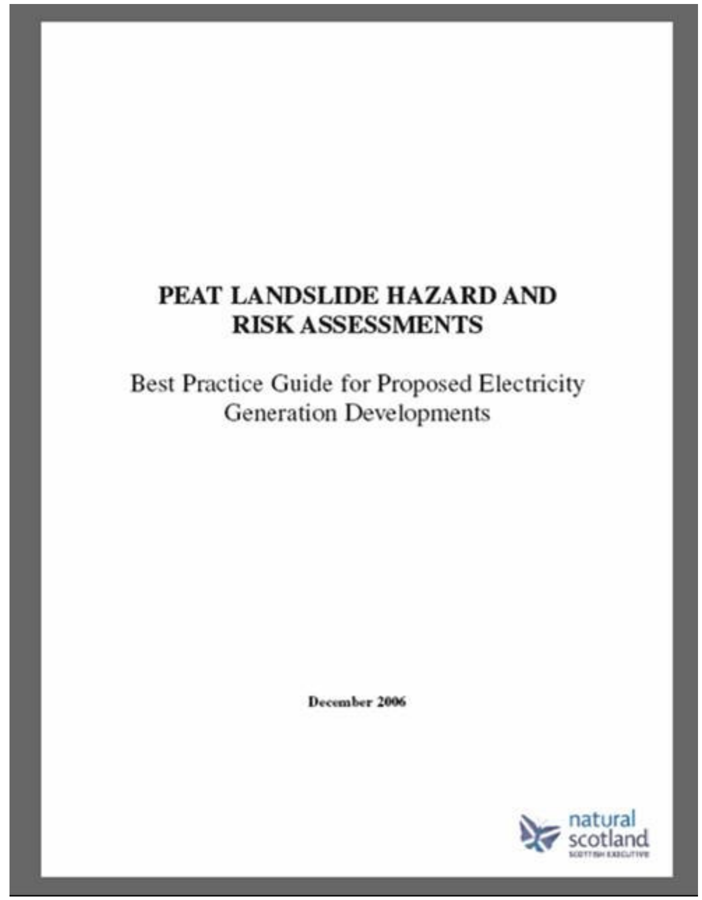
Problems with Testing Peat for Stability Analysis

Dick Gosling & Peter Keeton
Soil Mechanics

Scottish Executive Document

- Published December 2006
- Includes requirement for slope stability analysis using “infinite slope equation” (Skempton & DeLory, 1957)



PEAT LANDSLIDE HAZARD AND RISK ASSESSMENTS

Best Practice Guide for Proposed Electricity Generation Developments

December 2006

natural scotland
SCOTTISH EXECUTIVE

Peat

- Is an organic soil

- It may be defined as:
  - consisting of the remains of dead vegetation in various stages of decomposition which accumulates in a mire

- It is characterised by:
  - High water content, often several hundred or even thousand percent (geotechnical definition, ie weight of water/weight of solids)
  - Correspondingly high Liquid and Plastic Limits
  - Low bulk density, typically around 1.1 Mg/m^3

Infinite Slope Equation

The stability of a slope can be assessed by calculating the factor of safety *F*, which is the ratio of the sum of resisting forces (shear strength) and the sum of the destabilising forces (shear stress):

$$F = \frac{c' + (\gamma - m\gamma_w)z\cos^2\beta\tan\phi'}{\gamma z\sin\beta\cos\beta}$$

where c' is the effective cohesion, γ is the bulk unit weight of saturated peat, γ_w is the unit weight of water, m is the height of the water table as a fraction of the peat depth, z is the peat depth in the direction of normal stress, β is the angle of the slope to the horizontal and ϕ' is the effective angle of internal friction.

- Nothing wrong with equation itself, regularly used for inorganic soils
- However, its use pre-supposes that the effective stress parameters, c′ and Φ′, are appropriate for peat
- Furthermore, by implication, that these parameters can be obtained from standard laboratory testing

Overburden pressure

- The $(\gamma - m\gamma_w)z$ term in the equation is the effective pressure, which is alternatively given the symbol p_0'

- It will be very low due to peat overburden

  - eg at base of 2 m thick layer with water level at ground level p_0' only about 2 kPa

  - Compare this to an inorganic soil where the same layer thickness and water level would impose a p_0' of 20 kPa, ie some 10 times greater

Effective stress shear strength

- Muskeg Engineering Handbook (1969) states that:
  "recent research has shown conclusively that it [peat] is essentially a frictional material and that it behaves closely in accordance with the principles of effective stress"

