Strain fields and mechanical response of fissured clays

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Introduction and Scope

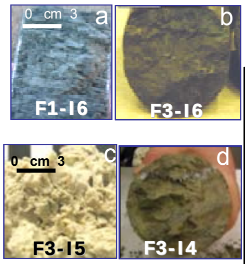
Fissuring is the result of the localisation of intense deformation that develops within the soil during its loading history as a consequence of several geological processes (e.g., erosion, tectonic forces associated with orogeny, weathering). It follows that fissured soil outcroppings are widespread all over the world: from the British stiff fissured clays (London clay, Barton clay in England) to the fissured clays in Italy, France, Denmark and Germany. Several authors [e.g., 1-3] pointed out how fissuring is generally responsible for a huge decay of the clay mechanical properties with respect to the same material when unfissured, even if reconstituted in the laboratory [4]. This is why important instability processes frequently involve fissured clay outcroppings [e.g., 5-8] so that the interpretation and modelling of the fissured clay behaviour is important for engineering practice. [4] and [9] have presented element test results that give evidence of the general influence of fissuring on the clay behaviour. These results allowed for the definition of an extended sensitivity framework that applies also to clays of different fissuring features. However, behavioural discrepancies with respect to the framework may be recorded when testing fissured clay specimens that are likely to be smaller than the clay Representative Element Volume (REV). The causes of these discrepancies were investigated by analysing the results of the application of the Digital Image Correlation (DIC hereafter) method to plane strain compression test data for different fissured clay specimens from the South of Italy [10, 11]. In this respect, a key aspect to the research was that the standard global stress-strain measurements were enriched by full-field displacement and strain measurements through 2D DIC. Access to incremental strain fields provided information about slight details or anomalies as well as the complexity of deformation processes, which is of crucial importance for proper interpretation of test results at the global, macroscopic level.

Fissuring identity, macro-response and local patterns of behaviour

The meso-fabric of the fissured clay has been characterized according to the fissuring characterization chart (Fig. 1) proposed by [4]. Within this chart, each soil corresponds to a set of coordinates that represents the soil 'Fissuring IDentity' (F-ID). Fissuring orientation (F, from single, F1, to random, F3) and intensity (I) have been found to influence most the clay behaviour. In Fig. 1 specific keys distinguish the F-IDs of four clays taken from different sites within chain areas in the South of Italy.

Given the approach to fissuring as a feature of the clay structure, the effects on the clay mechanics have been interpreted by comparing the fissured clay behaviour with that of the same clay when reconstituted in the laboratory [12, 13]. In particular, this comparison has been reported for the clays in Figure 1 based upon laboratory test results [4]. Here-forth the authors have derived the applicability to fissured clays of the sensitivity framework. Fig 2 reports the sketches of the behavioural trends recognized in compression and shear for I6 to I4 clays, together with the corresponding trends for unfissured clays. For unfissured clays, either sensitive or reconstituted, [13] introduced the parameter stress sensitivity ratio, $S_\sigma = p'_y / p^*_e$, to quantify the influence on the clay bounding surface of the microstructure. $S_\sigma \geq 1$ for unfissured clays. Fig. 2 shows that fissuring may be considered as part of the structure internal state variable and as such it influences S_σ. For I4 to I6 clays, the compression gross yield states are found to lie to the left of the intrinsic compression [12], and are characterized by $S_\sigma < 1$. Moreover, the whole state boundary surface of the fissured clay (SBS) is even smaller than that of the reconstituted (Fig. 2).

However, in some cases fissured clays show behavioural trends which do not fit this framework. For example, during triaxial shearing of highly overconsolidated fissured clay specimens premature failure was recorded [4] due to the onset of sliding. DIC method shed light on the sources of such discrepancies showing that these are connected to strain localisation processes. In particular, several plane strain tests were carried out at Laboratoire 3SR in Grenoble either on F1-I6 or F3-I5 clay specimens [10, 11]. As commonly observed for REV of both sand and clay specimens [14, 15], also for fissured clay REV (Fig. 3a) it is only after one of the strain localisation regions 'wins the competition' and dominates the material response, that significant softening ensues (in terms of global response) and a complete shear band develops. Conversely, for specimens much smaller than REV (Fig. 3b), strain localisation is limited solely to few regions since early stages of loading. These regions act as catalysts of further strain localisation and control the specimen response up to large strains, bringing about a loss of strength, resulting in the erasure of peak strength and a very limited positive hardening [14, 15].



