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Methodology for quantification of waste generated in Spanish railway construction works

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ABSTRACT

In the last years, the European Union (EU) has been focused on the reduction of construction and demolition (C&D) waste. Specifically, in 2006, Spain generated roughly 47 million tons of C&D waste, of which only 13.6% was recycled. This situation has lead to the drawing up of many regulations on C&D waste during the past years forcing EU countries to include new measures for waste prevention and recycling. Among these measures, the mandatory obligation to quantify the C&D waste expected to be originated during a construction project is mandated. However, limited data is available on civil engineering projects.

Therefore, the aim of this research study is to improve C&D waste management in railway projects, by developing a model for C&D waste quantification. For this purpose, we develop two equations which estimate in advance the amount, both in weight and volume, of the C&D waste likely to be generated in railway construction projects, including the category of C&D waste generated for the entire project.

1. Introduction

The latest ratios found for construction and demolition (C&D) waste generation and recycling in Spain are from 2006. This country generated roughly 47 million tons of C&D waste and only 13.6% of the C&D waste generated was recycled (Eurostat, 2011). This ratio shows that the planning and carrying out of construction works have not considered environmental factors, as for the intensive construction activity from the last years, the low cost of dumping and the easy availability of natural resources has been the common trend. In addition, a study from the European Environment Agency (EEA) estimated that 65% on average of the waste was recycled in 2006 in the 27 European countries. Spain showed a quite lower figure for recycling than the EU average and was far from countries such as Denmark, Estonia and The Netherlands, with recycling indexes of over 90% (Tojo and Fischer, 2011).

The definition of C&D waste both includes waste generated in building projects and civil engineering (Ministry of the Presidency, 2008). In this respect, Eurostat does not distinguish between C&D waste generated in building projects and civil engineering works. However, the Spanish 2nd National Plan on C&D waste shows a small distinction, claiming that civil works generated 28% from the total C&D waste generated in 2006 (Ministry of the Environment, 2009).

These data are still far from achieving the targets set by the EU to ensure that by 2020, 70% in weight increase is achieved in the treatment, recycling and other valorization operations of non-hazardous C&D waste, excluding the ones in the 17 05 04 category of the European Waste Catalogue (EWC) (Ministry of the Environment, 2002).

Aware of this situation, the EU countries are implementing national policies as well as different measures to increase recycling and recovering. In particular, the Spanish Government issued the 105/2008 Royal Decree (RD) (Ministry of the Presidency, 2008). This RD regulates the production and management of C&D waste and focuses on establishing a legal frame for the C&D waste production so as to encourage prevention, reuse and recycling, as well as other forms of valorization.

Within this RD, the obligation to develop a waste management plan for each construction project is of special interest. It should necessarily include an estimated approach of the amount of the C&D waste suitable to be generated. However, no tools or models are available to help construction agents in estimating in advance the C&D waste to be generated in civil engineering works, needed in the regulations. This unsustainable situation has not only worried EU countries, but it has been of great interest for researchers in the field, drawing special attention to the C&D waste management (Yuan and Shen, 2011).

During the last years, research within the civil engineering sector has focused on the use of the C&D waste as new construction materials for bases, sub-bases and firms. Among these studies,

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Poon and Chan (2006), Aatheesan et al. (2008), Courard et al. (2010), and Kuo et al. (2010) can be highlighted. In addition, other specific works using C&D waste in railway projects include research works by Helsen et al. (1998), Indraratna and Salim (2003) and Krezel et al. (2004). However, another pending research line to be emphasized in civil engineering is the way to optimize management including quantifying methods of C&D waste generation, as has already been developed in the building sector (Bossink and Brouwers, 1996 and Llatas, 2011).

