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Production and Recycling of Construction and Demolition Waste

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***Abstract*—**Recycling of construction and demolition waste (C&DW) and their new reuse in structures is one of the solutions of environmental problems. Construction and demolition waste creates a major portion of total solid waste production in the world and most of it is used in landfills all the time. The paper deals with the situation of the recycling of the building and demolition waste in the Czech Republic during the recent years. The paper is dealing with questions of C&D waste recycling, it also characterizes construction and demolition waste in general, furthermore it analyses production of construction waste and subsequent production of recycled materials.

***Keywords*—**Recycling, Construction and demolition waste, Recycled rubble, Waste management.

I. Introduction

CONSTRUCTION in the long term point of view registers steady development and is one of the largest consumers of raw materials and energy. It consumes about 30-40 % of energy and generates about 30-40 % of the total amount of all produced waste (in the EU). Building industry is also related to many side effects which lead to overall environmental burden. From this point of view it is an important element in the construction industry, which is characterized by a wide variety of interventions in the environment. A good quality environment is considered as one of the most fundamental necessities of human existence whereas environmental problems have been considered as a serious situation in the construction.

The large volume of materials consumed in the construction industry has, on the other hand, a considerable potential for its use in the form of recycled materials (raw waste) in new structures, which is now a prerequisite for sustainable development. The sustainable possibilities of using construction and demolition waste are shown on Fig. 1.

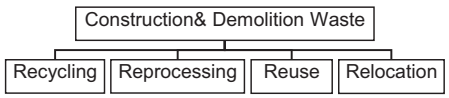

Fig. 1 Possibilities of using construction and demolition waste [1]

Rapidly dwindling non-renewable sources of raw materials, energy intensity of their acquisition and negative impacts on the environment during their production, processing and subsequent use are still one of the biggest problems of our time. It is therefore necessary to look for other possibilities of the use of the waste material after its initial life. One of the most economic ways to deal with the increasing number of existing waste with minimal environmental burden is recycling (recovery). There are many materials suitable for recycling and subsequent re-use in the construction. We can reprocess C&DW, industrial waste generated in the production or extraction of primary raw materials, as well as municipal waste. Although there are additional costs of change and technology development connected to the use of waste materials, it offers savings of raw materials and a significant reduction in the amount of waste going to the landfill.

Especially the end of the 20th century and early 21st century is marked by the rapid development of recycling technologies and processes in waste management in the context of the idea of sustainable development. Waste processing and its subsequent use in the construction is a subject related to special legislation. The final quality of recycled material is also influenced by the principles of recycling and technology in the recycling process.

Recycling can now be described as a science which is not only possible, but absolutely necessary for future sustainable development of our society. Principles of recycling in building industry have become an integral part of the cycle of building materials in the construction process. This paper deals with related issues in terms of the use of recycled and recyclable materials in the construction. The paper provides comprehensive survey about the state of the art related to recycling processes and utilization of construction and demolition waste.

II. Waste Management

Waste management is a relatively young, dynamically growing, sector of the national economy of most of the developed countries. With the development of recycling of construction and demolition waste (SDO) as we understand it today, we see more of it after the end of the Second World War in 1945. Industrially and economically advanced countries have developed their waste management intensively only over the last 30 years. The first Waste Act was adopted in the Czech Republic as recently as 1991. Prior to 1991, handling of waste was not subjected to any legislative control or rules in the Czech Republic, and was not governed by any sectoral rules with the exception of so-called secondary raw materials. Since 2004 our legislation is influenced mainly by the European Union regulations. [2]

Legal rights and obligations are closely related to administrative tasks. The current Act no. 185/2001 Coll. “On

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Waste and Amendment of Some Other Acts" emphasizes waste prevention, defines the hierarchy of waste handling, and promotes the fundamental principles of environmental and health protection in waste handling.

Waste is the most frequent and best documented "by-product" of human society. Construction and demolition waste creates a major portion of total solid waste production in the world, and most of it is used in landfills, for reclamation or landscaping all the time. Large volumes of C&D waste also end on illegal landfills which have became a big issue in the Czech Republic, although the illegal disposal of waste can be fined here up to 1900 EUR.

