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Ultralightweight foundation system for peaty ground

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Construction on peat deposits represents a major challenge for the geotechnical community. Waterlogged peat deposits have great potential for buoyancy generation. The premise of the present investigation is that this can be beneficially incorporated in foundation design practice, thereby reducing the net bearing pressure and hence resulting settlements. A novel foundation system, comprising a bamboo frame (BF) structure incorporating recycled plastic block (RPB) inclusions, is presented for supporting lightweight structures bearing on peaty ground. The buoyancy effect is produced by the lower bulk density of the foundation construction materials combined with the waterlogged condition of the peat deposit. A programme of reduced-scale 1g physical modelling was conducted to investigate the performance of BF- and BF–RPB-type footing bearing on remoulded peat with different water content and fibre content (FC) values. The mobilised undrained bearing capacity (q_f) increased for lower-water-content and higher-FC peat materials. Deeper BF footings and the inclusion of the RPBs within their cavities significantly improved the mobilised q_f value. Advantages of the presented foundation system over conventional solutions for peaty ground include its simple technology, reduced earthworks in construction, reduced settlement due to the buoyancy contribution and being more sustainable and economically viable.

Notation

A	footing area
d	bamboo frame depth
$\overline{F}_n$	net buoyancy force
$\boldsymbol{g}$	acceleration due to gravity
H_n	von Post humification number
q_f	undrained bearing capacity
s_u	undrained shear strength
V	volume
W	applied vertical load
w	water content
ρ	bulk density
σ_v	total bearing pressure
σ_{vn}	net bearing pressure

Introduction

Peat deposits are formed by the gradual accumulation of decomposing plant vestiges under waterlogged conditions. Peat material represents an extreme form of soft soil on account of its extremely high water and organic contents, very low undrained shear strength and very high compressibility and creep potentials. The organic material present decomposes over time, which affects the mechanical properties of the peat material, reducing the bearing capacity of these deposits. Depending on the degree of humification, the organic solids in peat material occur at various levels of decomposition, ranging from recently deposited intact plant and root fibres to ultimately amorphous organic material for completely decomposed peat. Comprehensive reviews of the shear strength and compressibility properties and behaviour of peat materials are presented in the publications by Hobbs (1986), Huat *et al*. (2014), O'Kelly (2015a, 2017) and O'Kelly and Pichan (2013), to name a few.

Owing to their very high compressibility and very low shear strength, allowable bearing pressure values for peat deposits are typically limited to <20 kPa (Huat *et al*., 2014). Hence, these deposits have tended to be avoided in earthwork projects. A range of construction techniques can be employed when this is not possible (e.g. due to the lack of adequate suitable land area for infrastructure development). These include excavation or displacement of the load-bearing peat material and its replacement with suitable engineering fill; preloading using conventional surcharging (Beales and O'Kelly, 2008; Nichol, 1998); vacuum consolidation (Griffin and O'Kelly, 2014; O'Kelly, 2015b); chemical stabilisation (Kalantari *et al*., 2011; Kazemian *et al*., 2009); structural solutions (e.g. using basal geosynthetic reinforcement with piles) that transfer the applied loading to competent underlying strata (Huang *et al*., 2005; van Eekelen *et al*., 2018); and the use of lightweight fill materials in order to reduce the magnitude of the applied loading. However, as explained in the next paragraph, such techniques are often uneconomical, ineffective and difficult to implement in practice on account of the very low shear strength and very high creep rate and compressibility of the peat material.

