Residual Soils and the Teaching of Soil Mechanics

Les sols résiduels et l'enseignement de la mécanique des sols

Wesley L.D.
University of Auckland, Auckland, New Zealand

ABSTRACT: There is a serious gap in the teaching of soil mechanics because of its failure to include coverage of residual soils as an integral part of such teaching. A rough estimate suggests that at least half of the earth's surface is covered by residual soils, and in today's world the most rapid growth and development is occurring in countries that contain a very high proportion of these soils. Civil engineering students are graduating from universities around the world having studied soil mechanics to varying levels, but without even being aware of the existence of residual soils, let alone having any understanding of their properties. The purpose of this paper is to highlight the fact that while much of what is taught in soil mechanics courses is common to both soil groups, there are significant and important areas where concepts applicable to sedimentary soils are completely irrelevant to residual soils.

RÉSUMÉ: L'omission de l'enseignement des sols résiduels est une lacune grave dans l'enseignement de la mécanique des sols. Une estimation approximative laisse à penser qu'au moins la moitié de la surface terrestre est recouverte par des sols résiduels, et la croissance et le développement les plus rapides dans le monde actuel a lieu dans des pays qui contiennent une proportion très élevée de ces sols. Les étudiants en génie civil terminent leurs études à travers le monde en ayant étudié la mécanique des sols à des niveaux variables, sans même être au courant de l'existence des sols résiduels ou de leurs propriétés. Cet article vise à mettre en évidence le fait qu'alors qu'une grande partie de ce qui est enseigné dans les cours de mécanique des sols est également valable pour les sols résiduels, il y a des chapitres significatifs et importants de l'enseignement où les concepts applicables aux sols sédimentaires sont complètement hors sujet pour les sols résiduels.

KEYWORDS: Residual soils, soil mechanics teaching, stress history, formation, compressibility, slope stability

1 INTRODUCTION

Although residual soils are found on the earth's surface almost as commonly as sedimentary soils, their existence and properties are rarely mentioned in soil mechanics courses and text books. The result is that certain concepts developed from sedimentary soil behaviour are routinely applied to residual soils and routinely result in a mistaken understanding of their behaviour. This is surely an indictment on those who teach soil mechanics in our universities. It is well past the time when residual soil behaviour should be an integral part of mainstream soil mechanics, especially of its syllabus in university courses. This paper is an attempt to highlight some significant aspects of residual soil behaviour that should be essential material in basic soil mechanics courses.

2 FORMATION

Figure 1 illustrates residual and sedimentary soil formation. Residual soils are formed directly from their parent rock by physical and chemical weathering, while. sedimentary soils undergo further processes including transportation by streams and rivers, sedimentation in lakes or in the sea,.followed by consolidation.

Their formation method has some obvious influences on the properties and behaviour of these two soil groups, the main ones being the following:

(a) sedimentary soils undergo a sorting process during erosion and re-deposition that give them a degree of homogeneity that is not present in residual soils.

(b) residual soils do not undergo a consolidation process, and their properties cannot be related to stress history. The terms normally and over-consolidated have no relevance to residual soils. Strictly speaking the parameters C_c and C_s are not applicable to residual soils. The parameter C_c is defined as the (log) slope of the virgin consolidation line. It is readily apparent from their formation process that there is no such thing as a virgin consolidation line for a residual soil.

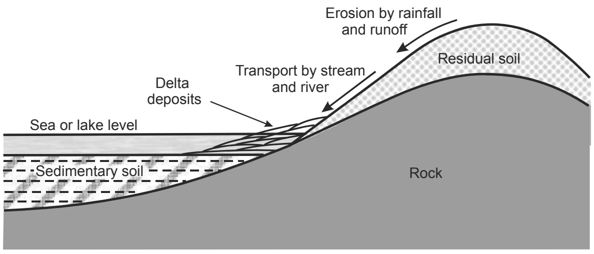

Figure 1. Soil formation (after Wesley, 2012)

(c) Some residual soils, especially those derived from volcanic parent material consist of unusual clay minerals not found in sedimentary soils

(d) Residual soils generally have much higher permeability than sedimentary soils, which has important implications for behaviour in oedometer tests and in estimates of short term and long term stability of cut slopes.

3 CONSOLIDATION BEHAVIOUR

Figure 2 shows results of oedometer tests on samples of a residual soil derived from the weathering of Peidmont formation in southeastern USA. Figure 2(a) shows the results plotted using the conventional log scale for pressure. This convention arises from the behaviour of sedimentary clays when deposited and consolidated under water. Values of pre-consolidation pressure and over-consolidation ratio have been determined from these graphs and are listed in the figure. As noted earlier, stress history has no significant relevance to residual soils, and assumptions that they should display pre-consolidation pressures are erroneous.

