# Mechanical Behaviour - Idealised Zones on Stress Space

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*Abstract:* - The paper reports laboratory investigation to evaluete the gross yield and idealised zones on stress space of a bonding soil through an empirical process. For this triaxial tests on bonded samples of granitic residual soil of Covilhã were carried out. After saturation, the samples were isotropically consolidated to the requested effective stress (35 to 400 kPa), and were then sheared in triaxial compression under undrained conditions. The deformations were measured using techniques normalised with the use of an external transducer. The initial stiffness cannot give true results due to bedding errors and final effects. They can be used as comparisons among the different tests and to study the type of the stress - strain curves and stress path for different stress levels, allowing formulating zones or domains of mechanical behaviour in the stress space p´- q. The gross yield behaviour in structured samples was observed, studying the changes in stiffness. The results seem to demonstrate the possibility of defining three zones by the distribution of the defined yield points in the stress – strain curves and stress paths on p´- q space.

*Key-Words:* - Mechanical Behaviour, Triaxial Tests, Stress Levels

## 1 Introduction

In recent years a number of researchers have investigated the fundamental mechanics of granitic residual soil in the triaxial apparatus. They have found that the fabric, the bonding, the degree of alteration, mineralogical and chemical composition, among other factors, have influence on the mechanical behaviour (Vaughan and Kawan, 1984), (Jia et al. 2011) and (Mantaras and Schnaid 2002).

*Vaughan (1985)* proved the necessity to develop a method of describing and clarifying the geotechnical properties of residual soils. He suggested that the bonding and porosity internally control the properties of these soils and a point in the stress space can represent the assignment of structural joints. *Vaughan (1985)* claimed that cemented artificial samples should be used in order to study the effect of bonding in the mechanical behaviour of the soil, thus providing a solution to common difficulties like variability, heterogeneity, transport, storage and laboratory testing. The sampled granitic residual soils generally maintain a fragile structure, from a mineralogical point of view they result plagioclase feldspar granite of two micas in which biotite predominates with mega crystals of plagioclase feldspars (*Lemos et al*, 1997).

*Toll and Malandraki (1993)* studied the mechanical behaviour of cemented artificial sands with a small amount of clay (kaolinite), placing the material in a 500ºC furnace. Non-drained compression triaxial tests were used with external readings for strain. Stress paths, stress – strain curves and stiffness were examined with the intention of verifying the effect of the fragile bonding in a granular soil. In these tests, the studies of the mechanical behaviour in artificial samples by approximation allow us to establish an understanding of residual soil with structure. Structured soil behaviour can be divided in zones in stress space, based on the stress levels

A series of non-drained compression triaxial tests were carried out in natural structure samples, using consolidation stress between $p'_0$ = 35 kPa and 400 kPa. Comparing the mechanical behaviours between structured and non-structured samples for the same void ratio and stress levels, the bonding effect can be observed. This effect was studied on resistance and stiffness, based on results obtained from cemented artificial soils and type of curves.

## 2 Geological setting

The plagioclase feldspar granites occupy a much larger extension in Portugal than the alkaline granites, possibly more than two thirds of the granitic area, predominantly in the central region of the territory, particularly in the Beiras region. The local variety is named Granite of Covilhã, Figure 1.

The granites which belong to the plagioclase-feldspar series contain two micas in which biotite predominate, and its texture frequently consists of mega crystals of feldspars and plagioclase. A more detailed description can be found in *Lemos et al., 1997*. It is accepted that they are prevenient from magmatic differentiation henceforth from mantle, probably by dry fusion of the base of the crust and mixture of materials, in general always associated. They are designated hybrids, of base or infracrostal origin, which are in general of late installation [Capdevila et al.,(1973), quoted in geological memoirs and news from *carta da Covilhã*].

