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REDEFINING CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT SYSTEMS: BEST PRACTICES ON CIVIL ENGINEERING WORKS

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Abstract. The civil engineering sector has to assume among its aims the reduction of the construction and demolition waste generated by it. To this end, foreseeing the amount of construction and demolition waste to be generated, as well as the time phase in which they might be produced, will allow for planning good environmental practices on site, both in a general way – for all the waste – as for each individual category of waste. The aim of this research paper is to determine the major categories of construction and demolition waste produced in railway construction works, and the construction stages where they are mainly generated. At the same time, a Best Practices Manual including a relation of best practices for on-site waste management is proposed and could be included in the Internal Quality System of the companies. Results of this study show that establishing and implementing a Best Practices Manual in engineering works for the phases of construction of tunnels, preliminary works and ground movement involves the management and minimization of almost 95% of the total waste generated. In addition, integrating the Report and Management Plan of construction and demolition waste together with the Best Practices Manual, promotes the environmental management of the company, favouring the cohesion of the construction process organization at all stages giving rise to establishing responsibilities in the field of waste and providing a greater control over the process.

Keywords: construction and demolition waste, waste management, best practices, waste minimization, civil engineering, railway works, quality management systems.

1. Introduction

During the last decades, the intense activity in the construction sector within the European Union (EU) has generated huge volumes of construction and demolition (C&D) waste, precisely 890 million tonnes per year. On average, 50% of the C&D waste generated in EU is recycled (Tojo, Fischer 2011). However, this percentage is overrated because some countries consider mineral wastes, such as soil and stones not containing hazardous materials in their ratios. According to this, EU State members are still far from achieving the quantitative target set by the *Directive 2008/98/EC on Waste (Waste Framework Directive)* for the year 2020. The reasons for this might include: high cost of C&D waste management, low cost of natural resources and landfill disposal, lack of knowledge regarding the consequences of waste, lack of interest by the clients for waste reduction or minimization, and lack of standards to regulate the inclusion of these wastes in the manufacturing of other materials.

Moreover, the official EU statistics for C&D waste generation do not distinguish between the waste generated in building works from those generated in civil engineering works. In this sense, the 2nd Spanish National Plan on C&D waste makes a distinction claiming that 28% of the total C&D waste generated in Spain for the year 2006 was originated in civil works.

In an attempt to correct the serious consequences this situation produces, the *Directive 2006/12/CE on Waste* stated that National Waste Management Plans should be drawn up by EU member states. At the same time, several countries are stating specific laws to establish a legal frame for C&D waste production and management, in a way to encourage prevention, reuse and recycling, ensuring that waste will be properly treated. For the particular case of Spain, the *Real Decreto 105/2008 que regula la producción y gestión de los residuos de construcción y demolición* (construction and demolition waste regulation in Spain)

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proposes a development of waste management systems for each construction project based on the drawing up of:

– a Waste Management Report (WMR), developed during the design phase of the project;

– a Waste Management Plan (WMP), developed during the planning of the construction work.

In spite of this the present management system does not incorporate any document adapted to the construction process, taking into account best practices related to each waste category or to the global construction process.

Although these measures have been implemented by EU countries, the professionals of the construction sectors are reluctant to calculate the volume of waste generated and how it is managed. Construction companies always follow the same management model in every construction work, without considering the specific characteristics of each one, and even without having a prior management plan to optimize the C&D waste management.

Moreover, this situation has not only worried EU governments, but it has been of great interest for researchers in the field. According to Yuan and Shen (2011) special attention to C&D waste management has been developed in recent years.

Lately, research within the civil engineering sector has focused on the use of the C&D waste as the matrix of new construction materials. Among these studies Poon and Chan (2006), Courard *et al.* (2010), Kuo *et al.* (2010) and Čygas *et al.* (2011) can be highlighted. Other specific studies on new materials used in railway works are: Indraratna and Salim (2003), Helsen and Van den Bulck (2005).