Due to specific properties of C&DW and varying degrees of environmental risk, each waste flow requires a specific treatment method. The basic rules for waste treatment are set out by the Waste Act and its executive regulations. The goals and targets for the various waste treatment methods and the optimum ways of achieving them are set out by the "Waste Management Plan of the Czech Republic for 2003-2013", which was published in the form of a Government Regulation in compliance with the Waste Act [3]. According to the Czech Waste Management Plan should 75% of the weight of produced C&DW be done by the end of 2012. The EU has introduced recycling targets for construction and demolition waste in 2008. A 70% recycling target was introduced in the new "EU Waste Framework Directive 2008/98/EC" to be achieved by 2020. It includes only recycling of non-hazardous construction and demolition waste and excludes all the soil and stone [9].

III. Recycling of Construction and Demolition Waste

Progress of recycling principles in construction industry is incorporated in waste management and is supported by state administration authorities. Current legislative requires increase of recycling of construction and demolition waste and subsequent utilization of recycled materials. Nevertheless the present state of recycling in the Czech Republic still does not meet the urgency of the problematic. Recycled materials from construction industry are mostly used as a groundwork filling in building of roadway and railway communications or in ground shaping and recultivations as background and filling material. Only very little of C&D waste is recycled for high specification applications because potential users are deterred by the perceived risks involved.

The traditional approach in the construction industry is based on fundamental criteria: costs, quality, time. Requirements in accordance with the principles of sustainable development in a comprehensive approach are increased by the criteria in the following areas:

- environmental quality,
- economic efficiency,
- social and cultural context.

The condition for achieving the above parameters is the integration of the various items of the proposal - material, design and environmental design into one process. Fig. 2 shows the different phases of the life cycle in the case of integrated structural design. Although recycling phase takes place in the last stage of the life cycle, we have to put the greater importance on it as a gateway to a new cycle of construction. Life cycle assessment is used to control and reduce the impact on the environment.

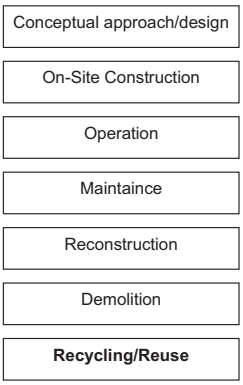

Fig. 2 Building life cycle in accordance with the principles of sustainable development [1]

The global crisis has widely affected the development of the construction industry. But it did not produce only negatives. Positive fact is the efforts of the whole society to reduce their costs. This effort supports the economic, energy and environmental aspects of an investment, which is a very good basis for the development and promotion of recycled products - for waste disposal as well as in the use of recycled products.

The development of recycling in the construction industry to incorporate waste management plans and its further development is therefore dependent on further action to government authorities, which have the waste in their jurisdiction and competence. The improvement of the recycling process and use of recycled materials in construction can establish these tasks:

- efficient use of primary raw materials,
- define the conditions to limit waste production,
- support business activities in the field of waste and recycling,
- prevention of illegal waste treatment ,
- reduce the environmental burden of production, technologies,
- application of prefabricated (demountable) construction and fully recyclable structures in the design,
- support research and development of technologies and other recycling options.

The recycled aggregates may be either fine recycled or coarse recycled aggregate which are obtained by crushing the construction and demolition waste. Recycling of construction and demolition waste is a relatively simple process which is based on quality recycled sorting (removing of unsuitable materials as plastic, wood, steel, glass) (Fig. 3).

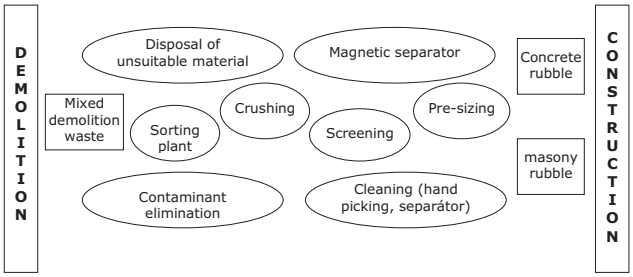

Fig. 3 Recycling process from demolition to material for new construction [4], [11]

The denominator is to start with clean; quality rubble in order to meet design criteria easily and ultimately yield a quality product that will go into end use. The more care that is put into the quality, the better product you will receive. The choice of one or several types of these recycle plants will be determined by the project. There are mobile or portable recycle plants [5].