- It goes on to note that an extensive body of test data indicates Φ' values are exceptionally high compared with inorganic soils citing Adams (1961) as measuring Φ' values as high as 50 degrees

- Results from consolidated undrained triaxial test with measurement of pore water pressure but this was not today's standard test; it lasted 3 months and required over 50% axial strain to reach failure

- However standard tests carried out recently can be interpreted to give similarly high Φ' values

Effective stress shear strength

- Hobbs (1986) in his major treatise on peat, does not concur with Muskeg Handbook
- He specifically excluded any discussion on shear strength
- Stated that:

  "it is clear that the strength depends not only on effective stress but also on time as the void ratio continuously decreases under maintained load"

Quarterly Journal of Engineering Geology, London, 1986, Vol. 19, pp. 7–80. Printed in Northern Ireland

Mire morphology and the properties and behaviour of some British and foreign peats

N. B. Hobbs

Soil Mechanics Ltd, Foundation House, Eastern Road, Bracknell, Berkshire RG12 2U2

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Laboratory tests

- SE list of tests that may be of value
- With classification tests, (i) to (vi), some variations to standard procedures (for inorganic soils) are appropriate for peat
- No such qualifications are noted for the strength tests, (vii) and (viii)
- Potential for confusion: undrained/drained not necessarily synonymous with total/effective stress

Physical properties and shear strength tests

The following physical properties may be of value in characterising peat and substrate, although the applicability of (iv) to (viii) for certain peat depends on the specific peat conditions:

(i) Moisture content;
(ii) Bulk density;
(iii) Organic content (Loss on Ignition);
(iv) Plastic and liquid limit;
(v) Specific gravity;
(vi) Particle size distribution;
(vii) Triaxial tests for undrained shear strength parameters; and
(viii) Drained and undrained direct shear box testing.

Hobbs (1986) provides useful practical advice on the applicability of such standard index tests to peat soils, however caution should be exercised in any interpretation of ground conditions based upon these tests.

The following tests may also be of value in characterising the peat and substrate:

(ix) Soil pH and sulphate content – (if concrete design is a consideration);
(x) Linear shrinkage; and
(xi) Fibre content.

Tests should be carried out in accordance with BS1377 (1990a), however, some variations are required in certain test procedures to account for the highly organic

Laboratory strength tests

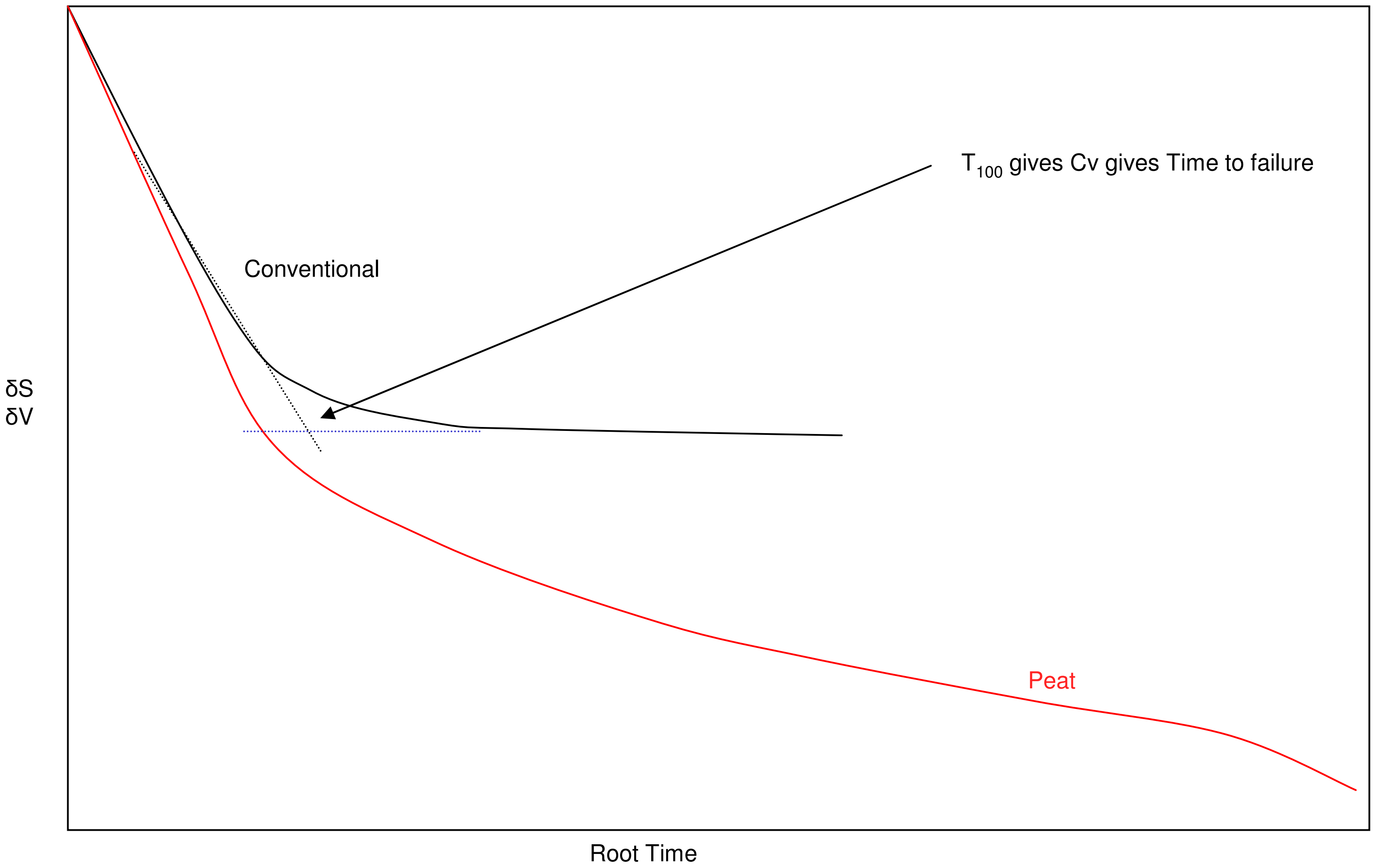
- SE document states that all shear strength tests should be performed on undisturbed samples taken from intact block samples
- In practice
  - Some clients are supplying block samples and scheduling drained direct shear tests
  - Others have been supplying tube samples and scheduling effective stress triaxial tests, either consolidated drained or consolidated undrained with measurement of pore water pressure