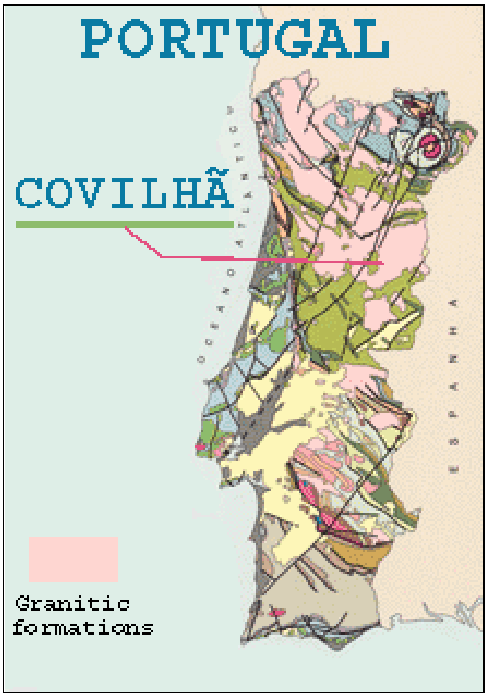



Figure 1 - Main granitic formations of continental Portugal. (I.G.M., 1999)

Weathering is severe on Covilhã's Granite and mechanical properties of the rock massif vary shortly in time and space. Depth of weathering frequently varies in short distances, in a differentially manner preferably along cracks and mechanical discontinuities producing boulders and "balls", being the former to determine the "in situ" mechanical parameters. Small scale analysis is difficult due to granitic residual soil heterogeneity, becoming important for sampling representativeness the dimension and frequency so to obtain a general behaviour even if in some occasions it is admissible the homogeneity of such soils.

The mineralogical composition along vertical profiles barely changes, being noticeable however, as it approaches surface, a gradual increase on clay content with illite and kaolinite sometimes associated with chlorite, being feldspar minerals more common at depth. The massif under study presents a high degree of weathering (W-5 according to IAEG, 1981, classification).

## 3 Tests and procedures

The classified soil belongs to group SW-SM with gravel, and clay activity is normal to low, revealing the presence of kaolinite, low expansion clay. Liquid limit is between 29% and 34% and low plasticity limit reflecting the presence of mica minerals and feldspar, retaining water in internal cleavage. As the representativeness of the sampling carried out on granitic residual soil from Covilhã is not an issue, neighbouring samples were gathered so the samples for triaxial testing were physically similar (specific volume $v_0$ = 1,840 a 1,890), also to reduce the potential macro heterogeneity.

A conventional triaxial chamber was used with external readings for the axial strain during the sheared non-drained condition for structured and destructured samples of 100 mm in diameter and 200 mm longer. The test consisted of consolidated undrained triaxial compression tests (CU) with pore water pressure measurement. The specimens placed on the triaxial cells are saturated ($B=\Delta u/\Delta\sigma_3>95\%$; $\Delta u$, pore pressure variation and $\Delta\sigma_3$ cell pressure variation) and consolidated for different confinement stress - initial mean effective stress ($p'_0$). Drainage is assured by the base and top of the sample during the isotropic consolidation phase in a series of samples for: $p'_0$ = 35 kPa, $p'_0$ = 50 kPa, $p'_0$ = 100 kPa, $p'_0$ = 200 kPa and $p'_0$ = 400 kPa. The maximum rate of axial displacement applied is equal to 0.038 mm/minute.

## 4 Stiffness and yield

The estimate of gross yield is based on empirical processes, which are affected by the possible influence of the observer. In triaxial testing samples can be carried along a variety of stress paths in order to examine the behaviour of yield. It is common to have q= ($\sigma'_1$ - $\sigma'_3$) versus $\varepsilon_a$ (deviator stress: axial extension – stress space), p´ versus ν (mean effective stress: specific volume – volumetric space), graphs and the absorption of energy per unit of volume versus the length of the stress vector, where the yield value should be coherent in the various graphs.

In this paper the yield behaviour of the samples with structure was observed, studying the changes in stiffness ($E_{tg}$) in graphs log $\varepsilon_a$ versus log $E_{tg}$. For those tests whose applied isotropic consolidation stress is below to the virtual preconsolidation stress, a first yield is observed where the curve presents a first discontinuity for small strains. A second gross yield is observed where the greatest discontinuity is noted, with an abrupt decrease in stiffness, Figure 2. Virtual preconsolidation stress is 70 kPa in this soil.

