Peat behaviour – Some conceptual mechanisms and challenges

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ABSTRACT The aim of this paper is to provoke discussion about the best way forward for understanding the behaviour of peat. Current design practice in peat is heavily reliant on field measurements and practical experience and, where necessary, quantitative predictions are based on constitutive models developed for inorganic soils. In order to replicate observed peat behaviour these soil models are often adapted based on empirical evidence and engineering judgement. This empirical approach can produce perfectly adequate results, but the key limitation is that this approach is only valid for patterns and magnitudes of behaviour which are similar to the previously observed cases. If a theoretical framework could be developed, it would provide a more widely applicable process for qualitative and quantitative predictions, while also providing designers with a point of reference for discussing case histories. This paper provides some conceptual ideas for a theoretical framework based on simple principles.

Introduction

It is generally acknowledged that peat is a poor engineering material, typically exhibiting large deformations, coupled with low resistance (Hobbs 1986, Mesri and Ajlouni 2007). Furthermore, peat is also known to be difficult to characterise and model, on account of its inherent natural variability, difficulties in sampling and testing and a propensity for deformation mechanisms and phenomena which are not readily predicted by conventional soil models. As such, most geotechnical designs in peat are heavily reliant on empirical rules and the observational method.

This paper is not an indictment of current practice, it is simply a proposition that the profession should discuss the potential for development of alternative theoretical frameworks to explain and predict peat behaviour. This paper sets out to discuss which physical characteristics of peat make it difficult to assimilate into soil models and provides discussion on alternative ways of modelling peat.

The key items for consideration are the use of fluid flows and particle mechanics, as an alternative to the conventional continuum mechanics used in soil modelling. A series of new parameters, principles and mechanisms are presented, but these are only intended for discussion – more detailed research is required before quantitative models of this type could be put into practice.

Usage of the term “peat” varies, but a typical definition used by geotechnical engineers is “soil composed predominantly of non-colloidal organic material”. In this paper the term “peat” will be used to refer to an idealised material composed entirely of organic particles, whose properties and characteristics will be discussed below.

Peat particle hypotheses

In order to develop a conceptual understanding of small scale soil behaviour, soil particles are often idealised as being:

- Composed of “minerals”,
- Solid (i.e. without internal voids),
- Incompressible (i.e. cannot change volume),
- Rigid (i.e. cannot distort),
- Approximately spherical or cubical.

To clarify this last item, it is acknowledged that soil particles can take a wide range of shapes, sizes and arrangements (Terzaghi et al 1996), but they are conventionally characterised using a single dimension for particle size, without the need to define length, width and height ratios or distortions.

Peat particles do not readily conform to the five criteria listed above. In the simplest terms, peat particles are made up of decomposed leaves and plant stems. Peat particles might be described as:

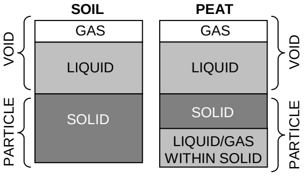
- Composed of “organics”,
- Porous (i.e. containing internal fluids),
- Compressible,
- Flexible,
- Elongated, laminar or fibrous.

As a result of these differences, the transfer of stress and strain between particles (and to the surrounding fluid) will be very different for soil and peat particles. While there are indications that soil mechanics may be applicable to such particles (Mesri and Ajlouni

2007) it is necessary to consider the underlying assumptions when using soil models with peats.

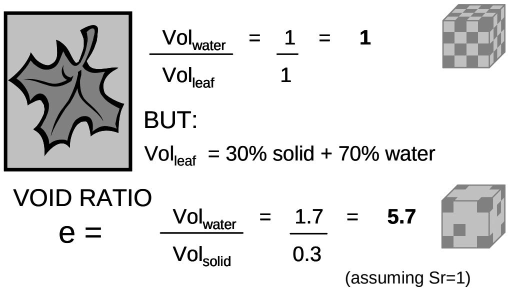
As well as the particle characteristics themselves, it is important to consider the particle–void structure formed by peat particles. Where soils are typically considered to contain solids (particles), liquids and gases (voids), a peat structure will contain additional liquids and gases within the particle phase. These internal fluids are not expected to behave as a continuation of the fluids in voids between particles and hence should be considered separately. Figure 1 illustrates the different components for soil and peat.