There is no reason at all to use a log scale for pressure when illustrating the compression behaviour of residual soils. The graphs have therefore been re-plotted using a linear scale in Figure 2(b). These graphs show a very different picture; there is no indication at all of "pre-consolidation" pressures. Those inferred from the log plot are not soil properties; they are purely the product of the way the data are plotted

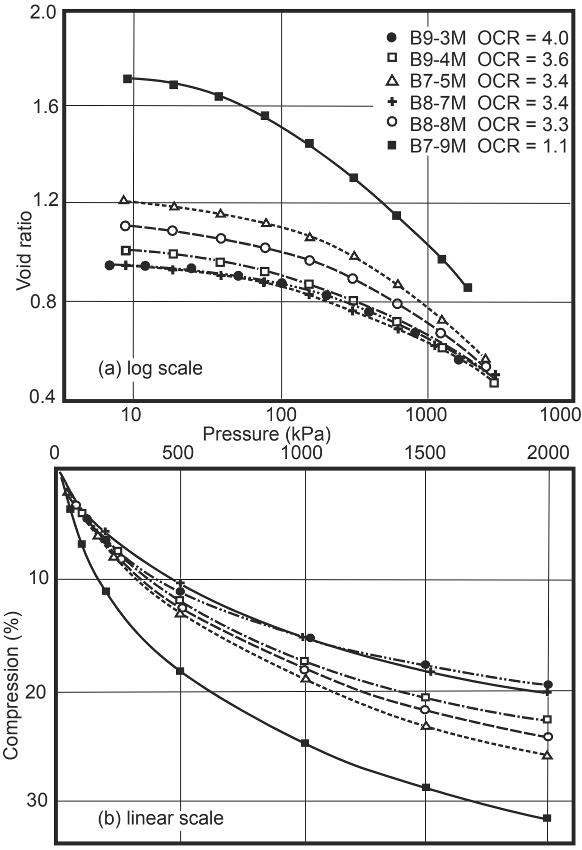

Figure 2. Misinterpretation of the e-log(p) graph (after Wesley, 2000).

A second example of the misleading nature of log plots is given in Figure 3, which shows the results of oedometer tests on a residual clay found in the Auckland region of New Zealand. The graph using a log scale suggests the existence of a pre-consolidation pressure at about 600 kPa, while the linear plot shows no trace of this; in fact the behaviour is almost linear.

While residual soils, by definition, cannot have pre-consolidation pressures because they are not formed by a consolidation process, they may still show a significant increase in compressibility at certain stress levels. This arises because some residual soils are highly structured and at a certain stress level this structure begins to collapse causing the increased compressibility This stress is best termed a vertical yield pressure rather than a pre-consolidation pressure.

Some residual soils can show extremely variable compression behaviour, such as that illustrated in Figure 4 which shows oedometer tests on three samples of clay derived from the weathering of andesitic volcanic ash. When plotted using a log scale, the behavour appears similar, and yield pressure could be inferred from all three graphs. However, when re-plotted using a linear scale the picture is very different.

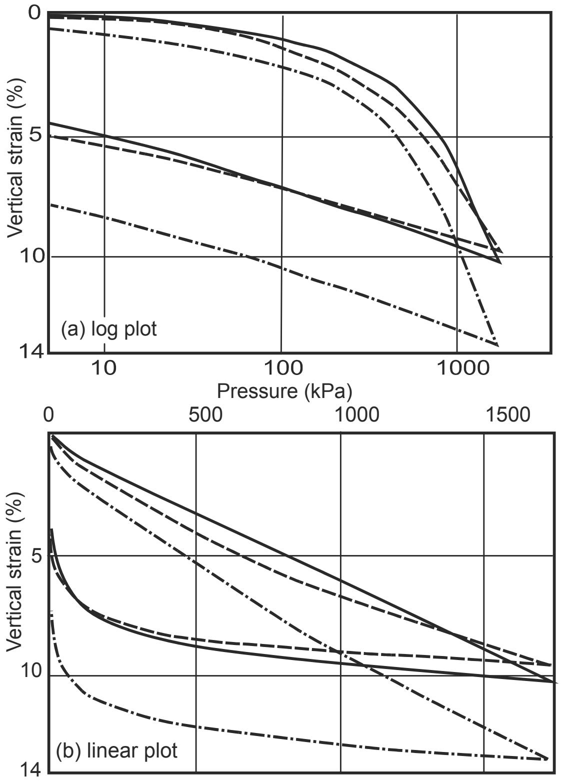

Figure 3. Behaviour of an Auckland residual soil (after Pender et al, 2000)