For instance, the excavation and replacement approach can prove technically challenging in so far as maintaining the sides of the excavation stable, particularly for peat depths >4 m (Munro, 2004). The excavated peat material is replaced with imported compacted engineering fill material that forms the foundation for the new infrastructure (e.g. road pavement or embankment). From an economic viewpoint, the costs of the fill material, including its haulage to the construction site, and those associated with the disposal (reuse) of the excavated peat are such that this approach is limited to peat deposit depths of typically up to between 3 and 4 m (Munro, 2004). For the displacement approach, the total stress of the intended infrastructure is adequately applied in the form of fill material placed on the ground surface which produces shear failure of the underlying peat deposit, with the encroaching fill material causing its sideways displacement. This approach can take a very long time period to complete and some pockets of peat material may remain within the displacement zone, such that bearing capacity and (or) settlement problems may arise for the completed infrastructure on account of the very low shear strength and very high compressibility of these remaining peat pockets (Munro, 2004). The preloading approach generally involves the stage construction technique, with extra (surcharge) fill material having to be imported and subsequently removed (double handling) once the residual settlement rate has reduced to acceptable levels, as determined using an active ground monitoring programme (Beales and O'Kelly, 2008). Vertical drains incorporated in the peat layer accelerate the rate of primary consolidation settlement, but not the secondary compression settlement rate, which typically produces the majority of the settlement for peat deposits (O'Kelly, 2006; 2015b). Hence, the preloading approach generally also takes a long time period to complete and residual settlements occurring over the infrastructure's lifetime may still be excessive on account of the peat material's very high creep rate. Vacuum consolidation has been widely applied for soft soil ground improvement, but for only a few cases involving peat and other highly organic soil deposits, as described in the papers by Griffin and O'Kelly (2014), O'Kelly (2015b) and Osorio *et al.* (2010). Reasons include various technical challenges in implementing this technique for peaty ground on account of the very large differential ground-surface settlements expected (O'Kelly, 2015b; Osorio *et al.*, 2010), and, as mentioned earlier, the majority of the settlement arises from secondary compression rather than the consolidation process. Piling and piled-raft construction (Huat *et al.*, 2014; Satibi, 2009) approaches that distribute the applied load to stronger underlying strata are not economical for very large peat depths (e.g. peat deposits in Ireland and Malaysia, may be >20 m deep). Other approaches include the use of geosynthetic reinforcement, mass stabilisation (Munro, 2004), concrete or timber raft construction (described in more detail in the next paragraph), vibro-stone columns and in situ mixing of the peat material with a binder to form stabilised columns (Axelsson *et al.*, 2002; Banadaki *et al.*, 2012; Kazemian and Huat, 2009; Kazemian *et al.*, 2009). Stabilised column and mass stabilisation techniques require large additions of binder material(s) on account of the extremely high water content and very low shear strength of the in situ peat, which often make these approaches prohibitively expensive for large-scale infrastructure construction (Hebib and Farrell, 2003). The performance of vibro-stone columns is largely controlled by the lateral confinment pressure provided by the adjacent soil, although its value can be very low for very soft deposits, including peat (Black *et al.*, 2007; Murugesan and Rajagopal, 2009). Hence, even for modest applied loading, the stone columns require large diameters to prevent their excessive bulging deformation and, ultimately, failure. Nevertheless, the longer-term foundation settlement may still be excessive on account of the high creep rate of the peat material surrounding these columns (Noor Muneerah PG Haji Jeludin *et al.*, 2016). Greater peat depths require larger column diameters, with the situation even more onerous where the level of humification of the peat deposit increases with depth, which is generally the case in practice. For instance, a 4 m deep peat deposit may typically require a stone column diameter of >2 m, such that this approach would become technically and economically not practical.

The extremely high water content and void ratio values (typically ranging 500–2000% and 7–30, respectively (Hobbs, 1986)) of waterlogged peat deposits provide potential for buoyancy generation. In various parts of the world, it has been common practice for minor road and railway embankment construction on peat subgrade to incorporate a timber or bamboo mattress (raft) (e.g. see the publication by MacFarlane (1969)). Historical overviews of timber mattress techniques employed in Ireland are presented in the publications by O'Keeffe (1973), Osorio *et al.* (2008) and Raftery (1990). Essentially, timber logs placed upon stringers were laid out perpendicular to the centreline of the proposed road or embankment, thereby serving as a basal reinforcement layer and also providing some buoyancy effect when the timber raft settled into the underlying waterlogged peat due to the load applied by the road and (or) embankment construction. In other parts of the world, bamboo has been used without much difficulty as a sustainable foundation construction material (Huat *et al.*, 2014; Munro, 2004; Munro *et al.*, 2007). For instance, Rahardjo (2005) described the use of a bamboo pile–raft system for embankment construction on a peat deposit. Above the groundwater level, expanded polystyrene (EPS) blocks can be used as lightweight fill in constructing the embankment core (Aabøe and Frydenlund, 2011). Prototype EPS footings, each capable of carrying a 1 t load, have been proposed and they are designed as floating foundations using the weight compensation technique (Abdullah *et al.*, 2007).

The current experimental investigation presents a novel foundation system for supporting lightweight structures bearing on waterlogged peat deposits. The proposed system utilises simple technology and employs green and recycled materials with density values lower than that of the waterlogged peat material. The bulk density (ρ) value of waterlogged peat ranges from typically 0·9 to 1·2 t/m^3. In other words, rather than having to increase the footing area, the total bearing pressure acting on the underlying peat foundation can be reduced overall by employing lighter foundation construction materials. The net bearing pressure is further reduced on account of the buoyancy effect produced for the submerged portion of the footing. The reduced foundation settlement means that the reduction in the hydraulic conductivity of the underling peat is not as severe. Consequently, the impacts of the loaded footing on the natural groundwater regime and finely balanced eco-hydrological system of the peat bog are also reduced (O'Kelly, 2008, 2009).

The construction materials employed for the proposed ultralightweight foundation system are bamboo culms and recycled plastic blocks (RPBs) produced from compressed plastic bags. The form of the foundation (footing) comprises a bamboo-frame (BF) structure that incorporates the RPBs. Bamboo was chosen as it is a quick-maturing species, commonly found in tropical, subtropical and temperate zones, and a low-cost material with a good strength-to-weight ratio (Abang Abdullah, 1984). Further, over a typical foundation design life, anticipated levels of decomposition for the submerged BF are not significant (O'Kelly and Pichan, 2013, 2014; Pichan and O'Kelly, 2012; Rahardjo, 2005).

A number of studies have investigated plastic bag recycling for engineering construction purposes (Chebet and Kalumba, 2014; Khan and Kamal, 2012; Shaukat and Kamal, 2010) including the utilisation of RPBs in constructing prestressed structures (e.g. arches and retaining walls) and access ramps for pedestrian bridges (Shaukat and Kamal, 2010). As such, the proposed foundation technology is greener and, when compared for similar scale projects, is arguably more economical to conventional construction techniques for peaty ground.