Construction and demolition waste arising in the production of building materials and construction activity covers a whole range of materials which, thanks to their typical properties, offer a wide scale of exploitation. These are mineral inorganic materials of mostly inert nature without hazardous properties in which no significant physical, chemical or biological transformations occur.

Construction and demolition waste is the waste material which arises from the construction or demolition of buildings and/or civil engineering infrastructure, including hard C&D waste and excavation waste, whether segregated or mixed. Recycled aggregate arises by crushing of C&D waste and then is divided by the coarseness into different fractions, usually 0-8, 8-16, 16-32, 32-63, 63-120, 0-63 mm. Recycled rubble products of recycling centers can be graded according to the customer's requirements at the most strict grading.

IV. Analysis of Construction and Demolition Waste in EU

In 2005, the European Union (EU) formulated a vision of "the EU as a recycling community". The objective of this vision was to achieve construction with a lower exploitation rate of natural materials, energies and a lower production of greenhouse gas emissions, less polluting emissions into soil, water and the air.

According to the final report of Service contract on management of construction and demolition waste – SR1, the amount of SDO in the EU-27 ranges from 310 to 700 million tones per year [6].

Data on total construction and demolition waste in EU countries files The European Environment Agency (EEA). According to data published by this agency was in 2006/2007 generated about 971 million tonnes of the construction and demolition waste including soil (for 18 countries).

Of this amount was currently achieved recycling or reuse rate 518 million tonnes (54%). The generation of construction and demolition waste, 32% of Europe's total waste (EAA 2010), is closely related to economic activity in the construction sector.

National data shows that in 16 out of 20 EU and EFTA countries, construction and demolition waste amounts increased between 1995 and 2006 but again with large differences between countries.

The EU Commission Environment Committee of the European Parliament estimates that so far only 50 % of the 300 to 700 million tonnes of mineral construction and demolition waste produced throughout Europe a year are recycled. It is the target of the EU (The new Waste Framework Directive 2008) to achieve a recycling rate of at least 70 % for building and demolition waste (without soil and stone), to be met by 2020.

The high recycling level for construction and demolition waste means that many virgin resources are saved. It can be assumed that the majority of the recovered products are recycled aggregates that replace virgin aggregates. The average annual use of aggregates is 7 tonnes per capita (EEA, 2008), and it is estimated that only around 7 % or about 250 million tonnes of the total used in 2006 were recycled aggregates (ETC/SCP, 2009), indicating considerable room for improvement [7].

The development of waste generation in the EU depends largely on economic development, consumption, structural changes and resource efficiency, especially in the industrial production, construction and demolition and mining and quarrying sectors which together account for 70 % of all waste generated. For all these reasons a fast reorganization of the European economy in the sense of a recycling economy will be indispensable and is a declared aim of the European Union.

V. Analysis of Construction and Demolition Waste in Czech Republic

According Czech Environmental Information Agency (CENIA) was produced overall 30 million tonnes of waste and C&DW generated 58% in 2012. This is 26% more than the EU average.

Waste Catalogue in the Czech Republic harmonizes separation of the waste material with the European Waste Catalogue. Construction waste is given as a separate group of 17 00 00 - Construction and demolition waste and is divided into the following subgroups [3]:

- 17 01 00 – concrete, masonry, ceramics
- 17 02 00 – wood, glass, plastic,
- 17 03 00 – asphalt, tar product,
- 17 04 00 – metals and metal alloys,
- 17 05 00 – mined soil,
- 17 06 00 – insulating materials,
- 17 08 00 – gypsum product,
- 17 09 00 – other construction and demolition waste.

Nowadays the mostly recycled materials in the Czech Republic come from the recycled waste of bricks, concrete, asphalt, mixed building waste, various types of aggregates and soil. Unfortunately the current recycling rate in the Czech Republic is still way behind the urgency of this problem. In 2008 there were registered 124 landfills (deposits) of C&DW

and 47 recycling centers with 70 crushers with total yearly capacity about 7.5 million tons [1].

