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Aspects of Soil Mechanics Teaching

L. D. Wesley[1], PhD.M.ASCE
M. J. Pender[1], PhD, FIPENZ, M.ASCE

[1]Department of Civil and Environmental Engineering, University of Auckland , Private Bag 92019, Auckland, Ph 62 9 373 7599; l.wesley@auckland.ac.n.z; m.pender@auckland.ac.nz

ABSTRACT

There are some weaknesses in the teaching of soil mechanics that are detrimental to the subject becoming a relevant and well balanced theoretical basis for the practice of geotechnical engineering. Firstly, there is an emphasis on methods rather than on concepts and principles. The writers experiences in training or mentoring new graduates is that they are well versed in methods but much weaker in their grasp of basic concepts. Secondly, the order in which the subject is taught can put students off the subject at the start of their soil mechanics courses. Thirdly, some of the material taught presents a simplistic and highly idealised version of soil behaviour, and many students, in their careers, do not move on from these simplistic concepts.

Keywords: teaching soil mechanics, residual soil, compressibility, seepage, stability analysis

1 INTRODUCTION

Judging from the most widely used soil mechanics text books, the teaching of basic soil mechanics concepts has not changed much for many years, despite adequate evidence that some concepts are of very limited relevance to many natural soils. The most obvious example is the existence of residual soils and the fact that geotechnical engineers are routinely treating these as though they are sedimentary soils. This paper addresses this issue along with several others that are worthy of reconsideration.

2 THE ORDER OF TEACHING AND THE PRINCIPAL OF EFFCTIVE STRESS

The principle of effective stress is at the core of the subject, and should be presented at the very beginning of soil mechanics courses and returned to on numerous occasions throughout all courses.

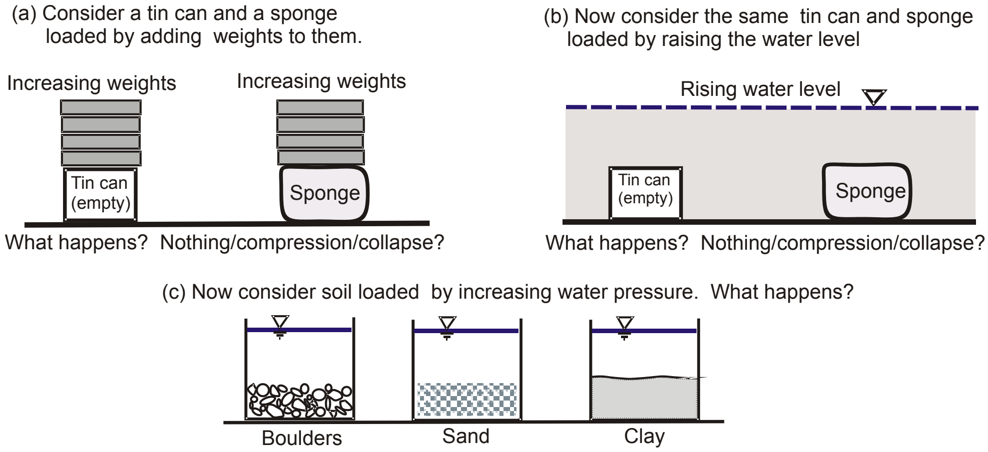
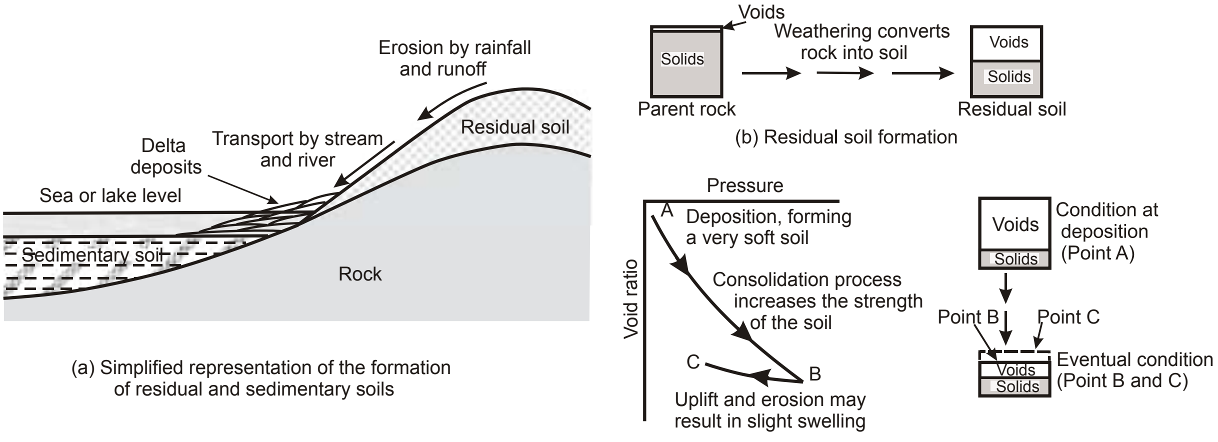


