Experimental reinforced soil walls built with recycled construction and demolition waste (RCDW).

Murs expérimentaux de sol renforcé construits avec résidus de construction et démolition recyclés

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ABSTRACT: In spite of its well known evolution, the Civil Engineering is yet pointed out as remarkable raw material consumer and one of the leading waste generators in modern society. Nowadays, construction and demolition waste became a complex problem to government authorities due to its economical and environmental impacts. Bearing in mind these aspects, the use of recycled construction and demolition waste (RCDW) in reinforced soil structures appears to be an interesting proposition. In order to investigate this proposal, two instrumented full-scale wrapped face geosynthetic reinforced walls were constructed using recycled construction and demolition waste as backfill material. The instrumentation plan consisted of more than 400 instruments and required the adoption of a careful installation process due to the presence of coarse particles of RCDW. The results have shown that RCDW has excellent mechanical properties - with low variation – which allow its use not just in the suggested proposal but in other geotechnical works. Additionally, based on lessons learned during the construction process, some recommendations are presented with the intention of promoting a better performance of reinforced walls built with this "novel construction material".

RÉSUMÉ : Malgré sa nette évolution, le génie civil est toujours indiqué comme un grand consommateur de matière première et un des leaders de la génération de résidus dans la société moderne. Actuellement, le résidu de construction et démolition est devenu un problème complexe pour les autorités municipales en raison des impacts économiques et environnementaux. Compte tenu de ces aspects, l'utilisation des résidus de construction et démolition recyclés (RCD-R) dans les structures de sol renforcé, émerge comme une proposition intéressante. Pour investiguer cette proposition, deux murs renforcés avec géosynthétiques de face enveloppé ont été construits avec RCD-R comme matériaux de remplissage. Les murs ont été construits à l'échèle réel et instrumentés. L'instrumentation consistait a plus de 400 instruments et elle a demandé l'adoption d'un procès minutieux d'installation en raison de la présence des cailloux du RCD-R. Les résultats ont montré que le RCD-R possède d'excellentes propriétés mécaniques – avec faibles coefficients de variation – qui permettent leur utilisation non seulement dans la proposition suggérée, mais aussi sur d'autres ouvrages géotechniques. De plus, basée sur les leçons apprises au cours du processus de construction, certaines recommandations ont été déposées dans le but de promouvoir une meilleure performance des murs renforcés construits avec ce "nouveau matériaux".

KEYWORDS: reinforced soil wall, geosynthetics, recycled construction and demolition waste, instrumentation.

1 INTRODUCTION.

The Geotechnical Engineering has provided the development of innovative solutions to complex Civil Engineering problems. This proves its technical capacity to face new challenges. However, besides its well known evolution, the Civil Engineering is yet pointed out as remarkable raw material consumer and one of the leading waste generators in our modern society. Nowadays, construction and demolition waste (CDW) became a complex problem to government authorities due to its economical and environmental impacts.

In this scenario, some aspects related to growth of cities and to the need for adoption of sustainable development concepts may threaten the technical and economical advantages of reinforced soil structures: i) lack of good quality backfill material near to site construction and ii) compliance with environmental laws, which became more strict with respect to exploitation of new raw materials deposits. Bearing in mind these aspects, the use of recycled construction and demolition waste (RCDW) in reinforced soil structures appears to be an interesting proposition.

In order to investigate this proposal, two instrumented full-scale wrapped face geosynthetic reinforced walls were constructed using RCDW as backfill material.

1.1 *RCDW geotechnical characterization for use in reinforced walls*

The Brazilian Environmental National Council (CONAMA), in its Resolution 307/2002, states that wastes generated in "[…] site preparation and excavation […]" are classified as construction and demolition waste (CDW). Due to this, huge amounts of soil stockpiles can be found in some Brazilian recycling plants. According to the Construction Waste Collecting Association (2011), in Brasília (capital city of Brazil) approximately 70% of mass of municipal solid waste consist of CDW. According to Santos (2011), approximately 65% of mass of the recycled construction and demolition waste (RCDW) produced in Brasília is composed of soil. This fact reveals an interesting perspective to the use of RCDW in geotechnical works.