Currently there are about 80 recycling centers in the Czech Republic which process construction and demolition waste and 160 landfills of C&DW. Mobile crushing and screening on site is possible from 500 t. The total yearly capacity of all the recycling centers in the Czech Republic is about 14.5 million tons (assuming a yearly period of the use 1500 hours and an hourly capacity of 9700 tons/hour). The most significant recycling centers in Czech Republic are documented in Fig. 4.

Fig. 4 Map of Czech Republic with marked recycling centers [9]

A. Production of Construction and Demolition Waste

The Association for development in recycling of building materials (ARSM) summarizes the yearly output of C&DW in the CR from 1999 to 2008.

Between 2002 and 2006, the data were administered by the T. G. Masaryk Water Research Institute, a public research institution – the Waste Management Centre.

Since 2007 the Czech Environmental Information Agency (CENIA) summarizes the yearly data of waste inclusive construction and demolition waste. This agency records the information of waste management in database ISOH.

Data on waste production also collects the Czech Statistical Office (CSU).

The total production of construction and demolition waste in CR according database CENIA – ISOH is shown in Fig. 5.

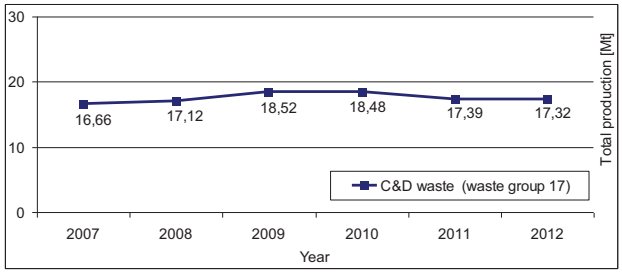

Fig. 5 The total production of C&D waste in CR (CENIA, ISOH) (including soil and stones) [12]

Unfortunately the obtained data in database ISOH are probably incomplete. Based on the analysis of ARSM around 50% of the waste is not accounted in the database. The reason is a difficult material flow analysis of construction and demolition waste. Due to the current trends in recycling, where many construction companies have their own recycling facilities (crushers and screens), is the determination of the actual state very difficult. Construction companies use the obtained recycled material for their own needs and therefore it is not legally recorded in the database.

Obtaining relevant information is not easy. As in the past ten years has shown the correct analysis of material flows in this area almost impossible. Table I shows the difference of total production of mineral debris according ISOH and ARSM databases. This volume of waste goes through recycling centers.

TABLE I
TOTAL PRODUCTION OF MINERAL DEBRIS

	2001	2002	2003	2004	2005	2006	2007	2008
ISOH	1739	2295	3189	4142	3128	3818	4029	3778
ARSM	3776 až 4280	4200 až 4700	5000 až 5500	5000 až 5500	5000 až 5500	5300 až 5700	5300 až 5700	5300 až 5700

Mineral debris = waste group 1701+1703+1709 in thousand tonnes

The specified figures (with respect to the valid definition of waste stated in the law 185/2001 Sb. about wastes) do not include whole production of waste in categories 1701, 1703 and 1705. The major part of CDW is directly recycled and repeatedly used at the place of its production and thereby do not satisfy the definition of waste according to the law [10].

The volume of all C&D waste without stone and soil in the Czech Republic (according to data obtained ARSM and ISOH) is between 10 to 12 million tonnes/year [8]. The largest production of recycled waste is in the larger urban areas. In regions with lower population density and lower rates of industry is permanently at a low level.

The processed masonry, concrete and asphalt demolition waste in recycling centers based on a survey of The Association for development in recycling of building materials (ARSM), Czech Environmental Information Agency (CENIA) database ISOH and Czech Statistical Office (CSU) are documented in Figs. 6-8. This inert, inorganic waste is most suitable for use in new constructions. These values show large differences in presented volumes of C&DW and complicated data collection.

