Use of Construction and Demolition Solid Wastes (C&DW) for Basket Gabion Filling

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ABSTRACT:
The building growth has resulted in a significant amount of solid wastes and the consumption of vast amounts of natural aggregates. On the other hand, the use of gabions is a well-established technical solution for retaining walls construction. This research intends to assess the use of C&DW (Construction and Demolition Wastes) as filling material for basket gabions. Nowadays, a significant part of basket gabions is filled with rocks. However, the extraction of these natural materials usually causes environmental damages. Facing this situation, the use of C&DW for rock substitution on gabions filling can reduce these environmental impacts and the costs. Due to this situation, laboratory tests were performed to obtain the compressive strength of C&DW. The specimens were carved as recommended by ABNT NBR NM 7680-1/2015 “Concrete - Sampling, preparing, testing and result analysis of concrete cores Part 1: Axial compressive strength”. To verify internal fissures existence, that could affect the specimen's compressive strength; ultrasound tests were performed according to ABNT NBR 8802/2019 “Hardened concrete-Determination of ultrasonic wave transmission velocity”. Compressive tests were performed to obtain the specimen's strength following the procedures given by ABNT NBR NM 8522/2017 “Concrete - Determination of the elasticity modulus by compression”. For gabions behavior, compressive tests using reduced models were performed. It can be concluded that the use of C&DW for gabion baskets filling trends to be an alternative solution for retaining walls design and construction. Besides, it has environmental advantages such as reducing natural raw materials exploitations, lower greenhouse gas emissions, and others.

KEYWORDS: Gabion, Construction and Demolition Wastes, Sustainability

RESUMO:
O crescimento da construção civil resultou em uma quantidade significativa de resíduos sólidos e no consumo de grandes quantidades de agregados naturais. Por outro lado, o uso de gabões é uma solução técnica bem estabelecida para a construção de muros de contenção. Esta pesquisa pretende avaliar o uso de Resíduo da Construção Civil (RCC) como material de enchimento para gabões tipo caixa. Atualmente, uma parte significativa dos gabões é preenchida com rochas. No entanto, a extração desses materiais naturais geralmente causa danos ambientais e tem custo elevado. Diante dessa situação, o uso de RCC para substituição de rochas no preenchimento de gabões deve reduzir impactos ambientais e os custos. Dessa forma, testes de laboratório
foram realizados para obter a resistência à compressão do RCC. As amostras foram usinadas conforme recomendado pela ABNT NBR 8522 “Concreto - Determinação dos módulos estáticos de elasticidade e de deformação à compressão”. Para verificar a existência de fissuras internas, que poderiam afetar a resistência à compressão da amostra, foram realizados testes de ultrassom de acordo com a ABNT NBR 8802/2019 “Concreto endurecido - Determinação da velocidade de propagação de onda ultrassônica”. Ensaios de compressão foram realizados para obter a resistência das amostras tal como recomendado pela ABNT NBR NM 8522 “Concreto - Determinação dos módulos estáticos de elasticidade e de deformação à compressão”. Para estudo do comportamento dos gabiões, foram realizados testes de compressão usando modelos reduzidos. Pode-se concluir que o uso do RCC para o enchimento de gabiões consiste em uma solução alternativa para o projeto e construção de muros de contenção. Além disso, esta prática possui vantagens ambientais, como: redução da exploração natural de matérias-primas, menor emissão de gases de efeito estufa e outras.

PALAVRAS-CHAVE: Gabiões, Resíduos de Construção Civil, Sustentabilidade.

1 Introduction

To Yuan (2017), there is a lack of C&DW (Construction and Demolition Wastes) definition, but it is almost always defined as the solid waste that rises from construction and demolition activities. C&DW can be defined as a mixture of different materials generated by demolition, renovation, and construction activities (Menegaki & Damigos, 2018). The amount of C&DW comes from various sources, such as asphalt, concrete, wood, soil, tiles, ceramic materials. The C&DW accounts for 30 to 40% of the total mass of produced solid urban waste worldwide (Jin, Yuan & Chen, 2018). When improperly managed, this waste causes soil, water, and air pollution (Mahpour, 2018).

