Acta Polytechnica CTU Proceedings **43**:111–116, 2023
https://doi.org/10.14311/APP.2023.43.0111

RECYCLED MATERIALS FOR SUBLAYERS

Richard Svoboda*, Dana Hubáčková, Jan Valehrach

Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00 Brno, Czech Republic
* corresponding author: svoboda.r@fce.vutbr.cz

Abstract. The article focuses on the recycled materials used in sleeper substructure. In the introduction, it summarizes the requirements for bearing layers of railway substructure and recycling of waste construction materials. The article presents the materials on which laboratory tests have been carried out and discusses in detail the most perspective – recycled concrete. For concrete recyclate, the article describes the results of laboratory tests – sieve analysis, determination of optimum moisture, and determination of bearing capacity using California bearing ratio, Immediate bearing index and Static deformation modulus.

Keywords: Recycled construction materials, concrete recyclate, sieve analysis, optimum moisture, California bearing ratio, static plate load test.

1. Introduction

The reuse of construction waste in the construction industry is becoming a topical issue, due to the ecology and the increasing pressure to recycle all waste materials, but also due to the increasing scarcity of building materials generating a rapid increase in their price. We are responding to this global trend by researching the applicability of recycled materials in the sleeper substructure of railway tracks.

The paper focuses on recycled construction waste, its possible use in railway substructure and laboratory tests carried out on recycled construction waste with regard to its possible use in sublayers of railway substructure.

2. Design of the railway substructure

The design of the substructure for the Czech Republic is prescribed by the Instruction SŽ S4 (valid from 1st January 2021) [1]. The layers that distribute the loads from the ballast are (from top to bottom) the sub ballast layers and the capping layers, see Figure 1.

Structural layers are designed according to Annex 6, Table 3 of the Instruction SŽ S4. This table specifies, according to the highest speed limit and the expected operational load, what grain size and thickness of the gravel layer must be used, see the Table 1.

The capping layers are designed according to a special calculation that determines the equivalent static deformation modulus on each layer, the calculation is based on the Dornii method.

3. Requirements for the capping layers

Instruction SŽ S4 prescribes very high requirements for the material of sub ballast layers, therefore it is rather considered to use them in the capping layers. The following requirements are imposed on the materials of unbonded layers according to Chapter 6 of the Instruction TKP [2]:

- grain size;
- non-frosting and permeability;
- heterogeneity;
- content of fine-grained and foreign particles;
- resistance to weathering and mechanical wear.

According to Instruction SŽ S4 [1], suitable materials for the capping layers are:

- gravel;
- crushed aggregate;
- stabilization and improved soil;
- geosynthetics;
- asphalt concrete;
- other materials, with the approval of SŽ GŘ 013 [1], to ensure the required load-bearing capacity throughout the service life of the structure.

4. Recycling of construction waste

Construction and demolition waste comes from the demolition, reconstruction and construction of building facility, not only buildings but also linear structures. In 2020, nearly 16.5 million tonnes of waste were produced in the Czech construction sector, which is 42.9 % of the total waste production of 38.5 million tonnes [3]. The construction sector thus holds the first place among the different sectors (see Figure 2).

The largest share of waste is tailings, which are not recycled and should be reused. Most other construction waste is recyclable. Their effective recycling

[1]Railway Infrastructure Administration, Department of track management

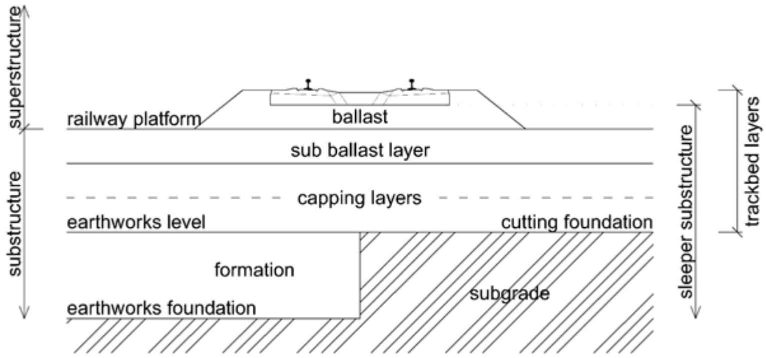

Figure 1. Construction of the railway substructure according to the Instruction SŽ S4.