Laboratory Test Problems

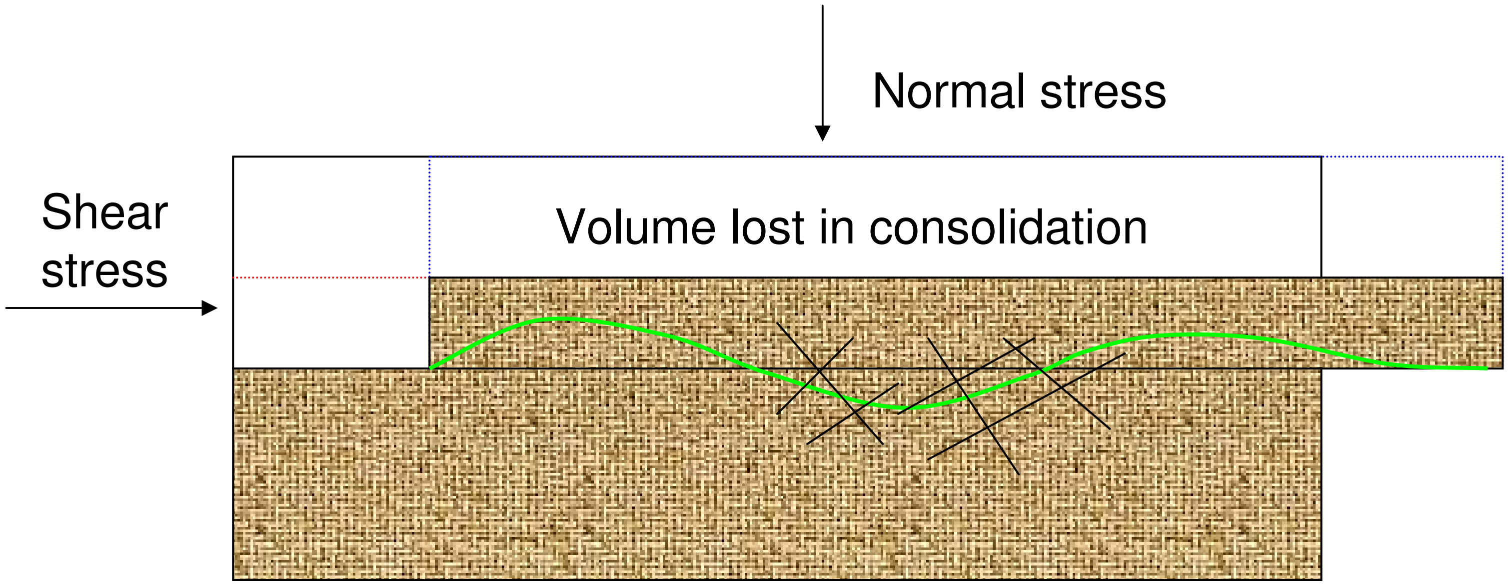
- There are major problems when either direct shear or triaxial tests are performed on peat

