Statistical Analysis of Geotechnical Parameters of Recycled Construction and Demolition Waste (RCDW)

Analyse statistique des paramètres géotechniques des déchets de construction et de démolition recyclés (DCDR)

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ABSTRACT
Construction and demolition waste has become a serious trouble to public administration authorities due to adoption of repeated, expensive and inefficient management solutions. These actions are generally supported by the feeling that construction and demolition wastes present a high variability in their compounds, thus being inappropriate to reuse. In considering a competent approach in engineering practice, the decisive factors for the use of recycled construction and demolition wastes are their properties as a construction material, and the fact that variability may only be assessed by the use of statistical tools. In this investigation the authors have carried out a laboratory testing program (characterization, Proctor compaction, pH and direct shear test) on RCDW sampled in different times in order to conduct statistical analyses of its chemical and geotechnical parameters. The results have shown that recycled construction and demolition waste has a low variation of its properties and high levels of confidence that justify its use in a range of geotechnical application.

RÉSUMÉ
Les déchets de construction et de démolition sont devenues un problème sérieux aux autorités de l'administration public dues à l'adoption des solutions de gestion répétées, chères et inefficaces. Ces actions sont généralement soutenues par le sentiment que les déchets de construction et de démolition présentent une variabilité élevée de leurs composés, ainsi ils ont été jugés inadéquats pour être réutilisés. En considérant une approche compétente dans la pratique en ingénierie, les facteurs décisifs pour l'utilisation des déchets de construction recyclés sont leurs propriétés comme matériau de construction, et la conclusion de l'existence de la variabilité peut seulement être faite en employant les outils statistiques. Dans cette recherche les auteurs ont effectué un programme d'essai en laboratoire (la caractérisation, le compactage Proctor, pH et l'essai de cisaillement direct) sur DCDR prélevés dans différentes occasions afin de réaliser des analyses statistiques de ses paramètres chimiques et géotechniques. Les résultats ont montré que les déchets de construction et de démolition recyclés ont une basse variation de ses propriétés et niveaux de confiance élevés qui justifient leur utilisation dans une gamme d'application géotechnique.

Keywords : construction and demolition waste, statistical analysis, geotechnical parameter, confidence level.

1 INTRODUCTION

1.1 *Construction and Demolition Waste*

Despite all development showed by more and more modern, sophisticated and daring construction, the civil construction industry keeps a strong characteristic trait of handmade process which can be seen by the generation of a large amount of waste.

With a significant participation of construction and demolition wastes (CDW) in municipal solid wastes, the garbage treatment commonly given to CDW: (i) ignores its high recycling potential; (ii) compromises the useful life of landfills remarkably; (iii) encourages the irregular dumping in empty lot and in road border, etc.; and (iv) motivates the needs of exploration of new quarrying raw material areas to the construction industry.

In this scenario, bearing in mind the environmental, social and economical impacts caused by CDW, the need of adoption of public management waste policy, for example recycling, is showed.

Nowadays, different Brazilian universities and centers have researched use of recycled construction and demolition wastes (RCDW) as aggregate for use in pavement and concrete.

The use of RCDW in the base of pavement is known as a technologically consolidated alternative. However, national data show that the pavement sector alone would be unable to consume the whole RCDW produced. (Angulo et al. 2003).

On the other hand, the emphasis given to CDW recycling for production of aggregates for use in concrete seems not to be appropriate to national reality, mainly if the quality criterion proposed by international standard is adopted (John et al. 2004) and the aggregates production process practiced on the Brazilian recycling plants at present is considered.

Given the facts, as Santos (2008) emphasizes, in its Resolution 307, the CONAMA (Brazilian Environmental National Council) states that the wastes generated in "[...] site preparation and excavation [...]" are classified as CDW. Due to this fact, huge amounts of soil have been found in Brazilian recycling plants. Hereby justifying the effort of researches aiming at the use of RCDW in geotechnical applications.

It is known that many barriers should be overcome to achieve effective use of RCDW. Among which is the impression that these materials present high variability, which is caused by RCDW being generated in different activities, such as: (i) site preparation and excavation; (ii) construction material breakage, due to unsuitable storage; (iii) during construction; and (iv) during renovation and demolition processes.

However, in considering a competent approach in engineering practice, the decisive factors for the use of recycled construction and demolition wastes are their properties as construction material, and the fact that variability may only be assessed by the use of statistical tools.

1.2 *Statistical analysis*

According to Lumb (1968), it is common to find variation coefficients between 10 and 25% in soil properties. However,

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such coefficients can vary remarkably, as reported by Lee et al. (1983). Based on this finding, statistical tools were used to investigate the RCDW property variability.