Figure 1 Introducing the principle of effective stress.

When teaching the first soil mechanics course in the civil engineering curriculum, the authors have sought to explain the principle with reference to simple situations, and get across the message that the concept is not something new and esoteric, but something they can already grasp from their own experience and understanding of the physical world around them. Figure 1 illustrates some simple thought exercises that can be used as a starting point in presenting the principle. Most students readily perceive that the reaction of the sponge subject to loading with water pressure is quite different from loading it with weights, and that this is related to the fact that the external pressure is resisted by the water within the sponge. It is generally better to introduce the principle of effective stress with examples of its physical reality than by presenting an equation and defining its components.

3 SOIL FORMATION AND THE PROPERTIES OF RESIDUAL SOILS

Early in the soil mechanics curriculum the modes of soil formation should be described and students made aware of the two basic soil types, namely residual and sedimentary (or transported) soils. In fact, it is high time that residual soil behaviour became part of mainstream soil mechanics, and their properties covered as necessary throughout soil mechanics courses. Figure 2 illustrates the modes of formation of residual and sedimentary soils.



(a) Simplified representation of the formation of residual and sedimentary soils

(b) Residual soil formation

(c) Sedimentary soil formation

Figure 2.Process of formation of residual and sedimentary soils.

The most important points students should appreciate are the following:

(a) The erosion, transport and re-deposition of sedimentary soils means that they tend to have a degree of homogeneity and predictability that is absent from residual soils;
(b) Probably more of the earth's surface is covered by residual soils than sedimentary soils;
(c) Soil mechanics courses and text books are almost invariably based on the behaviour of sedimentary soils and residual soils are scarcely mentioned;
(d) Concepts or models of soil behaviour that relate to the mode of formation of sedimentary soils are hardly likely to be valid for residual soils.

4 COMPRESSION BEHAVIOUR

We do not have to look far to find serious misinterpretations of soil behaviour because of the use of the log scale for pressure. Figure 3 shows a typical text book example. The conventional log plot is shown on the left, and the same graphs redrawn using a linear scale on the right. It is clear that the pre-consolidation pressure determined from the log graph is not present in the linear plot. Soil mechanics literature is riddled with examples of pre-consolidation pressures derived from e-log(p) graphs that are only reflections of the way the data are plotted, and are not soil properties at all.

Figure 4 shows a further example from tests on a real soil. Pre-consolidation pressures have been inferred from the log graphs and over-consolidation ratios determined, as the figure indicates. This is an example of simplistic ideas derived from sedimentary soils being applied blindly to a situation to which they have no relevance. The linear plots reverse the curvature of the graphs, and illustrate clearly that these are "strain-hardening" materials devoid of any pre-consolidation or yield pressure. The e-log(p) graph is routinely misinterpreted with both sedimentary soils and residual soils. While there is some justification for using the log plot with sedimentary soils, there is no reason at all for doing so with residual soils. Stress history is entirely irrelevant, and there is no such thing as a virgin consolidation line with a residual soil.

