Technical and Economic Analysis of Construction and Demolition Waste Used in Paving Project

Analyse technique et économique des déchets dans la construction de pavage

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ABSTRACT: In this research, the technical and economic feasibility was analyzed as to the use of wastes originated from the deep excavation activity (continuous helical piles) and by demolition of old constructions for the application in layers of subgrade, sub-base and base in paving project. For such, laboratory tests were conducted for the verification of granulometry, real density, limits of consistence, compaction with intermediate energy, California Bearing Ratio (CBR) with measuring of expansion, which exposed the quality of the materials and its potentials. A comparative analysis was carried out between recycled material costs and the aggregate commonly used in paving project, discovering, besides the technical advantage, also the economic advantage of this alternative material.

RÉSUMÉ: Dans cette étude, nous avons analysé la faisabilité technique et économique de l'utilisation des déchets générés par l'activité des fondations profondes (type pieux CFA) et la démolition des anciens bâtiments pour une utilisation dans des couches de renforcement de la couche de forme, couche de fondation et le revêtement de base. Par conséquent, les tests de laboratoire ont été effectués afin de vérifier la taille des particules, les limites de densité réelles, avec compactage d'énergie intermédiaire, de soutien Californie Index pour mesurer l'expansion, qui a exposé la qualité des matériaux et de leur potentiel. Toujours en détention une analyse comparative entre le coût des matériaux recyclés et des agrégats couramment utilisé dans le revêtement, encontando, outre l'avantage technique, l'avantage de ce matériau alternative économique.

KEYWORDS: Construction and Demolition Waste, Recycling, Paving.

1 INTRODUCTION

The civil construction chain is one of the most important economic sectors in Brazil, between the years of 2004 and 2010, this sector grew 42.41%, representing an annual average of 5.18%. In 2011, between January and September, there was an increment of 3.8% over the same period last year, with the creation of 309 425 formal jobs during the first ten months of this year (CBIC, 2011). Moreover, constructive activities still have great social importance for countries, since they employ, direct or indirectly, a large percentage of manpower.

However, despite the economic importance, the construction industry has significant negative impacts to society, such as large waste generation, since the Construction and Demolition Waste - CDW, as it is in the city of Recife, capital of the state of Pernambuco, Brazil, represents 41% of all municipal solid waste (Gusmão, 2008).

Current Brazilian legislation, through the CONAMA Resolution 307/2002 predicts the principle of the polluter-payer for the civil construction sector, in other words, all the CDW is responsibility of the own sector, involving all the responsibility for waste management, including the final disposition only in places duly licensed.

In this scenario, it is essential that construction practices sustainable principles, with construction technologies that emphasize prevention, reduction, reuse and recycling of materials, besides the collection and disposal of waste committed.

In order to encourage the reuse and recycle of CDW in the construction itself, there are already technical rules to standardize and regulate the use of these materials, and one of them is the 15.116:2004 NBR, which deals with recycled aggregates from CDW – the use in preparation of concrete with no structural function and paving projects.

The paper presents a case of construction work to build a shopping center in Recife, where the waste from excavation (soil) of continuous helical displacement piles and the recycled CDW were used in an innovative way in the paving projects of the worksite itself, obtaining at the end of the construction, a significant economy of resources and materials.

1.1 Continuous helical displacement pile

The continuous helical displacement piles were introduced in Recife in the 1990s. At the time the equipment was brought from the Southeast region, with high mobilization costs. Its more frequent use in the construction of buildings started in the city in 2001 and is currently the most widely used type of pile in the construction of buildings in Recife. In 2010, it is estimated that the helical piles accounted for about three quarters of the pile market for buildings in the city (Gusmão, 2011).

The continuous helical piles have some peculiarities that popularized their use in the urban environment, especially the fact of not causing vibrations and for having great productivity compared to other solutions, such as pre-molded, metal and excavated piles.

However, there is one particular aspect which can be a limiting factor to its use: the production of excavation waste (soil). According to CONAMA Resolution 307/2002, the excavated soil is a CDW, and as such, it should be tracked throughout the whole building process: separation, storage, transportation, recycling and final disposal. Current legislation does not allow the soil to be disposed without any control.

Even in licensed areas, landfills of CDW occupy large areas, which could have a nobler purpose in the urban environment.

2 CHARACTERIZATION OF THE ENTERPRISE

It consists in the construction of a horizontal shopping center in Recife, Pernambuco, Brazil. The edification is formed by an pre-molded arched concrete structure with a total construction area (shopping areas and garages) of 255,500 m².

From the topographic point of view, the natural terrain did not possess pronounced leveling differences. As for the geological point of view, the land is located in the fluvial-marine plain, within the undifferentiated marine terrace.