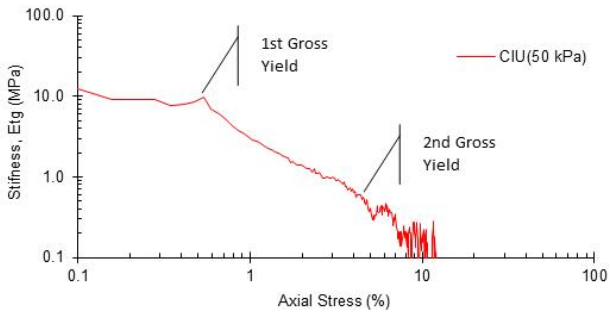



Figure 2 - Granitic residual soil from structured: defining the yield points (p`$_0$ = 50 kPa).

## 5 Discussion

Based on these results, the behaviour of granitic residual soil can be divided in three zones in space p´: q, based on the stress levels, Figure 3.

The three zones were identified in conformity with the proposed for artificially cemented soils (*Toll & Maladraki, 1993)*. Each zone has a typical stress path and stress – strain curve, characterised by the position of three points:

*m*- Maximum tension rate $(q/p')_{max}$.
*s* – 2$^{nd}$ gross yield surface.
*u* – Maximum pressure variation rate of water in pours $(\Delta u/\Delta\varepsilon_{máx})$.

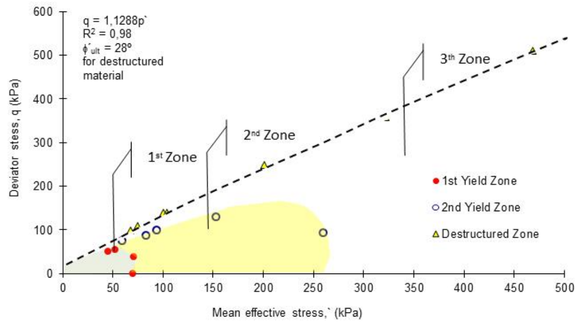



Figure 3 - Structured granitic residual soil from Covilhã: idealised zones on stress space p´: q.

**Zone 1 [p´$_0$ < 100 kPa]**

In this zone, the 2$^{nd}$ gross yield surface *(s)* coincides with the surface defined by the loss of structure. The point of maximum stress rate *(m)* is hit in the first place with the increase of stress and strain. The *(s)* point occurs later, when a break in resistance becomes visible. The mechanical behaviour of the soil becomes an additional resistance in this zone, but tends to show the maximum rate of stress below the surface yield and loss of structure for low strains.

*a)*

*b)*

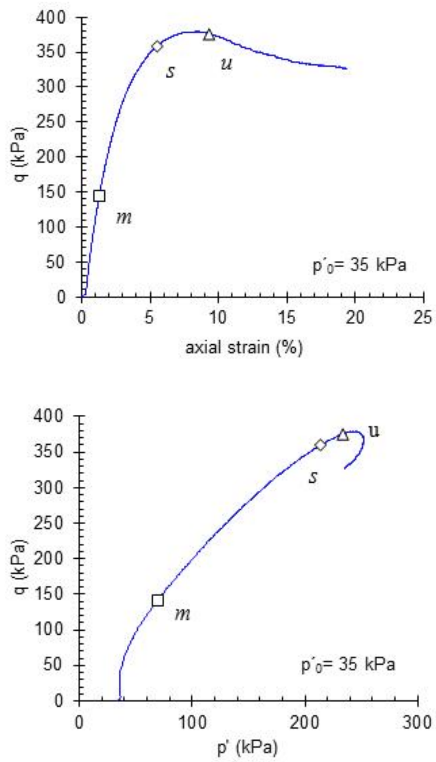
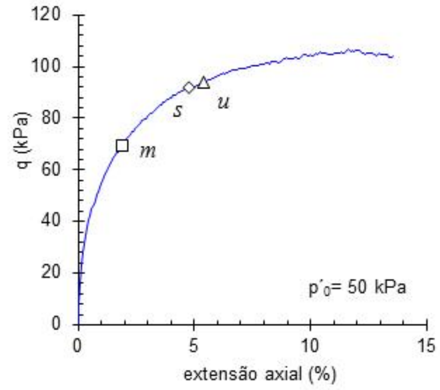