Fig. 1. Components of soil and peat micro-structure.



It is important to note that the most common methods for determining the relative proportions of voids and particles are based on the measurement of gravimetric moisture content by drying samples in an oven. This method does not permit differentiation between void liquids (referred to here as "void water") and liquids within the particles ("particle water"). Moisture contents well in excess of 500% are common in peats. If one were to assume that all the measured moisture content exists as void water (which is a common assumption in soils) this could easily give voids ratios well in excess of 5 (even accounting for a very low specific gravity for peat). Thinking about this practically, it is difficult to explain how a material made up of 1 part solids to 5 parts fluid could support itself structurally. Figure 2 below provides an illustrative example of this problem.

Fig. 2. Effect of particle water on voids ratio.



Hence it is difficult for engineers to visualise the physical structure or anticipated behaviour of peats using voids ratios calculated in the conventional way. It would be useful, for modelling purposes, if a single parameter could be developed to define the relative quantity of "particle water" within peat. This new parameter will be referred to as the Oversaturation Ratio, Ω, and defined as follows:

[1] $$\Omega = \frac{V_{ws}}{V_s}$$

Where V_{ws} is the volume of particle water and V_s is the volume of solid material (i.e. after oven drying). Using this new parameter, a more useful alternative to void ratio can be found, referred to here as Mechanical Voids Ratio, e_m:

[2] $$e_m = \frac{w \cdot Gs}{S_r\,(1+\Omega)}$$

And hence e_m can be related to the conventional soil voids ratio by:

[3] $$e_m = \frac{e - \Omega}{1 + \Omega}$$

Where w is gravimetric moisture content, G_s is specific gravity, S_r is degree of saturation and e is the conventional soil void ratio. For peat, all deformation, strength and stiffness parameters which are deemed to be functions of void ratio might be better determined based on e_m, rather than e.

Ω is proposed here solely for discussion. Further research and testing will be required to determine a method for measuring Ω, but low temperature drying (which is already being used in some instances) or centrifuge may be worth considering. It is hypothesised here that Ω not only defines the relative proportion of particle water, but also the extent to which the characteristics and behaviour of peat deviate from an idealised soil. For example a material with a high moisture content, but low Ω could be modelled as a very wet soil. Conversely a material with a moderately high moisture content, but high Ω might be more accurately modelled as a relatively dry peat. Fibrous peat might be expected to have higher Ω than amorphous peat.

It should be noted that attempts have been made in the past to model soils with porous or compressible particles, however the author is not aware of any of these models which are widely used in practice.

Particle deformation micro-model

The particle characteristics described above can be used to predict how peat particles might behave on their own and interact with one another. If the peat particles are deposited naturally so that they adopt a random orientation and somewhat folded shape, their deformations under different stress conditions are likely to be as follows. Figure 3 shows these four conditions schematically.

Single particle in tension (Fig 3a)

Assuming that the particle is highly flexible, there will be little resistance to deformation until such time that the particle is taut. Peat materials are typically made up of plant matter, composed of cellulose or lignin, both of which have a relatively high tensile strength and stiffness. As such, once the particle has become taut, it will have a reasonably high resistance to further deformation (extension of the particle).

Single particle in compression (Fig 3b – "stacked compression")

Assuming the particle is highly flexible, as above, the particle will provide little resistance to being folded or rotated. Which of the 2 modes of deformation occurs will depend on the orientation of the stress and the properties of the surrounding fluid medium. However, both modes result in a re-orientation of the particle perpendicular to the direction of the applied compressive stress. Once in this configuration we would expect significant resistance to further deformation (compression of the particle). This configuration, with particles aligned perpendicular to the applied stress and under compression, will be referred to as "stacked compression". Further compression would require consolidation of the particle itself, by squeezing out fluids from within the particle.