Pollution and emissions generated during the lifetime of the infrastructure has been a major concern for many researchers such as Sanchez-Alonso *et al.* (2011), while waste and emissions generated during the construction of those infrastructures stills needs to be further studied, as stated in the study by De Guzmán Báez *et al.* (2012). Therefore, another research line to be considered is optimizing waste management including quantifying methods of C&D waste generation as Lu and Yuan (2011) claim, specifically for civil engineering works. On the contrary, this issue has widely been developed in building works such as Villoria Sáez *et al.* (2012) and Solís-Guzmán *et al.* (2009).

Furthermore, best practices in C&D waste management have also been of interest to many authors. Regarding these practices, the study by Osmani *et al.* (2008) revealed that architects assume waste is mainly produced during site operations and rarely generated during the design stages. However, about one-third of construction waste essentially arises from design decisions. Tam (2008) has researched the effectiveness of the implementation of the existing waste management plan method in Hong Kong. The results showed that proposed methods for on-site reuse of materials, for waste reducing and waste separation, are the main benefits gained. To that end, the use of prefabricated components is considered as the major measure to encourage its implementation.

In addition, Begum *et al.* (2009) stated that the majority of contractors do not practice source separation, source reduction, reuse or recycling at Malaysian construction sites. The results of the study showed that factors such as: construction-related education among employees, contractor experience in construction works, source reduction measures, etc. are the most significant factors affecting contractor's performance.

Other researchers have focused their analysis on the causes influencing the C&D waste management on site, e.g. Yuan *et al.* (2011) and Wang *et al.* (2010). They have identified several critical success factors (CSFs) for C&D waste management in China.

Table 1 shows a summary of the studies performed regarding best practices for C&D waste management.

Even though best practices regarding C&D waste management have been suggested and studied, specifying these practices according to the type of construction and to the different waste categories generated is still a research to be performed.

Therefore, the main objective of this research study is to improve the current C&D waste management systems by determining the major C&D waste flows generated at each construction stage of a railway work, in order to propose a Best Practices Manual (BPM). This BPM to be used on site includes a relation of C&D waste management procedures serving as valuable references for agents to develop effective C&D waste management strategies. Following this BPM, together with the WMP and WMR, an integrated waste management system is proposed, taking into account the design, planning and construction processes.

The BPM together with WMP and WMR will be part of the internal quality management system used by companies, unifying these aspects in a comprehensive management system allowing for the introduction of a culture based on the minimization and proper segregation of waste and, at the same time, the quality of the works.

In short, with these three fundamental documents tracking the C&D waste management in a railway work will be successfully accomplished. This proposed model will have an immediate effect on improving managerial methods and will be likely to be applied by the construction companies. Therefore, this study dealing with topics of great social concern will be undoubtedly useful and essential in the activity of civil engineering to achieve the goal of "zero waste" generation.

2. Methodology

The methodology followed in this research unfolds in three different phases:

– selection of works and determination of the construction stages;

– data collection;

– BPM proposal.

2.1. Selection of works and determination of the construction stages

This research focuses on railway infrastructure works in Spain. For this study, two railway works carried out by

Table 1. Previous studies regarding best practices for C&D waste management

Author	Year	Country	Phase	Major best practices
Osmani *et al.*	2008	United Kingdom	Design	– Design with standard dimensions and prefabricated units; – Design for deconstruction; – Study of waste estimation.
Tam	2008	Hong Kong	On-site	– Use of prefabricated materials; – Purchase management; – Education and training; – Proper site layout planning; – On-site waste recycling operation.
Begum *et al.*	2009	Malaysia	On-site	– Education among employees; – Contractor experience; – Source reduction measures; – Reuse of materials; – Waste disposal behaviours; – Attitudes towards waste management.
Lu and Yuan	2010	China	All stages	– Waste management regulations; – Waste Management System (WMS); – Awareness C&D waste management; – Low-waste building technologies; – Fewer design changes; – Research and development in waste management; – Vocational training in waste management.
Wang *et al.*	2010	China	On-site	– Workforce; – Market for recycled material; – Waste sortability; – Better management; – Site space; – Equipment for sorting waste.