In order to demonstrate the proposed technology, this paper presents 1$\boldsymbol{g}$ model load testing of various-sized BF with RPB inclusion (BF–RPB) footings that are founded on peat test beds. The test beds were prepared using peat materials with different fibre content (FC) values and at different values of water content (w). Load testing of identically sized BF-type footings was also performed on similarly prepared peat test beds. This approach facilitated investigations of the effects of the peat FC and water content, the BF depth and the RPB inclusions on the mobilised undrained bearing capacity (q_f).

Experimental section

Materials

Peat materials and preparation of test beds

Uniform test beds of peat materials with four different FC values were prepared at various water contents for the footing load tests. The testing programme investigated fibric (FC > 66%), hemic (33% < FC < 66%) and sapric peats (FC < 33%) (ASTM D 4427-18 (ASTM, 2018)). Each bulk sample of the different FC peat materials was disaggregated and remoulded, and then water was added in the required amount (see Table 1) while manually mixed. The water content and FC values of the remoulded peat test materials were determined in accordance with BS 1377-2:1990 (BSI, 1990a) and ASTM D 1997-13 (ASTM, 2013), respectively, with the FC value determined as the percentage solids mass retained on the 150 μm sieve size (dry mass basis). There has been much debate in the literature over the past 60 years regarding the appropriate oven-drying temperature range for water content determinations on peat and other highly organic soils, with the general consensus now being that oven drying at 105°C is acceptable for routine water content determinations of peat (Hobbs, 1986; Li *et al.*, 2018; O'Kelly, 2014; O'Kelly and Li, 2018; O'Kelly and Sivakumar, 2014; Skempton and Petley, 1970). Hence, in the present investigation, the water content values were determined for an oven-drying temperature of 105°C.

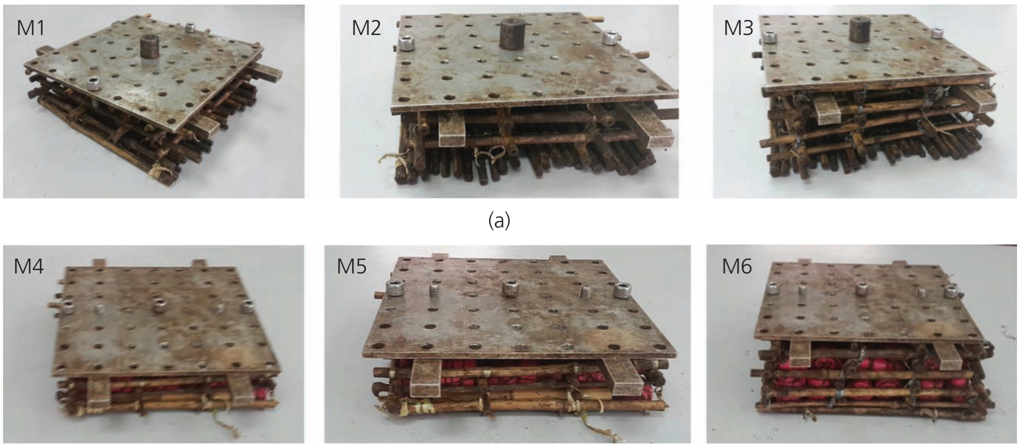
For the sapric peats (FC = 17 and 30%) investigated, the test beds were prepared by pouring the slurry materials from the mixing drum into the 0·6 m by 0·5 m deep test tank. For the hemic (FC = 54%) and fibric (FC = 87%) peats investigated, the test beds were prepared by placing the very soft materials in the tank as separate layers which were individually tamped to reduce their air void content to <5%. In all cases, the top surface of the test bed was levelled using a straight edge and then covered with plastic film to prevent moisture loss and allowed to stand for a 24 h period before starting of the footing load test. Immediately before placement of the footings, vane shear tests were performed at the centre and near the four corners of the peat test bed to estimate its undrained shear strength (s_u) value. The 25 mm wide by 50 mm high cruciform vane used was rotated at an angular rotation rate of 12°/min (BS 1377-9:1990 (BSI, 1990b)).

As described in the paper by O'Kelly (2016), although there are various challenges and shortcomings with vane shear testing of organic soils, particularly for more fibrous ones (Landva, 1980; Long and Boylan, 2012), this approach is widely used in practice and provides a reliable index for establishing relative changes in strength.

The tank size was sufficiently large that its side-walls had negligible influence on the punching failure mode responses of the model footings (Dehghanbanadaki *et al.*, 2016; Razali *et al.*, 2013).

Table 1. Water content and FC values of the remoulded peat materials used in preparing the test beds

Test bed	Peat type	Water content: %	FC: %
1	Sapric	621	17
2	Sapric	1185	17
3	Sapric	1634	17
4	Sapric	405	30
5	Sapric	852	30
6	Sapric	1356	30
7	Hemic	634	54
8	Hemic	1213	54
9	Hemic	1698	54
10	Fibric	715	87
11	Fibric	1221	87
12	Fibric	1759	87



(a)

(b)

Figure 1. Footings (250 mm) tested in present investigation: d = 50 mm for M1 and M4; 70 mm for M2 and M5; 100 mm for M3 and M6: (a) BF type, (b) BF with RPB inclusions (BF–RPB) type