Previous studies quantifying C&D waste generation in building construction works can be classified in two groups: ones which quantify C&D waste in relation to the built area and others estimating the annual generation of C&D waste in relation to a region. Among the researchers in the first group, Mañà I Reixach et al. (2000) obtained the C&D waste generated per surface area for different constructive systems, considering the construction stages. Furthermore, the study carried out by Chadrakanthi et al. (2002) in Canada uses simulation models to establish the generation of waste in construction projects based on the schedule of construction activities. Specifically for the situation in Spain, Solís-Guzmán et al. (2009) and Villoria Sáez et al. (2011) studied models for C&D waste quantification and management based on budget data of building works. Among studies using annual data, such as the construction licenses, Hsiao et al. (2002), Conchran et al. (2007) and Kofoworola and Gheewala (2009) can be pointed out. Regarding the second group – estimating annual generation of C&D waste by region – the studies performed are: Yost and Halstead (1996), Fatta et al. (2003), Müller (2006) and Martínez Lage et al. (2010).

In short, research on C&D waste quantification states that waste generation rates serve as valuable benchmark quantitative information for different C&D waste management practices in the building sector (Yuan and Shen, 2011). In this regard, from the literature review analyzed, further studies should be launched to determine waste generation rates in the civil engineering sector.

Therefore, this study aims to define two equations to quantify in advance the C&D waste expected to be generated in railway construction projects. Moreover, C&D waste percentages are obtained regarding the categories defined in the EWC and the amount of the C&D waste produced in each construction stage. This information will be necessary to fulfil the C&D waste estimation in the Management Plan.

2. Materials and methods

The estimation of the C&D waste generated in railway projects needs to be assessed regarding the characteristics of the project. In order to do so, the methodology followed in this study unfolds in four different phases:

- Selection of works.
- Structure of the bill of quantities.
- Data collection of the waste generated in the selected works.
- Procedure for the calculation of the amount of C&D waste generated in railway works.

2.1. Selection of works

This research focuses on railway projects in Spain. In general, these infrastructures present a series of common characteristics (functional units), from which a number of them are distinguished:

- Kilometres of railway (L_r).
- Number of intersections, junctions (N_j).
- Number of transversal drainage (N_{td}).
- Number of underpasses (N_u).
- Number of overpasses (N_o).
- Kilometres of viaduct (L_v).
- Kilometres of tunnel (L_t).

For this study, railway projects carried out by Fomento Construcciones y Contratas (FCC) Company have been used. A total of 14.60 km of railway road have been analyzed with up to 4 km of intersections and junctions, 11 units of transversal drainage, 10 underpasses, 1 overpass, a viaduct of 0.59 km and a tunnel of 9.53 km.

2.2. Structure of the bill of quantities

This study collects data from the reports and bill of quantities of the selected work projects. Due to the lack of homogeneity in the structure of the construction stages in the bill of quantities, the following guidelines were established to facilitate the comparison of the results:

- Bills of quantities had to have a similar construction stage structure in the different projects, where the elements of work were clearly identified.
- A standardized classification of the bill of quantities should be provided so that it can be extrapolated to other projects of similar characteristics.
- The construction work stages should contain similar elements of work.

Regarding these guidelines, bills of quantities are divided into the following stages and substages of work:

- Preliminary and explanation works
- Drainage:
  - Longitudinal drainage; Transversal drainage (TD)
- Structures:
  - Underpasses; Overpasses; Viaducts
- Junction
  - Linking paths
- Tunnel
- Temporary detours

2.3. Data collection of the waste generated in the selected works

To quantify the weight and volume of C&D waste generated, the online available BEDEC database from the Technological Institute of Catalonia (ITeC) has been used (BEDEC, 2011). This database gives environmental parameters for each element of work in the bill of quantities of the projects. In this sense, values of the following environmental parameters for the analyzed railway works have been obtained from BEDEC: volume (m^3) and weight (kg) for each waste category (EWC code). Both environmental parameters have been identified not only for each of the substages from the analyzed projects, but also for each stage and for the whole railway construction.

In this study, soil and rocks not containing hazardous substances have been excluded (EWC code: 17 05 04) because the 2008/98/EC Directive of 19 November on waste does not consider them as such (European Parliament, 2008). An example of how the data is obtained can be seen in Table 1 which shows, a fragment from one of the analyzed substages for the quantification of C&D waste generated in a viaduct construction.

2.4. Procedure for the calculation of the amount of C&D waste generated in railway works

A method is determined to calculate C&D waste volume and weight generated in railway projects, through two empirical

Table 1
Example of C&D waste quantification generated in the viaduct substage (Structures stage) in volume.