- The following slides, show that peat behaves radically different from an inorganic soil

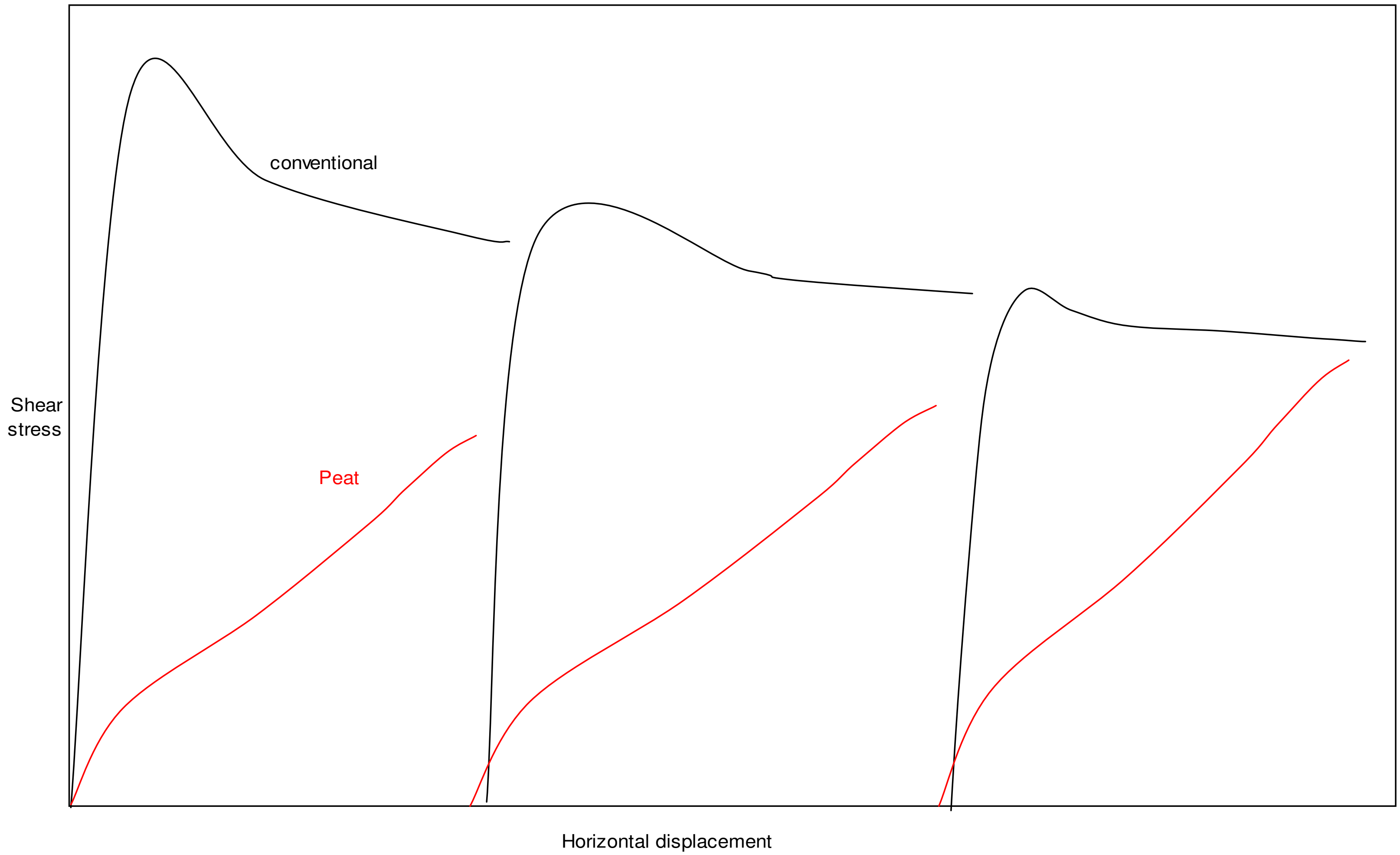
Consolidation



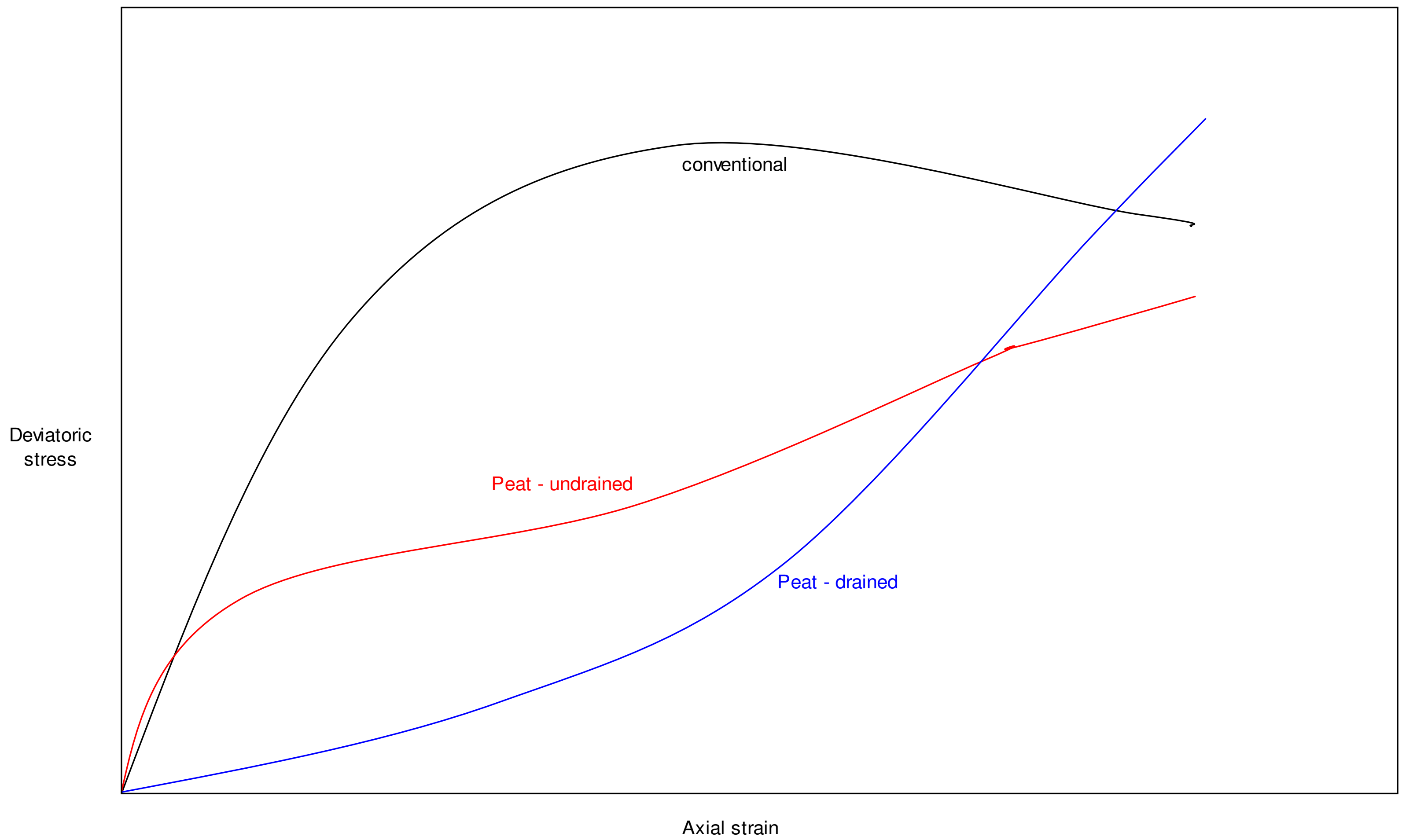
Shear box test



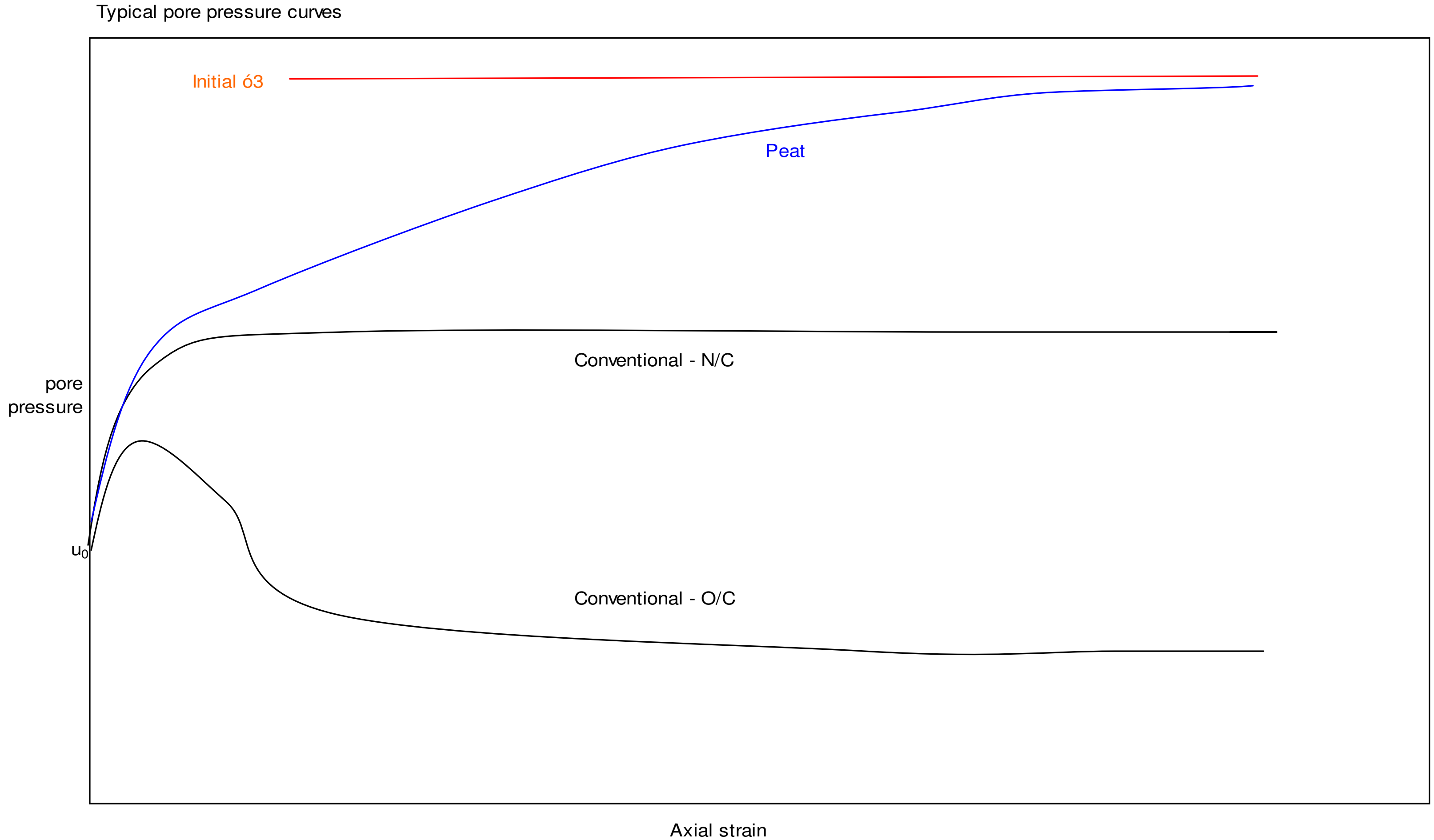
Direct shear test – stress/strain



Deviatoric Stress v Axial Strain

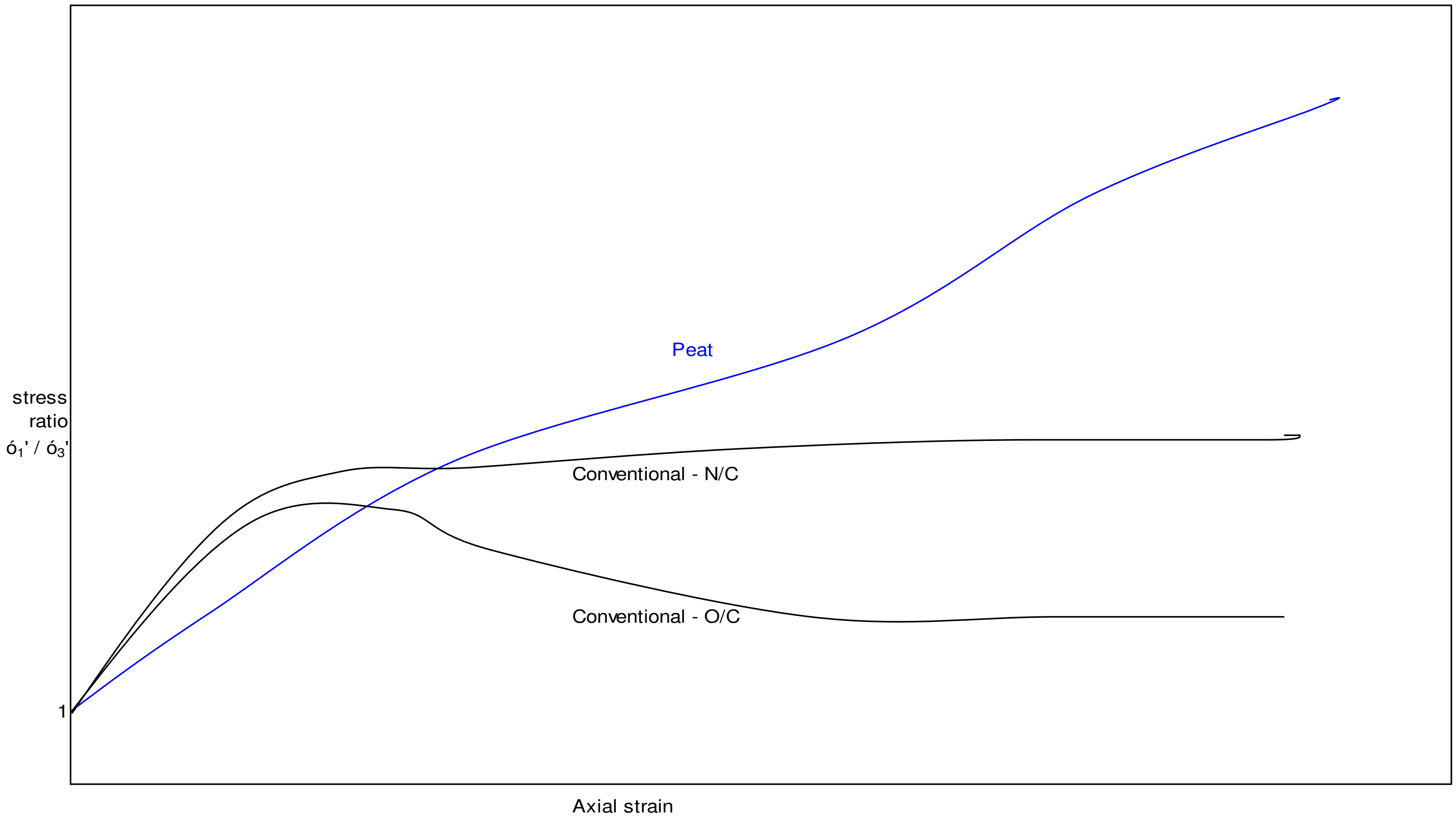


Pore pressure v Axial strain



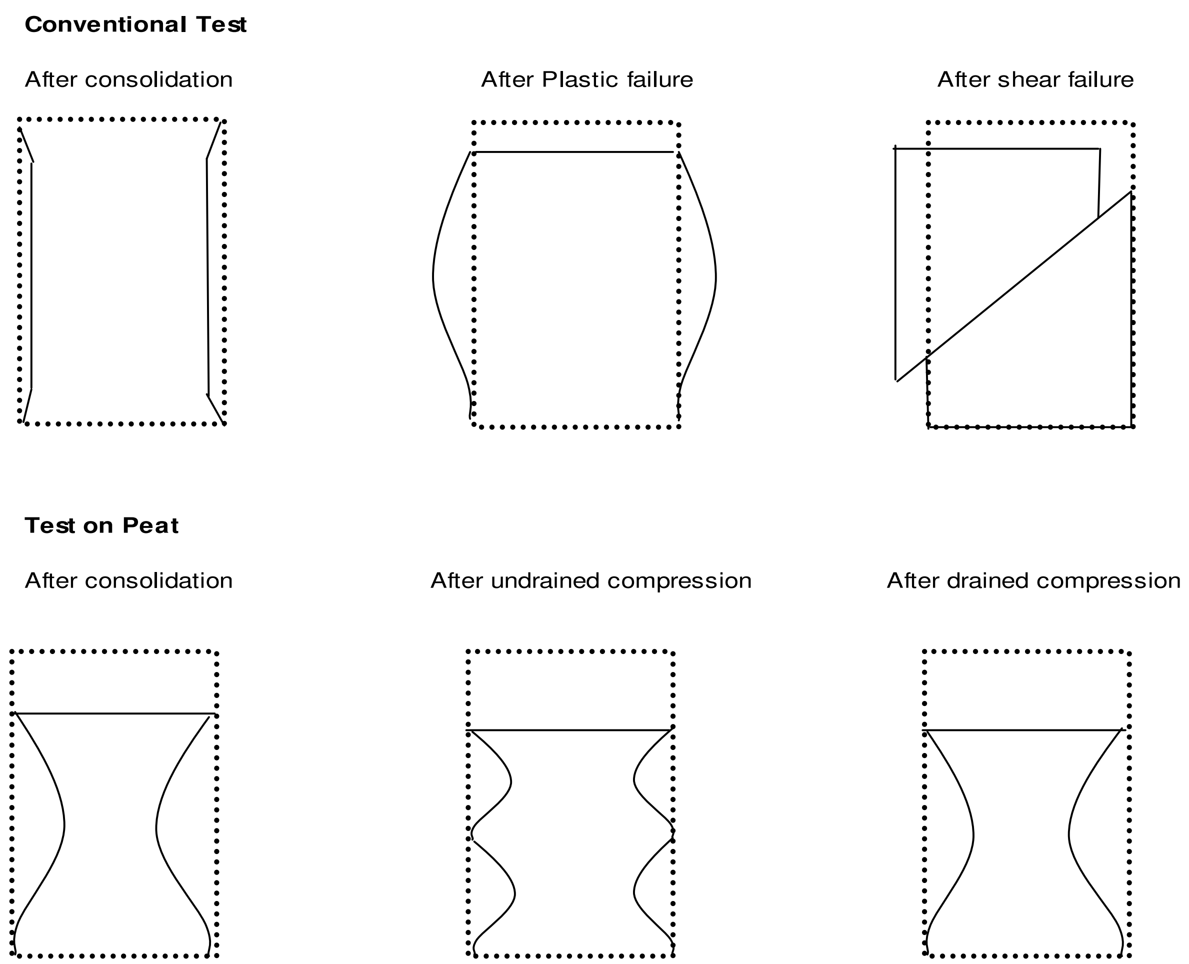
Volume change in drained tests behaves as pore pressure in undrained

