation. The only solution is to reduce the loads, transfer them to a stronger bearing layer by using piles, or peat stabilization. Among these methods, the load reduction may have potential for innovative research area for construction over peat. The load reduction may be achieved by using floating foundation. The high water content in peat which results in rise in water table almost throughout the year suggest that floating foundation system has a great potential as an alternative method of construction and need to be investigated.

Low, Tioh and Ng (2013) proposed a new floating foundation system entitled "Lightweight Concrete Infill Buoyant System and the Method Thereof". The density of the overall structural system can be controlled at ease by suitable apportioning bamboo, plastic bottles and lightweight concrete etc. Since the water content of peat is high, there may be a potential for this system to be used in peat phenomena. Two conditions may be considered as potential area of investigation for the floatation to occur. These are the air pressure and lightweight material. Some of the hazardous waste material bedeviling the environment (e. g. polythene bags, used tires and tubes, plastic containers, etc.) could be transformed to serve as lightweight materials or entrap air and have a low density that could provide floatation which will allow sustainable, cost effective and green foundation construction over peat land. Plastic gallons, water and cosmetics bottles, used tire tubes, etc, could be used (with cap on) to entrap air which is lighter than water and make the system float. Balls from polythene bags, used tires and tubes, etc, are lighter in density compared to peat soil and could serve as lightweight material for foundation construction therein. Some organic materials such as bamboo (also lighter in density) and bakau could be used to encapsulate the waste materials and form a composite floating foundation. The bamboo material will serve as reinforcement to take care of the applied tensile load while the waste materials will provide the buoyancy effect. Bamboo is fast growing specie which attains its full length in 2 to 3 months and its maturity in 2 to 3 years (Gnanaharan, Janseen & Arce, 1994). It is available in all the continents of the world except Europe (Nor, 1995) and known to possess a good strength to weight ratio (Ali & Abdullahi, 1984). Malaysia has about 70 different species of bamboo.
Stronger species are found in the northern states while a specie known as ‘Bambusa vulgaris’ is found in all states (Ali & Abdullahi, 1984).

Peat soil with high thickness (depth ≥ 10m) that with minor excavation could generate a capillarity rise may provide a comparable situation with an open body of water and allow floating foundation to be erected therein. There is a potential for plastic drums or plastic balls to be used to entrap air and provide a platform for deck or raft construction atop. The techniques may include, excavation of the soil material to generate a capillarity rise, placing inverted plastic drums with open-bottom chambers that will trap air underneath and constructing a deck or raft foundation on top. This proposed system is quite different from the conventional constructions using plastic drums in which the drums are covered such as the floating school in Lagos, Nigeria (floatSCHOOL, 2014). With open bottom chambers, more air pressure could be inflated or deflated into the system so as to take care of fluctuation in water table throughout the year. Sirlin et al. (1986) used the same method for active control of a floating structure in order to reduce the influence of wave motion on it by using open-bottom chamber structure supported by a cushion of trapped air underneath.

However, the potential application of this system in peat and the design methods entail investigations on the settlement, water fluctuation, peat degree of decomposition, and durability of bakhu/bambo in peat environment.

**CONCLUSION**

This paper has explored and presented some of the conventional methods of construction over peat. Construction techniques such as excavation, displacement, replacement, preloading, cement columns, soil columns, geopiers, geotextile and geogrids, offloading, etc, have been discussed under two major aspects of construction over peat; peat removal and peat left in place. Potential area of investigation on construction over peat has also been presented as the use of air pressure and lightweight materials from some of the hazardous waste material bedeviling the environment which will not only allow sustainable, cost effective and green foundation construction over peat land, but also will serve as a new waste management strategy.

**REFERENCES**


