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USING OF RECYCLED MATERIALS IN SUBSTRUCTURE

Richard Svoboda *, Dana Hubáčková **, Jan Valehrach ***

1. Introduction

The use of recycled materials has become a very topical issue in recent years. From an ecological point of view it is necessary to reuse construction waste of which around 16 million tons are produced annually only in the Czech Republic. Another reason for using of recycled materials is the limited amount of primary resources which are gradually running out. In the last 2 years the reason for recycling construction waste is also the economic point of view when thanks to the increasing demand for natural aggregates and the current mining sites capacity restrictions we can observe a rocket rise in the prices of natural aggregates which surpass the price of recycled aggregates.

2. Construction waste and its recycling

Construction and demolition waste comes from the demolition, reconstruction and construction of buildings which can include not only buildings but also engineering and line structures. Data from the Czech Statistical Office [1] shows that in 2020 a total of 38.5 million tons of waste were produced in the Czech Republic of which construction waste accounted for almost 16.5 million tons. Waste from the construction industry thus occupies the first place among individual sectors and in 2020 its share in total waste production was almost 43 %.

According to [2], the largest share in the amount of construction waste is tailings. This is excavated soil which makes up roughly half of all construction waste. It is not recycled it should be reused. Other construction and demolition waste includes masonry, ceramic tiles, concrete, roof tiles, wood, glass, plastics, asphalt mixtures and tar products, metals, stone, insulating materials and materials containing asbestos.

* Ing. Richard Svoboda, Ph.D., tutor, Brno University of Technology, Faculty of Civil Engineering , Institute of Railway Structures and Constructions, Veveří 331/95, 602 00 Brno, tel.: +420 54114 7336, e-mail: svoboda.r@fce.vutbr.cz

** Ing. Dana Hubáčková, scientist, Brno University of Technology, Faculty of Civil Engineering , Institute of Railway Structures and Constructions, Veveří 331/95, 602 00 Brno, tel.: +420 54114 7326, e-mail: hubackova.d@vutbr.cz.

*** Ing. Jan Valehrach, Ph.D., tutor, Brno University of Technology, Faculty of Civil Engineering , Institute of Railway Structures and Constructions, Veveří 331/95, 602 00 Brno, tel.: +420 54114 7337, e-mail: valehrach.j@fce.vutbr.cz.

Most construction waste is recyclable. To a large extent it is so-called downcycling. It means recycling in which the quality of the material is reduced. Successful recycling of construction waste must be preceded by selective demolition. This is understandably more economically demanding and also places great demands on the organization of demolition work.

According to [2] and [3], the actual recycling of construction waste usually consists in modifying the physical properties of the materials. Most often this involves crushing and cleaning construction waste and then sorting it into the required fractions. For this modification recycling lines are used which can be mobile - deployed at the demolition site or stationary which are usually technologically more complex. It is actually a system of machines (shredders, sorters and separators) that adjust and clean the construction waste so that it achieves the required properties for further use.

3. Natural aggregate, its extraction and price

Natural aggregate is a mineral raw material used in practically all construction sectors. According to [4] at the present time in the Czech Republic there is a significant decrease in the reserves of deposits permitted to be mined. This situation is caused by the decline of the mining industry after 1989 when no new deposits of building stone have been opened in the Czech Republic since that year. A 2021 study by the Czech Geological Service shows that 50 to 60% of active quarries will cease production within 10 years. This impending shortage of construction raw materials can result in a threat to construction production but also to a significant ecological burden when the missing aggregates will have to be imported from more distant regions or even from abroad.

At the same time, in the last 10 years, the consumption of crushed aggregate has grown significantly. In addition the requirements for the volume and quality of the raw material have increased and thus the price of this product has increased significantly. When comparing recycled concrete 0/32 mm and natural aggregate of the same fraction natural aggregate would clearly come out as the cheaper raw material. However, according to [5] and [6], due to the development of natural aggregate prices caused by high demand and insufficient supply, at the end of 2021, the price of natural crushed stone fraction 0/32 mm in the Brno region is twice the price of recycled concrete fraction 0/32 mm.

The problems described above could be partially solved by increased use of recycled construction waste.

4. Using of waste material in substructure

Recycled materials can be used quite widely throughout the railway substructure. The simplest and least problematic use appears to be the backfilling of excavations, drainage ditches, backfilling or backfilling of ditch blocks, platform prefabs, etc. These materials are subject to significantly lower requirements compared to active sleeper subgrade layers, as they do not have to meet the demanding load-bearing requirements.