Fomento Construcciones y Contratas Company (Spanish construction company) have been studied. The first project analyzed is a new railway junction between the Spanish regions of Palencia and A Coruña. The second spreads entirely through the province of Valencia. All together, a total of 14.60 km of railway road have been analyzed.

The study has focused on collecting data from the reports and the bill of quantities of the selected works, determining the following construction stages: Preliminary and Explanation works (P); Drainage (D); Structures (S); Junction (J); Tunnel (T); Temporary detours (TD).

2.2. Data collection

To quantify the amount of C&D waste categories generated in each construction stage according to the European Waste Catalogue Code (*EWC*), the online available BEDEC database from the *Instituto de Tecnología de la Construcción de Cataluña* (Catalonia Technical Institute of Construction) has been used. This database previously followed by Llatas (2011) and Pons and Aguado (2012), establishes environmental parameters for each work item in the bill of quantities of the construction works. In this sense, values for waste generated in the analyzed works were calculated in volume and classified according to the *EWC*. Regarding this, the volume of waste generated (m^3) has been identified not only for the whole railway project but also for each construction stage.

An example of how the data is obtained is seen in Table 2, which shows a fragment from one of the analyzed stages for the quantification of C&D waste generated. In the present study, as stated by the *WFD*, earth and rocks not containing hazardous substances have been excluded.

As mentioned before, this data has been analyzed according to the whole construction work. For this, the following two empirical equations have been used. Eq (1) is used to obtain the volume of a particular C&D waste category (x) generated in the whole construction work.

$$Q_x = \left(Qe_{Px} + Qe_{Dx} + Qe_{Sx} + Qe_{Jx} + Qe_{Tx} + Qe_{TDx} \right), \quad (1)$$

where Qe_{Px}, Qe_{Dx}, Qe_{Sx}, Qe_{Jx}, Qe_{Tx}, Qe_{TDx} correspond to the total volume, of a particular C&D waste category generated in each construction stage, m^3: Qe_{Px} – preliminary and explanation works; Qe_{Dx} – drainage; Qe_{Sx} – structures; Qe_{Jx} – junction; Qe_{Tx} – tunnel; Qe_{TDx} – temporary detours.

Table 2. Example of C&D waste quantification generated in the tunnel stage

Work item			Environmental parameters		
			Waste per unit[a]		$Qe_T{}^{b}$, m³
Description	Unit	Quantity (unit)	*EWC*	Volume, m³	
Mass concrete for levelling layers and cleaning	m³	6334.56	17 01 01	$1.00{\cdot}10^{-02}$	63.3
Reinforced concrete for tunnels including polypropylene fiber	m³	21 038.88	17 01 01	$1.00{\cdot}10^{-02}$	210.4
Reinforcement steel bars	kg	2 329 388.16	17 04 05	$8.03{\cdot}10^{-06}$	18.7
Wood works (formwork)	m²	16 688.64	17 02 01	$9.00{\cdot}10^{-04}$	15.0
			17 04 05	$6.20{\cdot}10^{-06}$	0.1
			15 01 01	$3.04{\cdot}10^{-06}$	$5.1{\cdot}10^{-02}$
			15 01 10*	$4.41{\cdot}10^{-05}$	0.7
					$Q_T{}^{c} = \sum Qe_T$

Notes: [a] – data obtained from BEDEC; [b] – total waste generated in each work item of the tunnel stage; [c] – total waste generated in the tunnel stage.