Unit	Element of work		Environmental parameters		
			Waste per Unit[a]		T_e[b] (m^3)
	Description	Quantity (Unit)	EWC Code	Volume (m^3)	
m^3	Mass concrete for packings, levelling layers and cleaning.	79.732	170101	1.00×10^{-02}	0.80
m^3	Reinforced concrete in foundations, piles, screens, etc.	1990.690	170101	1.00×10^{-02}	19.91
kg	Reinforcement steel bars.	431,329.601	170405	8.03×10^{-06}	3.46
Total waste of the substage					$\sum T_e$

[a] Data obtained from BEDEC.
[b] Total C&D waste for each element work.

equations. Eqs. (1) and (2) relate these quantities – volume and weight – to the functional units (railway length, number of junctions, length of viaducts, etc.) of the railway project to be analyzed.

$$Q_p = a_p \cdot L_r + b_p \cdot N_j + c_p \cdot N_{td} + d_p \cdot N_u + e_p \cdot N_o + f_p \cdot L_v + g_p \cdot L_t \quad (1)$$

$$Q_v = a_v \cdot L_r + b_v \cdot N_j + c_v \cdot N_{td} + d_v \cdot N_u + e_v \cdot N_o + f_v \cdot L_v + g_v \cdot L_t \quad (2)$$

where Q_p is C&D waste weight (kg), Q_v is C&D waste volume (m^3), n_p is a constant value for weight calculation (kg/unit) and n_v is a constant value for volume calculation (m^3/unit).

In Eqs. (1) and (2) the functional units are determined by the railway project characteristics. In addition, Eq. (3) has been used to obtain the constants (n_p or n_v).

$$n = Q/Q_{fu} \quad (3)$$

where n is the constant value, Q is the total C&D waste and Q_{fu} is the quantity of functional unit.

At the same time, the percentages for each C&D waste category and for each construction stage, from the total C&D waste generated, have also been obtained.

3. Results and discussion

3.1. Analysis of the total C&D waste generated

From the relation between the amount of C&D waste obtained in the analysis of the studied projects and their functional units (Eq. (3)), seven empirical constants have been obtained (Table 2).

These constant values achieved can be used to estimate in advance the C&D waste generated in similar railway projects, by introducing them in Eqs. (1) and (2) along with the particular functional units of the railway project to be studied.While the constant values determined are derived from Spanish railway constructions works, this methodology can be applied to other similar areas or infrastructures in different scenarios.

3.2. Analysis according to C&D waste category

The generated waste in the railway projects analyzed, according to the EWC code, is identified as follows:

- 15 01 01 Paper and cardboard packaging
- 15 01 02 Plastic packaging
- 15 01 03 Wooden packaging
- 15 01 10* Packaging containing residues of or contaminated by dangerous substances
- 17 01 01 Concrete
- 17 01 03 Tiles and ceramics
- 17 02 01 Wood
- 17 02 03 Plastic
- 17 03 02 Asphalt not containing tar 17 04 05 Iron and steel
- 17 04 07 Mixed metals
- 17 09 04 Mixed construction and demolition waste or separated fractions not containing dangerous substances.

Once the total quantities, both in weight and in volume, have been obtained for each category (see example in Table 1), results show that the mixed C&D waste not containing hazardous substances (EWC code: 17 09 04) are the most generated ones in railway construction works (Fig. 1). They represent 55% in weight and 85% in volume of the total C&D waste generated.

Mixed C&D waste not containing hazardous substances are the most generated mainly due to the lack of C&D waste segregation onsite, despite the usual space available in railway construction works to do so. This waste category is followed by the bituminous mixtures (EWC code: 17 03 02) that in turn, represent 7% in volume and 25% in weight. On the other hand, plastic (EWC code: 15 01 02), wood packaging wastes (EWC code: 15 01 03) and empty hazardous waste containers (EWC code: 15 01 10*) are

Table 2
Empirical constants calculation.