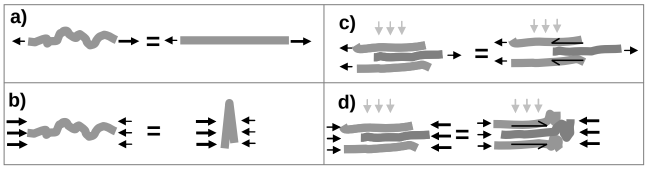
Interacting particles in tension (Fig 3c – "taut shear")

As with the single particle, we would not expect significant resistance to deformation until such time that the particles becomes taut. Once taut, we would expect some resistance to deformation (extension of the group of particles). In this case the resistance is governed by shear stresses along the interface between particles, rather than by the tensile strength of the particles. Based on traditional soil mechanics, the magnitude of this shear resistance will be proportional to the normal confining stress. This condition, with taut particles shearing against each other under tension, will be referred to as "taut shear".

Interacting particles in compression (Fig 3d – "gripped shear")

Under these conditions we might expect some initial deformation due to folding/buckling of the individual flexible particles, with very little resistance. At low confining stress this folding might continue, with complete re-arrangement of all the particles until they are perpendicular to the applied stress. However, at high confining stresses (relative to the applied compressive stress), the interaction with other particles will limit the space available for folding or rotation of the particles. Further deformation (compression of the group of particles along the applied stress axis) will be resisted by shear stresses along the particle interfaces. Again, the resistance will be proportional to the normal confining stress. This condition will be referred to as "gripped shear".

Fig. 3. Schematics - Individual and interacting peat particles under tensile and compressive stresses.



Translations

The schematics in figure 3 indicate differential stresses from one side to the other. As well as the compressive/tensile/shear behaviour discussed above, these will also result in a net translation, unless this is resisted by external forces.

Fluid stresses/deformations

Un-resisted fluid stresses

Peat has a naturally loose structure with large fluid-filled voids between particles. Fluids are, by definition, unable to sustain shear stresses. Under an applied shear stress a fluid will deform. The rate at which a fluid deforms under an applied stress is proportional to its viscosity. As such, a fluid can appear to generate a viscous resistance to applied stresses, but only if the rate of shearing is sufficiently fast. The rate of application of stresses in most geotechnical applications is relatively slow and this viscous resistance dissipates with time, hence it seems reasonable to assume no permanent viscous resistance.

Fluids have a resistance to volumetric compression or tension, under a uniform, all-around applied stress. A stress applied locally to one part of the fluid will result in a stress differential between different locations in the fluid. As the fluid cannot sustain shear stresses, this stress differential will result in flows from high to low stress. This flow will lead to deformation, which in term leads to changes in the applied stresses on the fluid. Deformation continues until there are no differential stresses within the fluid.

Typical patterns of fluid deformation

While fluids cannot sustain shear without deformation, shear stresses can develop along solid boundaries at the edge of the fluid. The fluid's viscosity and the rate of deformation determine how far the effect of the boundary shear extends into the fluid. As such, deformations (or velocities) will tend to develop the typical pattern shown in Figure 4. It is a common assumption in fluid mechanics that velocity/deformation will be zero at the boundary.

Fluid stress on particles

As noted above, applying a stress locally to the fluid will generate differential stresses (and flows) across the fluid. These differential stresses will act on each fluid particle, with different stress orientations at different locations in the fluid. This will result in an applied compressive stress and a net translation on each particle. For a very loose peat structure there will be folding and rotation of the particles, with little resistance. The particles will re-orientate themselves perpendicular to the applied stress, until they are able to interact in such a way as to generate compressive or shear resistance.

Essentially, the combined particle/fluid material will deform like a fluid, until such time that the particles are either in "stacked compression", "taut shear" or "gripped shear". Figure 5 illustrates the development of one such condition.

Fig. 4. Schematic – Typical fluid velocity profile.