Moreover, a second equation is used to obtain the percentage of a particular C&D waste category generated in the whole construction work (Eq (2)).

$$\%x = \left(\frac{Q_x}{\sum Qe}\right) 100, \quad (2)$$

where Qe – the total volume of C&D waste generated in each work item, m³.

Besides knowing the categories in which the greatest amount of C&D waste is generated throughout the construction work, analyzing them according to the construction stage is also important. Therefore, to determine the percentage of each C&D waste category generated per construction stage (y_x), Eq (3) has been used.

$$\%y_x = \left(\frac{\sum Qey_x}{Q_x}\right) 100, \quad (3)$$

where $\%y_x$ – the percentage of a particular C&D waste category generated in the construction stage to be studied; Qey_x – the total volume of a particular C&D waste category generated in the construction stage to be studied, m³.

2.3. Best Practices Manual proposal

A proposal to draw a BPM is further included, considering not only best practices for each of the major waste type identified, but also a list of best practices in relation to the different activities:

- hiring subcontracting companies;
- purchase of materials;
- construction works planning;
- stock up and storage of materials;
- documentation filing;
- managing on-site waste.

3. Results and discussion

Results on waste quantification have been analyzed according to:

- the C&D waste category generated for the total work;
- the C&D waste category generated per construction stage.

3.1. C&D waste category generated for the total work

The waste flow generated in railway works, according to the *EWC*, 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 remains of or contaminated by hazardous substances;
- 17 01 01 concrete;
- 17 01 03 tiles and ceramics;
- 17 02 01 wood;
- 17 02 03 plastic;
- 17 03 02 bituminous mixtures containing other than coal tar and tarred products;
- 17 04 05 iron and steel;
- 17 04 07 mixed metals;
- 17 09 04 mixed C&D waste other than those containing hazardous substances.

Fig. 1 shows the percentage of each C&D waste category generated for the whole construction work. These values have been obtained using Eqs (1) and (2). Results show that mixed C&D waste not containing hazardous substances (*EWC category*: 17 09 04) is the most generated one, representing 89.29% in volume of the total waste generated. In order to clarify the data obtained, Fig. 1 does not present results for the mixed C&D waste category.

On the other hand, the least generated C&D waste corresponds to packaging in general and metal waste – not even reaching 1.5% in volume. Furthermore, waste categories such as mixed C&D waste (*EWC category*: 17 09 04) or wood (*EWC category*: 17 02 01), occupy huge volumes in the construction site, so the use of mobile waste treatment plants for grinding and crushing or other measures have to be considered.

3.2. C&D waste category for each construction stage

In addition, considering when each C&D waste category will be generated during the process of the railway construction is important. Eqs (1) and (3) have been used to obtain the percentage of each C&D waste category generated for each construction stage studied (Fig. 2).

Fig. 2 shows that mixed C&D waste (*EWC category*: 17 09 04) is mainly generated during the construction of tunnels and preliminary and explanation work. Therefore, the mixed C&D waste is the greatest generated waste and it is produced mostly in two of the work stages.

On the other hand, virtually all packaging waste is generated during the tunnel construction, except the wooden containers and hazardous waste which are generated in a 50% during the preliminary work, and approximately up to 40% in the structures stage.

Plastics, metal waste and wood packing (*EWC categories*: 15 01 02, 15 01 03, 17 02 03, 17 04 05 and 17 04 07) are very scarcely generated (Fig. 1), and they are just significantly produced – more than 10% – in one or two of the construction stages (Fig. 2). This means that special attention needs to be paid to the management of this waste, specifically during the tunnel construction.

4. Definition of the Best Practice Manual

As a conclusion from the above, a Best Practice Manual (BPM) is proposed. This manual includes a number of procedures, similar to those used in internal quality management systems, developed in order to describe and facilitate the proper management of each category of waste, as well as to establish a process control. These procedures shall at least:

- detail in depth the various tasks and responsibilities regarding the management of C&D waste, of the relevant agents implied in the process;
- describe the guidelines to be followed for a correct performance, in terms of waste, by suppliers and subcontractors involved in the work;
- explain the way to put into practice the planned separation measures during the construction;
- define the necessary procedure to be performed for the correct management of both inert and hazardous C&D waste that will be produced during the construction process;
- identify best practices associated with each category of waste generated on site;
- establish the methodology for monitoring and controlling of various activities related to the management of waste.

