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The effect of grain size on G_{max} of a demolished structural concrete: A study through energy dispersive spectroscopy analysis and dynamic element testing

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ABSTRACT

Recycled concrete aggregate (RCA) composed of demolition-crushed structural concrete is a promising material in geotechnical engineering applications, for example, as a backfill in retaining walls or as an embankment fill and pavement construction material. Due to the presence of cement mortar component, RCA has a lower unit weight than that of typical soils, thus its use may be considered beneficial in engineering infrastructures with a demand in the reduction of settlements or lateral earth pressures. In this study, a set of torsional resonant column and bender element tests were carried out on uniform fractions of a recycled concrete aggregate with origin from New South Wales, Australia, with varying the mean grain size. The created in the laboratory samples, were prepared in a dry state and tested under isotropic conditions of the confinement varying the effective confining stress from 25 to 800 kPa in a resonant column and in a triaxial apparatus with embedded piezo-element inserts with a particular focus on the elastic stiffness G_{max}. The results showed that the sensitivity of G_{max} to pressure increased with decreasing mean grain size. This observed trend was attributed, partly, to the higher cement mortar component for fractions with a smaller grain size. The different composition of the fractions was verified through Scanning Electron Microscope - Energy Dispersive Spectroscopy (SEM-EDS) analysis in particular quantifying the ratio of Silicon over Calcium contents. The performance of expressions proposed in the literature for the prediction of G_{max} of sands and gravels, was rigorously evaluated by means of measured against predicted elastic stiffness for all the fractions as well as by means of the state parameter for a particular RCA fraction.

1. Introduction

The prediction of ground deformations and the response of geo-structures subjected to static or dynamic load patterns, require the knowledge of soil shear modulus (G) and its dependency to the confining stress and shear strain levels [18]. At very small strains, in general less than 10^{-3}%, G corresponds to its maximum value (denoted as G_{max}) and expresses an elastic property. For any geo-material, G_{max} is a constant-state property [9,28] and it can be described by two independent quantities: the current confining pressure (p′) and the current void ratio (e). Accurate measurements of G_{max} in the laboratory, require the application of dynamic test methods. The resonant column is one of the popular and standardized methods for this purpose [18,27,3]. Recently, the use of piezo-element testing has received great attention and applications in soil mechanics and dynamics research due to the easy implementation of the piezo-element inserts in any triaxial-type device and the straightforward determination of the shear wave velocity from the distance between the inserts and the determination of the time arrival of the waves [15,21,35].

In the past decades, the elastic shear-modulus of geo-materials has been examined extensively. With respect to granular geo-materials subjected to isotropic or closely isotropic conditions of the confining pressure, the basic concluding remarks from the literature are that G_{max} is affected, apart from the important roles of (p′) and (e), by the coefficient of uniformity [11,19,24,40,30,32], the shape of particles [13,14,25] and the type of the soil by means of mineral components and grain morphology [30–33]. A recent research work by Yang and Gu [38] showed that the grain size, which is commonly expressed through the mean grain size (d_{50}), does not affect significantly the elastic shear-modulus of sand-size soils, which observation is in agreement with the previous works by Menq [24], Wichtmann and Triantafyllidis [40] and Senetakis et al. [30]. The sensitivity of G_{max} to pressure has been linked to the behavior at the grain scale, the nature of the grain-to-grain contact response and the magnitude and distribution of the

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contact forces within a granular assembly of grains [28,29,9], which in turn are affected by the previously mentioned characteristics, for example, the grain size distribution or the shape of the grains.

Referring to granular geo-materials, most published research works in the literature have focused on natural soils or crushed rock of a single mineral type or, soils with one dominant mineral. In the present study, an effort was attempted to study in the laboratory the elastic shear-modulus of an engineered sand composed of recycled concrete aggregate (RCA) which is the product of demolition-crushed structural concrete. Due to the presence of aggregate and cement mortar as the dominant components, the behavior of this material may be more complex since the exact percentages of the variable components may not be known always. In particular, the content of cement decreases with increases the size of the RCA fraction [36]. Apart of its academic interest as a complex granular material with a low unit weight and the presence of two dominant solid components, i.e. aggregate and cement mortar, as well as the challenges to study in the laboratory the dynamic properties of RCA, it is a material that may find many applications in civil engineering projects and pavement geotechnics [1,12,2,26,34,36,37,8]. This is because of the recent pressing need to utilize recycled and demolition aggregates in beneficial ways. Recycled concrete aggregate composed of demolished-crushed structural concrete is one of these waste materials that the research community has recently focused on due to its interesting properties and promising performance from both structural and geotechnical engineering perspectives.