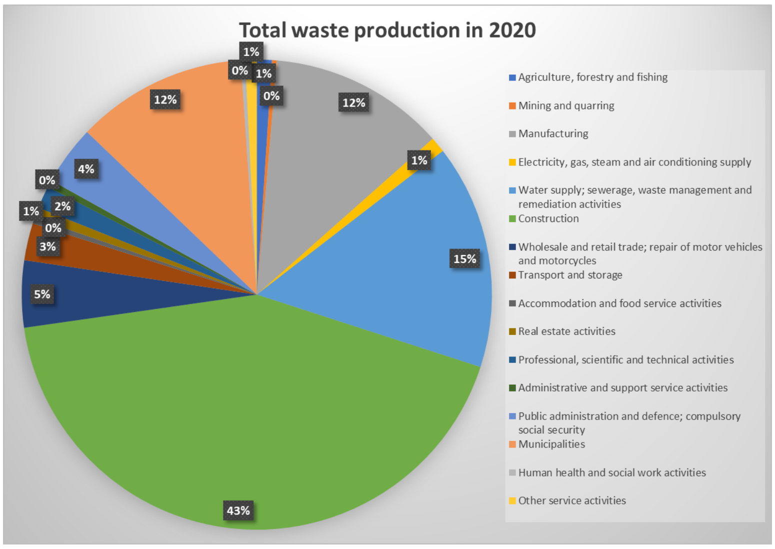

Figure 2. Waste production in 2020.

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/ŠD 0/32 kv (min. 150 with the) agreement of infrastructure manager)
	2-8	A – D	min. 250/ŠD 0/32 kv
	>8	A – D	min. 300/ŠD
81-120	<2	A – D	min. 250/ŠD 0/32 kv
	2-8	A – D	min. 300/ŠD 0/32 kv
	>8	A – D	min. 300/ŠD
121-160	<2	A – D	min. 300/ŠD 0/32 kv
	2-8	A – D	Var. I: min. 400/ŠD 0/32 kv Var. II: min. 250/ŠD 0/63 kv
	>8	A – D	Var. I: min. 400/ŠD 0/32 kv Var. II: min. 250/ŠD 0/63 kv
161-200 (incl.)	For all operational loads	A – D	Var. I: min. 400/ŠD 0/63 kv Var. II: min. 100/asphalt concrete + 250/ŠD 0/63 kv

Table 1. Design of sub ballast layers according to the Instruction SŽ S4.

Figure 3. Samples of waste material from ballast cleaning.

Figure 4. Recycled concrete.

should be preceded by selective demolition, which is both economically demanding and places high demands on the organisation and timing of demolition work [4].

The recycling of construction waste itself usually consists of a simple modification of its physical characteristics. In the case of concrete, asphalt or brick waste, recycling consists of crushing and sorting the material into the required fractions. During the process, the recycler is further cleaned of unwanted particles, for example by removing floating particles or by magnetic separation [5].

5. Considered waste for use in the railway substructure

In the first phase of the project, we were searching for possible wastes that could be used as capping layers. For bonded capping layers, which are mixed with soil in varying proportions, we considered the following materials [6, 7]:

- high temperature fly ash;
- fluid fly ash;
- bottom ash;
- coal slag;
- cement kiln dust.

Furthermore, we searched for suitable waste materials for unbonded capping layers, as possible materials

Figure 5. Recycled asphalt.

we considered [6, 7]:

- waste material from ballast cleaning;
- recycled concrete;
- recycled asphalt;
- recycled brick;
- waste from washing concrete mixers;
- waste from washing concrete mixers;
- waste from washing concrete mixer trucks;
- foam glass.

6. Available recyclates for capping layers

The following were subsequently selected as suitable and available recyclates for the base layers of the railway substructure:

- waste material from ballast cleaning;
- recycled concrete;
- recycled asphalt.

Waste material from ballast cleaning (see Figure 3) was collected at several different locations. Its investigation has shown that its physical and mechanical properties are highly dependent on the content and origin of fine-grained particles. Sample 2, which was significantly darker than the other two samples, probably contained a large amount of coal dust, which significantly degraded its properties.

Concrete recyclate from company Dufonev R.C., a.s. was selected as another suitable material (see Figure 4). Recycled concrete has the best physical and mechanical properties in the current state of research and is described in detail below.