These procedures shall be accompanied by flowcharts easily explaining the described procedure, since the productivity of the agents involved in the construction process is affected by the complexity present in some over-detailed procedures (Tam 2008). As an example, the flowchart describing the process for the proper management of mixed C&D wastes (*EWC category*: 17 09 04) is shown in Fig. 3.

This BPM will help technicians implementing on site the WMP, compulsory by the construction and demolition waste regulation in Spain, identifying best practices that have to be followed during the construction phase and positively influencing the management of generated

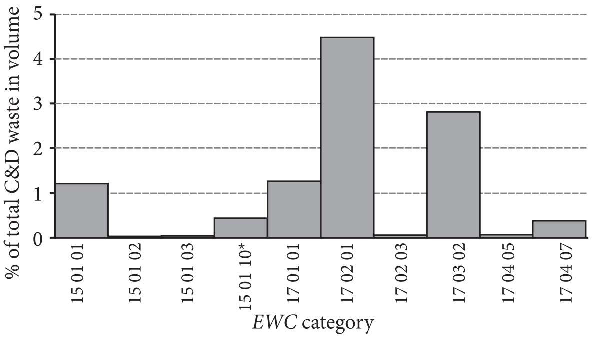
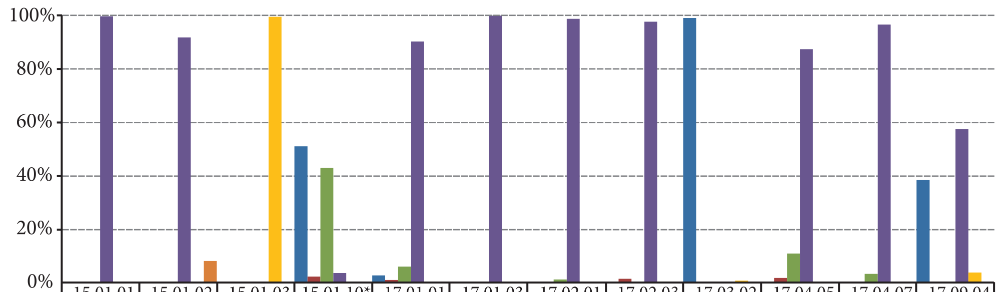


Fig. 1. Percentage of each C&D waste category generated in the whole construction work excluding 17 09 04



	15 01 01	15 01 02	15 01 03	15 01 10*	17 01 01	17 01 03	17 02 01	17 02 03	17 03 02	17 04 05	17 04 07	17 09 04
Preliminary and explanation works	0%	0%	0%	51.06%	2.72%	0%	0%	0%	99.08%	0%	0%	38.37%
Drainage	0.01%	0.12%	0.09%	2.24%	1.00%	0%	0.06%	1.42%	0%	1.73%	0.05%	0%
Structures	0.23%	0%	0.38%	42.98%	5.99%	0%	1.18%	0.30%	0%	10.88%	3.31%	0.02%
Tunnel	99.75%	91.77%	0%	3.60%	90.29%	100%	98.77%	97.73%	0%	87.39%	96.64%	57.52%
Junction	0.01%	0.01%	99.53%	0.06%	0%	0%	0%	0.41%	0.74%	0%	0%	3.82%
Temporary detours	0%	8.10%	0%	0.03%	0%	0%	0%	0.14%	0.18%	0%	0.01%	0.27%

Fig. 2. Percentage of each C&D waste category generated in each construction stage

C&D waste. Some best practices have been identified, common to all waste generated according to the different activities such as:

a. Hiring subcontracting companies:

– the reduction of packaging as well as the possibility of returning surplus materials and packaging will be agreed with suppliers;

– environmental agreements on the matter shall be verified. Check that operations are being done in compliance with them;

– verify that containers are those specified in the project;

– limit the maximum volume of waste that will be generated for each construction stage.

b. Purchase of materials:

– check that materials and products are those specified in the project and that they include seals and corresponding environmental certifications;

– avoid unnecessary packaging in the purchase of materials (bulk, wherever possible);

– minimize and reduce the amount of raw materials used;

– consider the wide range of commonly available recycled products and use them when they meet the specifications;

– reuse waste for on-site temporary constructions, office supplies, and containers;

– foresee the amount of materials needed for the construction work. Emphasizing the potential of certain

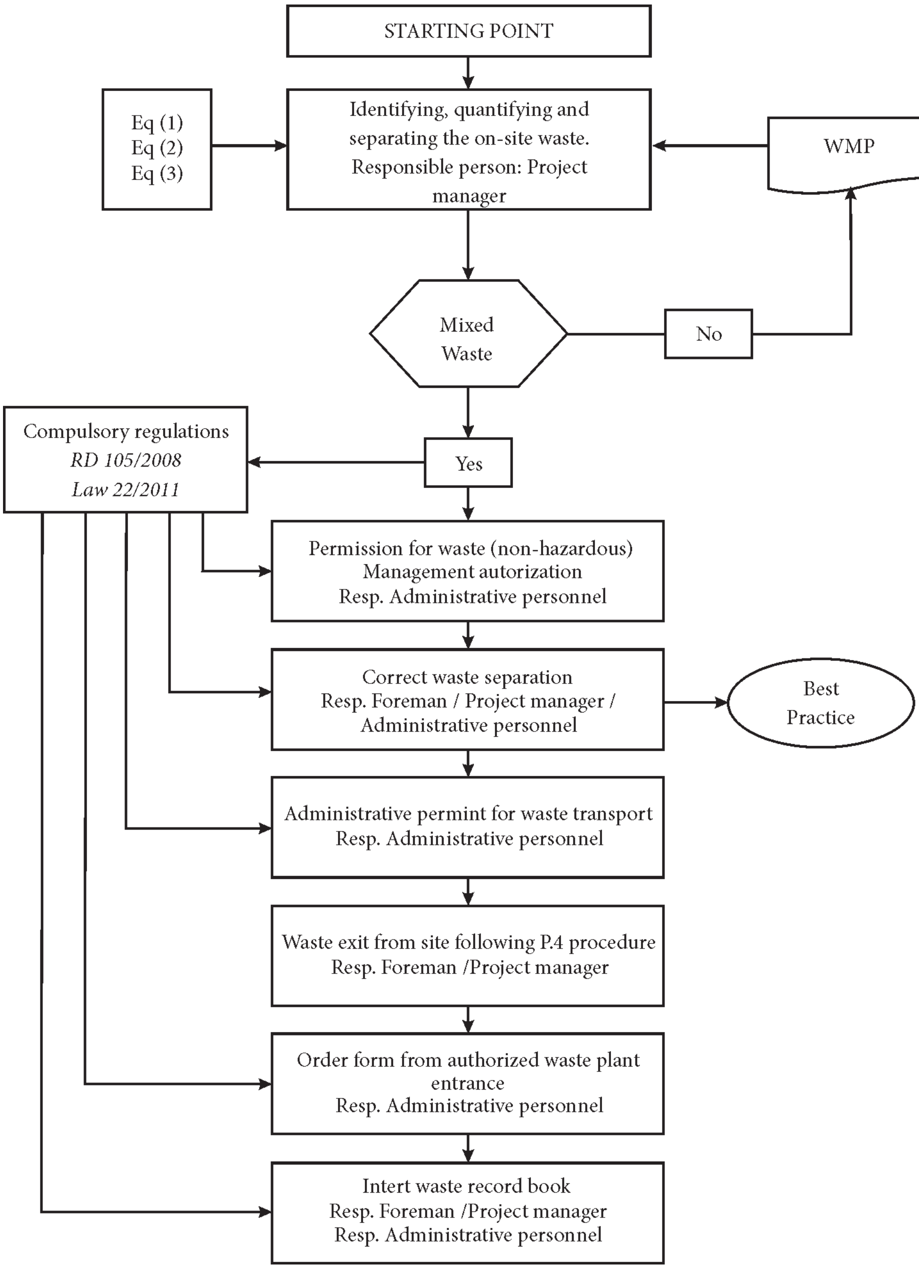


Fig. 3. Flowchart for mixed C&D waste management procedure

Table 3. List of best practices applied to the waste categories generated in railway works

Waste category	Generated[1]	Best practices
17 09 04 Mixed C&D waste	During the construction of tunnels and preliminary works	– Check that waste is treated to avoid possible dispersion by the action of atmospheric agents, either by covering it with a waterproof cove or through water spraying or other procedures to achieve the same purpose; – protective screens against the wind in loading and unloading areas need be checked. At the same time, material transport of in the urban areas needs to be checked.
15 01 03 17 02 01 Wood waste	During the construction of junctions and tunnels, when formwork is used	– For cutting wooden pieces machinery with particles suction systems incorporated is to be used; – wooden panels to be reused, have to be immediately cleaned after usage to extend their useful life; – avoid wood waste in contact with the soil to prevent the transmission of moisture through the support, or the waste dirt.
17 01 01 Concrete	During the tunnel construction	– Never pour concrete remains in fluid state in the drainpipes. They have to be reused wherever possible (for improving the accesses, traffic zones, etc.); – fluid concrete waste will not be managed in work, they must be returned to the concrete plant in compliance with the agreements made with the subcontracting company; – the arrival of concrete trucks will be correctly scheduled to avoid early setting and, therefore, the need to return it to the plant causing more the generation of waste and transport emissions; – workers have to be trained to use the correct proportions. Concrete placing will cause much waste if it is not correctly placed covering the surface totally and the setting time will differ.