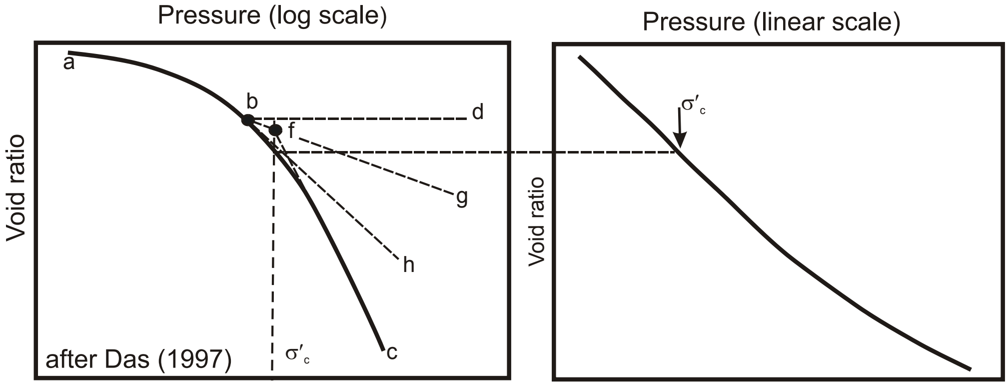


Figure 3 Textbook log and linear scale representations of soil compressibility

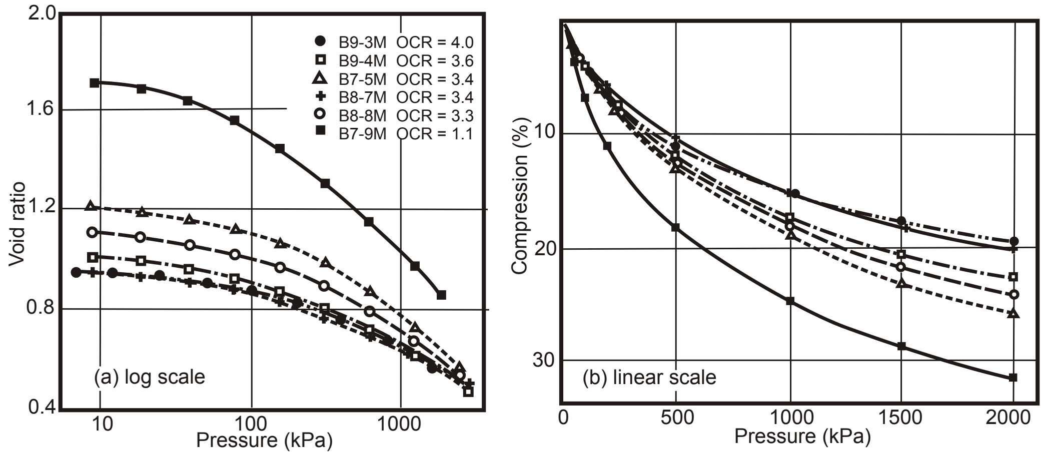


Figure 4 Oedometer tests on a residual soil as log and linear plots (after Wesley, 2000).

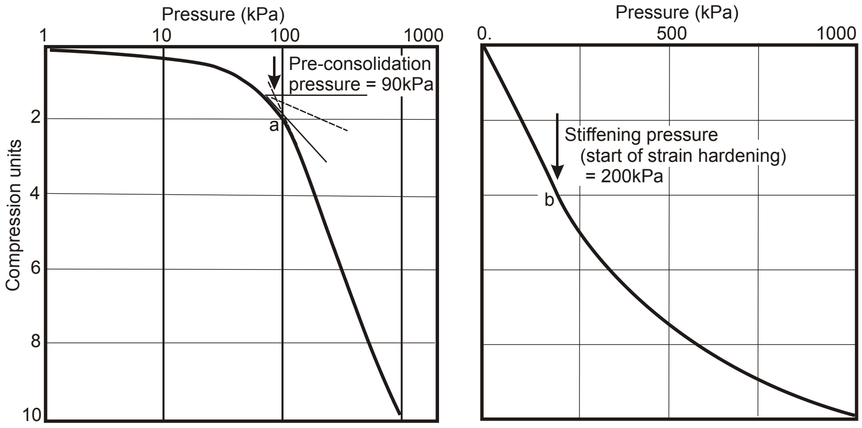


Figure 5 A conceptual comparison of log and linear plots.

Figure 5 illustrates the fundamental difference between a log and a linear plot, and the “trap” into which the former leads geotechnical engineers. Point a on the first graph is the pre-consolidation pressure according to conventional practice. The second graph shows this to be entirely illusory and Point b on the second graph is the only point indicating a change of behaviour in the soil, namely the onset of strain hardening. A straight line on a log plot always indicates a soil becoming steadily stiffer. The pre-consolidation pressure inferred from the log plot is not an indication of the start of yield, and is in fact not far below the start of strain hardening.