Functional unit		Q_{fu}[a]	Q_p[b]	Q_v[c]	Weight (kg/unit)		Volume (m^3/unit)	
					n_p		n_v	
L_r	(km)	14.60	3.24×10^7	7.39×10^4	a_p	2.22×10^6	a_v	5.06×10^3
N_j	(unit)	4	1.13×10^6	10.1	b_p	2.82×10^5	b_v	2.53
N_{td}	(unit)	11	1.15×10^5	47.1	c_p	1.05×10^4	c_v	4.28
N_u	(unit)	10	4.16×10^5	1.94×10^2	d_p	4.16×10^4	d_v	19.4
N_o	(unit)	1	1.21×10^4	4.83	e_p	1.21×10^4	e_v	4.83
L_v	(km)	0.59	5.23×10^5	2.53×10^2	f_p	8.87×10^5	f_v	4.29×10^2
L_t	(km)	9.528	1.71×10^7	5.49×10^4	g_p	1.80×10^6	g_v	5.76×10^3

[a] Quantities of the functional units.
[b] Total weight of C&D waste (kg).
[c] Total volume of C&D waste (m^3).

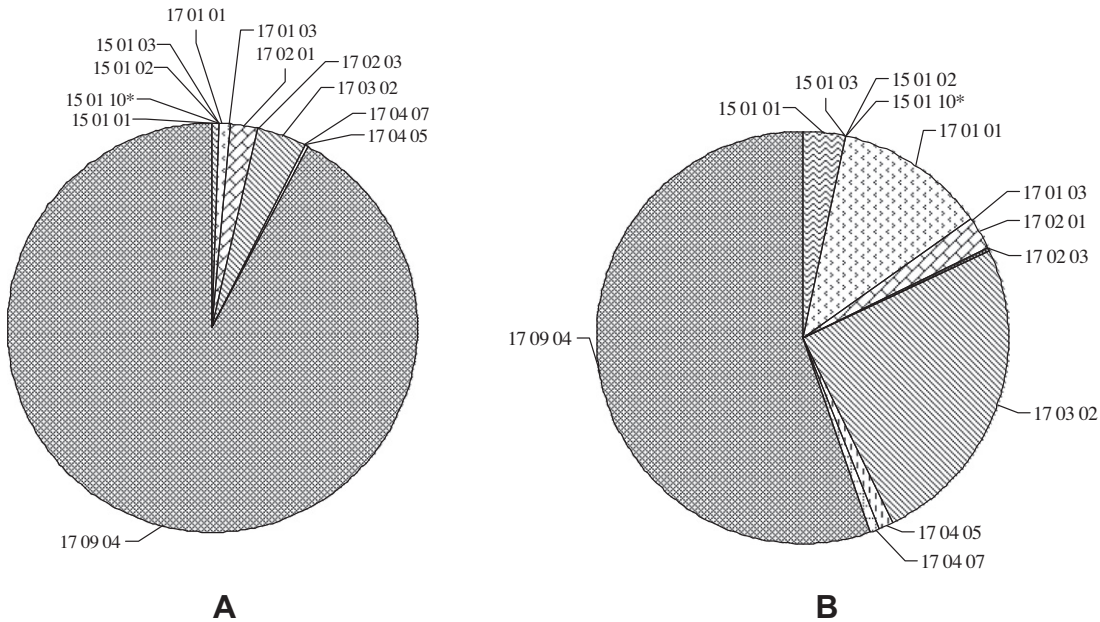

Fig. 1. Percentage of C&D waste generated in (A) volume (m^3) and (B) weight (kg) for railway projects as categorized by the EWC.