15 01 01 Paper and cardboard packaging	During the tunnel construction	– Proper use and functioning of compacting machines have to be ensured to compact the paper and cardboard waste.
17 04 07 17 04 05 Mixed metals	During the structures phase and the construction of tunnels	– Choose electro-welded meshes which better fit the surface to be covered. The use of these electro-welded meshes in small surfaces generates numerous cuttings; – protect the construction elements to avoid weathering deterioration of the surface; – separate metal materials from the floor to avoid the transmission of humidity; – during the cutting process of metal parts choose the most suitable saw disk depending on the type of steel and diameter to prevent material damage; – metal elements used will be immediately cleaned after usage to extend their useful life; – centralize, wherever possible, the assembly of reinforced elements. Thus, the metal cuttings will be recovered and uncontrolled appearances of wires, scrap, etc avoided.
17 02 03 15 01 02 Plastic waste	During the tunnel construction	– Choose the dimensions of the plastic canvas so as to adapt correctly to the surface to cover; – reuse plastic to cover the collected materials; – good use of compaction machines for plastics, films, etc on site have to be checked. The volume of material to be transported is greatly reduced and this processing increases the chances of the waste to be accepted by a recycling company.
15 01 10* Packaging contaminated by hazardous materials	During the preliminary and explanation works, as well as during the structure stage	– Avoid mixing hazardous waste with other waste categories. If this happens, the best thing to do is to handle the whole as a hazardous waste; – products safety data needs to be checked so as to provide appropriate safety measures for waste storage, handling and management; – avoid pouring hazardous liquid waste in the sink; – protection of containers against weather agents shall be verified; – correct labelling of the place of storage shall be verified as well as that of the stored waste; – a procedure in cases of accidental release of hazardous waste has to be followed. In addition, absorbent material will be available to act effectively; – drums and containers of this waste need to have retention buckets; – avoid storing hazardous waste more than six months in the work site.