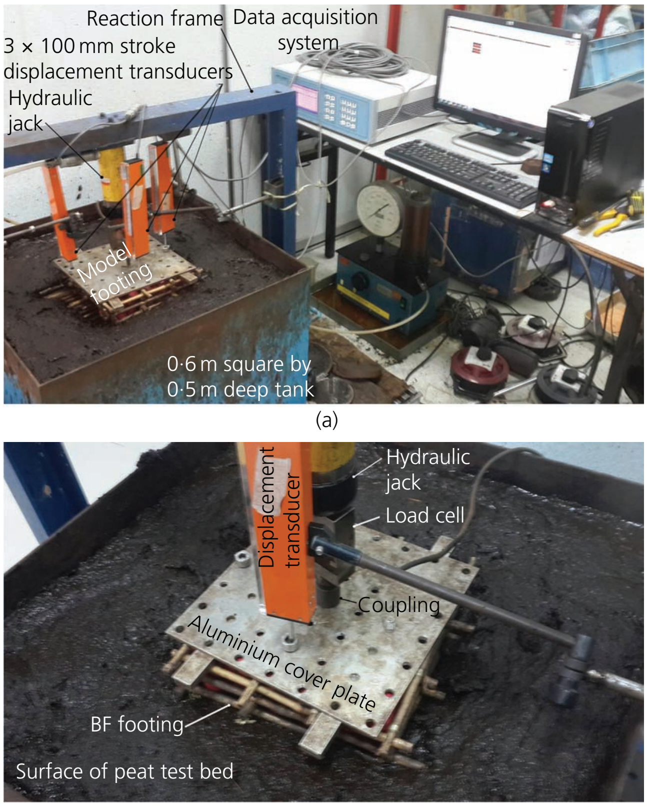
At full penetration depth, peat layer thickness of >0·35 m remaining between the tank base and the bottom of the deepest footings was investigated. The punching mode is typical of bearing capacity failure for peat deposits.

Model footings

Three BF-type and three BF–RPB-type footings with overall depths of 55, 75 and 105 mm (i.e. models M1–M3 and M4–M6, respectively, shown in Figure 1) were investigated. Each footing comprised a perforated 250 × 5 mm deep aluminium cover plate that was connected using a system of two aluminium rods and fasteners to a 250 mm^2 BF with a bamboo mat base. In addition, the BF–RPB footings incorporated multiple RPBs fitted within the various compartments of their BFs. The bulk density values of the bamboo-culm and RPB materials were determined as 0·62 and 0·44 t/m^3, respectively.

Method

The experimental set-up for the testing programme is shown in Figure 2. The model footing was placed centrally on the levelled surface of the peat test bed. The vertical ram of the hydraulic jack was lowered to contact the central coupling on the top side of the aluminium cover plate, which acted as a platform for uniform load application to the BF or BF–RPB footing under investigation. The 100 mm stroke loading ram was set to displace downwards at a rate of 1·7 mm/s, thereby pushing the footing 100 mm downwards into the peat test bed within a 1 min period (i.e. undrained loading condition). A load cell and three 100 mm stroke displacement transducers recorded the applied load and the footing settlement response. The load tests were terminated when the loading ram reached its full stroke capacity. In other words, the final footing penetration depth was 100 mm, meaning that all of the model footing configurations investigated were fully embedded (submerged) in the test beds, which equated to a normalised displacement level of 40%.



(a)

(b)

Figure 2. Model load testing: (a) experimental set-up; (b) close-up view of displacement-controlled loading of BF footing M1

Test programme

The six model footing configurations investigated were loaded on 42 test beds prepared using the remoulded sapric, hemic and fibric peat materials compacted at different water content values.

The first stage of the test programme investigated the effects of water content and FC of the peat beds on the undrained bearing capacity (q_f) values mobilised for the BF footing system. The reported q_f values correspond to the total bearing pressures mobilised for a footing settlement of 100 mm (i.e. when the loading ram had reached the end of its 100 mm stroke). This is justified since, although the total bearing pressure continued to increase in value with increasing footing settlement, it had substantially equilibrated for all cases at 100 mm footing settlement. This is evident from data plots presented later in the next section. Further, the full buoyancy effect was developed for all of the footings investigated since they had BF depth (d) values ranging 50–100 mm.

The second stage of the testing programme investigated the effect of the BF depth on the undrained bearing capacity by comparing the performances of BF footings M1–M3 for similar test beds. The final stage of the test programme investigated the bearing capacity enhancement achieved by incorporating the RPBs inside the BFs; that is, for the BF–RPB type system.

Results and discussion

In performing the load testing, the model footings experienced a punching shear failure mode, consistent with the observation that no significant heave of the peat bed surface was noticeable away from the footing edges. Values of the water content and FC of the 12 different peat test beds investigated are listed in Table 1. The value of the undrained bearing capacity was calculated as

$$1.\quad q_f = \frac{W}{A}$$

where W is the vertical load applied by the hydraulic jack together with the combined self-weight of 11·8 N for the 250 mm^2 aluminium cover plate and the rods and fasteners that connected it to the BF; A is the footing plan area (0·0625 m^2 for the present investigation).

As described in the previous section, the reported q_f values correspond to the total bearing pressures mobilised for 100 mm footing settlement. The experimental results are presented and discussed in the following sections, considering the effects of the water content and FC of the remoulded sapric, hemic and fibric peat materials; the BF depth; and the RPB inclusions on the mobilised q_f values.