On the terrain of the enterprise, there were 07 major warehouses and 10 smaller deposits, totaling an area of 20,949 m² of demolition, responsible for generating approximately 18,900 tons or 13,500 m³ of CDW. Considering also the temporary installations and concrete slabs of the service paths, it is estimated that globally 23,560 tons or 16,830 m³ of CDW were generated.

Given the geotechnical characteristics of the land and construction schedule, continuous helical piles were designed and implemented for the foundation of all edifications. Table 1 shows the total quantitative at the end of the work, as well as the production of excavated soil. A total of 25,013m ³ or 42,522 tons of soil (admitting an apparent specific weight of 17 kN/m³).

There is, therefore, a total waste (demolition + soil deriving from piling) of 66.082 tons. If all this material was taken to a licensed landfill, the cost of provision would be of US$ 28,00/ton, or a total of US$1.9 million, besides environmental costs.

Having this in mind and the large area of paving of the site, a technical and economic study for the reuse of waste from the excavation residues in the pavement layers of the work was proposed. The excavated material was then separated and stored in an area of the own work site.

Table 1 – Quantitative of piles.

Diameter of Pile	Quantity	Length Medium (m)	Excavated Soil (m^3)
400	504	21.68	1,713
500	2,965	23.30	17,506
600	692	22.67	5,794

3 PAVING OF THE ENTERPRISE

The total paved area of the work was of 96,463 m² and is in accordance with the specifications of the paving project, the sub-base layer in the circulation of the exterior parking lot (flexible pavement) should be stabilized granulometrically with sandy material, and have a thickness of 0.20 m and minimum California Bearing Ration (CBR) of 20%.

In the parking spaces outside (semi-rigid pavement), the sub-base layer should consist of improved soil with 4% cement, 0.10 m thick and minimum CBR of 20%.

Data showed that the paving and land leveling work would require 22,631 m³ of natural noble aggregates, in other words, there was a potential for the use of much of the residues in the work site.

4 METHODOLOGY

In order to enable the use of its own wastes in the paving projects of the work, the following actions were established:

i) Processing of waste from demolition of the warehouses through a mobile unit installed at the construction site. These wastes are in this paper called recycled residues of civil construction - RRCC;
ii) Separation and storage of excavated soil in the implementation of continuous helical piles;
iii) Conduction of laboratory tests to characterize the RRCC and the excavated soil.

For the study of the technical viability of the use of excavated soil in the paving process, several laboratory tests in four distinct phases were conducted, whose tests are summarized in Table 2.

Table 2 – Summary of the characterization tests and assayed samples.

Phase	RRCC or Mixture	Tests
1	Soil, RRCC, R30S70 and R60S40	Granulometry, CBR and Limits of Consistency
2	Soil, RRCC and R60S40	Granulometry, Limits of Consistency, Real Density of grains, Compactation, CBR, shape Index, Abrasion “Los Angeles” e Level of sulphates
3	R40S60 (samples collected in experimental field)	Granulometry, Compactation and CBR
4	RRCC, R60S40, R40S60 e R30S70 (samples collected in experimental field)	Compactation, Humidity *in situ,* Density in *situ* (Sand Flask)

RRCCR – recycled residues of civil construction; R30S70 – 30% RCCR + 70% pile soil; R40S60 – 40% RCCR + 60% pile soil; R60S40 – 60% RCCR + 40% pile soil

5 TECHNOLOGICAL CHARACTERIZATION OF THE MATERIAL

5.1 Composition of RRCC

Figure 1 shows the gravimetric composition of RRCC. It is observed that is predominant the concrete, since warehouses had large areas of concrete floor. In the small material, with diameter less than 4,8 mm, it was not possible to differentiate the waste just by sight.

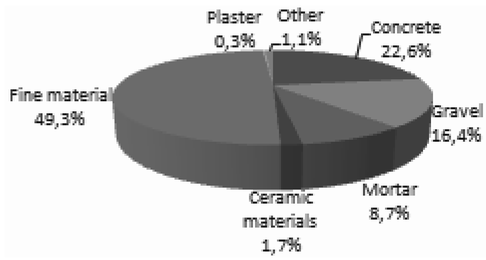

Figure 1 – Gravimetric composition of RRCC.

5.2 Composition of the excavation soil

For the development of the design of the foundations of the project, a total of 65 reconnaissance assays for percussion were performed. Initially, it was thought that the land would present deposits of soft soils, which are typical for this region of the city, but tests showed a basement formed by predominantly sandy soils.

Figure 2 shows the prediction of the type of excavated soil obtained from surveys conducted initially in the terrain. It is observed that sandy soils represent 85% of total soils present in the subsoil up to an average depth of 23m. The major difficulty in reusing soil from the excavation of a pile is that the excavated material is the result of full depth of the pile, and there are no means to segregate it. For a stratified profile, a completely heterogeneous material will be found.