[1] Fig. 2.

purchasing procedures that will contribute to the reduction of an excessive on site material waste. Excessive supply of materials, is not only expensive but it originates a greater volume of surplus remains;

– select suppliers which remove packaging, pallets and unused or scrap materials supplied;

– order materials accurately and as needed, to minimize the risk of damage. A common practice is to order an extra 5–10% of materials to allow for site waste by damage, spillage, under-supply and vandalism. These figures have to be reduced.

c. Planning construction works:

– training courses for operators will be planned in the field of waste management;

– reception of materials will be done according to the needs of the construction work;

– planning and indication of the location of C&D waste storage have to be considered;

– planning the location of small containers in the working areas to facilitate the separation of the different waste categories have to be also regarded;

– training of workers has to be planned so that they conveniently perform proportions of the mixtures;

– accurate plotting will be performed so that voids and ducts have the proper location and size to avoid superfluous waste;

– material remains have to be promoted to be reused during the construction.

d. Stock up and storage of materials:

– respect the manufacturer's instructions. Materials will not be over stacked;

– protect materials from rain, sun, wind and moisture;

– plan the storage of materials supply out of the transit areas in the construction site, keeping them well packed and protected until the moment of their use.

e. Documents filing:

– register the quantities and characteristics of the waste transported from containers to their intended destination (authorized managers, controlled landfills …);

– save the order forms of waste transference and any other document showing that the waste has been properly managed through an authorised manager (whether it will be allocated in a landfill, recycled or sent to transformation plants, etc.)

f. Managing on-site waste:

– label waste correctly at its storage point indicating their hazardous degree;

– respect and monitor the selective breakdown stipulated in the project and the good use of containers, respecting the separation stage foreseen in the WMP;

– efforts will be made to pour each waste category into the proper containers. In this sense, special attention has to be drawn so that non-hazardous waste is contaminated by toxic waste;

– protective screens against the wind in areas of loading and unloading and transport of waste will be checked in works located in urban areas;

– in construction works with enough waste volume, equipment for grinding the debris is needed to produce recycled aggregate. In this case, the proper functioning of the mobile recycling plants located on site have to be checked;

– conclusions of the effectiveness of the waste management model used have to be drawn to be applied to other similar construction works (waste disposal records).

In addition to the previous mentioned practices, the specific categories of waste generated during the railway works have to be considered and are shown in Table 3.

5. Conclusions

From the results obtained the following conclusions are drawn:

1. Few research works deal with the study of waste generated in the civil engineering works in the different construction stages. Thus, this study offers an innovative comprehensive methodology of waste management considering the different stages in a railway work.

2. From all construction stages of a railway works, the tunnel construction and the preliminary works are the ones generating more waste. Regarding the categories of waste generated, mixed construction and demolition waste, wood and concrete waste are the most greatly generated ones.

3. The model proposed, consisting of the Best practices Manual with the Waste Management Report and the Waste Management Plan provides an accurate waste management follow-up for each and every one of the phases of the work (design, planning and construction).

4. The implementation of the proposed Best practices Manual during the stages of construction of tunnels and preliminary work and land movement implies a correct management and minimization of almost 95% of the total waste generated in railway works

5. The Best Practices Manual is a useful and operational tool to help the agents in implementing the management of C&D waste previously planned in the Waste Management Plan, through a series of procedures. In addition, it establishes responsibilities for waste and provides greater control over the process.

6. The proposed model will be part of the Internal Quality System of companies in order to integrate waste procedures and quality in a comprehensive management system.

7. Ultimately, this article offers a model to improve the civil construction sector and, consequently it proposes management methods easily applied by the construction companies.

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