1.2.1 *Student distribution or " t" distribution*

Student Distribution is applied to statistical inference, particularly when population standard deviation (σ) is not known and the sample size is lower than 30 ($n < 30$). In this case the Normal Distribution is not suitable to determine the confidence interval for average. The "t" Distribution shape is symmetrical to θ, similar to Normal Distribution, but presents a higher variance.

There is one value of "t" for each sample; and to calculate the "t" value to be used it is necessary to have:

- One desired confidence level ($1-\alpha$);
- The freedom level (ν) to be used.

This statistic distribution is carried out with $\nu = n-1$ degrees of freedom, where "n" is the sample size.

1.2.2 *Confidence interval*

The average is an important characteristic of a population, so it is interesting to estimate it by confidence level. Therefore the confidence interval is used to indicate the reliability of an estimate. The calculation is worked firstly by selection of the desired confidence level, so being determined, in terms of Student Distribution, using the Equation 1:

$$\overline{X} \pm t_{\alpha/2} \cdot \frac{s}{\sqrt{n}} \quad (1)$$

where: $\overline{X}$ = sample average; $t_{\alpha/2}$ = value of standard "t" distribution; s = sample standard deviation; e n = sample size.

1.2.3 *Estimative error*

The estimative error, or the admitted error of an estimate, is the difference between the sample average and the true sample average.

Bearing in mind that the confidence interval is centered on the sample average, the maximum probable error which is being admitted is equal to half of the interval values. So the estimative error can be calculated by using the Equation 2.

$$d = t_{\alpha/2} \cdot \frac{s}{\sqrt{n}} \quad (2)$$

where d = estimative error.

1.2.4 *Sample size determination*

In some special situations, it is possible to calculate the sample size necessary for inference. If the objective is to estimate the average, the interval confidence can be used, fixing the higher acceptable error and the desired confidence level. This way, it is possible to obtain "n", the sample size.

It is known that most of the measures of soil properties fit with the Normal Distribution, or Gaussian distribution (Lee et al. 1983).

In the case of average, accepting a maximum error "d", with probability $1-\alpha$, with interval of confidence level $100(1-\alpha)\%$, and with the value of "s", the sample size can be obtained by Equation 3, reorganizing Equation 2 in terms of Normal Distribution:

$$n = \left[\frac{Z_{\alpha/2} \times s}{d}\right]^2 \quad (3)$$

where $Z_{\alpha/2}$ = value of standard normal distribution.

However, it is noticed that the value of "s" is necessary to obtain the sample size. When this value is completely unknown, this problem is solved in two steps: (i) a preliminary sample is used to supply "s", and (ii) from this value, the necessary sample size is calculated.

2 MATERIALS AND METHODS

2.1 *Sampling*

Firstly, two Brazilian Standard (ABNT): NBR NM26 – Sampling of aggregates; e NBR10007 – Sampling of municipal solid waste – were consulted. However, considering that the "bica-corrida" of RCDW – the product of crushing and sieving of soil, brick, and small particles of concrete – grain size variation over the height of pile is not so homogeneous as aggregates, nor so heterogeneous as municipal solid waste (Fig. 1), the adoption of one or another standard mentioned above proved to be an inappropriate option.

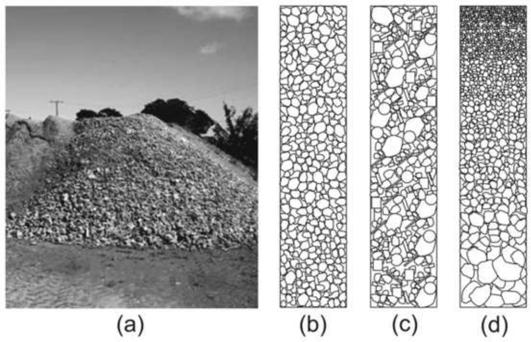

Figure 1. Grain size variation: (a) Picture of RCDW pile; (b) natural aggregate; (c) MSW; e (d) RCDW.

RCDW sampling was performed in two different ways, as follows: (i) RCDW arriving directly on tarpaulin, which was laid out below the conveyor belt; and (ii) sampling of RCDW stored in RMPSC patio area using a backhoe loader. Table 1 presents the sampling program RCDW carried out.

Table 1. Sampling program of RCDW.

Sample	Date	Amount (kg)
RCDW-01	April 12th, 2006	137
RCDW-02	April 20th, 2006	160
RCDW-03	May 10th, 2006	166
RCDW-04	May 18th, 2006	154
RCDW-05	August 17th, 2006	4,000

2.2 *Equipments and instrumentation*

Besides using accessories and equipment commonly found in soil mechanics laboratories, it was necessary to use large scale equipments due to the presence of large size particles.

The direct shear tests were carried out at the Rock Mechanic Laboratory of Engineering School of São Carlos - EESC-USP. The device allows testing samples with 500 x 500 x 500 mm. The instrumentation consisted of 6 (six) LVDT, where 4 (four) were to measure the vertical displacements, and 2 (two) to measure the horizontal displacements.