Figure 4 - Structured granitic residual soil from Covilhã: a) stress – strain curve (p´$_0$ = 35 kPa); b) stress path (p´$_0$ = 35 kPa).

The point of maximum variation rate of water pressure in *(u)* occurs shortly after the 2nd yield, and an axial strain in the range of 6-7%, Figure 4 and 5. The yield occurs near or coincides with the peak strength due to instability of the structure by the accumulated energy due to expansion.

*a)*

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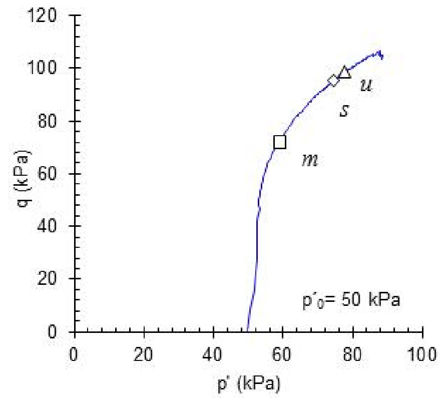
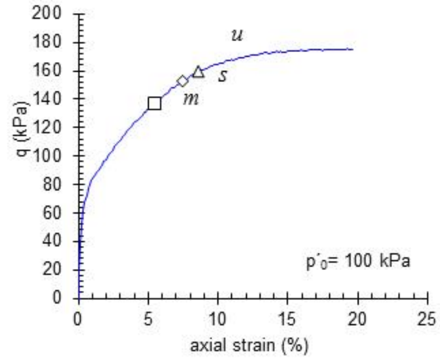



Figure 5 - Structured granitic residual soil from Covilhã: a) stress – strain curve ($p´_0$ = 50 kPa); b) stress path ($p´_0$ = 50 kPa).

With the increase of isotropic stress to 100 kPa the three points kept the same order, but point *m* becomes closer to *s*, this can mean the beginning zone 2, Figure 6.

*a)*

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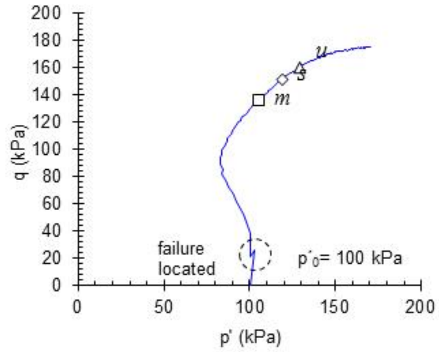


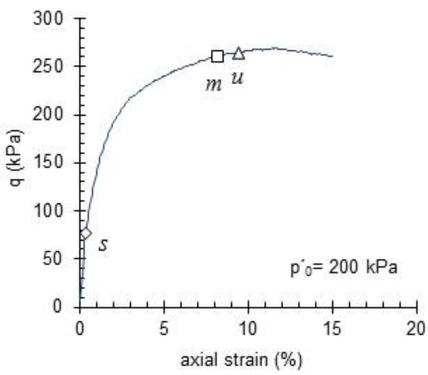

Figure 6 - Structured granitic residual soil from Covilhã: a) stress – strain curve ($p´_0$ = 100 kPa); b) stress path ($p´_0$ = 100 kPa).

**Zone 2 [70 kPa < $p´_0$ < 300 kPa]**

In this zone the 2nd gross yield surface is reached first, Figure 7. Even after *s* point was reached, the sample continues to display *m* values greater than the ones obtained in tests of the same material destructured and reshaped in the same physical conditions as the structured soil, suggesting that some structured potential is still present.