Undrained Test - Stress Ratio v Axial Strain



Stress ratio at failure, normally in single figures, for peat between 10 and 100.

Triaxial Tests - Mode of Failure



Stability Analysis – Case Histories

- Rarely undertaken for peat in past but two references given (Carling, 1986 & Warburton et al, 2004)
- Total of 6 slides back analysed
  - peat typically 1 to 2 m thick
  - slopes around 10 degrees
- Strength parameters assigned to peat
  - c′ = 5 to 9 kPa
  - Φ′ = 21.5 to 23 (or possibly 13.5) degrees
- Back analyses (with water level at ground level) generally gave F between 2 & 6, ie do not explain failure
- Several of the slides appear to have occurred in the clay substrate rather than in peat itself
- Need to invoke residual parameters in substrate or excess pore water pressure and/or water filled tension cracks to reduce F to unity

Stability Analysis – Parametric Studies

- Given the very low effective overburden pressure F is much more sensitive to c′ than Φ′

- See next two slides, both start from the parameters for Landgon Head quoted by Carling (c′ = 6.52 kPa, Φ′ = 14.45^{o})

Langdon Head

- Peat depth 1.13 m
- Peat density 10.24 kN/m^3
- Water level at ground level
- Gradient 7.8 degrees

Φ′	14.45	20	30	50
F	4.27	4.30	4.37	4.56

Langdon Head

- Peat depth 1.13 m
- Peat density 10.24 kN/m^3
- Water level at ground level
- Gradient 7.8 degrees

c′	6.52	5	2.5	0
F	4.27	3.29	1.60	0.08

Stability Analysis – Parametric Studies

- Given that c′ is established by projecting the Mohr-Coulomb envelope back to axis, it is thus intimately dependent on the interpretation of Φ′

- In the light of uncertainties in testing as discussed in this presentation the reliability of calculated F is open to very serious question

The Future

- Questions raised about whether conventional strength parameters are appropriate to peat and even if they are our ability to measure them reliably
- Current research into mechanical behaviour of peat (direct simple shear / axial shear device – see Ground engineering Dec 2007) may help
- What do we do in the meantime?
- Can we really continue to ignore tensile strength?