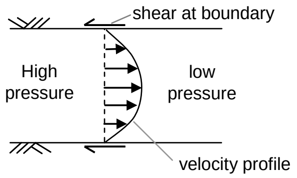
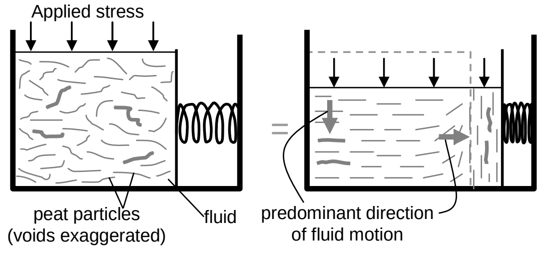


Fig. 5. Schematic – Peat particle re-orientation with fluid flow.



Particle resistance to fluid motion

Once the peat particles are aligned in such a way that they are able to resist the applied fluid stresses (either through compressive or shear resistance), then the deformation behaviour of the combined particle/fluid material changes. Now the combined material is able to sustain shear stresses and hence can sustain differential stresses. The fluid can still move, but only around and between particles, greatly reducing flow rates and preventing further development of the typical fluid deformation shapes. While the large fluid flows stop, deformations of the material as a whole continue, only now governed by the combined material's compressibility and consolidation properties. There is likely to be a gradual transition from fluid-dominated behaviour to particle-dominated behaviour. The following sections discuss possible mechanisms of behaviour once into the particle-dominated condition.

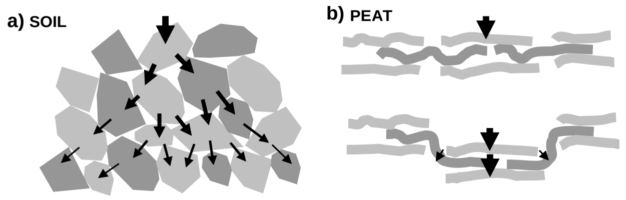
Stress distributions in peat

Particle contact stresses

Soils are sometimes idealised as stacked particles with discrete contacts (see Figure 6a). As the particles are assumed to be rigid and incompressible, vertical stresses applied to a single particle at the top of the stack will be redistributed across multiple supporting particles, thus spreading and reducing the magnitude of stresses in lower layers. In conventional continuum soil mechanics, this is represented by Boussinesq's theory.

Given the shape and flexibility of peat particles, localised vertical stresses may result in significant vertical deformation before stresses begin to transfer laterally to adjacent particles. If particles are suitably elongated and stacked in a loose, parallel configuration (see Figure 6b), then vertical stresses may be transferred to underlying particles, with minimal redistribution of stresses laterally. This would suggest little dissipation of vertical stress with depth (i.e. a more uniform stress distribution). It should be noted that vertical stress increases during fluid-dominated behaviour may also be uniform with depth, rather than in accordance with Boussinesq' stress distribution.

Fig. 6. Schematic – Transfer of stress between particles for soil and peat.



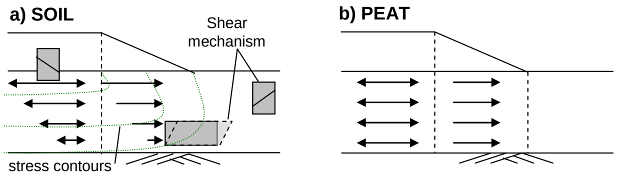
The uniform stress distributions discussed above will result in very different patterns of deformation than those resulting from a Boussinesq's stress distribution. Boussinesq distributions should be used with caution in peats. Further investigation and research into this issue are required.

As described in Figure 3, above, after some deformation the peat particles will become more taut and may develop significant shear stresses at interfaces with neighbouring particles. In this configuration a higher proportion of vertical stresses can be redistributed laterally. Taking this into account, it seems reasonable to assume that the first loading of virgin peat will tend to produce little dissipation of load with depth (i.e. a uniform vertical distribution). However under subsequent loading there will be more lateral redistribution of stresses, leading to a pattern closer to the Boussinesq's approximation. Peat parameters e_m and Ω may give an indication of which pattern will occur, with more uniform stress distributions expected at high e_m and Ω values.

