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Weibull distribution to describe grading evolution of materials with crushable grains

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Abstract

This work presents a study on the evolution of the Grain Size Distribution (GSD) of an artificial granular material with crushable grains and its relation with the observed mechanical behaviour. The main aim of the work is to find a relationship between the initial GSD, its evolution and the mechanical behaviour. The artificial material used is a Light Expanded Clay Aggregate (LECA) subject to one-dimensional compression at various stress levels with eight initial GSDs characterised by four coefficients of uniformity and two mean diameters. The evolution of the GSD is characterised by a double mechanism depending on the initial GSD and on the applied stress level. A link between the evolution of the GSD, breakage and the compressibility curves is observed. A bimodal Weibull distribution function is proposed to describe the GSD before and after testing. The long term objective of the work is to link the evolution of breakage, from moderate to high stress, with the mechanical behaviour and to formulate a constitutive model able to describe the observed behaviour.

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1. Introduction

Particles break when the applied stress exceeds their strength. In the usual geotechnical applications, grain crushing occurs especially in areas of high stress concentration (*e.g*. shear bands, soil-structure interfaces, *etc.*) and significant amounts of crushing are observed in nature in faults and glacial deposits, characterised by high stress concentrations along particular planes. Breakage causes variations of the aggregate Grain Size Distribution (GSD) and of the particles shape. The percentage of finer particles increases and the particles resulting from fragmentation are usually more angular and irregular than the original grains. It follows that packing density, permeability, and mechanical properties of the granular aggregate are affected by breakage. Grain crushing depends on many factors such as, *e.g.*: particle size, shape, strength, mineral composition, stress path, and porosity. The experimental work was carried out on samples of a Light Expanded Clay Aggregate (LECA), an artificial granular material with crushable grains, which has already been studied in previous works [1,2]. The testing programme consisted of 24 one-dimensional compression tests performed under controlled displacement rate with eight different initial GSDs, characterised by four coefficients of uniformity, U (= 3.5, 7, 14, and 28) and two mean diameters, d_{50} (= 0.5 and 1.0 mm) (Fig. 1). To understand the effects of breakage and its physical effects on the particles assembly, the evolving GSDs were fitted using a Weibull statistical distribution, whose parameters were found to depend on the initial GSD and on the stress level applied. The main aim of this work is to study the evolution of the grading of LECA at high stress level in order to get the ultimate GSD and link it to the observed mechanical behaviour.

2. Experimental work

Systematic experimental investigations of grain crushing occurring in natural materials are often difficult due to the relatively high stress required to crush the grains and the variability and heterogeneity of natural deposits, which makes it difficult to obtain repeatable results. For these reasons, the experimental work was carried on an artificial granular material consisting of crushed expanded clay pellet, whose grains break at relatively low stress. The expanded clay pellets are commercially available under the acronym LECA (Light Expanded Clay Aggregate), both as intact or crushed, in different grain sizes. The main physical characteristic of the material is its very low apparent unit weight. This is due to the existence of a double order of porosity: "inter-granular", or voids existing between particles, and "intra-granular", or closed voids existing within individual particles. The apparent specific unit weight of the particles, γ_s, is a function of particle diameter d [3]. The value of γ_s increases significantly with decreasing grain size and tends to the unit weight of the constituent clay, $\gamma_a \cong 26.5$ kN/m^3, for the smallest particles. In the same way, the intra-porosity, calculated as $n_i = 1- \gamma_s/\gamma_a$, increases with the particle size and tends, for the bigger particles, to a value of 0.6 [2].

Table 1. Experimental program and stress, deformation at the end of the tests.

				Series 1		Series 2		Series 3	
				D = 100 mm; H = 40 mm		D = 100 mm; H = 40 mm		D = 50 mm; H = 80 mm	
d_{50}	U	d_{max}	β	ε_a	σ_v	ε_a	σ_v	ε_a	σ_v
[mm]	[-]	[mm]	[-]	[-]	[MPa]	[-]	[MPa]	[-]	[MPa]
0.5	3.5	0.812	1.430	0.33	3.4	0.50	12.6	0.57	50.0
	7.0	1.061	0.921	0.33	6.1	0.44	12.6	0.57	50.0
	14.0	1.388	0.679	0.33	6.1	0.42	12.6	0.50	50.0
	28.0	1.815	0.538	0.33	3.9	0.41	12.6	0.49	50.0
1.0	3.5	1.624	1.430	0.33	1.9	0.56	11.8	0.59	50.0
	7.0	2.123	0.921	0.33	3.2	0.52	12.6	0.58	50.0
	14.0	2.776	0.679	0.33	5.0	0.44	12.6	0.51	50.0
	28.0	3.629	0.538	0.33	7.3	0.40	12.6	0.50	50.0