Properties of Peat Deposits

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ABSTRACT

Peatlands constitute 5% to 8% of the world's land. In the North Island of New Zealand large peat deposits are present in the Lower Waikato and northern Hamilton lowlands, the Hauraki Plains and the Ardmore area south of Auckland. The increasing scarceness of land requires engineers to face up to the challenges of building on these highly organic soils. Important and largely unknown key factors for foundation assessment are the engineering properties of peat deposits.

This paper presents a summary of the published literature on the engineering properties of peat. A comparison is made between the findings from the literature on the suggested compressibility parameters of peaty soils with results from laboratory tests on selected undisturbed samples from several sites in Auckland.

A 12m square trial embankment was built on a site in south Auckland to study the actual behaviour and quantify the compressibility of peaty deposits. The settlements underneath the trial embankment were monitored to provide a comparison between the theoretical settlements and the observed values from the large-scale static load test.

1 INTRODUCTION

Peat is a partially reduced plant or wood material, containing approximately 60 percent carbon and 30 percent oxygen. It is an intermediate material in the process of coal formation. Generally, peat has a yellowish brown to brownish black colour, can be either plastic or friable, has a very high moisture content (generally above 90%), and may contain plant material in a reasonably preserved state.

Peat is distinguished from other organic soil materials by its lower ash content (the percentage by dry weight of material remaining after the oven dried peat is burned using the Test Method in ASTM D 2974). Commonly ash content of peat is less than 25% ash by dry weight.

ASTM D4427 classifies Peat according to its fibre content (the dry weight of fibres remaining on a 100mm mesh sieve after wet sieving) to designating Fibric-Peat with greater than 67% fibres, Hemic–Peat with between 33% and 67% fibres and Sapric–Peat with less than 33% fibres. Other properties used in the classification of peat are ash content, acidity, absorbency (water holding capacity), and botanical composition (the dominant plant identified by visual inspection as comprising at least 75% of the fibre content in the peat).

In addition to the above classification, peat behaviour is related to the degree of humification (decomposition) which can be expressed in different ways. The Von Post scale (vP) is the most widely used system. The vP scale ranges from 1 to 10 with each point representing about 10% decomposition, with H-1 being totally undecomposed plant material and H-10 completely decomposed peat. The degree of decomposition is determined by squeezing the peat in the hand and examining the compressed peat and water. This method is useful for assessing sphagnum peat but not as suitable for woody peat. For geotechnical applications, peat whose degree of humification ranges from H1 to H3 has been described as **fibrous peat** (generally spongy, moderately tough, non-plastic and shrinks little on drying). While peat with the humification range from H4 to H10 has been described as **amorphous peat** (commonly heavy, compact, and plastic when wet).

2 ENGINEERING PROPERTIES OF PEAT

Peat behaviour is influenced by its geological age together with physical, chemical and biological properties of the organic materials. Some of the recognized factors that influence peat behaviour are fibre content, fibre source (botanical composition), degree of humification and peat structure. (Fang 1991) introduced sixteen categories of peat structures based on the presence of three types of structure components. These are amorphous-granular, fine-fibrous, and coarse-fibrous. Fang suggested that the amorphous-granular peat have the highest unit weight and the lowest permeability. The fine-fibrous peat has the highest compressibility and the lowest unit weight, while the coarse-fibrous (woody) peat has the highest permeability and lowest compressibility.

Important engineering properties of the peat include unit weight, grades of peat and particle size, water content, void ratio/water holding capacity, shear strength, tensile strength, hydraulic conductivity, and compressibility.

2.1 Unit Weight and Shear Strength

The low specific gravity of both organic matter and water leads to low unit weights for the natural peat. The specific gravity of peats range from 1.1 to 2.5, values above 2 indicate marked contribution by mineral matter (Fang 1991).