It estimated that more than 10 billion tonnes of C&DW were generated over the world in 2017 (Wang, Wu, Tam & Zuo, 2019). In 2016 the European Union produced 923,540,000 tonnes of C&DW (Eurostat, 2017), in the USA, in 2014, approximately 540 million tonnes were generated. Australia and China in 2014 produced 19.5 million tonnes and 1.13 billion tonnes, respectively (Menegaki & Damigos, 2018). The United Kingdom, in 2012, generated 200 million tonnes of waste, of which 50% was produced in Construction and Demolition. Blaisi (2019) informs that in Saudi Arabia in 2016 was generated 131,436 tonnes of C&DW. Comparing 2016 to 2017, the author relates an increase near 10%.

Authors highlighted environmental, social, and economic advantages of C&DW recycling in the construction sites as like Arif, Bendí, and Tomá-Sabbagh (2012); Oyedele, Regan, Meding, Ahmed, and Elnokali (2013); Paschoalin Filho, Bezerra, Oliveira and Faria (2017), among others. In the last decade, the feasibility and efficient management of C&DW has been widely studied by many research types. As informed by Blaisi (2019), the critical elements for successful C&DW management include (i) awareness of waste management, (ii) waste management regulations and systems, (iii) sustainable building technologies, and (iv) C&DW management plans for construction and demolition work.

The use of gabions is a well-established technical solution for retaining walls construction. However, despite the wide diffusion of this methodology, the knowledge of gabions' mechanical behavior is still limited. Only a small number of researches focused on gabions' structural behavior when used as retaining wall construction material (Mazzon, Ferraíolo & Vicari, 2016). C&DW materials, such as concrete and bricks, were studied by Nawagamuwa et al. (2012) to verify the possibility of being used as gabion filling material. According to their study, considering the durability and compressive strength, only concrete waste could be viewed as suitable for use in gabions; other materials may not present enough compressive strength or durability. However, despite the pioneer studies of Nawagamuwa et al. (2012), the technical means still demands new researches focused on the use of C&DW materials for gabion filling.

2 Material and Methods

A gabion retaining wall design must assess horizontal efforts for stability, thrust analysis, and compressive efforts to study the maximum height that the wall can reach. The baskets overlap to get a design height that causes compressive stress on those, inducing horizontal displacements that could take the gabion's wire to...
failure. That is why compressive stress and horizontal displacements analysis are essential to foresee gabion's retaining wall performance.

Aiming to characterize the filling materials, laboratory tests were performed to obtain the compressive strength of C&DW samples at the Laboratory of Construction Materials of Agricultural Engineering Faculty of State University of Campinas (Unicamp). The specimens were carved as recommended by ABNT NBR NM 7680-1/2015 "Concrete - Sampling, preparing, testing and result analysis of concrete cores Part 1: Axial compressive strength". To verify internal fissures existence could affect the specimen's compressive strength; ultrasound tests were performed by ABNT NBR 8802/2019 "Hardened concrete — Determination of ultrasonic wave transmission velocity" recommendations. Compressive tests were performed to obtain the specimen's strength following the procedures given by ABNT NBR NM 8522/2017 "Concrete - Determination of static modulus of elasticity and deformation by compression".

For gabions behavior obtaining, compressive tests using reduced models (0.4x0.4x0.4 m) were performed. However, three basket gabions were filled in real size (1.0x1.0x1.0 m), aiming to obtain physical values such as mass and specific weight. These data were used to build the test gabions for the compressive tests performed. Each model test gabion was measured and weighed to confirm if these characteristics represent the real size gabions. The filling material had an average grain size distribution of 10 to 30 mm. The gabion's meshes were composed of an annealed mild steel wire.

During the performed compressive test, the vertical displacements were observed by four deflectometer positioned on the top of test gabions. Aiming to find horizontal displacements, each gabion was marked in three different heights (top, medium, and bottom). The following figures (1 and 2) present the studied models.

![Figure 1. Test gabions filled with C&DW.](image)

![Figure 2. The compressive test being performed (C&DW) and deflectometer R1, R2, R3, and R4 positioned above the gabion.](image)

3 Achievements

The average mass (m) and specific weight (γ) obtained for the specimens were: $m_{C&DW} = 3.8N$ (sd = 0.01, cv = 3.4%) and $\gamma_{C&DW} = 22.35 \text{ kN/m}^3$ (sd = 0.8 kN/m$^3$, cv = 3.4%). These average values were obtained by the measures performed on all the C&DW blocks used for tested gabions. In general, all construction waste specimens had specific weights according to ABNT NBR 9778/2009 "Hardened mortar and concrete - Determination of absorption, voids and specific gravity", i.e between 20 and 28 kN/m$^3$. 