Effects of water content and FC of peat materials

Figure 3(a) presents the total bearing pressure–settlement responses of BF footing M1 for the sapric peat test beds 1, 2 and 3 (FC = 17%; H_7–H_8 range on the von Post humification scale (refer to the paper of Landva and Pheeney (1980))) having slurry consistencies. The respective q_f values of 0·41, 0·49 and 0·56 kPa were extremely small. Nevertheless, other factors being equal, these results indicate that the undrained bearing capacity of the M1 footing founded on the sapric peat increased by 37% for reducing water content from 1634 to 621%. Figure 3(b) shows the performance of the M1 footing for the very soft hemic peat test beds 7, 8 and 9 (H_5 on the von Post humification scale; FC = 54%; s_u = 3–8 kPa), with very small mobilised q_f values of 4·2, 6·1 and 8·5 kPa, respectively. These results indicate that the undrained bearing capacity of the M1 footing increased by 102% for reducing water content from 1698 to 634%. For the fibric peat test beds 10, 11 and 12 (H_3–H_4 range on the von Post humification scale; FC = 87%; s_u = 8–17 kPa), the respective q_f values for the M1 footing increased significantly from 11·7 to 18·9 to 25·6 kPa for reducing water content from 1759 to 1221 to 715% (Figure 3(c)).

To allow a more holistic assessment of the different variables, all of the BF footing M1 test data are presented in Figure 4(b) as q_f against FC plots for the mean water content values of 660, 1210 and 1700% for the peat test beds investigated. Based on these results, the q_f value of the M1 footing increased significantly with increasing FC and also with reducing water content, particularly for higher-FC material. This behaviour is simply explained as follows: for higher-FC peat material, (*a*) the measured s_u increases significantly in value with reducing water content (Figure 4(a)) and (*b*) there was greater resistance against intrusion of the peat material into the BF cavities. which had the effect of increasing the total bearing pressure of the underling peat as the footing was pushed further into the test bed. The buoyancy contribution can be simply calculated using Archimedes's principle – that is, the net buoyancy force ($\overline{F}_n$) generated by the proposed foundation system is given as

$$2.\quad \overline{F}_n = [(\rho_1 - \rho_2)V_2 + (\rho_1 - \rho_3)V_3]\boldsymbol{g}$$

where ρ is the bulk density, V is the volume and $\boldsymbol{g}$ is the acceleration due to gravity, with the subscripts 1, 2 and 3 denoting the displaced waterlogged peat material, the saturated BF material and the RPBs, respectively.

The peat material is considered as a slurry material for the purposes of the calculations owing to its flow characteristics – that is, the influence of the constituent fibres is neglected (conservative approach). Slurry peat and RPB materials have typical ρ values of approximately 1·1 and 0·44 t/m^3, respectively.

The neutral buoyancy condition occurs when the magnitude of the applied footing load (W) equals that of the net buoyancy force. In other words, the net bearing pressure (σ_{vn}) is given as

$$3.\quad \sigma_{vn} = \frac{W - \overline{F}_n}{A}$$

where A is the footing plan area.

