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Construction and demolition waste parameters for rational pavement design

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HIGHLIGHTS

- Compaction caused aggregate breaking, though its classification held unaltered (SP).
- CDW presented quite good resilient behaviour, similar to sound crushed basalt.
- In pavement layers with $\sigma_d/\sigma_3 < 2$ and $\sigma_d \leq 210$ kPa, CDW will respond nearly elastically.
- CDW may be used for bases and subbases of low to medium traffic volume pavements.
- CDW effective shear strength parameters and Poisson's ratio were obtained.

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ABSTRACT

This paper analyses the strength and stress–strain behaviour of construction and demolition wastes (CDW) to obtain parameters for pavement design, using large cylindrical specimens (25×50 cm). Though CDW friction angle (41°) is lower than that of densely graded crushed basalt, its cohesion (136 kPa), Poisson's ratio (0.38) and resilient response are quite similar. Permanent strain test results indicate that in pavement layers with $\sigma_d/\sigma_3 < 2$ and $\sigma_d \leq 210$ kPa, CDW will respond nearly elastically and be safe against rutting. Therefore, CDW may be used in bases of low to medium traffic volume urban pavements, managing wastes whose generation continuously increases.

1. Introduction

Construction and demolition waste (CDW) is one of the heaviest and most voluminous waste streams generated in the European Union, as well as in many countries. In Europe, it accounts for approximately 25–30% of all waste generated and consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled. Kofoworola and Gheewala [1] state that each European citizen generates, in average, 480 kg of CDW per year.

In the United States, in 2013, the amount of CDW generated included 17.49 millions of tons of Portland cement concrete and 0.27 millions of tons of bricks and clay tiles. Most of CDW ends up in landfills increasing the burden on landfill loading and operation. It is estimated that anywhere from 25 to 40 percent of the solid waste stream is building-related waste and only 20 percent of construction waste or demolition debris (C&D) is actually recycled. In Brazil, just in 2014, 46 millions of tons of CDW were produced.

Leite et al. [2] mention that several studies confirm that CDW has a great potential to be reused as aggregate in road construction [3–8]. They add that aggregates from recycled construction and demolition waste (RCDW) are cost-effective alternative material for bases and subbases due to its resistance and its non-expansive behaviour. Also, due to the short distances from their sites of classification and stocking, it is advisable to use CDW in urban pavements, especially those carrying low to medium traffic volumes.

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It is acknowledged that, in many countries, the most common practice is to consider empirical approaches (or even not to design at all) when using CDW for pavement construction. Moreover, the lack of stress–strain and strength parameters makes difficult the rational design of pavements including layers of such materials.

To help to overcome that deficiency, this paper reports part of a research on the mechanical behaviour of CDW produced in southern Brazil. The results of shear strength and resilient modulus tests are presented and discussed and the material behaviour regarding permanent deformation is predicted using the shakedown theory. Taking into account that in many countries carrying out those tests is not a common practice, design parameters are recommended as default.

2. Short overview on unbound aggregates

2.1. Resilient response

The resilient modulus (M_R) is an elastic parameter based on the recoverable strain under repeated loads. It is defined as the ratio between the applied deviator stress ($\sigma_d = \sigma_1 - \sigma_3$) and the resultant recoverable strain (ε_r). This parameter is mandatory for rational pavement design, which should consider the elastic characteristics of the materials under different climate and loading conditions and regarding different failure mechanisms.

The M_R of unbound aggregates is obtained by carrying out triaxial repeated load tests. Since this kind of materials are highly sensitive to the confining stress (σ_3), the model presented in Eq. (1) is often used to predict their behaviour [9]. In Eq. (1), k_2 displays the modulus dependence upon the confining stress and k_1 is the modulus value for $\sigma_3 = 1$.

$$M_R = k_1(\sigma_3)^{k_2} \tag{1}$$

Although σ_3 is one of the main factors affecting the M_R of unbound aggregates, there are other variables that affect it (for instance, the deviator stress). As a result, several researchers have developed different models to predict the M_R of unbound aggregates. Lekarp et al. [10] e Mohajerani et al. [11] reported a series of these models in their works.