In the solution of our project we mainly dealt with the possibilities of using recycled materials in the active area of the substructure, i.e. the possibility of using them in the capping layer (or sub ballast layer), see *Fig. 1.*

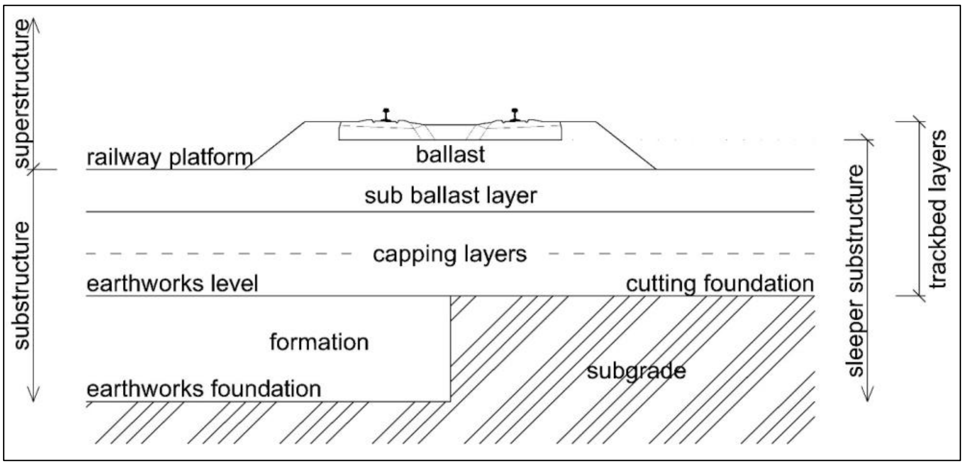

Fig. 1 – Construction of the railway substructure according to the Instruction SŽ S4 [8]

The following requirements are imposed on the materials in these layers according to the Technical Quality Conditions for State Railway Constructions (TKP), Chapter 6 (valid from 04/07/2008) [7]:

- Granularity.
- Non-frosting and permeability.
- Heterogeneity.
- Content of fine-grained and foreign particles.
- Resistance to weathering and mechanical wear.

4.1 Design of subballast and capping layers according to[8]

The design of subballast and capping layers in the Czech Republic is carried out according to the Instruction Správa železnic (Czech Railway infrastructure manager) SŽ S4 (valid from 1/1/2021), [191]. Suitable materials for subballast layers are:

- Crushed stone fraction 0/32 mm and fraction 0/63 mm.
- Recycled crushed stone.
- Mineral mixture.
- Asphalt concrete.
- Geosynthetics.
- Other materials with the consent of Správa železnic (Czech railway infrastructure manager).

The prerequisite for the design of the subballast layer is the fulfillment of the required load-bearing value on the subgrade. At the same time, it is an effort to make the subballast layers typified and the same in the longest possible sections. Instruction SŽ S4 therefore prescribes specific compositions of subballast layers (see Tab. 1).

In the event that the subgrade does not meet the required load-bearing value it is necessary to design the capping layer.

The following materials can be used for the capping layers:

- Gravel.
- Crushed aggregate.
- Stabilization and improved soil.
- Geosynthetics.
- Asphalt concrete.
- Other materials with the consent of Správa železnic (Czech railway infrastructure manager).

The actual design of the capping layers is carried out by the prescribed calculation using the DORNII method.

Tab. 1 - Design of subballast layers according to Instruction SŽ S4 [8]

Highest speed limit (kph)	**Expected operational loads (millions gross tons/year)**	**Track class throughout whole lifetime**	**Composition of trackbed layers**
≤80	<2	A – D	min. 200 crushed stone fraction 0/32 kv (min. 150 with the agreement of infrastructure manager)
	2-8	A – D	min. 250 crushed stone fraction 0/32 kv
	>8	A – D	min. 300 crushed stone fraction 0/32
81-120	<2	A – D	min. 250 crushed stone fraction 0/32 kv
	2-8	A – D	min. 300 crushed stone fraction 0/32 kv
	>8	A – D	min. 300 crushed stone fraction 0/32
121-160	<2	A – D	min. 300 crushed stone fraction 0/32 kv
	2-8	A – D	Var. I: min. 400 crushed stone fraction 0/32 kv Var. II: min. 250 crushed stone fraction 0/63 kv
	>8	A – D	Var. I: min. 400 crushed stone fraction 0/32 kv Var. II: min. 250 crushed stone fraction 0/63 kv
161-200 (incl.)	For all operational loads	A – D	Var. I: min. 400 crushed stone fraction 0/63 kv Var. II: min. 100/asphalt concrete +250 crushed stone fraction 0/63 kv

4.2 Waste material for bonded layers

Due to their hydraulic properties waste ash produced during combustion or other materials that are mixed with the soil in the prescribed amount can be used in the railway substructure specifically for the improvement of the capping layers. The unstable composition of these waste materials appears to be problematic. In the case of ashes it is also necessary to monitor their volume stability.