Santos (2007), in order to evaluate the potential use of RCDW in geosynthetic reinforced walls, carried out a laboratory testing program focused on geotechnical characterization and pH tests. Furthermore, pullout tests with geogrids were performed using clayey sand [typical soil from the southeast part of Brazil] and sand obtained from a local supplier. Clayey sand was chosen in order to compare the behavior of RCDW to others materials. The sand material was compliant with FHWA recommendations for backfill materials.

The RCDW material revealed a low coefficient of variation with respect to geotechnical properties and low alkalinity applicable to be used with geogrid products. The mechanical properties were excellent for the proposed application. The results of pullout tests with RCDW showed that the recycled material yielded a better performance when compared with the standard sand.

Based on the facts listed above and results observed by Santos (2007) as well as on interesting perspective for the use of this waste in geotechnical structures, a research programme aimed at investigating the performance of reinforced soil structures using RCDW as backfill material started in 2009 at the University of Brasilia, Brazil.

2 EXPERIMENTAL REINFORCED RCDW WALLS.

2.1 *Recylced Construction and Demolition Waste (RCDW)*

The recycled construction and demolition waste (RCDW) used as backfill material consisted of the product of the crushing process of construction and demolition waste (CDW), which is composed mainly of mixed materials including soil, bricks, and small particles of concrete. The RCDW was sampled at the CDW Re-cycling Plant of Brasília-DF, located at Jockey Club Landfill (Figure 2). Usually, this material is used by the local government as cover for unpaved roads.

Figure 1. CDW Recycling Plant of Brasília-DF.

A large-scale equipment was used for the determination of the RCDW shear strength parameters. Because of the presence of coarse grained particles (Figure 2), the dimensions of the shear box used were 800x800x450mm. Table 1 presents the main geotechnical parameters of the RCDW tested.

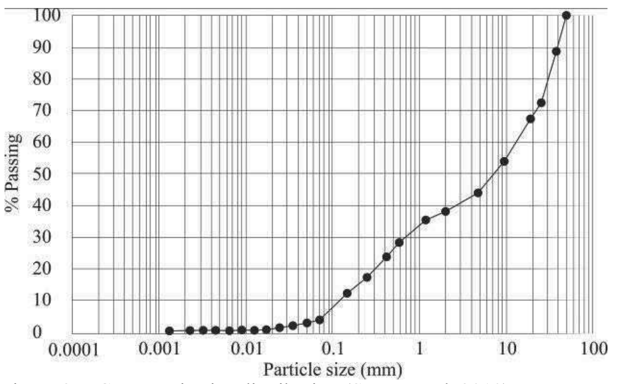

Figure 2. RCDW grain size distribution (Santos et al. 2010).

Table 1. Geotechnical properties of RCDW.

Parameter	*Value*
Specific gravity (g/cm^3)	2.74
Liquid limit (%)	35
Plastic limit (%)	28
Maximum dry unit weight (kN/m^3)	16.9
Optimum water content (%)	18
Friction angle (°)	38
Cohesion (kN/m^2)	14

2.2 *Geosynthetics*

The geosynthetics used as reinforcement for the walls in this investigation consisted of a polyester geogrid and a polypropelene nonwoven geotextile. Table 2 summarizes the main properties of the reinforcement.

Table 2. Geosynthetics properties.

Parameter	*Data/Value*	
	Geogrid	*Geotextile*
Polymer	PET	PP
Longitudinal tensile strength (kN/m)	20	19
Transverse tensile strength (kN/m)	9	21
Maximum tensile strain (%)	12	70

2.3 *UnB Retaining Wall Test Facility*

Experimental walls were constructed in the UnB Retaining Walls Test Facility located outdoor at the Foundation, Field Test and Geosynthetics Experimental Field area. The test facility was designed to allow two walls to be constructed up to 3.6 m high by 3.7m wide and extending up to 7.2m from the front edge of the facilityedge. The facility can contain up to 214 m3 of backfill material for the construction of two walls simultaneously. Figure 3 shows an overview of the test facility.

Figure 3. UnB Retaining Wall Test Facility (Santos et al. 2010).

3 CONSTRUCTION PROCEDURE AND INSTRUMENTATION.

The walls construction process was conducted using the moving formwork technique, which is a common method for the construction of wrapped-faced walls in the field. In order to reduce the side wall friction, the whole internal walls of the test facility were covered with three polypropylene sheets interspersed with lubrication (liquid silicone).