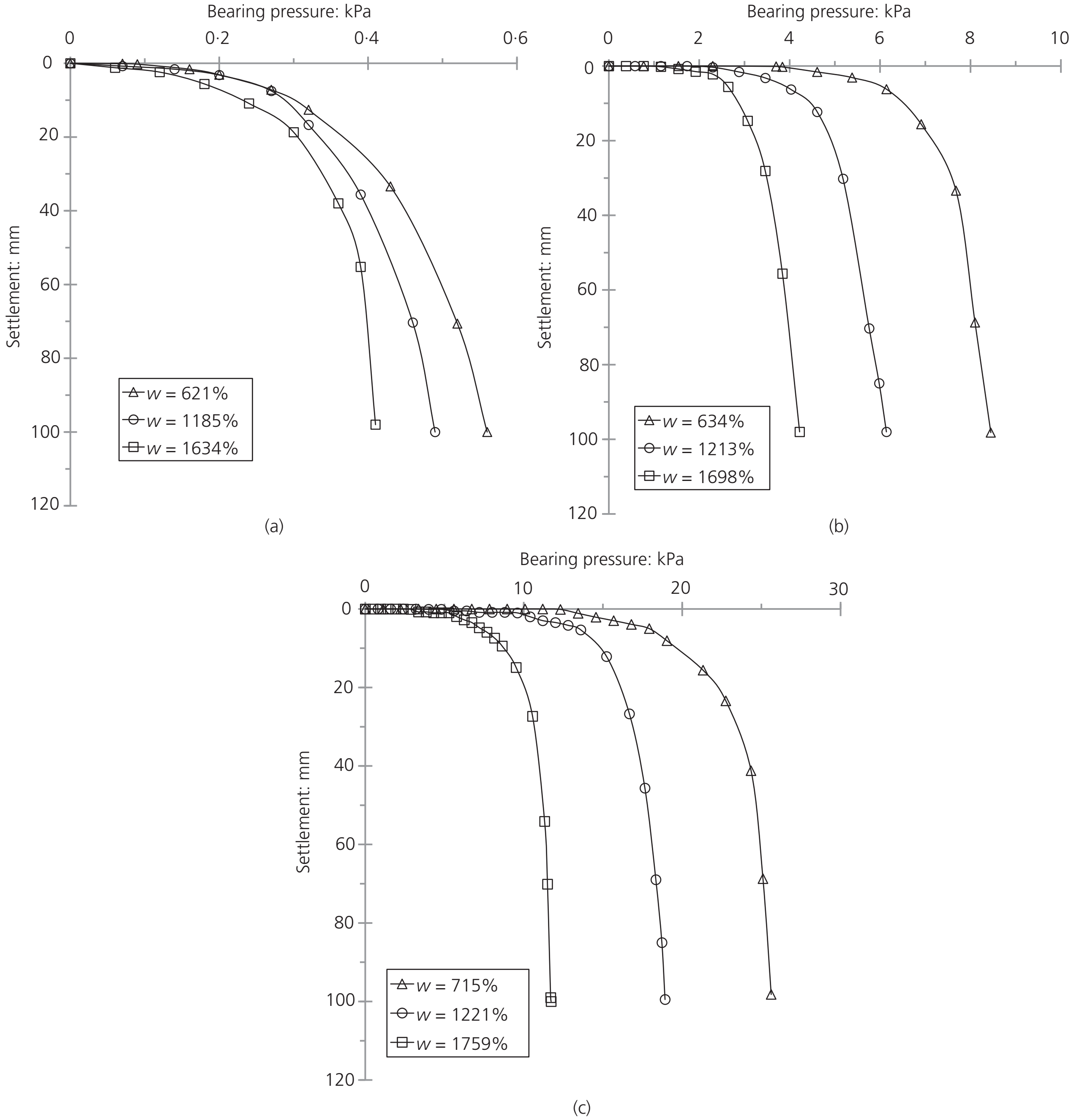
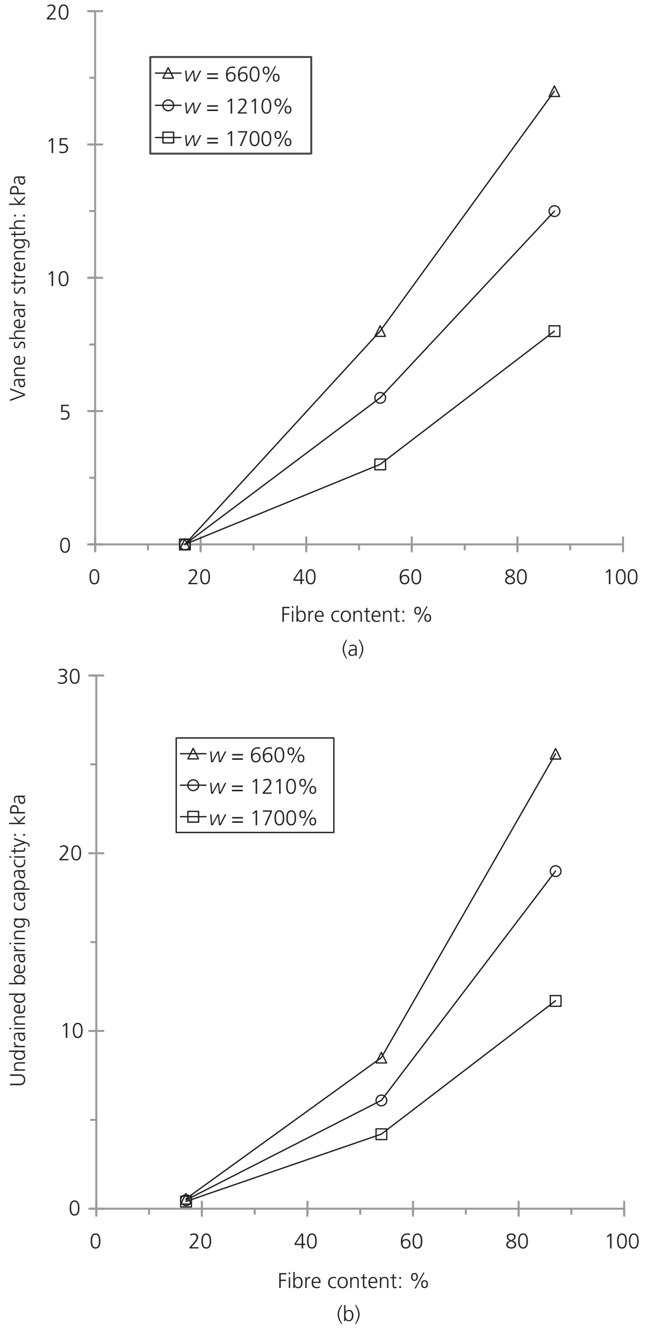


Figure 3. Total bearing pressure responses of BF footing M1 for peat test beds with different water contents and FCs: (a) sapric peat (FC = 17%); (b) hemic peat (FC = 54%); (c) fibric peat (FC = 87%)

Effect of BF depth

Figure 5 plots the q_f values mobilised for BF footings M1, M2 and M3 (with d values of 50, 70 and 100 mm, respectively) against the FC of the tested peat beds 1–3 and 7–12 detailed in Table 1. From this figure, the undrained bearing capacity significantly increased in value with increasing FC and reducing water content of the waterlogged peat material and for increasing footing depth. These findings are simply explained as follows: (*a*) the s_u values of the peat materials significantly increase with increasing FC and reducing water content; (*b*) a modest increase in the buoyancy contribution occurs for deeper BF footings and lower water content peat material. The modest increase in buoyancy occurs since the deeper BF footings comprised larger quantities (volumes) of bamboo-culm strips with a significantly lower ρ value of 0·62 t/m^3 compared to the waterlogged peat material (refer to Equation 2). The buoyancy contribution is



(a)

(b)

Figure 4. Effects of water and FCs of the peat materials: (a) vane shear strength; (b) undrained bearing capacity of BF footing M1

greater for lower-water-content peat material on account of its higher ρ value (again, see Equation 2).