The model proposed by Seed et al. [12], which is known as bulk stress (θ) model, is presented in Eq. (2). This model is quite often used for pavement design. The software Everstress 5.0, used in this paper when analysing pavement structures (Section 4.2), applies the bulk stress model for granular materials.

$$M_R = k_1\left(\frac{\theta}{P_{atm}}\right)^{k_2} \tag{2}$$

In Eq. (2), $\theta = \sigma_1 + \sigma_2 + \sigma_3 = \sigma_1 + 2\sigma_3 = \sigma_d + 3\sigma_3$, σ_1 is the major principal stress, σ_2 is the intermediate principal stress, σ_3 is the minor principal stress, P_{atm} is the atmospheric pressure (1014 kPa) e k_1 e k_2 are model parameters.

2.2. Shear strength

The deformation of granular soils under loading is the result of three main mechanisms: consolidation, distortion, and attrition. The consolidation mechanism is the change in shape and compressibility of particle assemblies, whereas the distortion mechanism is characterized by bending, sliding, and rolling of individual particles. The attrition mechanism is the crushing and breakage that occurs when the applied load exceeds the strength of the particles. When the behaviour of granular materials is analysed at the macroscopic level, the observed deformation may be volumetric, shear, or, more normally, a combination of the two. These volume and shear strains result from various combinations of the three mechanisms mentioned [10].

Therefore, granular layers fail due to shear deformation resulting of cyclic lateral translation of a section of the granular material that leads to rutting or heave at the surface, as well as due to densification under the wheel path [13]. These may become a critical failure mechanism under thin asphalt layers. Although, it is possible to design granular layers safe against these failure mechanisms using Eq. (3), based on the Mohr-Coulomb theory for static loading condition [14].

$$F = \frac{\sigma_3[K(tan^2(45 + \frac{\phi\prime}{2}) - 1)] + 2Kc\prime\ tan(45 + \frac{\phi\prime}{2})}{(\sigma_1 - \sigma_3)} \tag{3}$$

In Eq. (3), F is the ratio between the shear strength and the applied shear stress, σ_1 and σ_3 are the major and minor principle stresses acting in the middle of the granular layer, c' is the cohesion, ϕ' is the angle of internal friction and K is a constant depending on the moisture condition. Once computed the stress ratio F it is possible to estimate the life of a granular layer considering a rational approach. Therefore, to protect a granular base against shear failure it is mandatory to determine its shear strength effective parameters.

2.3. Permanent strain response

The permanent strain response of unbound aggregates is a subject that is less studied than the resilient response and shear strength. However, it may rule the mechanical behaviour of unbound aggregates layers, so the assessment of such response is also required for rational pavement design.

Two types of deformation are produced in a granular layer of a pavement subjected to traffic loading: (a) resilient (recoverable) deformation and (b) plastic (irrecoverable) deformation [15]. One of the main problems that unbound aggregates exhibit in pavements is related to the increase of rutting due to the permanent deformation generated by traffic loading.

An interesting way for evaluating the material behaviour regarding permanent strains was proposed by Werkmeister et al. [16] and is known as the shakedown theory. The essence of a shakedown analysis is to determine the critical shakedown load for a given pavement. Pavements operating above the critical shakedown limit are predicted to exhibit increased accumulation of permanent strains under long term repeated loading conditions that eventually lead to incremental collapse (e.g. rutting). Those pavements operating at load levels below this critical shakedown load may exhibit some distress, but should settle down and reach an equilibrium state in which no further mechanical deterioration occurs [16]. Behaviours can be categorized in three possible ranges: A, B or C, as seen in Fig. 1.

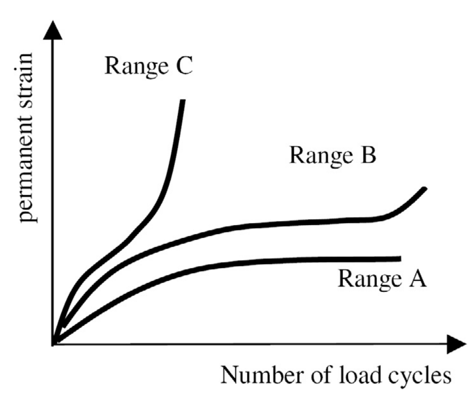

Fig. 1. Indicative permanent strain behaviour [17].