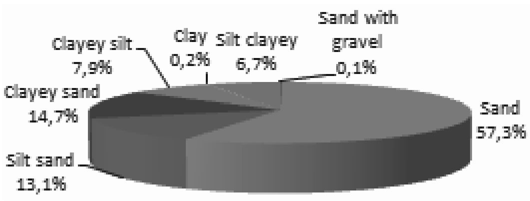

Figure 2 – Prediction of the excavated soil by piles through assays.

5.3 Granulometry

Figure 3 shows the granulometric curve of soil samples and of RRCC. It is observed that the RCCR is classified as gravel with thick and medium-sized sand. On the other hand, the soil is medium-sized and thin sand, which coincides with the prior prediction made by the assays.

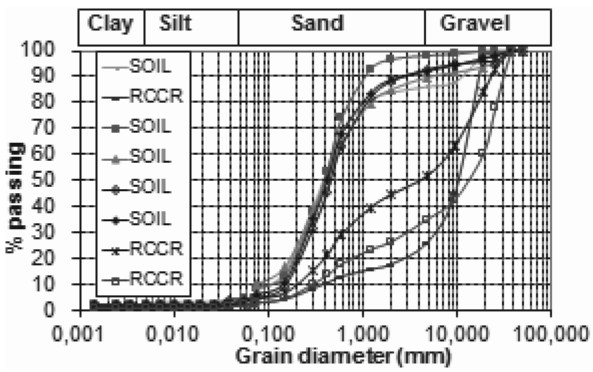

Figure 3 – Grain size curve of soil and of RRCC.

5.4 Compaction curves

Figure 4 shows some compaction tests with intermediate energy. It is observed that the optimum moisture varies between 4.1 and 9.1%, which are typical values for granular soils. It is also observed that the mixture soil + RRCC presented higher densities than the materials isolated, probably due to the fact that a higher degree of the group was reached.

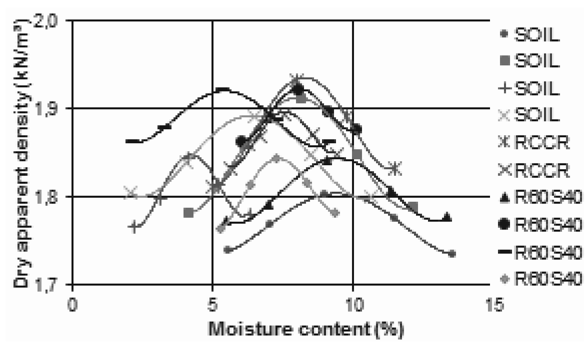

Figure 4 – Compaction Curves for soil, RRCC and mixture.

5.5 California Bearing Ratio (CBR)

Table 3 shows the CBR values obtained for the soil, RRCC and mixture of 60% RRCC and 40% soil (R60S40). The average values were equal to 39, 189 and 115%, respectively. The expansion values ranged from 0 to 0.2%.

Table 3 – Summary of the CBR values.

Material	CBR (%)	Avarage Value (%)	Variance Coefficient (%)
Soil	10	39	78
	76		
	19		
	51		
RCCR	191	189	1
	188		
R60S40	84	115	21
	108		
	130		
	138		

Regarding the NBR 15.116/04, for the possibility to use recycled material in the sub-base layers and pavement bases, CBR minimum is of 20% and 60%, respectively, implying that all mixtures have adapted to the requirements of the standard.

5.6 Shape Index

As the shape index approaches only the coarse aggregate with maximum characteristic dimension superior to 9.5 mm, only the RRCC samples were assayed. According to NBR 7809:1983, the maximum limit in the relation length/thickness is 3.0. This condition was met in both samples.

5.7 "Los Angeles" Abrasion

Just as in shape index, the "Los Angeles" abrasion test refers only to the coarse aggregate. For the two RRCC samples, the values were equal to 26.8 and 26.3% of depreciation, which are below the maximum limit of 50% set in the standard.

5.8 Sulphate levels

The maximum level of sulphate in relation to the mass of the recycled aggregate is 2%, according to NBR 15.116:2004. The values obtained in the assays of the soil and RRCC ranged between 0.04 and 0.09%, in other words, they were below the maximum limit set in the standard.

5.9 Technical Feasibility for using CDW in Paving Projects

Table 4 summarizes the results of some samples of soil, RRCC and the mixture soil-RRCC, comparing the values with the recommendation of NBR 15.116:2004. It was observed that only the soil did not meet the requirements for the use in paving layers. However, both the isolated RRCC as well as mixed with soil from the excavation of piles, meet all the criteria of the standard.

5.10 Economic feasibility of the use of CDW in paving projects

For the study of the economic feasibility of using CDW in paving layers in the project, an inquiry of the unitary cost of the acquisition of the aggregates specified in the paving project was initially performed, whose values are shown in Table 5. The costs of implementing the layers were not considered in the comparison, as it would be the same with the use of natural aggregates or CDW.