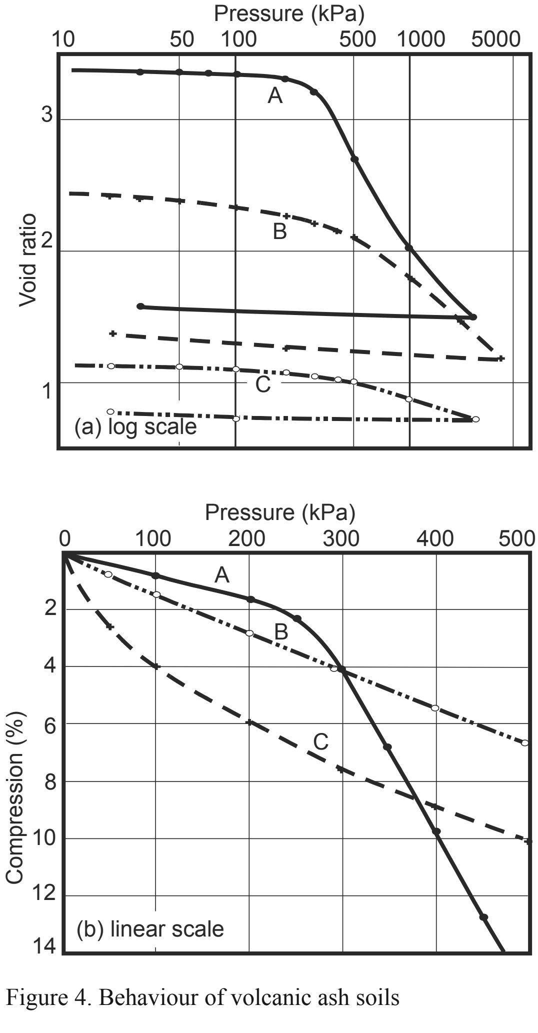

Figure 4. Behaviour of volcanic ash soils

It is now seen that only Sample A shows a yield pressure, of about 250 kPa. Sample B shows almost linear behaviour, while Sample C shows steadily decreasing compressibility, or "strain hardening" characteristics.

A general representation of soil compressibility, especially over the pressure range of interest to geotechnical engineers, is shown in Figure 5. This gives a far more realistic picture than the conventional e-lot(p) plot. The almost universal use of the log plot has created the belief that the compressibility of all soils can be adequately represented by two straight lines on a log graph, which is certainly not the case.

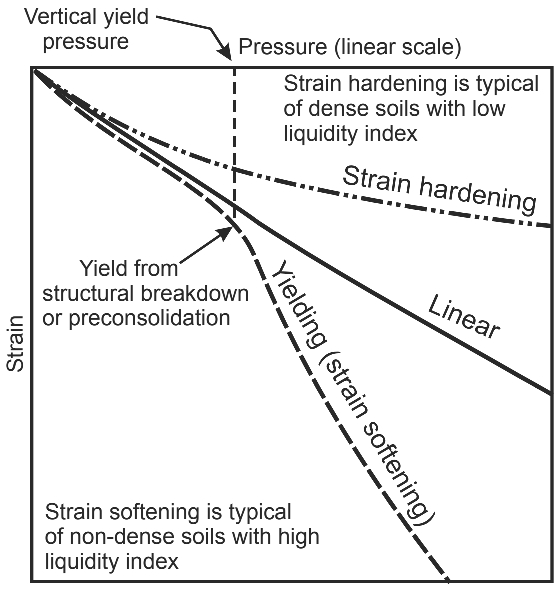

Figure 5. A better representation of soil compressibility, valid for all soils. (after Wesley, 2010).

It is a regrettable that the profession and those who teach soil mechanics have not taken more notice of what Professor Nilmar Janbu has been saying for many years. His message is summarised in the following statement (Janbu, 1998):

> "--- *it remains a mystery why the international profession still uses the awkward e-log p plots, and the incomplete and useless coefficient C_c which is not even determined from the measured data, but from a constructed line outside the measurements* ---".

Janbu made the above comments based on experience with sedimentary soils. The mystery remains even greater with residual soils. There is little doubt that if teachers of soil mechanics always plotted results of oedometer tests on undisturbed soils using both linear and log scales they would very quickly realise how misguided the continued use of the log scale is.