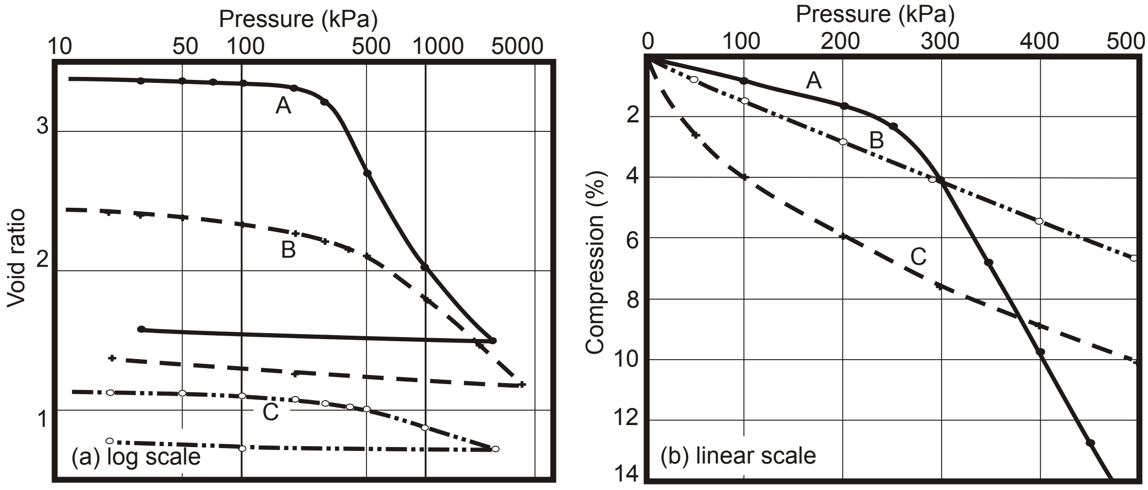
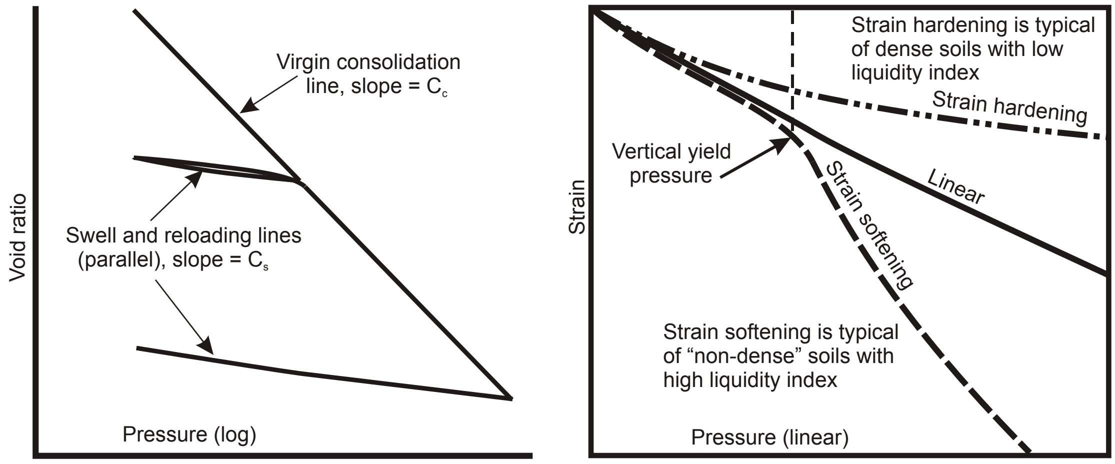


Figure 6 Oedometer tests on sample of volcanic ash clay (after Wesley, 2009)



(a) The conventional portrayal

(b) A more realistic and informative plot

Figure 7 The conventional portrayal of soil compressibility and an alternative more realistic version

A very serious defect of the e-log(p) plot is that it creates the impression that the compressibility of all soils is similar and can be adequately represented by two straight lines on a log plot of pressure, as shown in Figure 7(a). There is overwhelming evidence that this is not the case, as illustrated in Figure 6 which shows the results of oedometer tests on three samples of volcanic ash clay plotted using both log and linear scales. The log plot suggests that apart from the large differences in void ratio the samples show similar behaviour and yield pressures could be inferred from the graphs. When plotted using a linear scale, the behaviour is no longer similar at all, at least not over the pressure range of interest in practical foundation design situations. Only sample A shows evidence of a yield pressure. Sample B shows linear behaviour, and sample C becomes steadily stiffer as the stress level rises.