Previous research works have focused, primarily, on the re-use of RCA for the production of new structural concrete, but recently many studies have shown promising properties and potential applications of RCA in geotechnical projects, for example in pavement geotechnics and earth retaining support structures. In this regard, the present work focused on the elastic shear modulus (G_{max}) of a recycled concrete aggregate with origin from New South Wales, Australia, and in particular on the sensitivity of G_{max} to pressure (p') and mean grain size (d_{50}). For this purpose, samples with varying d_{50} were prepared in the laboratory and tested in a resonant column in the range of very small shear strains with $\gamma < 10^{-3}$%. The performance of literature expressions for the prediction of G_{max} of sands and gravels was evaluated by means of predicted against measured shear modulus, denoted as $G_{max,p}$ and $G_{max,m}$, respectively, for all the RCA fractions as well as by means of the ratio $G_{max,m}/G_{max,p}$ against the state parameter for a particular RCA fraction. In order to assess the changes of cement mortar and aggregate components for the different fractions, Scanning Electron Microscope - Energy Dispersive Spectroscopy (SEM-EDS) analysis was carried out on different fractions as well as on a sample composed of pure cement and the ratio of silicon over the calcium contents was quantified.

2. Materials and methods

2.1. Parent demolition material and uniform fractions used in the study

A recycled concrete aggregate composed of demolished-crushed structural concrete from New South Wales, Australia, was used in the study. The parent aggregate is a well-graded material composed of aggregate and cement mortar as the dominant components, with the presence of silt-size grains and brick. The parent aggregate was prepared through a set of sieves and five uniform fractions were separated and used in the study, denoted as RCA02 (fraction 0.15–0.30 mm), RCA03 (fraction 0.30–0.60 mm), RCA04 (fraction 0.60–1.18 mm), RCA05 (fraction 1.18–2.36 mm) and RCA06 (fraction 2.36–4.75 mm). The grading curves of the five fractions are illustrated in Fig. 1. The grain size characteristics (mean grain size, d_{50}, and coefficient of uniformity, C_u) and the specific gravity of solids (G_s) are summarized in Table 1. G_s was determined adopting the ASTM D854-02 specification [4]. It was found that G_s varied slightly with the RCA fraction but the values did not monotonically increase or decrease with d_{50}. An image for the fraction RCA05 is given in Fig. 2.

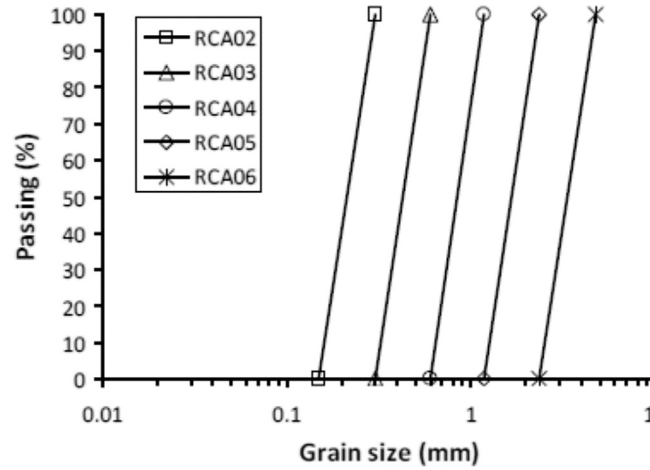

Fig. 1. Grading curves of recycled concrete aggregate (RCA) fractions used in the study and typical image taken from an optical microscope of an individual grain.

Table 1
Recycled concrete aggregate (RCA) fractions used in the study.

Code of sample	RCA02	RCA03	RCA04	RCA05	RCA06
Fraction (mm)	0.15–0.30	0.30–0.60	0.60–1.18	1.18–2.36	2.35–4.75
Specific gravity G_s	2.62	2.48	2.47	2.47	2.59
Mean grain size d_{50} (mm)	0.21	0.42	0.84	1.67	3.35
Coefficient of uniformity C_u	1.35	1.62	1.35	1.37	1.42
Sphericity R (mean)	0.71	0.59	0.71	0.67	0.56
Sphericity standard deviation	0.16	0.17	0.15	0.21	0.19
Roundness (mean)	0.49	0.29	0.29	0.31	0.23
Roundness standard deviation	0.17	0.13	0.13	0.16	0.11
Regularity ρ	0.60	0.44	0.50	0.49	0.40
Regularity standard deviation	0.13	0.11	0.13	0.15	0.12

Fig. 2. Typical image of recycled concrete aggregate fraction 1.18–2.36 mm.