3 RESULTS AND ANALYSIS

3.1 *Characterization*

The results of the grain-size analysis of RCDW (Fig. 2) revealed a low variability of grain-size distribution curves. All RCDW samples classify as gravely sand.

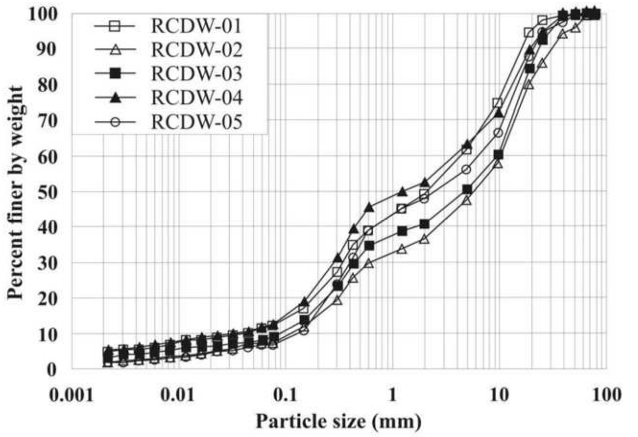

Figure 2 – Grain size distribution.

The analyses of confidence levels versus particle size showed confidence levels between 95 and 99% (Fig. 3). The analysis of confidence levels presented a mean value equal to 98%. This result can be explained by the fact that RCDW were submitted to a standard of production.

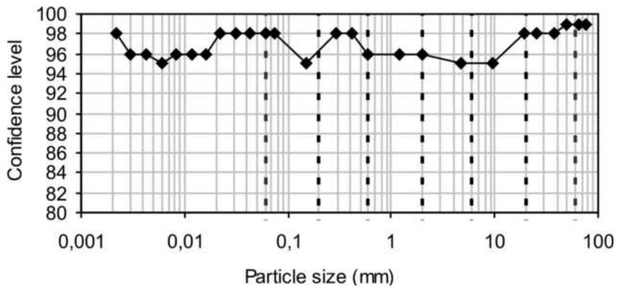

Figure 3 – Confidence levels versus particle size.

The Atterberg limit determination tests showed that RCDW have a non-plastic behavior.

The result of specific gravity determination (Table 2) of RCDW showed a mean value of 2.819g/cm^3, with a coefficient of variability of 3.1%.

Table 2. Results of specific gravity.

Sample	Specific gravity (g/cm³)
RCDW-01	2.734
RCDW-02	2.716
RCDW-03	2.889
RCDW-04	2.882
RCDW-05	2.875

The specific gravity values presented by RCDW were within confidence interval of 96%. Table 3 presents the intervals of specific gravity for different confidence levels, and the calculated sample sizes.

Table 3. Specific gravity confidence intervals and sample sizes.

Confidence level (%)	Confidence interval for specific gravity (g/cm³)	Calculated sample size
99	2.634 to 3.004	493
98	2.674 to 2.964	101
96	2.703 to 2.935	20
95	2.712 to 2.926	11
90	2.737 to 2.901	2

3.2 *Proctor compaction test*

Proctor compaction test results showed mean value of unit dry weight equal to 1.844kN/m³, with a coefficient of variability equal to 2.1%. The optimum water content presented mean value of 14.9%, with a coefficient of variability equal to 13.3%. Figure 4 presents the results of Proctor compaction test.

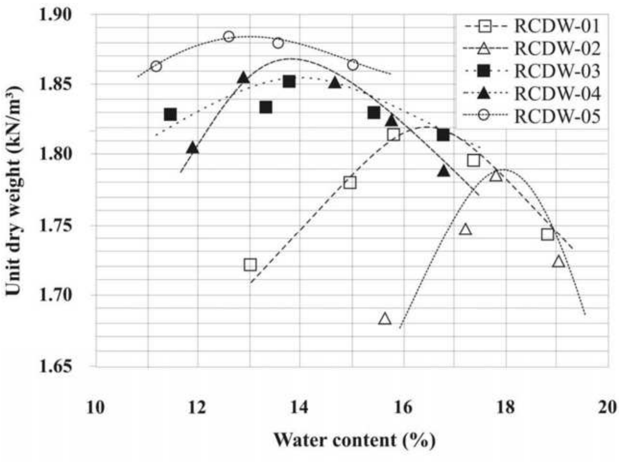

Figure 4. Proctor compaction results.

It was observed that $\gamma d_{MÁX}$ values were within confidence interval of 96%. Table 4 presents the □$d_{MÁX}$ intervals with different confidence levels and the calculated sample sizes.

Table 4. $\gamma d_{MÁX}$ confidence intervals and samples sizes.