4 INFLUENCE OF HIGH PERMEABILITY

The high permeability of residual soils is caused by various factors, including their relatively coarse nature, the presence of unusual clay minerals, and particular forms of micro structure. The high permeability has various practical implications and students should be made aware of these in basic soil mechanics courses. Only two will be described here; the first is the determination of the coefficient of permeability from oedometer tests, and the second is the short and long term stability of cut slopes in clay.

Figure 6 shows typical root time graphs from conventional oedometer tests on residual soils. According to one dimensional consolidation theory these graphs should show an initial linear section, from which the well known Taylor construction can be used to determine the coefficient of consolidation. The graphs in Figure 6 do not display this linear section, simply because the pore pressure dissipates almost as soon as the load increment is applied, and the shape of the graphs is a creep phenomenon unrelated to the rate of pore pressure dissipation.

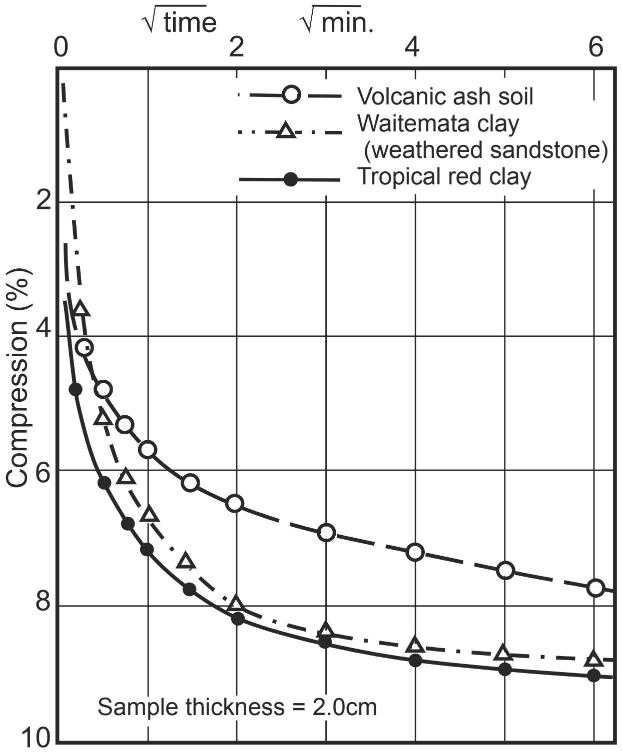

Figure 6 Root time graphs from tests on residual soils.

It is not difficult to show that the highest value of the coefficient of consolidation that can be reliably determined from an oedometer test with a sample thickness of 2.0cm is approximately 0.1m^2/day (= 0.012cm^2/sec.). Readings taken in the first minute will only lie on a straight line if the c_v value is less than 0.1m^2/day; many residual soils have higher values. Because most geotechnical engineers and laboratory technicians are unaware of this, the Taylor construction continues to be regularly applied to graphs such as those in Figure 6, and erroneously low values of c_v are determined.

5 SLOPE STABILITY

The main trigger for slips or landslides in residual soil slopes is intense and prolonged rainfall, a fact that reflects the relatively high permeability of such soils. In the case of cut slopes, therefore, it is very unlikely that behaviour during excavation will be undrained. It is much more likely that a new long term seepage pattern will develop as excavation proceeds. However, this pattern will only be an average state, and there will be frequent changes with time reflecting the weather changes. This situation is illustrated in Figure 7, alongside the commonly assumed behaviour of sedimentary soils. In residual slopes changes in the water table and pore pressure occur in both a regular seasonal pattern and in a random and unpredictable manner as a result of sudden storm events. The challenge to the geotechnical engineer is to estimate the worst case situation.

A further significant feature of slopes in residual soils is that they are often much steeper than those in sedimentary soils. This means that water tables may also be relatively steep, and if analytical methods are used to assess stability, then care is needed in the way the pore pressure is included in the analysis. The example in Figure 8 illustrates this point.