Therefore, according to the standard deviation values and coefficients of variation determined, it can be assumed that the dimensions of the specimens presented low changes concerning height and diameter, which shows that they were satisfactory carved. Besides, the height/diameter ratios were near to 2.0, which meets the requirements of ABNT NBR 12024/2012 “Soil-cement — Molding and curing of cylindric specimens — Procedure”.

Aiming to verify the specimens’ internal integrity and the presence of micro-cracks and discontinuities within, then ultrasound tests were performed in all samples before their submission to the compression tests. After that, compressive strength tests were performed. As shown by ultrasound tests performed, the average wave propagation velocities were above 4,000 m/s, which, according to ABNT NBR 8802/2019 “Hardened concrete - Determination of ultrasonic wave transmission velocity”, indicates the excellent quality of the specimens tested and the absence of pathologies and non-visible heterogeneities that could reduce their compressive strength. According to Leal (2012), the typical wave propagation velocity for good quality concretes ranges from 3,000 to 5,000 m/s. The compressive strength for C&DW specimens ranged from 11.22 MPa to 32.46 MPa, resulting in an average value of 20 MPa (concrete Class CA20). The obtained average data is lower than determined by Leal (2012), who found an average of 33 MPa for 28-day-old concretes. Leal (2012) performed compressive tests on concrete specimens (age 28 days) and obtained average compressive strengths among 28.8 and 49.14 MPa. Table 1 shows the standard errors and the upper and lower confidence intervals for a 95% probability of occurrence.

Table 1. Average C&DW compressive strength (CS)

<table>
<thead>
<tr>
<th>Statistic</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>20 MPa</td>
</tr>
<tr>
<td>Sd</td>
<td>6.1</td>
</tr>
<tr>
<td>cv</td>
<td>30.5%</td>
</tr>
<tr>
<td>Standard error</td>
<td>1.92 MPa</td>
</tr>
<tr>
<td>Confidence interval (+)*</td>
<td>23.80 kN</td>
</tr>
<tr>
<td>Confidence interval (-)*</td>
<td>16.30 kN</td>
</tr>
</tbody>
</table>

*For 95% of the confidence interval

The small standard error values presented in Table 1 justify the proximity between the upper and lower confidence interval values and the low standard deviation values calculated. After specimens characterization, unconfined compression tests were performed on reduced size gabions. Figures 3 and 4 present the obtained curves.

![Figure 3. Load versus vertical displacement (average)](image-url)
Figure 4. Load versus vertical displacement – $R_{\text{average}}$, $R_{\text{superior}}$, and $R_{\text{inferior}}$ (for 95% of confidence interval) trend curves.

Figure 3 has indicated an average compressive displacement near 31.5 mm, while Figure 4 has presented load-increase vs. displacement curves concerning the average R values and upper and lower limits. In this situation, the upper limit curve indicates a 29.5mm for total displacement, while the lower limit curve has demonstrated a displacement of 31.5 mm. By trend curves analysis, it can be seen that the vertical displacements were oriented by well-adjusted polynomial curves, which can be observed through the determination coefficients $R^2$ near to the unit. At a load increase near to 2.1 tonnes, the C&DW grains have begun to crack inside the gabion, which increased vertical displacements. The maximum load has reached 30kN; because from this value, the gabions have presented excessive deformations, which could cause any damage for the researchers safe. Figures 5 and 6 illustrate the horizontal displacements observed.

Figure 5. Load versus horizontal displacement (average)
Analyzing Figures 5 and 6, the L1, L2, and L3 markings have indicated an average horizontal displacement of 93 mm. Figure 6 shows the load increase vs. displacement curves considering the mean values and the upper and lower limits from the averages. In this situation, the upper limit curve indicates a total displacement of 248 mm, while the lower limit curve suggests a displacement of 8.5 mm. Figures 7 and 8 show C&DW failures after the performed tests.