Recent studies do not support the use of common measures of soil testing to predict peat shear strength. A detailed program was initiated in this direction to study the shearing characteristics of the sphagnum bog peat from chat moss in Greater Manchester, and the relevance of these properties to certain field situations. Experimental work has included triaxial compression, direct shear, ring shear, tension and beam tests in an attempt to observe the stress-strain response and to measure the shear strength parameters of the peat. Behavior of the bog peat was found to be greatly influenced by the reinforcing action of the fibres, to the extent that the ultimate failure did not occur in the triaxial compression tests even at high axial strains. The peat seemed rather to compress further and become progressively stronger as the shear strain increased (Haghi 1991).

Furthermore, the properties assigned to peat may not remain the same under the circumstances (stresses, water table level, etc,) during the life of the project. Disturbance of the natural peat structure decreases its strength properties. For that reason, a well known engineering practice is to leave the fibrous peaty layer intact without removing part of the peat or disturbing the layer during development of sites covered by peat deposits. The sensitivity of peats ranges from 1.5 to 10 (Fang 1991).

2.2 Hydraulic conductivity

Saturated hydraulic conductivity of peat (k_s), which is initially relatively high, may decrease dramatically during compression. Historically, there has been a debate whether or not Darcy’s law applies to saturated organic soils. (Hemond and Goldman 1985) suggest that Darcy’s law is applicable only to the upper layer of slightly decomposed peat. They have identified two possible causes for departure from Darcy’s law in deeper layer. First, the flow rate may vary nonlinearly with hydraulic gradient or with absolute magnitude of head applied. Second, the structure of the medium may not remain constant and may vary with hydraulic gradient or with absolute head, leading to a nonlinear variation in hydraulic properties. Despite this, many studies have investigated the hydraulic properties of peat using Darcy’s law to define hydraulic conductivities for peat samples. (Rycroft et al. 1975) evaluated the relationship between the hydraulic conductivity and values of the von Post humification scale for the samples from six studies. The relationship confirmed that hydraulic conductivity decreased with increasing humification. Literature values of K_s were categorized into fibric, hemic or sapric peat classes based on description of peat quality mostly using von Post humification index. The reported median values are $0.24x10^{2}$ m/day, $0.17x10^{-2}$ m/day and $0.86x10^{-2}$ m/day for fibric, hemic and sapric peat, respectively. The median of K_s values were reported rather than the mean as these values vary by several orders of magnitude within each class of peat (Letts et al. 1991). Other, published values of peat hydraulic conductivity range between $1x10^{-4}$ and $1x10^{2}$ m/day (Wise 2002).

2.3 Compressibility

Volume change mechanisms in peatland are commonly identified as oxidation, shrinkage, and compression. Peat oxidation consists of irreversible subsidence due to mineralization of carbon to water and CO_2. Shrinkage occurs within the peat layers above water-table due to the development of negative pore-water pressures as the peat dries. Compression is due to changes in effective stress on peat layers below the water table and comprises primary and secondary consolidations (Kennedy et al. 2005). The primary consolidation, which is the focus of this study, can be described by classical one dimensional consolidation theory (Terzaghi 1943) whereby peat volume changes are due to an equivalent change in pore-water volume. Coefficient of volume compressibility (m_v) varies with the magnitude of the applied stress change and can be predicted using equation (1).

$$m_v = (\Delta e) / [\Delta P` \times (1+ e_o)] \qquad (1)$$

Where (Δe) is the change in void ratio, ($\Delta P`$) is the change in the effective stress, and (e_o) is the initial void ratio.

Similar to the mineral soils, volume changes of peat on unloading and reloading (swelling and recompression) are much less than volume changes on first loading (compression). Pre-consolidation pressure (Pc) is the previous stresses that the peat has experienced. At effective stress less than the pre-consolidation pressure (Pc), volume changes are reversible and peat compressibility can be estimated as the slope of the recompression curve (m_r), whereas at effective stresses greater than Pc, irreversible structural changes occur, and peat compressibility can be estimated as the slope of the virgin consolidation curve (m_v). (Tomlinson 2003) suggested (m_v) values above 1.50(m^2/MN) for very highly compressible organic alluvial clays and peat.