The possibility of using asphalt recyclate (see Figure 5) is also currently being investigated. Its use alone in base layers seems rather inappropriate and

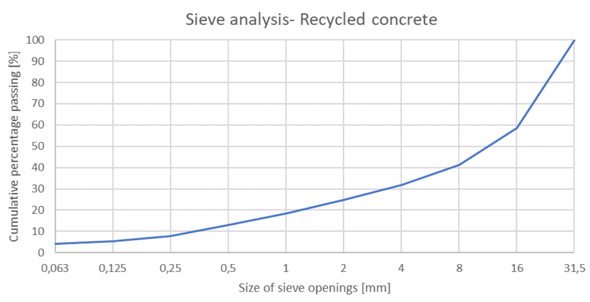

Figure 6. Sieve analysis for concrete recyclate.

Figure 7. Apparatus for the Proctor compaction test.

it is being tested to increase its load-bearing capacity by mixing it with other materials.

7. Recycled concrete

The following tests were carried out on concrete recyclate from Dufonev R.C., a.s.:

- grain size determination (according to Czech State Standard ČSN EN 933-1 [8]);
- determination of moisture content and maximum bulk density (according to Czech State Standard ČSN EN 13286-2 [9]);
- determination of Immediate bearing index (IBI) and California bearing ratio (CBR) (according to Czech State Standard ČSN EN 13286-47 [10]);

Figure 8. Modified Proctor compaction test.

- plate load test (according to Instruction SŽ S4 Železniční spodek [1]).

7.1. Sieve analysis

The sieve analysis confirmed the declared fraction of 0/32 concrete recyclate, showing that it has a continuous grain line and a content of fine particles only 3.2 %, see Figure 6.

7.2. Determination of moisture content and maximum bulk density

Considering the grain size of the samples and the subsequent CBR (IBI) test, the Modified Proctor compaction test was chosen as a suitable option for determining the optimum moisture. Specifically, a test type with a 4.5 kg hammer and a 150 mm wide Proctor mould was chosen (see Figure 7 and Figure 8).

The optimum moisture content, i.e. the moisture content at which the mixture of concrete recyclate and water reaches its highest bulk density, was determined to be 13 % (see Figure 9). This relatively high value is due to the natural water absorption of the concrete.

7.3. Determination of Immediate bearing index (IBI) and California bearing ratio (CBR)

Subsequently, the IBI and CBR tests were performed: the mixture of concrete recyclate and water was mixed to the optimum moisture content, the mixture was

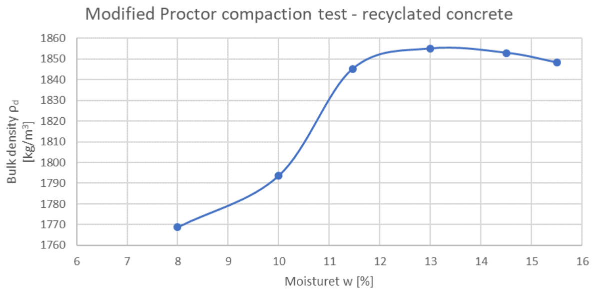

Figure 9. Determination of optimum moisture (recycled concrete).

Figure 10. The IBI test.

Figure 11. The CBR test.

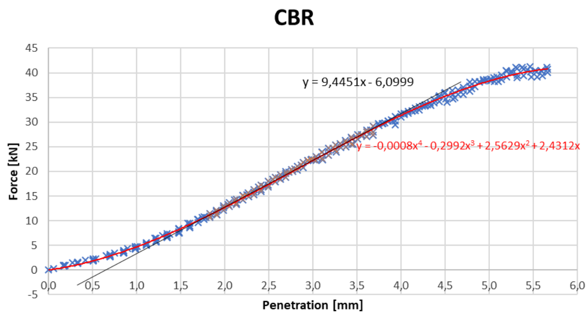

Figure 12. CBR test for concrete recyclate.

compacted in a Proctor mould using the same procedure used to determine the optimum moisture content, and then the IBI test was performed (see Figure 10). After the IBI test, the compacted body was turned bottom side up and placed under water for 96 hours to mature. The CBR test was then performed (see Figure 11).