Profiles of horizontal stress

Based on the stress distributions discussed above, Figure 7 shows a representation of the additional horizontal stresses experienced at varying depths (for "soil" and "peat") under a new embankment. The length of the arrows represents the magnitude of the stress. Double-ended arrows represent stresses acting equally in all horizontal directions, whereas single-ended arrows represent a net driving stress (or "stress differential") acting in the direction indicated. From the stress differentials shown, it is easy to see how the typical pattern of shear planes develops in the soil model. A differential between principal vertical and horizontal stresses will tend to create inclined shear planes under the full height embankment and beyond the toe. These planes will then connect with a horizontal shear plane caused by the horizontal stress differential, leading to the familiar "circular" failure mechanism. In the peat, the likely pattern of shearing is less clear.

Fig. 7. Schematic – Horizontal stresses due to embankment construction on soil and peat.



At this point it is necessary to discuss earth pressure coefficients in peat. It was discussed earlier that deformations are initially governed by the fluid, until the particles become re-orientated in such a way that they can produce resistance to stresses and deformations. Stresses at any point in a fluid are equal in all directions hence, while the fluid is dominating the behaviour, horizontal stresses can be assumed to equal vertical stresses (i.e. in-situ earth pressure, k_0, = 1). However it was also discussed above that naturally deposited peat particles may be able to deform vertically with little lateral redistribution of particle stresses (i.e. effective stresses), which would indicate a very low k_0 value. The k_0 value is likely to decrease initially as the material changes from a fluid-dominated to a particle-dominated state; however the k_0 value may subsequently increase over time, due to consolidation and particle re-orientation. Hence, when selecting an appropriate k_0 value one should consider the arrangement of the particles and also whether the fluid or the particles are expected to dominate behaviour under the next increment of load. These factors will be difficult to measure directly, however peat parameters e_m and Ω may give an indication of k_0.

Summary of qualitative concepts

The behaviour of peat is complicated by the fact that the natural behaviour of the fluid and the particles are very different from each other and it is not easy to visualise which of the two behaviours will dominate. Furthermore the behaviour of the particles changes as they re-orientate relative to each other and as they individually become taut. Hence, at this point in the paper, it is necessary to summarise some salient concepts which will be assumed going forwards:

On first loading of virgin peat, assume:

- Fluid initially dominates stress/deformation;
- Increase in horizontal stress is uniform with depth;
- $k_0 = 1$ (as fluid dominates);
- Peat particles will re-orientate perpendicular to direction of fluid motion;
- After some deformation, peat particles become arranged such that they can resist applied fluid stresses;
- After this point, the peat particles dominate stress/deformation;

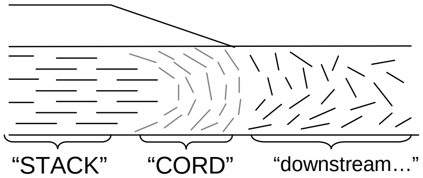
Quantitative modelling

The following section of this paper is a first attempt to build a quantitative model of the conditions discussed above. The formulae presented here are for preliminary discussion only and detailed assumptions and calculations have been omitted. These formulae are not suitable for use in design until further development and verification have been completed.

Peat resisting stresses

Based on the pattern of fluid deformations indicated in Figure 4, Figure 8 shows likely particle re-orientations. Peat particles are shown disconnected with large voids for clarity. There are 3 distinct structures generated by the embankment load.

Fig. 8. Schematic – Modes of peat particle re-orientation under embankment.



Firstly, the "Stack" structure represents horizontally aligned particles, which have been compressed flat under the vertical load/settlement of the embankment. This structure can resist vertical compression through a consolidation mechanism ("stacked compression"), similar to a soil. There is also some resistance to lateral deformation at its right end, as this will generate extension of the stack and hence inter-particle shear stresses ("taut shear").