On the basis of the behaviour illustrated above, a much more realistic portrayal of soil behaviour in general is that using a linear scale shown in Figure 7(b). This presents a far truer picture than the conventional portrayal in Figure 7(a). This portrayal is valid for all soils, whether sedimentary or residual, over the stress range of interest to foundation designers. Some soils show approximately linear behaviour (for example Auckland residual soils, Pender et al (2000)), some show strain hardening almost from the start of loading, and some show a clear yield pressure. This yield pressure may be due to pre-consolidation but is just as likely to be the result of chemical factors involved in the soil's formation, especially in the case of residual soils. It follows from this that the most appropriate parameter for expressing compressibility and estimating settlement is the linear parameter m_v. Over the pressure range involved in most foundation settlement estimates this parameter is unlikely to vary much and an average value can be adopted. Only in the case of soft normally consolidated clays is the compression index clearly the preferable parameter.

5 STABILITY ANALYSIS

Many of the available textbooks in geomechanics have a particularly confusing way of presenting methods of analysing the stability of slopes, estimating thrusts on retaining walls, and assessing the bearing capacity of foundations. These three topics are central to a wide range of design situations in applied geomechanics in which failure scenarios are examined. The fact that a consistent set of ideas can be developed and applied with small variations to the three situations mentioned above is “hidden” from the student. A simple progression is possible from the stability of slopes in rock masses (with a planar failure surface), to stability of slopes in soil (idealised as being approximately homogeneous), through earth pressures, and finally to the bearing capacity of foundations.

Stability analysis procedures can be considered within the context of the following six-step process, Pender (2012):

- Failure mechanism chosen
- Free body diagram sketched
- Equilibrium equations written
- Shear strength relations applied
- Factor of safety evaluated
- Search for the worst case.

An important motivation of this teaching approach is to utilise the elementary mechanics students have learnt earlier in their degree course and so enhance their understanding of these fundamental ideas.

Slope stability analysis is the simplest of the three cases and so is covered first. Initially a rock slope with a single planar defect is analysed, in this the failure mechanism is predefined and so the last step in the above list is not needed. The analysis is then extended to cover effects of water pressures on joint surfaces, horizontal acceleration, and the application of slope stabilisation measures. Next follows the stability of slopes in soil in which the failure mechanism is not predefined and so a search for the worst case is needed. In this section there is further discussion of the significance of water pressures. Curved failure surfaces are investigated and found to be more critical than planar with the exception of near vertical slopes for which the critical planar and curved failure surfaces give very similar results. A variety of chart solutions for slope stability are discussed. The method of slices is covered.

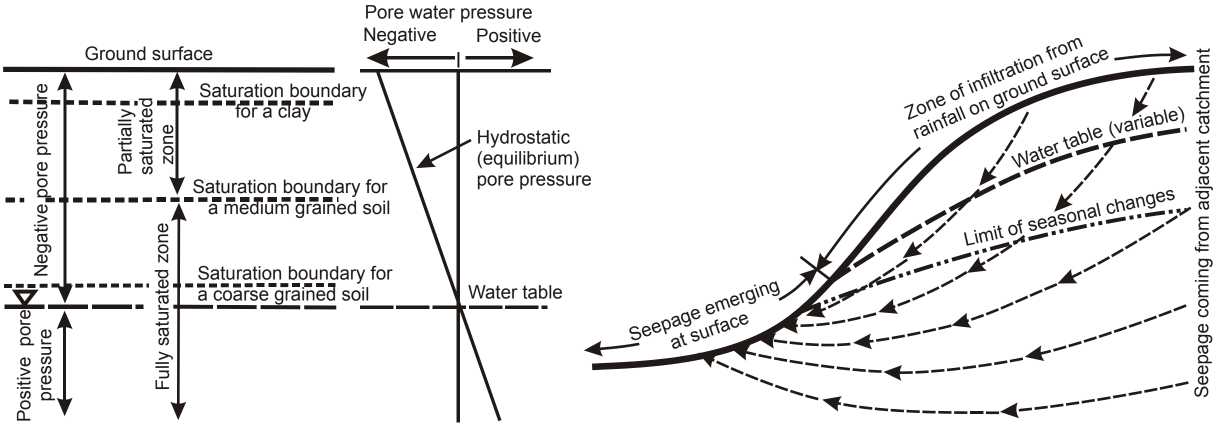
Next the thrust on a wall, simply a slope problem with an additional boundary force, is estimated. This is based on the Coulomb wedge analysis. The use of a planar failure surface for active thrust is justified because of the conclusion about the shapes critical failure surfaces reached in the slope stability work.