At initial loads, the vertical displacements occurred due to the accommodation among filler materials. After 20 kN of compressive load, the C&DW inside the gabions has run to failure, which induced additional displacements. It should be highlighted that 20 kN of the compressive load is equivalent to a compressive strain of 163 kN/m². This load measures up a vertical column of 7.5 m high of gabions filled with C&DW. Observing the displacements and compressive strains determined by performed tests, it was possible to estimate for studied gabions some essential physical parameters for designs and internal stability analysis:
specific strain (ε) and Poisson's ratio (ν). These parameters were estimated concerning the maximum applied load over gabions, 30 kN (Qt), and for an equivalent load of 50% of this (Qt/2). Regression equations were used to calculate the displacements for these loads. A load of 30 kN (Qt) measures up a compressive strain of 11 m high C&DW filled gabion column. So, a load of 15 kN (Qt/2) would be equivalent to a 5.5 m high column. These values are brought by tables 3 and 4.

### Table 3. Obtained values of vertical displacement (δ) and specific strain (ε) for Qt = 30 kN e Qt/2 = 15 kN.

<table>
<thead>
<tr>
<th>Date</th>
<th>Equation</th>
<th>δ0 (mm)</th>
<th>ΔQt/2 (mm)</th>
<th>ΔQt (mm)</th>
<th>ΔQt/2</th>
<th>δQt/2 (%)</th>
<th>ε Qt/2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&lt;sub&gt;average&lt;/sub&gt;</td>
<td>y = -0.0049x^2 - 0.9294x + 39.64</td>
<td>39.64</td>
<td>24.6</td>
<td>7.3</td>
<td>15.05</td>
<td>32.34</td>
<td>4.0</td>
</tr>
<tr>
<td>L&lt;sub&gt;average&lt;/sub&gt;</td>
<td>y = -0.2451x^2 + 11.624x + 1182.9</td>
<td>1182.9</td>
<td>1303.1</td>
<td>1311</td>
<td>-120.2</td>
<td>-128.1</td>
<td>30</td>
</tr>
</tbody>
</table>

Where ΔQt = δ0 - δQt; ΔQt/2 = δ0 - δQt/2

<table>
<thead>
<tr>
<th>Material</th>
<th>νQt/2</th>
<th>νQt</th>
</tr>
</thead>
<tbody>
<tr>
<td>C&amp;DW</td>
<td>0.12</td>
<td>0.25</td>
</tr>
</tbody>
</table>

By Table 3, it can be seen that for Qt/2 (15 kN), which could be related to a safety factor equal 2.0, the C&DW filled gabion showed vertical displacement (δQt/2) 6% of the initial height (400mm). This picture indicates a trend towards the technical feasibility of the design and execution of gabion filled with waste at vertical heights up to 5.5 m. Also, in Table 3, it can be seen that the C&DW filled gabion has shown a horizontal displacement to Qt/2 equivalent to 30% of the initial length (400mm). However, it should be highlighted that gabions are usually confined in a retaining wall, which can influence horizontal displacements values for low. In the performed compression tests, the gabions were unconfined. So the studied situation trends to be more unfavorable concerning gabions horizontal displacements.

### 4 Conclusions

The main goal of this research was the assessment of gabions filled with concrete C&DW to be used as a construction material for retaining walls. This way, laboratory tests were performed at the Laboratory of Construction Materials of Agricultural Engineering Faculty of State of Campinas. According to the performed analysis, the following conclusions can be drawn:

- The load versus displacement ratios (horizontal and vertical) obtained by performed gabion compression tests have demonstrated a well-adjusted behavior trending to a second-degree polynomial curve.
- For the gabions filled with C&DW, the horizontal displacements were higher than the vertical ones. However, for conventional gabion retaining walls, the baskets are confined, which limits horizontal displacements;
- Concerning an effort equivalent to Qt/2 and the C&DW gabion average specific weight (γnat = 16.35 kN/m³), it can be drawn that these gabions have been submitted by a compressive load equivalent to a vertical column of gabions equal to 5.5 m.
- By performed tests, gabion's compressive strength and deformation parameters were estimated for Qt and Qt/2 loads. These may be used for preliminary analysis of the behavior of gabion retaining walls filled with C&DW.
- The obtained results bring light to the possibility of C&DW use for gabion filling that could be used for retaining wall construction until 5.5 m height, concerning safety factor 2.0;
- The use of construction wastes for gabion baskets filling trends to be an alternative solution for retaining walls design and construction. Besides, it has environmental advantages such as reducing natural raw materials acquisition, lower greenhouse gas emissions produced by extractive activities and transportation, reuse wastes inside construction works, and others.
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