Three walls sections were named according to their cardinal orientation as West, Central and East. This configuration allows for the instrumented portion of the wall (Central section) to approach a plane-strain condition, free from side wall effects, as far as practical. This procedure has been adopted at Royal Military College of Canada (RMC) in a successful long-standing program on construction of full-scale reinforced walls (Santos et al. 2010).

The construction procedure consisted of placing the backfill material and compacting it in 200mm lifts. In order to provide a light compaction and a satisfactory surface leveling, a manual compaction roll was used. Near to the face, a hand tamping cylinder was used to minimize the effects of the compaction on the facing displacements. The total construction time was 29 days. Figure 4 and Table 3 present RCDW reinforced walls construction history and their main characteristics.

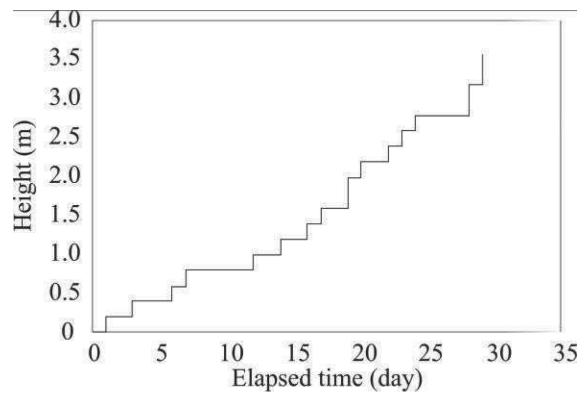

Figure 4. RCDW reinforced walls construction history (Santos et al. 2010).

Table 3. Main walls characteristics.

Characteristic	Value	
	Wall #1	*Wall #2*
Geosynthetics	Geogrid	Geotextile
Height (m)	3.60	
Facing batter (°)	13	
Reinforcement spacing (m)	0.60	
Reinforcement length (m)	2.52	

Approximately 400 instruments were installed in the two walls in order to record the following:

a. strain in reinforcement layers (strain gauges and wire-line extensometers installed in wall #1 and wall #2, respectively);
b. wall face displacements;
c. vertical earth pressure at the base of the RCDW (earth pressure cells - EPC);
d. horizontal earth pressure within the RCDW mass (EPC);
e. settlements along the surface of the RCDW mass (superficial marks);
f. horizontal displacement of the foundation soil (inclinometer).

Figure 5 shows the instrument distribution profile.

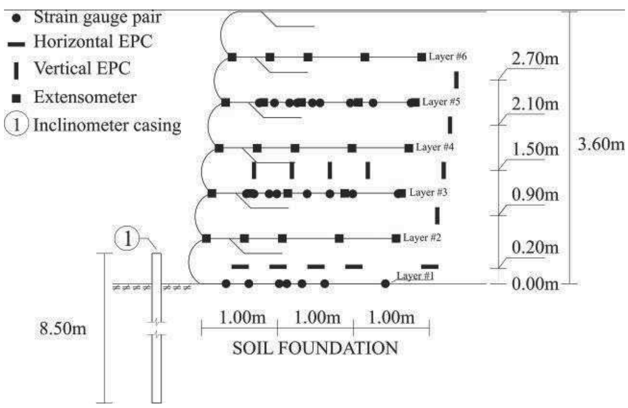

Figure 5.Instruments distribution profile.

Additional procedures were necessary to protect the instruments devices against mechanical damages during the walls construction. Because of the presence of coarse grained particles (Figure 2), the installation of the instrumented geogrid layers and earth pressure cells (EPC) were carried out using fine grained particles around the instruments. PVC tubes were used to create a region with selected fine RCDW - smaller than 2mm around EPC and strain gauges. Figure 6 presents a scheme of the region around strain gauges after geogrid layer installation process.