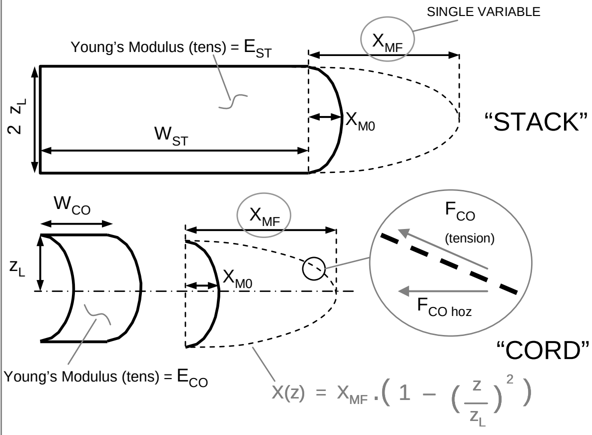
The "Cord" structure represents an arc of particles aligned perpendicular to the fluid flow. Assuming that this cord can be restrained by shear stresses at the top and bottom of the peat layer, any further lateral deformation requires an extension of this cord. Hence there is a resistance to lateral deformations due to inter-particle shear stresses in the cord ("taut shear").

The "downstream" zone is considered to continue behaving like a fluid. The presence of other embankments or obstructions in the downstream zone is discussed later.

To quantify the extension of the stack and cord, a mathematical shape for the fluid deformation curve was modelled as a polynomial with constant second derivative (i.e. $\delta^2x/\delta z^2$ = constant). Vertical coordinates are defined outwards from the middle of the curve. Inter-particle shear stresses are modelled as a net elastic tensile stiffness of the peat material (E_{ST} in the stack and E_{CO} in the cord). As discussed, there will be some un-resisted fluid deformation before the peat particles are able to produce any resistance. This deformation is denoted as X_{m0}.

Figure 9 explains the geometric input parameters and shows the resulting formulae for total horizontal forces, generated by tension in the stack and cord. These formulae demonstrate that it is possible to determine a unique value of total horizontal resisting force for a given mid-point deflection (X_m). It should be noted that forces were calculated rather than stresses solely to simplify mathematical integration and directional resolution. Total horizontal forces can be easily converted to average horizontal stresses in the peat layer.

Fig. 9. Peat model parameters and formulae.



$$X(z) = X_{MF} \cdot \left(1 - \left(\frac{z}{z_L} \right)^2 \right)$$

"STACK":

$$F_{tot\ st\ hoz} = \frac{4}{3} E_{ST} \cdot z_L \cdot \frac{(\boxed{X_{MF}} - X_{M0})}{(W_{ST} + \frac{2}{3} X_{M0})}$$

"CORD":

$$F_{tot\ co\ hoz} = \frac{F_{CO} \cdot z_L^{1.5}}{2\boxed{X_{MF}}}$$

[Forces per unit length (plane strain)]

$$F_{CO} = W_{CO} \cdot E_{CO} \frac{L_F - L_0}{L_0}$$

$$L_{(0/F)} = z_L \cdot \sqrt{1 + 4\frac{\boxed{X_M}^2}{z_L^2}} - \frac{z_L^2}{2\boxed{X_M}} \cdot \ln \left| \sqrt{1 + 4\frac{\boxed{X_M}^2}{z_L^2}} - \frac{2\boxed{X_M}}{z_L} \right|$$

As a first approximation, geometric parameters W_{ST} and W_{CO} are taken to be half the embankment width and the length of the slope, respectively. Further work is required to refine these parameters, based on field trials.

Rate of deformation

In soils, driving and resisting stresses are predicted and compared. If driving stresses are greater than resisting stresses then the soil is assumed to "fail". As suggested in Figure 9, peat generates increasing resistance with increasing deformation. As such it is less useful to discuss peat in terms of "Factors of Safety" and more useful to discuss magnitudes of deformation required to reach equilibrium.

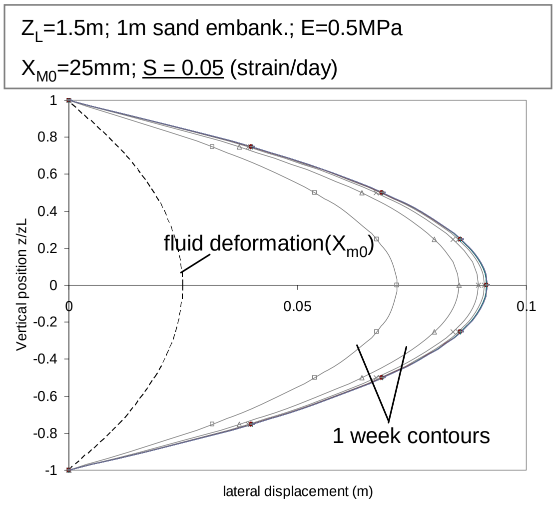
The formulae within Figure 9 give the resisting force for a given deformation. They do not enable the direct determination of a deformation for a given applied force. Total deformation can only be determined by considering the gradual development of deformations and resistance over time. Initially there is little resistance and hence we would expect large deformations. With deformation comes an increase in resistance and hence the rate of deformation will decelerate over time. The rate of deformation will tend towards zero as the total resisting force tends towards the driving force. The simplest mathematical method for calculating this deceleration is by using a simple incremental approach.