Table 6 shows the costs for the disposal at two sites licensed by the environmental agencies, which is an inert landfill or a processing plant for CDW. Both are located in the Metropolitan area of Recife.

Table 4 – Samples that did not meet the requirements of NBR 15.116:2004.

Parameters	NBR 15.116	Samples			
		i	i	ii	iii
Uniformity Coefficient (%)	≥ 10	**4.88**	**3.62**	39.28	14.88
Material through strainer Nº 40 (%)	Between 10 e 40mm	**53.47**	**45.76**	21.47	31.24
CBR (%) - Subgrade	≥ 12	**10.20**	**18.70**	190.5	129.7
CBR (%) - Sub-base	≥ 20	**10.20**	**18.70**	190.5	129.7
CBR (%) - Base	≥ 60	**10.20**	**18.70**	190.5	129.7
Subgrade Expansion	≤ 1	0.20	0.10	0	0
Sub-base Expansion (%)	≤ 1	0.20	0.10	0	0
Expansion (%) – Base	≤ 0,5	0.20	0.10	0	0
Maximum dimension of grains (mm)	63.5	19.10	19.10	38.10	38.10
Shape Index	< 3.0	*	*	2.20	*
Depreciation	< 50	*	*	26.76	*
Sulphate Content (%)	< 2.0	0	0	0.05	*

i – Soil; ii – RCCR; iii – R60S40
* *Not determined

Table 5– Costs of the acquisition of materials for paving project.

Material	Unit	Unitary cost of the acquisition (US$)
Sand for landfill	m^3	14,00
RRCC obtained with mobile plant onsite	m^3	14,00
RRCC obtained from processing plant outside the site	m^3	9,11
Simple graduated gravel (SGG)	m^3	20,41
Soil of the continuous helical pile	m^3	0*

* cost of transportation onsite disconsidered

Table 6 – Costs for the final disposition of wastes in licensed places.

Disposition place	Unit	Unitary cost (US$)
Inert Landfill	m^3	47,30
Processing plant	m^3	18,36

* cost of transportation onsite disconsidered

For the calculation of the financial impact of the use of the investigated materials in paving project, two scenarios for reuse of waste were considered:

- Scenario 1: all the brute RRCC is taken to the processing mill for recycling, and the pile soil is deposited in the inert landfill. The layers of paving are executed with natural aggregates;
- Scenario 2: use of mixture of pile soil with RRCC in the regularization of the terrain and the sub-base layer. The base layer is performed with the remaining available RRCC and another portion of natural aggregate (SGG).

In simulations, the volumes were calculated from the paving projects (flexible and semi-rigid), land leveling and gabion wall containment. In all cases, a bulking of 12% was admitted (project value) and apparent specific weight of RRCC and the soil is equal to 14 and 17 KN/m^3, respectively.

The estimation of Scenario 1 presented a cost of US$ 2.2 million, while Scenario 2 showed a total cost of US$ 320,498.21, in other words, the use of residues represent a direct saving of about US$ 1.9 million continuing to meet the technical requirements of the paving project, and allowing a very significant reduction of environmental impacts that were not valued.

In the implementation of the paving, the base layer only contained simple graduated gravel (SGG), as an option of the designer. Still, the direct saving obtained was almost the same as in scenario 2.

In summary, demolition residues and the soil from the excavation of helical piles were transformed into the “worksite quarry”. The sustainable construction was cheaper than conventional work, showing the potential of the "green economy".

6 CONCLUSION

The article presents a case of building a shopping center in Recife where the excavation residues of the 4,000 helical foundation piles, in other words, about 25,000 m^3 of soil were used in the layers of the paving work (regularization of the terraind and sub-base). Demolition residues were also used from old existing warehouses on the land, which were transformed into recycled aggregates with a mobile plant installed at the worksite.

The demolition residues and soil from the excavation of the helical piles were transformed into the "worksite quarry". The sustainable work was cheaper than the conventional construction, showing the potential of the "green economy".

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8 REFERENCES

CÂMARA BRASILEIRA DA INDÚSTRIA DA CONSTRUÇÃO – CBIC. Construção Civil: Desempenho e Perspectivas. Informativo Econômico. Brasília, 2011.

Gusmão, A. D. (2008). *Manual de Gestão dos Resíduos da Construção Civil*. 1a Edição. ISBN: 978-85-60917-04-4. CCS Editora. Camaragibe.

Gusmão, A. D. (2011). Prática de Fundações no Recife. Fórum da Construção do Recife.

NBR 7809:1983 NBR 7809:1983 – Agregado graúdo – Determinação do índice de forma pelo método do paquímetro – Método de ensaio. ABNT. Rio de Janeiro.