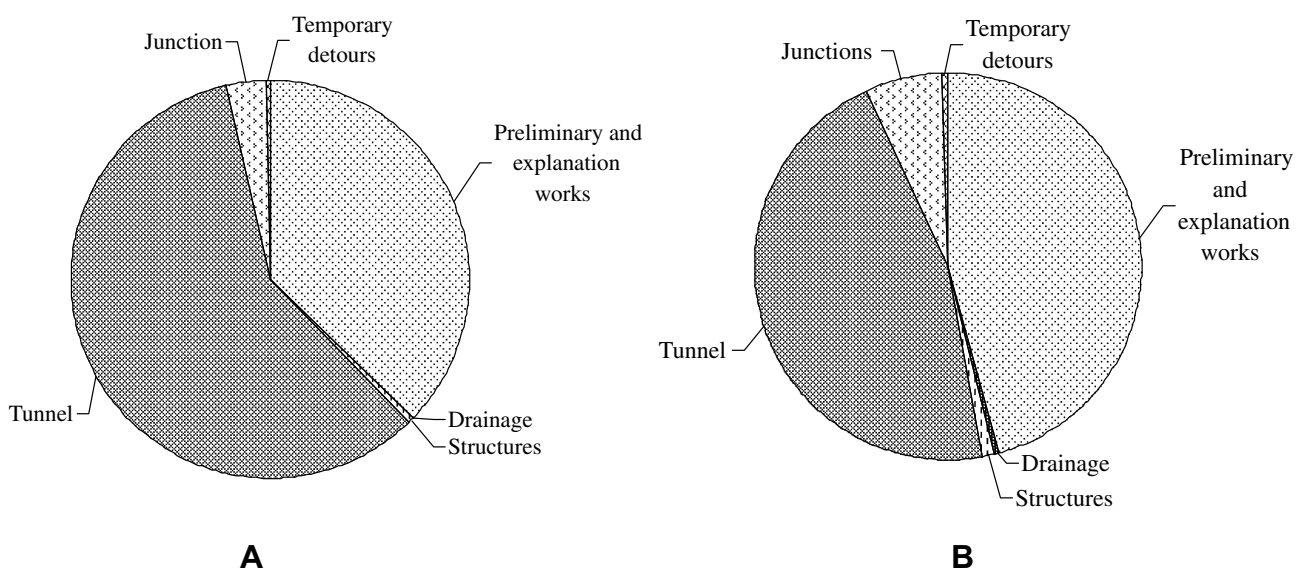

Fig. 2. Percentage of C&D waste generated in (A) volume (m^3) and (B) weight (kg) for railway projects according to the construction stages.

generated in smaller proportions, not even reaching 0.1% in weight and volume.

Furthermore, waste categories such as mixed C&D waste (EWC code: 17 09 04) or wood (EWC code: 17 02 01), occupy huge volumes in the construction site in relation to their weight. In this sense, the use of mobile waste treatment plants for grinding and crushing or other measures could be considered.

3.3. Analysis according to the construction stage

Besides knowing the most generated C&D waste category regarding the EWC code, considering the construction stage in which the waste is generated, is also important. Therefore, the data obtained has been also analysed regarding the construction stages.

Fig. 2 shows that the largest amount of C&D waste is generated during the tunnel construction, accounting for 59% of the total waste generated in volume and 46% in weight. This construction stage is followed by the preliminary and explanation works, which represent 37% in volume of the total C&D waste generated, and 46% in weight. These two construction stages are to be deeply analyzed by engineers during the design phase of a railway construction work in order to plan the appropriate management for each waste category to be generated. On the other hand, the construction stages that generate less C&D waste correspond to drainage and temporary detours, not exceeding 7% both in weight and in volume.

4. Conclusions

From the analysis performed in this study the following conclusions can be drawn:

- The quantification tools for C&D waste generation presently being used in civil projects are not detailed enough to answer to the increasing social pressure in relation to environmental concerns.
- A relationship between the amount of C&D waste generated and the functional units of the railway has been proved and stated in the two equations proposed in this study (Eqs. (1) and (2)).
- The most generated C&D waste category in railway works corresponds to mixed C&D waste (EWC code: 17 09 04). In general, packaging wastes and empty hazardous waste containers are the less significant waste generated.
- The construction of a tunnel in a railway becomes essential to quantify in advance the waste suitable to be generated during the works. Moreover, if construction agents focus their efforts in the waste generated in tunnels and preliminary and explanation works, more than 90% of the total waste generated in railway works could be properly managed.
- The C&D waste percentages obtained imply a thorough knowledge of the kind of waste, the quantity and even the stage within the construction process in which it will be generated.
- The methodology provided can be applied to obtain new equations for other particular areas, with new constant values representing their specific characteristics.

In short, the methodology presented can help in assigning an optimal and systematic management of the C&D waste produced and assist the construction agents in developing the waste management plans according to the existing legislation.

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