Confidence level (%)	Confidence interval for $\gamma d_{MÁX}$ (kN/m³)	Calculated sample size
99	1.759 to 1.929	104
98	1.777 to 1.911	21
96	1.791 to 1.897	4
95	1.795 to 1.893	2
90	1.806 to 1.882	0

3.3 *pH Test*

The results of pH tests using distilled water showed a mean value of 9.1, with a coefficient of variation of 4.3%. It was observed that RCDW aqueous extract is alkaline.

The pH values presented by RCDW were within confidence interval of 95%. Table 5 presents the pH intervals for different confidence levels and the calculated sample sizes

Table 5. pH confidence intervals.

Confidence level (%)	Confidence interval for pH	Calculated sample size
99	8.27 to 9.97	10,370
98	8.46 to 9.78	2,131
96	8.59 to 9.65	412
95	8.63 to 9.61	241
90	8.74 to 9.50	42

3.4 *Direct shear test*

The results of direct shear test showed a plastic behavior of RCDW, with stress and displacement increasing to a certain point and a subsequent increase on displacements with no significant changes in stresses (Fig. 5).

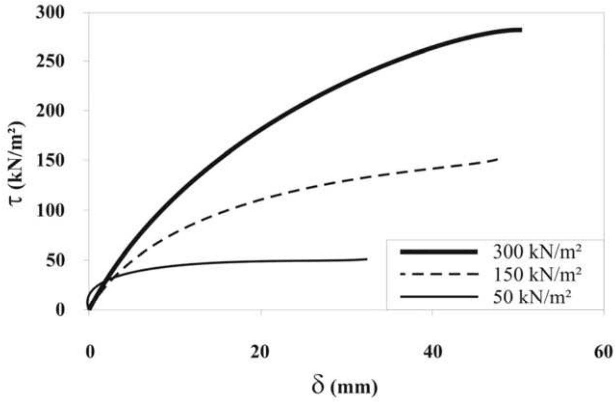

Figure 5.Stress-displacement curves of RCDW-R05.

The volume variation revealed a reduction on sample volume (Fig. 6).

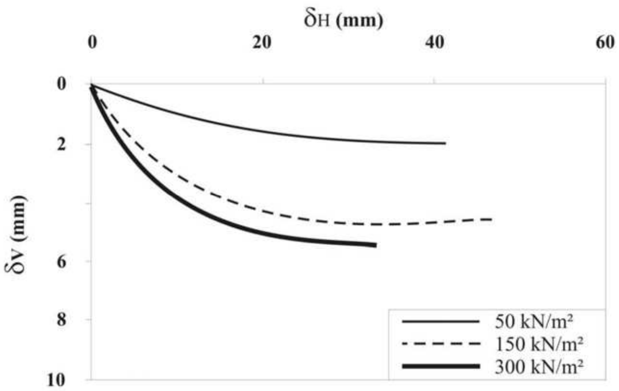

Figure 6. Vertical and horizontal displacement curves of RCDW-05.

Equation 4 presents the shear strength equation for RCDW.

$$\tau = 13 + \sigma \tan 41°(kN / m^2) \quad (4)$$

where: τ = shear strength and σ = normal stress.

Using the values obtained from direct shear test and adopting the standard deviation (σ[Xi]) based on coefficient of variability reported by Lumb (1974), upper and lower shear strength curves of RCDW-05 were drawn. Table 6 shows the adopted standard deviation values. Figure 7 presents the shear strength curves.

Table 6. Obtained and adopted parameters.

Xi	C (kN/m²)	f' (°)
Xj	13	41
s	± 5.2	± 4.1

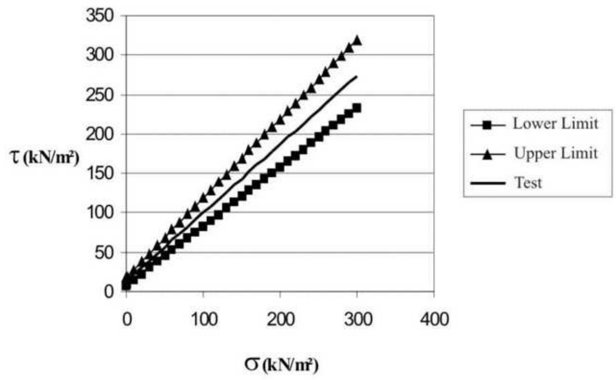

Figure 7. Shear strength curves of RCDW-05.

4 CONCLUSION

The results showed that recycled construction and demolition waste has a low variation of its properties and high levels of confidence that justify its use in a range of geotechnical application.

The statistical tools proved that RCDW, despite presenting a high variability in its composition material, presents ranges of values of geotechnical parameters with high confidence levels. By calculating the sample size, it was possible verify that high confidence levels can be guaranteed by adoption of sample size applicable for soil laboratory.

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