A research program has conducted an extensive series of laboratory tests on undisturbed block samples of peat deposits. Testing procedures, interpretation of test results, and theory of consolidation, developed for clay and silt deposits, were evaluated for peats. This research concluded that most of the fundamental concepts as well as the theory of consolidation, which were developed for mineral soils, are applicable to peat with some modification (Mesri et al. 1999).

In peatlands, changes in water table position can cause changes in effective stress large enough to alter the peat volume significantly. A study report was prepared for Environment Waikato in June 2003 on the subsidence rates of peat since 1923 on the Hauraki Plains. Significant areas of peatland have been drained resulting in subsidence from consolidation and the loss of organic matter. The study considered 90 observations of peat thickness made along 13 transects in the peatland. The study concluded that since 1923 the thickness of peat in the Hauraki Plains peatlands has decreased 1.85cm per year on average (McLeod et al. 2003).

3 GEOTECHNICAL INVESTIGATIONS AND LABORATORY TEST RESULTS

The data utilized for this study were collected from geotechnical investigations on three sites (A, B & C) located in the Mangere area south of Auckland. Geological map indicates that the Mangere general area is covered by Puketoka Formation which comprises pumiceous mud, sand and gravel with muddy peat and lignite; rhyolite pumice, including non welded ignimbrite, tephra, and alluvial pumice deposits, massive micaceous sand. These investigations showed that the sites are underlain by volcanic deposits consisting of mainly silts, clay and peaty clay, peat and sands. Further detailed investigation was carried out on the site A. This investigation indicated that two peat layers are present within the soil stratigraphy. The first peat layer was between 2m and 3m depth, which was described as soft fibrous peat with peaty clay, and the second was encountered between 6.5 and 9.5m depth and was described as amorphous with some fibrous. Undisturbed samples were collected from both layers, however poor quality samples retrieved from the first layer. Therefore, samples suitable for testing could only be prepared from the second layer. Consolidation tests were carried out on six selective undisturbed peat samples collected from sites A, B & C and the determined compressibility parameters are summarized in Table 1. The pressure-voids ratio curves from the consolidation test results indicated that the soils are slightly over consolidated. The m_v values were determined for applied stress change relevant to the stress increase imposed by the fill. Other tests such as von Post number (vP) were not conducted as these tests are not available locally.

Table 1: Compressibility parameters from consolidation test results

Sample No	Depth (m)	Classification	Initial Void Ratio	(m_v) m^2/MN	(m_r) m^2/MN	Hydraulic Conductivity K (m/day)	Modulus of Elasticity (Eoed.) MPA
1-A	8.0 - 8.5	Peat - amorphous	6.070	0.250	0.084	1.40 x10^{-4}	4.0
2-A	7.5 – 8.0	Peat clayey - amorphous.	5.748	0.287	0.28*	1.34x10^{-4}	3.48
3-B	4.5 -5.0	Peat – fibrous Woody	2.505	0.290	0.036	0.44x 10^{-4}	3.45
4-B	7.5 – 8.0	Peat – fibrous Woody	3.158	0.637	0.196	0.68x 10^{-4}	1.57
5-C	6.0 - 6.5	Peat – fibrous	8.709	0.845	0.165	0.67x10^{-3}	1.18
6-C	6.5 – 7.0	Peat – fibrous	5.623	1.17	0.128	0.31x10^{-3}	0.85

* Recompression coefficient (m_r) is very high, possibly due to the presence of expansive clay.

4 PRELOAD TRIAL

A trial embankment was built on site (A), which is located in the Mangere area south of Auckland, to provide a comparison between the theoretical settlements and the observed values from a large-scale static load test. Initially, the vegetation cover was stripped off and the exposed formation levelled at the settlement plate locations using washed graded sand. These locations were surveyed in reference to onsite survey benchmark, which were checked regularly against an offsite survey benchmark during the preload trial. The survey monitoring points were established at the centre of the loaded area and the midpoint of both the base and crest of each edge i.e. 9 points. Two additional offset survey-monitoring points were also established (see Figure 1).