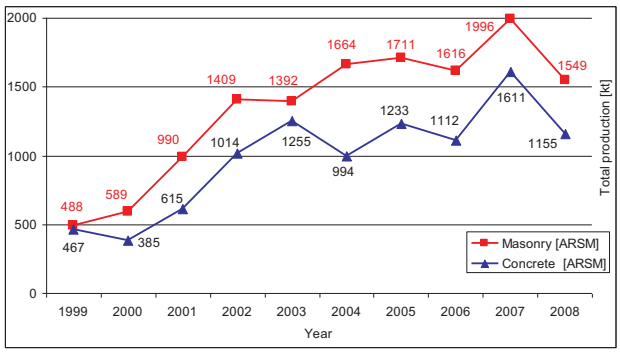

Fig. 6 C&D waste processed in recycling centers in CR (ARSM) [1]

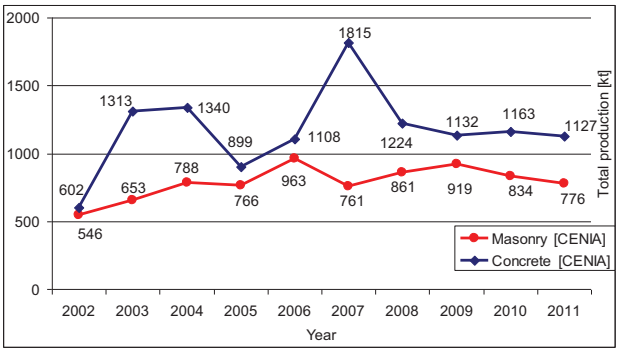

Fig. 7 C&D waste processed in recycling centers in CR (CENIA, ISOH) [12]

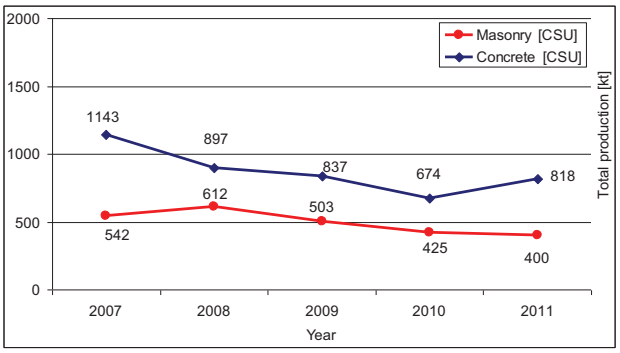

Fig. 8 C&D waste processed in recycling centers in CR (CSU) [13]

It is proven that the real production of recycled C&DW according ARSM is in comparison to the figures in ISOH database approx. by 80-100% higher in the individual years. At the first sight it is evident that the values obtained by the CSU are much lower. This is mainly influenced, among other things, by the survey methodology. The Czech Statistical Office carries out an annual survey on the production and waste management. The data presented in the database were for 2011 obtained by processing the reports from 8,466 companies and 982 municipalities.

For these values we can trace a development of recycling of Construction and demolition waste. In the years after 2004 there has been stagnation. In recent years there has been a decline of the recycling (especially in the area of waste - concrete, bricks, ceramics). The main reason is probably the sharp increase in the extraction of building stone and gravel in the country (Fig. 9).

The production of natural building stone and gravel in 2012 declined sharply and in 2013 it was at the same level, which means about 30% lower compared to year 2007.

Reported production is only du to reserved deposits. In fact the total production is approximately 25-30% higher. The production of recycled aggregates from construction and demolition waste varies across the EU around 5% - 15% of the natural building stone.

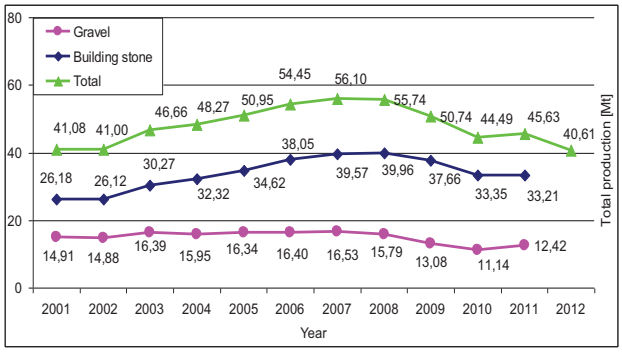

Fig. 9 The total production of extraction of stone in CR (CENIA, ISOH) [12]

B. Construction and Demolition Waste Management Costs

The price of recyclates is crucial for their subsequent utilization. The final price of the recycled material depends on many parameters. The transportation is the significant item of final costs of C&D waste. The profitable driving distance for the transport of waste is 40 km. Approximate cost distribution of recycling centres is shown in Fig. 10.