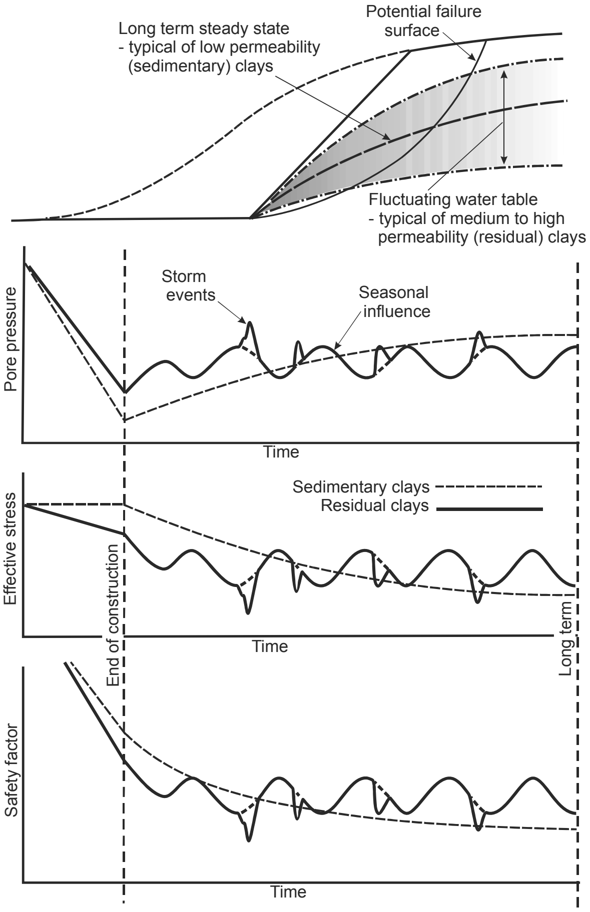

Figure 7 Short and long term stability of cut slopes (after Wesley, 2010).

This figure shows a steep cut slope subject to variable weather patterns. One way in which the worst case pore pressure state can be determined analytically is to assume that rainfall continues long enough for the water table to rise to the surface and create a stable seepage state. This may be excessively conservative, but does at least put a lower limit on the theoretical safety factor.

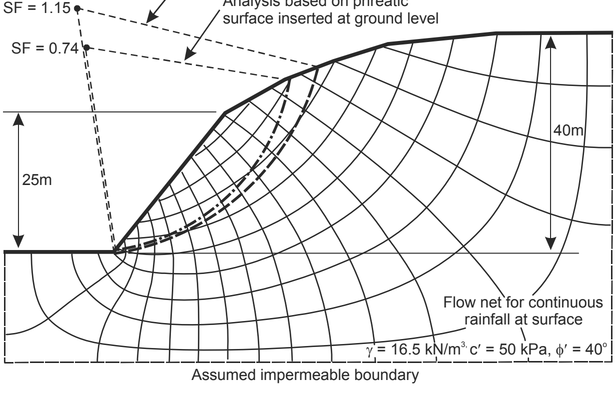

Figure 8 Influence of pore pressure assumptions on the estimate of safety factor.

There are then two ways of including the pore pressures from this state in a slip circle analysis. The first, and normal, method is to determine the pore pressure directly from the vertical intercept between the phreatic surface and the slip surface – the "vertical intercept" assumption. In this case it will be the vertical distance from the ground surface to the slip surface. Almost all computer programmes make this assumption, which may be reasonable in gentle slopes but can give very misleading results in steep slopes, which is what the example in Figure 8 illustrates.

The second method is to consider the practical situation realistically and determine a flow net compatible with the boundary conditions. The pore pressures can then be determined from this flow net. It is evident from Figure 8 that the vertical intercept assumption, which implies that equipotential lines are vertical is physically impossible. The short section of level ground at the top of the slope is an equipotential line and flow lines will begin perpendicular to this. The flow net shows that most of the equipotentials along the slip surfaces are far from vertical.

The safety factors determined by the two methods, using the computer programmes SeepW and SlopeW, are the following:

Vertical intercept assumption SF = 0.74
From the correct flow net: Safety Factor = 1.15

The difference is very large, and although many slopes in residual soils may not be as steep as that in Figure 8, there are many, especially in places like Hong Kong that are considerably steeper Thus the error in the safety factor could be even greater than that indicated in the Figure 8 analysis.

6. CONCLUSIONS

Although residual soils occupy about half the world's surface very few universities cover them in their soil mechanics courses. This includes many universities surrounded on all sides by residual soils. The result is that geotechnical engineers routinely apply concepts valid only for sedimentary soils to residual soils and gain a mistaken understanding of their behaviour.

It is long past the time when residual soil behaviour should be part of mainstream soil mechanics and an integral part of university courses. The importance of this cannot be overemphasised. Education today is globalised in a way it hasn't been in the past and large numbers of students from Asia, Africa and Latin America are obtaining their education in the universities of Western countries. Residual soils tend to be predominant in the former counties, but only sedimentary soil behaviour is covered by degree courses in the latter. Students thus return to their home countries unaware that significant parts of the soil mechanics they have been taught do not apply to the residual soils they are highly likely to encounter in their own countries.

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