Logically, the rate of deformation will be proportional to the difference between the applied stress and the resistance. It also seems logical that the rate of deformation will be inversely proportional to the stiffness of the material. As such, the simplest approximation for rate of deformation is to use a single linear constant of proportionality, S, as follows:

[4] $$\text{Strain per day} = \frac{S.\,\sigma_{net}}{E_{rep}}$$

Where σ_{net} is the net horizontal stress and E_{rep} is an average stiffness representative of both the stack and cord structures. S has units of day^{-1}. To clarify, the stress and stiffness at time zero could be used to predict an ultimate strain ($\varepsilon = \sigma/E$), but this does not account for the increase in resistance over the course of that deformation. A value of $S = 0.05$ means that after 1 day the strain is only 5% of the strain predicted from σ/E at time zero, due to deceleration over the course of the day. Figure 10 shows an example result, using this method.

Fig. 10. Example of deformations from peat model.



Stress on underlying layers

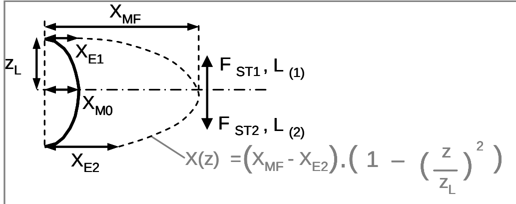
In the model described above, there are horizontal stresses acting at the top and bottom of the “Cord” structure. If these stresses exceed the shear strength of the peat/soil interface then, logically, there will be some slip of the “Cord” structure relative to the interface. In this instance the “Stack” would continue to function, but the “Cord” would not elongate and hence would not increase in resistance.

Alternatively, if there is no slip at the interface, these stresses will be applied to the adjacent soils and should be considered in their analyses. It should be noted that applying various combinations of typical values to this peat model would appear to indicate relatively small stress magnitudes at the interface (no more than a few kPa). However, the additional vertical stresses transferred to the underlying soil due to the non-Boussinesq stress profile (see Figure 7) may be significant.

This approach would suggest that Boussinesq modelling of stresses in peat may be un-conservative for underlying layers. However this has not yet been verified by lab or field measurements and further investigation is required to clarify this issue.

Whatever the reason, it is not uncommon for inclinometer measurements to show noticeable lateral displacements at the top of soil layers beneath peat. In this case it is necessary to adjust the mathematical shapes used in the peat model. Figure 11 shows an adapted model to account for this.

Fig. 11. Parameters and formulae adapted for deformations at peat/soil interfaces.



$$X(z) = (X_{MF} - X_{E2}).\left(1 - \left(\frac{z}{z_L}\right)^2\right)$$

“STACK”: $$F_{ST1} = \frac{2}{3}E_{ST}\,.\,z_L\,.\frac{\left(X_{MF} - X_{M0} + \frac{1}{2}X_{E1}\right)}{.\left(W_{ST} + \frac{2}{3}X_{M0}\right)}$$

$$F_{ST2} = \frac{2}{3}E_{ST}\,.\,z_L\,.\frac{\left(X_{MF} - X_{M0} + \frac{1}{2}X_{E2}\right)}{.\left(W_{ST} + \frac{2}{3}X_{M0}\right)}$$

$$\boxed{F_{ST\,HOZ} = F_{ST1} + F_{ST2}}$$

“CORD”:

$$L_{(1)} = z_L\,.\sqrt{1 + \frac{4(X_{MF}-X_{E1})^2}{z_L^2}} - \frac{z_L^2}{2(X_{MF}-X_{E1})}.\ln\left|\sqrt{1 + \frac{4(X_{MF}-X_{E1})^2}{z_L^2}} - \frac{2(X_{MF}-X_{E1})}{z_L}\right|$$

$$L_{(2)} = z_L\,.\sqrt{1 + \frac{4(X_{MF}-X_{E2})^2}{z_L^2}} - \frac{z_L^2}{2(X_{MF}-X_{E2})}.\ln\left|\sqrt{1 + \frac{4(X_{MF}-X_{E2})^2}{z_L^2}} - \frac{2(X_{MF}-X_{E2})}{z_L}\right|$$

$$\boxed{L_{CO} = L_{(1)} + L_{(2)}}$$

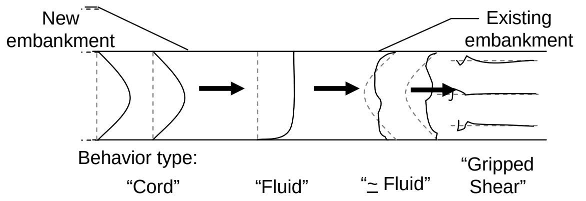
The model is fairly flexible to other adaptations to fit observed field behaviour, e.g. maximum deflection not coinciding with the middle of the peat layer, etc.

Downstream effects

Peat behaves like a fluid until the peat particles become re-orientated such that they can resist the fluid motion. Beyond the toe of the new embankment (see Figure 8) the initial deformation and particle re-orientation may be similar to the “Cord” structure. However, the downstream peat is unconfined at the surface and hence a cord-like mechanism is unlikely to develop (although it may be possible in cases with a significant vegetation mat at the surface). Instead there will probably be some temporary bulging or visible lateral deformations at the surface, followed by a return to the original condition (as would be observed in a fluid). If this zone is behaving like a fluid, horizontal deformations could propagate significant distances, until some resistance to the fluid motion is encountered.

The main reason for interest in downstream movements is the assessment of impacts on neighbouring embankments or infrastructure. While a quantitative model for such cases has not been developed as part of this paper, Figure 12 shows a schematic of the likely modes of behaviour at different locations.

Fig. 12. Schematic – Behaviour modes near existing embankment.



In the “Cord” zone of the existing embankment, the imposed deformations are now in the opposite direction and hence will not result in an extension of the cord (rather, a shortening). At worst this zone will revert to fluid-like behaviour and at best will retain its shape and translate somewhat laterally, transferring much of the applied lateral stresses/deformations to the existing “Stack” zone.

The “Stack” zone of the existing embankment is likely to have experienced significant consolidation over time and hence particles will be horizontally aligned and under a reasonable vertical effective stress. As such, applied lateral stresses/deformations can be resisted by shear between the particles (“gripped shear” – see Figure 3d) and are unlikely to extend very far into the existing embankment.

Conclusions and future work

Peat particles are unlike soil particles. The primary differences appear to be: 1) Void ratios should not be determined directly from “oven dried” moisture contents; and 2) The orientation of elongated peat particles will influence mechanical behaviour. Hopefully, the concepts and models discussed here provide some indication that the practical and mathematical obstacles to developing a theoretical model are not insurmountable. Furthermore, the first attempts at producing qualitative and quantitative models indicate how models of this type might provide interesting insight into *modes* of peat behaviour, which are difficult to visualise while using conventional soil models.

This paper was written in the hope of encouraging open-minded discussion about alternative models for peat. The paper does not include any real data for peat, but asks readers to compare against their own experience. Further development of these models should focus on expansion of the micro-mechanics and fluid flow mechanisms discussed in this paper. Field and laboratory testing should be carried out to confirm or improve upon the new parameters discussed (Ω, e_m, X_{m0}, $E_{tensile}$, S) and to investigate correlations between these and other parameters. This is likely to require a full spectrum of testing, including specialist laboratory tests, large scale physical models and instrumented field trials, to capture a wide range of modes of behaviour and to provide sufficient quantitative data for future models.

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