After the failure surface was reached, the sample continues to show evidence of an additional medium stress (p´) and reduction of *m*, which is still greater than the surface of destructured soil. Point *u* occurs after *m*, but closer each time as $p´_0$ increases.

*a)*

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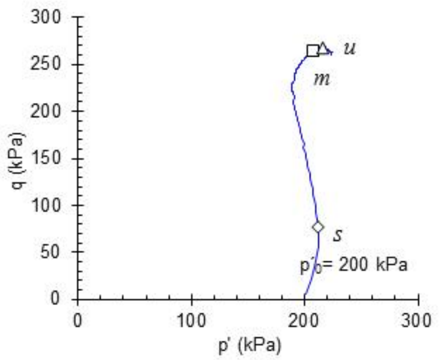


Figure 7 - Structured granitic residual soil from Covilhã: a) stress – strain curve ($p´_0$ = 200 kPa); b) stress path ($p´_0$ = 200 kPa).

**Zone 3 [$p'_0$ > 400 kPa]**

Just as in zone 2, *s* point is reached before the generalised failure surface, nevertheless the failure of surfaces for structured and destructured samples tend to coincide, Figure 8. Suggests that when the failure surface is reached the deformation was sufficient to destroy the structural body and *m* point is governed as a destructured soil.

Point *m* and *u* almost coincide, a fact that is coherent with the behaviour of a destructured soil for these stress levels, suggesting that the structure of the residual structured soil was destroyed before it reached the generalised failure surface.

*a)*

*b)*

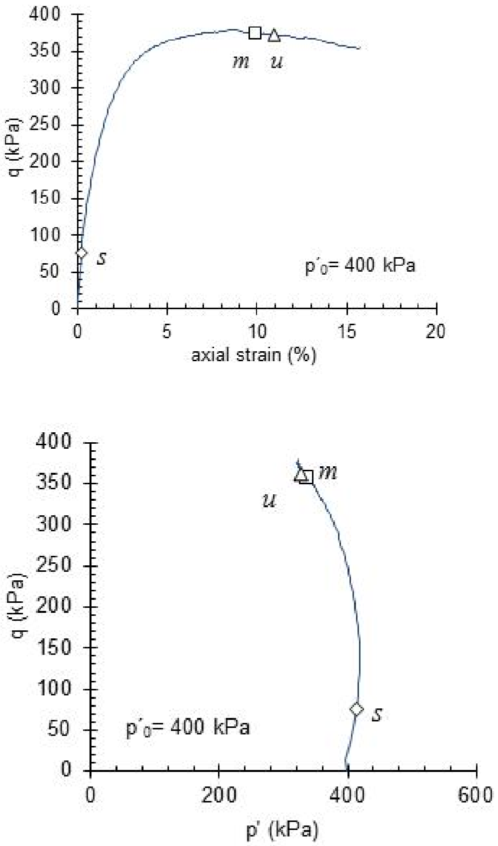


Figure 8 - Structured granitic residual soil from Covilhã: a) stress – strain curve ($p'_0$ = 400 kPa); b) stress path ($p'_0$ = 400 kPa).

# 6 Conclusion

The results of undrained isotropically consolidated triaxial tests, carried out in samples of preserved granitic residual soil seem to demonstrate the following:

1. a 2nd yield surface consistent and defined by the variation in stiffness, can be observed in structured soil;

2. possibility of defining three zones, by the type of the stress - strain curves and stress paths on the p´: q space, by the distribution of the defined points *m*, *s* e *u* in the curves;

3. for isotropic consolidation below 200 kPa the structured soil has superior *m* values than destructured soil, such a fact is due to the bonding effect for low tension;

4. for low isotropic consolidation, (approximately 50 kPa), *m* occurs before *s* and *u* occurs after it;

5. for isotropic consolidation between 70 and 300 kPa, point *s* is reached first and straight after *m* and *u* are also reached;

6. for isotropic consolidation greater than 400 kPa, point *s* is reached first but *m* and *u* coincide, a fact that is coherent with the behaviour of destructured soil confirming that general failure was reached.

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