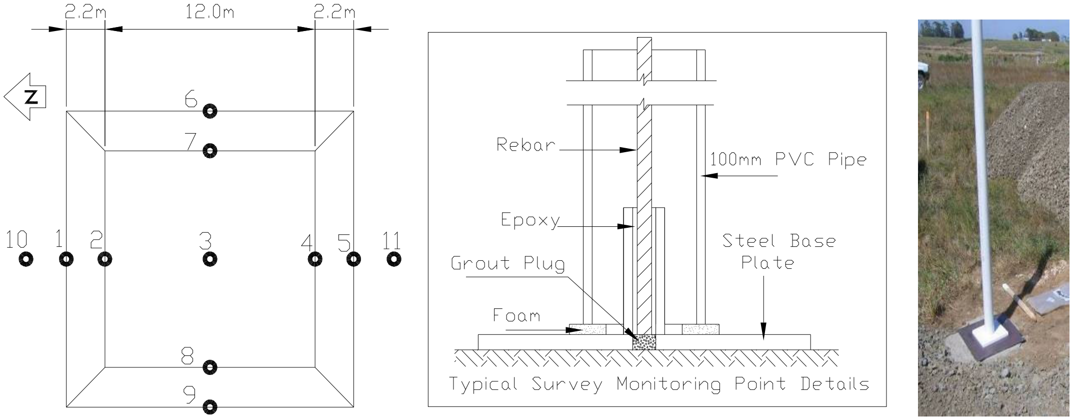

Figure 1: Preload trial layout with details and photo of a typical monitoring point.

After completion of the survey monitoring point installations and surveying the site, the embankment was build up from compacted granular fill (GAP 65). The loaded area measures 12*12m across the top with side slopes of 1V: 1H (45°) and an overall height of approximately 2.2m above original ground level. The settlements underneath the trial embankment were monitored at each location. Plots showing the displacement of the settlement markers with time are developed (see Figure 2). The preload trial results indicated that as of 20 April 2006 (approximately 44 days under the full preload) the ground beneath the centre of the surcharge (MP3) had settled by about 13mm.

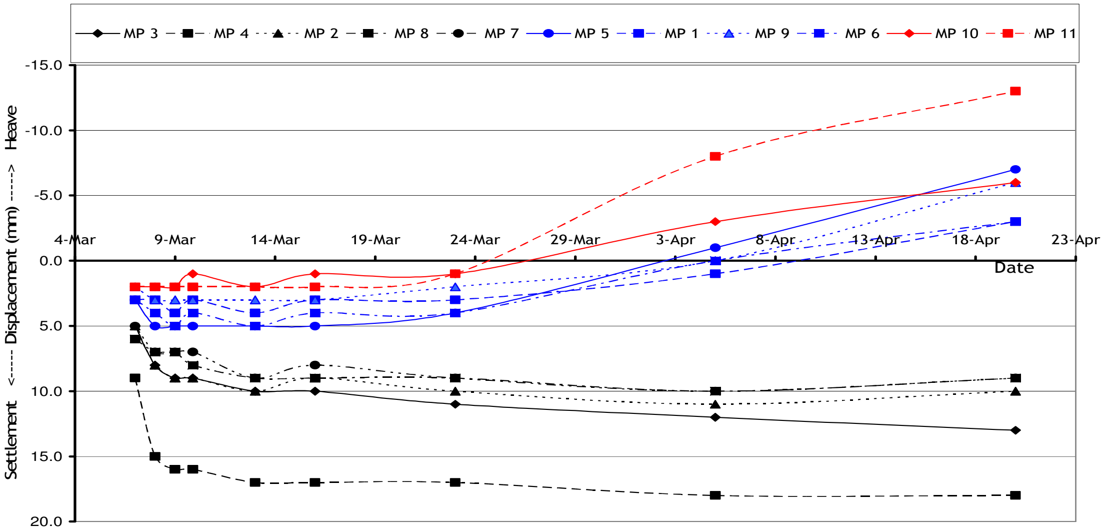

Figure 2: Preload trial settlement against time

The north, east and west edges (MP2, MP7 & MP8) had experienced maximum displacements of between 10 and 11mm. The readings taken on 20 April 2006 indicated that 1mm of heave had occurred since 5 April 2006 along the north, east and west edges, giving a cumulative displacement of about 10mm. The levelling plate at the south edge (MP4) showed a displacement of 18mm. We believe that this plate was displaced laterally during placement of the granular fill.