As explained in the previous section, the load resistance and ultimate capacity of the bearing peat is further enhanced for higher-FC peat material since its constituent fibres become entangled on the bamboo-culm strips of the penetrating footing, thereby expanding their effective diameters and hence increasing the overall resistance to intrusion of the peat material into the BF cavities.

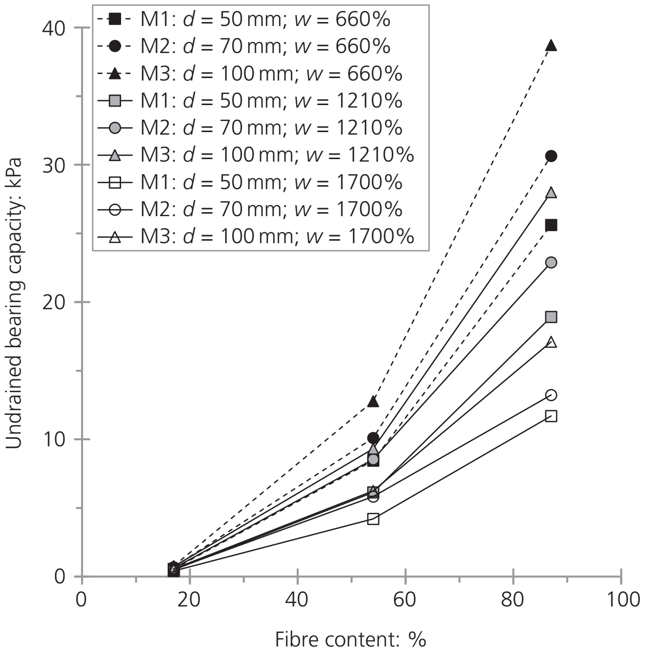


Figure 5. Effects of bamboo-frame depth and FC of the peat material on undrained bearing capacity

Effect of RPB inclusions

Figure 6 compares the q_f values of the BF–RPB footings M4, M5 and M6 (d = 50, 70 and 100 mm, respectively) with those mobilised for BF footings M1, M2 and M3. The peat test beds considered in this analysis had different FC values but the same mean water content value of approximately 1700%. Figure 7 compares the q_f values mobilised for the M3 and M6 footings founded on sapric peat beds 4, 5 and 6 (FC = 30%), which were prepared at three significantly different water content values.

As expected, the effect of the RPB inclusions was to produce a significant increase in the mobilised q_f values, with substantially greater improvements achieved for the higher-FC and lower-water-content peat materials and for the deeper BFs incorporating RPBs (i.e. the BF–RPB footings). These observations can be simply explained as follows: (*a*) the s_u of the peat materials significantly increases in value with increasing FC and reducing water content; (*b*) deeper BF and BF–RPB footings generate greater buoyancy contributions, especially for the latter footing type on account of the lower bulk density value of the RPBs compared to the waterlogged peat; (*c*) the peat materials had higher ρ values for reducing water content, further enhancing the buoyancy contribution; and (*d*) the resistance to intrusion of the peat material into the cavities of the BF increased for more fibrous peat material. Elaborating on point (*d*), compared to the BF footings, the bearing peat material cannot encroach to the same extent into the cavities of the BF for the BF–RPB footings since they are housing the RPBs. In other words, a greater volume of peat material must be displaced for the BF–RPB footings under

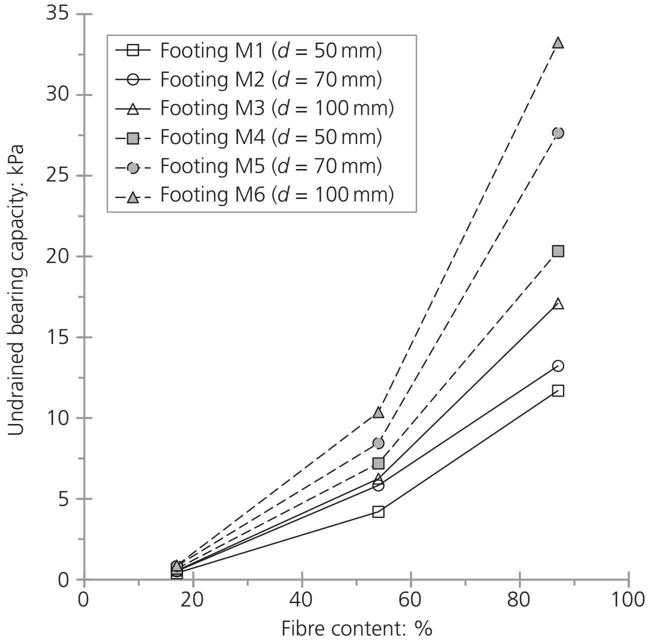


Figure 6. Effect of RPB inclusions on undrained bearing capacity for different BF depths and peat FCs (mean water content value of 1700%). Note: M1–M3, BF footings; M4–M6, BF–RPB footings