These materials are:

High temperature fly ash

According to [9], high-temperature fly ash is produced during coal combustion at temperatures of 1200 – 1700 °C and consists mainly of mullite ($3Al_2O_3 \cdot 2SiO_2$), quartz (quartz (SiO_2), iron minerals and remains of unburned coal).

Fluid fly ash

According to [9] and [10], fluid fly ash is produced by burning finely ground coal in fluid boilers at lower temperatures (850°C) and unlike high-temperature fly ash, fluid fly ash is characterized by a higher content of lime (Ca). This is due to the addition of ground limestone to desulphurise the coal during the combustion process.

During combustion, two types of ash are produced: bottom ash and fly ash. Fly ash is carried away with the flue gas and captured in electroprecipitators, while bottom ash is the coarser fraction that falls through the grate under the fluid ring during the combustion process.

Biomass bottom ash

It is created by burning biomass, i.e. mainly plants and mainly woody plants. As with coal bottom ash this is a coarser ash that is not carried away with the flue gas.

Coal slag

It is a solid inorganic waste. It is created on grates or in furnaces during the burning of coal, in addition to ash it also contains unburned remains of the combustible component of coal.

Cement kiln dust

They are a by-product of cement production. These are dust particles that are carried away with the flue gas when burning cement.

Fig. 2- High temperature fly ash

Fig. 3 - Fluid fly ash

Fig. 4 - Biomass bottom ash

Fig. 5 – Coal slag from Mělník

Fig. 6 - Cement kiln dust

4.3 Waste material for unbonded layers

We are currently doing tests on waste materials for unbonded capping layers. For all tested materials described below, we investigate:

– Grain size determination (sieve analysis).
– Determination of moisture content and maximum bulk density (Proctor's test).
– Determination of Immediate bearing index (IBI) and California bearing ratio (CBR).

Waste material from ballast cleaning

Investigation of ballast bed cleaning waste material shows that its physical and mechanical properties (including load-bearing capacity) are highly dependent on the content and origin of fine particles/pollution. The rest from the ballast bed contains clay or fine elements which can be blown from the surroundings or seep into the track bed from the subsoil, but it can also be significantly polluted by material dropped from vagons. You can see samples of waste from ballast cleaning from different locations in *Fig. 7*. Significantly darker colour can be seen with the naked eye in sample No. 2 – this is probably a significant contamination with coal dust, which significantly negatively changes the properties of the sample, and this sample shows a significantly lower load capacity than the other two samples.

Fig. 7 – Samples of waste material from ballast cleaning

Recycled concrete

Another very promising material for use in capping layers is recycled concrete fraction 0/32 mm. We currently have 2 samples of recycled concrete from the Brno company DUFONEV R.C. a. s., which were taken at a considerable time interval (approx. 10 months). Both samples have practically the same material composition, they contain a majority of mixed concrete rubble, to a lesser extent also brick fragments. According to the tests carried out, both samples of recycled concrete show the best properties in terms of load-bearing capacity.

Fig. 8 - Recycled concrete (sample from 11/2020)

Fig. 9 - Recycled concrete (sample from 09/2021)

Recycled asphalt

The last material we have tested so far is recycled asphalt fraction 0/16 mm also from the Brno company DUFONEV R. C. a.s. This is a material that can no longer be used for roads. Asphalt recycled has so far shown a very low load-bearing capacity in the tests carried out and will be the subject of further research into how to increase this load-bearing capacity (e.g. by mixing it with other material or adding larger fractions of aggregate).

Fig. 10 - Recycled asphalt

5. Conclusion

The time is coming in the Czech Republic when it will be necessary to look for new material sources to replace the use of natural aggregates in railway construction (as well as in other sectors). The use of waste materials appears to be a suitable alternative.

Suitable materials for bonded layers can be waste products produced during the combustion of coal, biomass or dedusting from a cement plant.

Natural aggregate for unbonded layers can be replaced with waste material from cleaning the ballast bed and concrete or asphalt recycled material.

We are currently doing tests on materials for unbonded layers. Recycled concrete appears to be the most suitable material at this moment, which we are planning to insert into the test section as a subballast or capping layer in the next phase of the project solution.

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