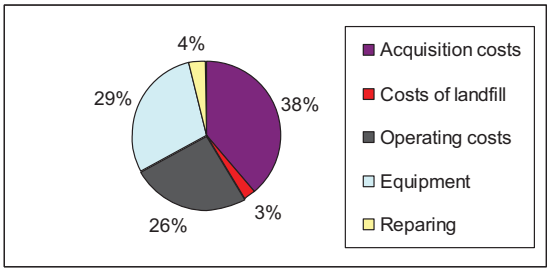

Fig. 10 Distribution of costs of recycling centre

The input (buyback) price of recycling companies depends on the individual companies and on the categories of waste, i.e. on the recycled C&DW characteristics, degree of pollution and possibilities of use. In Table II the price for waste recycling (buyback of construction and demolition waste) in the Czech Republic is shown.

It is proven that the price of the processing of one tone of sorted waste is around 3 EUR (includes crushing, screening at 3 fractions, manipulation and necessary tests). The most important step for recycling of construction waste is on-site separation. Initially, this takes some extra effort and training of construction personnel. Once separation habits are established, on-site separation can be done with only a little or with no additional costs at all. Buyout of unsorted waste is very expensive. Table II shows price for waste recycling and Table III shows the sale price of recycled aggregate (rubble).

Price of natural aggregate is 10-18 EUR per tonne depending on the fraction of the aggregate. The price of recycled materials is therefore more favorable for construction companies.

Recycling materials saves the cost of transport and storage of waste (landfill charge) and the cost of purchasing natural stone.

TABLE II
PRICE FOR WASTE RECYCLING

C&D	No.	Eur/ton
Concrete	17 01 01	3,70-6,00
Reinforced concrete	17 01 01	7,40-12,00
Masonry	17 01 02	5,00 - 7,20
Ceramic products	17 01 03	5,50 - 7,00
Soil and stones	17 01 04	5,50-8,30
Mix waste	17 01 07	5,50-11,50
Asphalt	17 03 01	4,40-12,40

The price range based on 16 recycling centres.

TABLE III
SALE PRICE OF RECYCLED MATERIALS

Recyclates	Fraction	Eur/ton
Concrete rubble	0/16 mm	1,90-5,10
Concrete rubble	16/63 mm	5,90-11,20
Concrete rubble	63/120 mm	3,70-5,50
Masonry (mix) rubble	0/8 mm	1,20-3,30
Masonry (mix) rubble	16/63 mm	1,20-2,50
Asphalt rubble	0/16 mm	3,20-5,50
Asphalt rubble	16/63 mm	1,70-4,80

The price range based on 16 recycling centres.

VI. CONCLUSION

Currently, there are two significant effects in the field of construction and demolition waste recycling. The first one is the construction recession of the last several years, the other one is the gradually increasing support of recycling of construction materials in the new legislation. The amount of produced waste grows constantly and the current utilization won't be sufficient in the future. Thus it is inevitable to support further utilization of these materials and enquire after more possibilities of its use. Detailed amount of production and recycling cannot be simply determined because of insufficient declaration in present legislation. Big mass of non-elaborated C&DW still ends on illegal stocks, speculative sanitations or recultivations.

Construction & Demolition Waste from production of construction materials and construction itself covers a wide range of materials that offer many possibilities of utilization due to their typical properties. In the Czech Republic, apart from some European Union countries, do not yet exist a unified technical standard of general application to the quality of recycled materials.

Longer-term development of material consumption is fluctuating and highly dependent on economic developments. Most of the base material makes up non-renewable resources whose consumption brings greater environmental burden than the consumption of renewable resources.

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