	INTACT SOIL		DISCONTINUITY NATURE			DISCONTINUITY ORIENTATION[1]	DISCONTINUITY GEOMETRY		
	Main sediment A	*Undrained strength*[2] B	*Type* C	*Roughness*[3] D	*State* E	F	*Shape*[4] G	*Continuity*[4] H	*Intensity*[5] I
1	Clay °/*/**	Mudstone	Depositional	Very rough	**Fresh** °/*/**	Single*	**Planar** °/*/**	Continuous	Rare: <3m²/m³->1m³
2	Silt	**Stiff clay**°/*	**Stress relief** **	Rough	**Slightly weathered** °/*/**	Few	Curved °/*	Many intersections°/*/**	Very low: $3\div10$ m²/m³ - $0.027\div1$ m³
3	Silty clay °	Firm clay*	**Shear induced** °/*/**	Slightly rough	Highly weathered °/*	**Random** °/**	Hinged °/*	**Some intersections**	Low: $10\div30$ m²/m³- $0.001\div0.027$ m³
4	Clayey silt	Soft clay**		**Smooth** °/*/**	Iron stained surfaces °		Folded °/*/**	Very few intersections	**Medium: $30\div100$ m²/m³-$27\div1000$ cm³**
5	**Marly clay**			Very smooth °/*	Coated		Conchoidal		High **: $100\div300$ m²/m³- $1\div27$ cm³
6				Slickensided °/*					Very high°/*: >300m²/m³ -<1cm³

Figure 1. Characterisation chart of fissured clays and F-IDs of four different clays from the South of Italy.

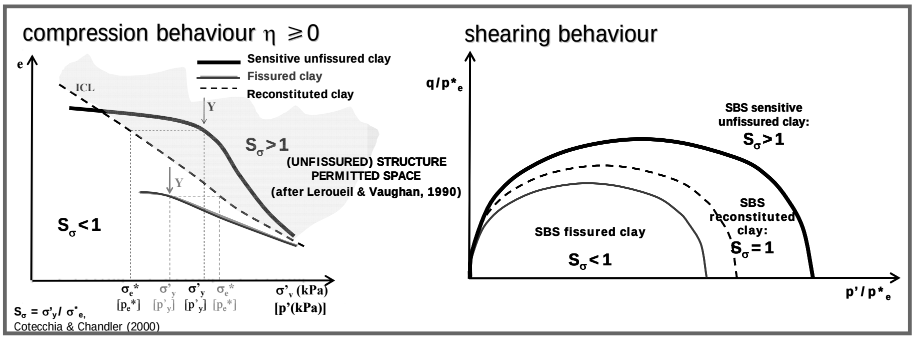


Figure 2. Behavioural trends in compression (left) and shear (right) of reconstituted and natural fissured and unfissured clays.

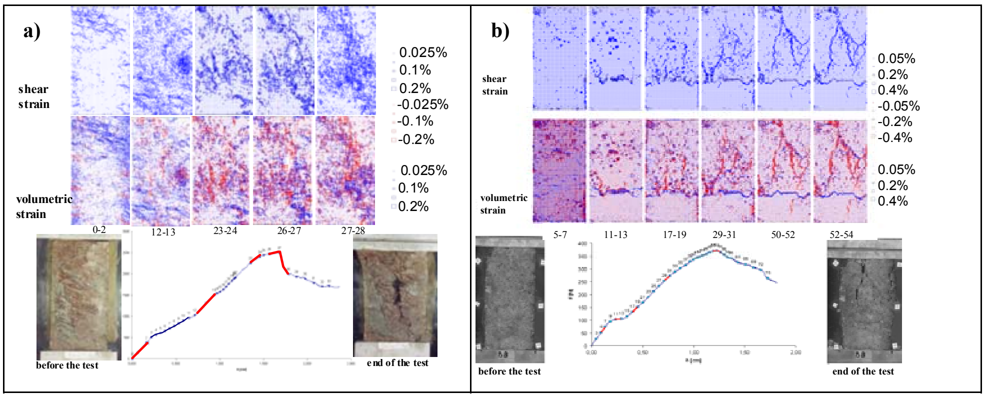


Figure 3. F1-I6scaly clay (a) and F3-I5 natural bentonite clay (b): load-displacement curve and DIC-derived shear and volumetric strain fields for selected load increments (in red along the curves).

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