Finally, the most complex of the stability analyses, the estimation of the bearing capacity of a foundation is covered. Exploiting the connection between bearing capacity and earth pressure means that a simple two-block failure mechanism can be analysed which gives the correct form of bearing capacity equation.

6 THE WATER TABLE AND SEEPAGE STATE

Many students leave universities with the impression that the water table is the upper boundary of a zone where seepage and pore pressures exist, and above which they are absent. This may be the case with coarse grained soils but is certainly not true of clays. Figure 8 illustrates the pore pressure state and seepage state for a level site and a hillside. Fine grained clays of low permeability in wet or temperate climates remain fully saturated for many metres or tens of metres above the water table, and students should be taught that water does not drain out of clays under gravity forces; clays only become unsaturated as a result of evaporation at the ground surface.

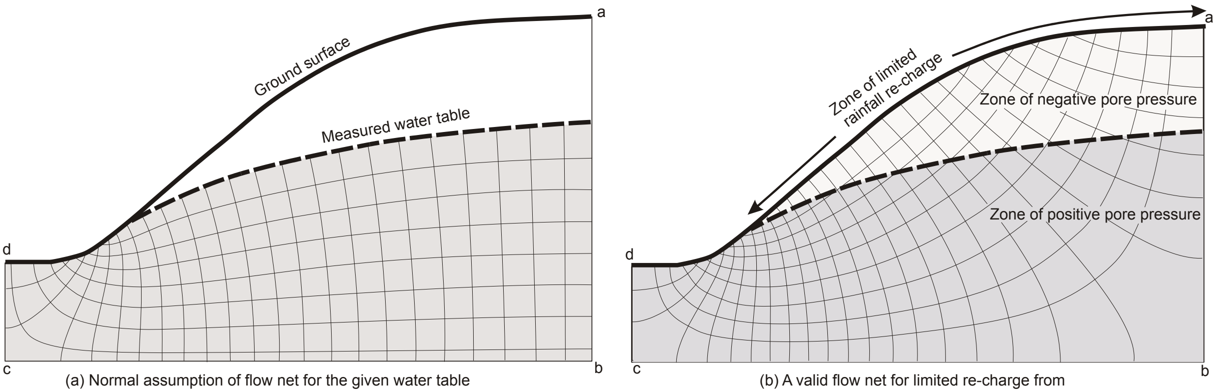
The water table is therefore a line of zero (atmospheric) pore pressure and nothing more. Pore pressures and seepage may exist above the water table and obey exactly the same laws as below the water table, in particular the Laplace equation or its equivalent for non-steady state flow. Where there is a seepage state, as in the hillside shown in Figure 8(b), the water table may well cut across the flow and equipotential lines. This reality is further illustrated in Figure 9, which shows two flow patterns compatible with the same water table. Figure 9(a) shows the seepage pattern normally assumed to be associated with such a water table, and indeed this may be a reasonable assumption if there is a large catchment to the right of the slope shown.



(a) a level site

(b) hillside seepage

Figure 8. Pore pressure and seepage state in a level site and in a hill slope.



(a) Normal assumption of flow net for the given water table (implies an external re-charge source)

(b) A valid flow net for limited re-charge from rainfall on the slope

Figure 9 Possible seepage patterns compatible with a measured water table (after Wesley, 2010)

If, however, there is no such catchment, and especially if it is a symmetrical, double sided hill, then the seepage pattern must be that in Figure 8(b), since the only source of recharge is rainfall directly on the slope itself. The two flow nets have been obtained using the computer programme Seep/W. The flow net in Figure 8(b) can be generated by stipulating a rainfall intensity less than the value that the slope is capable of absorbing. It can also be done by giving the surface nodes negative pore pressures, though this would not be a possible practical situation.

7 CONCLUSION

The geotechnical profession makes use of a number of conventional practices or portrayals of soil behaviour that have been in use since the early development of soil mechanics. It is shown that some lead to routine misunderstanding of soil behaviour, and are in need of reconsideration and replacement. The best hope of bringing about these changes is through the teaching profession giving them due consideration and passing on the necessary changes to their students.

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