The trial embankment and the subsoil layers below it down to 15m depth were simulated using finite element model (PLAXIS). The embankment construction staged to four phases, each taking 0.50 day and then consolidated under full load for 44 days. A consolidation analysis was used to introduce the dimension of the time in the calculations including the effect of changes to the active geometry. Initially the analysis was performed using Mohr-Coulomb model for the peaty layers with (Eoed) values obtained from the consolidation tests. Then the analyses were repeated using soft soil model for the peaty layers with the soil parameters obtained from the consolidation tests including over consolidation ratio of 1.50 to 1.80. The analyses indicated that the extreme total settlements for these cases vary from 50mm to 70mm. To limit the settlement to approximately 13mm similar to the preload trial results, very high values of (Eoed) were used in the analysis. These were 23.50 MPA for the upper peaty layer and 33.60 MPA for the lower peat layer (see Figure 3).

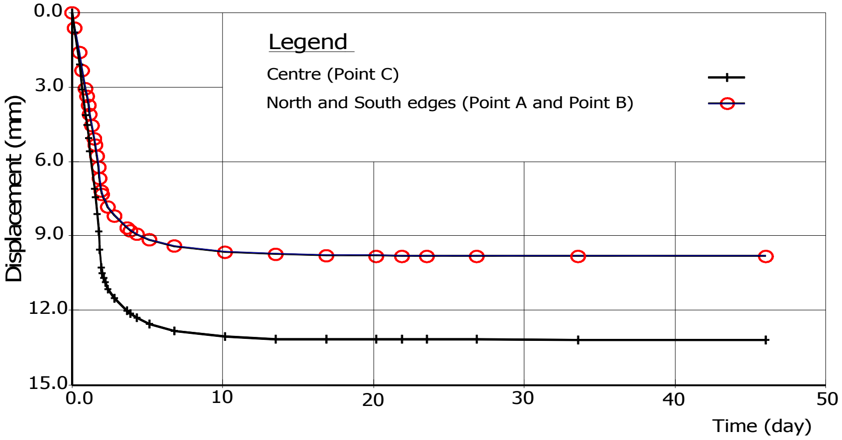

Figure 3: Analysis results of settlement against time

5 CONCLUSIONS

- From the preload trial, the measured settlement at the centre of the surcharge area after 44 days of full preload was about 13mm. Analyses of the FE model that simulated the trial embankment and the following subsoil layers gave extreme total settlements of 50mm to 70mm "using different material models and the parameters obtained from the consolidation tests for the peaty layers". Limiting the settlement to 13mm required much higher modulus of elasticity (Eoed) for the insitu soils that are far in excess of the values obtained from consolidation tests. Possible sources for this apparent discrepancy are (1) the structure of the peat samples may have been distorted due to size and edge effect and may not reflect the actual structure of the peat mass (2) displacement measured on the site is the net displacement; due to compression, swelling and lateral movements whereas the decrease in height of the tested sample is mainly due to vertical compression (3) the difference between the flexural rigidity of the steel ring loads applied on the sample and flexible fill surcharge applied on the site (4) shear strength of the insitu soils was reduced when sampled and subjected to disturbance and/or water.

- Peat behaviour is influenced by the geological, environmental and botanical factors which vary significantly from one region to another. Numerous studies on peat compressibility were undertaken in USA, Canada and Japan. Further studies are required to establish guidelines for assessment of peat compressibility parameters based on the local peat characteristics in New Zealand.

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