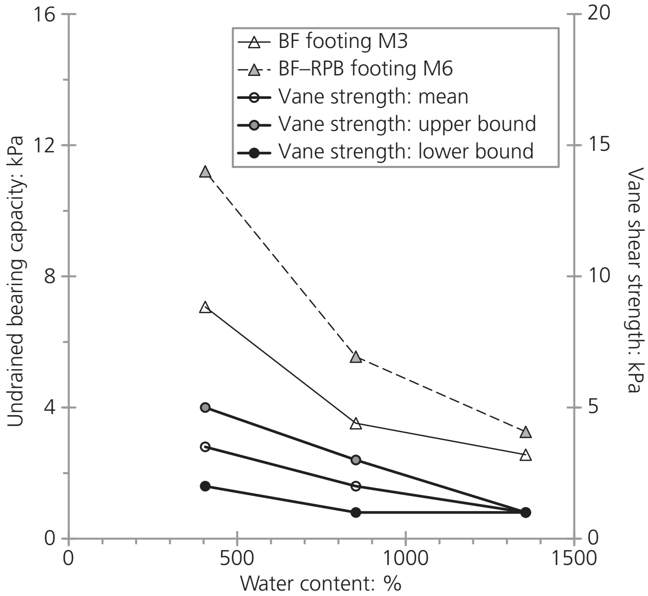


Figure 7. Effect of RPB inclusions on undrained bearing capacity for the M3 and M6 footings with a BF depth of 100 mm (FC = 30%)

the action of their displacement-controlled penetration into the peat test beds, thereby leading to enhanced bearing resistance.

This is best illustrated using a specific example – for instance, in comparing the performances of the M3 and M6 footing (both with d values of 100 mm) bearing on the remoulded fibric peat test beds (w = 1700%; FC = 87%) investigated. The inclusion of the RPBs within the cavities of the BF for the M6 footing had the effect of increasing the q_f value from 17·1 to 33·2 kPa – that is, a 94% increase in the undrained bearing capacity compared to the M3 footing. Alternatively, compared to deeper BF footings, at least the same undrained bearing capacity can be mobilised for significantly shallower BF–RPB footings. For instance, for the fibric peat material at 1700% water content, the BF–RPB footing M4 (d = 50 mm) mobilised a q_f value of 20·3 kPa compared to 17·1 kPa mobilised for the deeper BF footing M3 (d = 100 mm).

Summary and conclusions

Peat deposits have great potential for buoyancy generation. The premise of the present investigation was that this can be beneficially incorporated in foundation design practice for waterlogged peat deposits, thereby reducing the net bearing pressure and hence the resulting settlements. The presented novel foundation system for lightweight structures is constructed almost entirely using green and recycled materials – that is, bamboo culm and RPBs – contributing, despite climate change and increasing economic pressures, to sustainability in design (Johnston and O'Kelly, 2016). These materials have significantly lower ρ values compared to those of waterlogged peat materials.

Compared to the bamboo frame (BF-type) footing, the inclusion of the RPBs within the BF cavities (i.e. BF–RPB-type footing) significantly increased the undrained bearing capacity. Greater improvements in bearing capacity were achieved for deeper BF–RPB footings and higher-FC peat material on account of the increased buoyancy contribution and greater resistance to intrusion of the bearing peat material into the cavities of the BF frame.

Advantages of the presented lightweight foundation system over conventional foundation solutions for peaty ground include its simple technology, reduced earthworks for its construction, reduced net bearing pressure and settlement on account of the buoyancy contribution, as well as being more sustainable and economically viable to construct. By reducing the foundation settlement, the overall impacts on the natural groundwater regime and finely balanced eco-hydrological system of the peat bog are also reduced since the reductions in the void ratio and hence hydraulic conductivity of the bearing peat are not as severe. Possible disadvantages may include some or all of the following: it is suitable for supporting only lightweight structures (i.e. the net buoyancy force generated is limited by practical concerns for the manageable footing depth); the applied load must be approximately uniformly distributed on the buoyant footing to guard against its overturning; and the buoyancy effect requires that the footing remains submerged (i.e. the buoyancy contribution reduces, and is ultimately lost for lowering of the groundwater table below the footing base level).

The model scale considered in the presented investigation does not portray how practically possible it will be when applied in real construction work on peat. Hence, further research on the footing prototype, examining in particular probable scale effects and the bearing capacity and settlement responses for the longer term (drained) condition, is recommended. For instance, the size of the constituent peat fibres in relation to the dimensions of the bamboo-culm foundation frames is a likely scale effect. Their interactions and resulting contributions to the undrained bearing resistance are likely to be more significant for the model testing performed in the present investigation than for field-scale foundations, particularly for more fibrous peat deposits.

Other low-density 'waste' materials that plague the environment could be incorporated within the BF footing structure to serve the same role as the RPB material utilised in the present investigation. For instance, sealed plastic containers could be reused for this purpose, with their entrapped air pockets providing an additional buoyancy contribution.

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