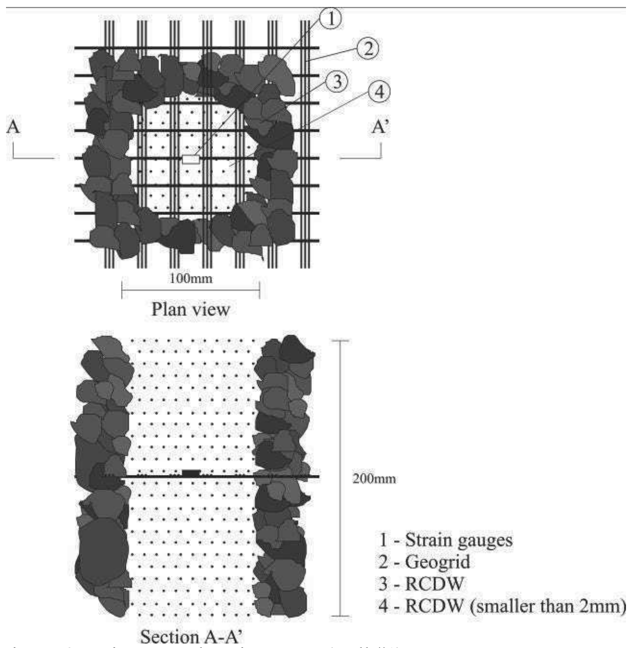

Figure 6.Region around strain gauges (wall #1).

The data recording after the walls construction revealed that just one strain gauge was mechanically damaged, which correspond to a survival level of 98% for installed strain gauges. This survival level kept stable until the end of research program even though the rainy seasons in Brasília. It was observed that all EPC survived to installation process but not to the first rainy season. After 110 days, all EPC failed.

Outward displacements of the walls faces during construction were measured. It was observed for the wall #1 (geogrid) a maximum end of construction face displacement measured with respect to formwork position of approximately 106 mm. Wall # 2 (geotextile) revealed a maximum end of construction face displacement - measured with respect to formwork position - approximately equal to 254 mm. Figure 7 shows wall #1 post-construction face profile.

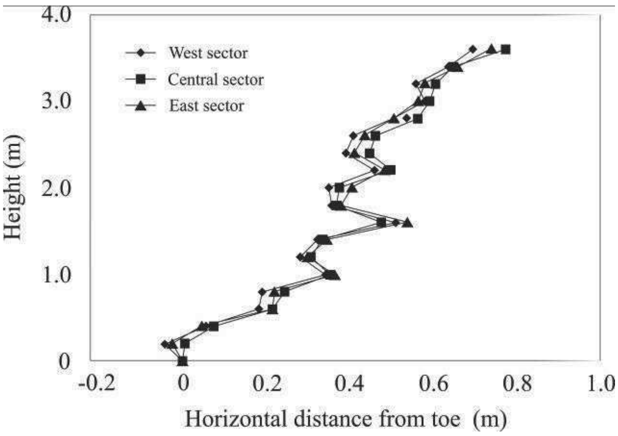

Figure 7. Post-construction face profile (Santos et al. 2010).

It was noticed for both walls that the presence of coarse particles near to face was responsible for the uneven surface and the different magnitude of facing displacements among the walls sectors at the same layer (Figure 8). Although this fact did not affect the mechanical performance of the walls, it is strongly advised to use a selected RCDW near the face in order to provide a better aesthetic aspect.

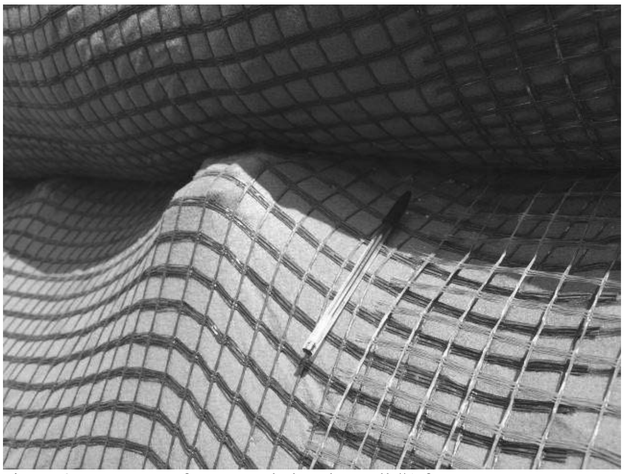

Figure 8. Uneven surface recorded at the wall #1 face.

4 CONCLUSIONS

The results obtained in the research programme have shown that the RCDW used has excellent mechanical properties - with low variation – which allow its use not just in the suggested proposal but in other geotechnical works. Additionally, the adoption of a careful installation process due to the presence of coarse particles of RCDW seemed to be successful once the strain gauges presented a high and stable survival level. Based on lessons learned during the construction process, some recommendations were presented with aiming at promoting a better performance of reinforced walls built with this "novel construction material".

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