In the IBI and CBR tests, a cylinder of prescribed dimensions is pressed into the test body. The dependence of force and penetration of the cylinder is recorded. The force required for 2.5 mm and 5 mm penetration is compared to the Standard force. In addition, if the force-displacement curve is concave in the beginning, the value of the initial penetration against which the standard force is compared is corrected (see Figure 12 and Table 2).

The CBR (IBI) value is defined as the higher of the two penetration values, rounded to the nearest 5 % for values greater than 29 %. By the procedure described above, the Immediate bearing index (IBI) was determined, which was 105 %, and the California Bearing Ratio (CBR) after the mature period, which was even 205 %. These high values confirm that recycled concrete is a suitable alternative in terms of load-bearing capacity for use in substructure.

7.4. Static plate load test in a test stand

The static plate load test in the test stand was carried out in the laboratories of the Faculty of Civil Engineering, Department of Railway Structures, Czech

Penetration [mm]	Revised penetration [mm]	Force [kN]	Standard force [kN]	CBR [%]
2.5	3.1	23.62	13.2	180
5.0	5.6	40.76	20.0	205

Table 2. Determination of the CBR value.

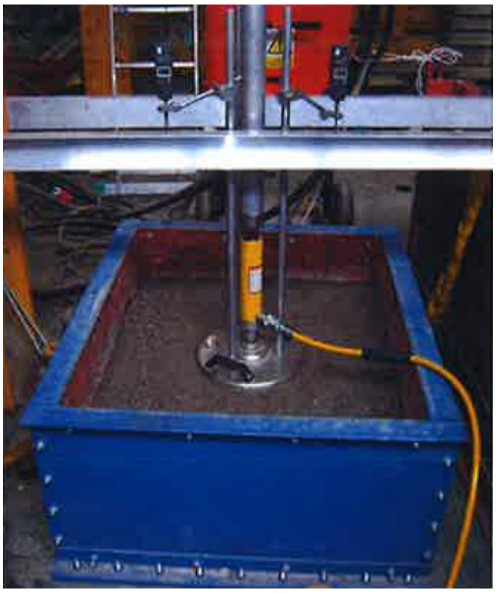

Figure 13. Static plate load test in the test stand (author CTU in Prague).

Technical University in Prague. The static plate load test was carried out in a small box with internal dimensions 790×900×460 mm, 3 compacted layers of recycled concrete were placed in the test stand. The test was made according to SŽ S4 Railway substructure with a load plate with a diameter of 0.3 m, see Figure 13.

The test results are clearly shown in the Table 3.

The high values of the static deformation modulus confirm suitable properties for use in the layers of the substructure in terms of load-bearing capacity.

Settlement in 1. loading cycle	y_1 [mm]	1.23
Static deformation modulus of 1. loading cycle	E_1 [MPa]	36.5
Settlement in 2. loading cycle	y_2 [mm]	0.46
Static deformation modulus of 2. loading cycle	E_2 [MPa]	97.1
Ratio of static deformation modulus	E_2/E_1	2.66

Table 3. Results of the static plate load test in the test stand.

8. Conclusion

Tests carried out on waste from ballast cleaning show a large variance of results according to the location and origin of the contamination of the ballast bed. For this reason the use of this material appears to be rather problematic.

The most perspective material at present is recycled concrete, which shows very high load-bearing capacity values in laboratory conditions. To verify other properties, we prepare test sections with recycled concrete in the capping or sub ballast layer.

Acknowledgements

This article was written with the support of the Ministry of Industry and Trade within the TRIO programme, project Advanced technologies for installation and restoration of the protective layers of railway substructure with the efficient use of secondary raw materials, number FV40081.

References

[1] Správa železnic, s.o. Instruction SŽ S4: Železniční spodek. Prague, 2021.

[2] Správa železnic, s.o. Instruction TKP: Technické kvalitativní podmínky staveb státních drah: Kapitola 6, Konstrukční vrstvy tělesa železničního spodku. Prague, 2008.

[3] Czech statistical office. Waste generation by NACE sections. [2022-06-01], `https://www.czso.cz/documents/10180/143330119/2800202101.pdf`.

[4] Třídění odpadu CZ. Stavební a demoliční odpady. [2022-06-02], `https://www.trideniodpadu.cz/stavebni-odpad`.

[5] Asociace pro rozvoj recyklace stavebních materiálů v České republice. Podstata recyklace stavebních odpadů. [2022-05-29], `https://www.trideniodpadu.cz/stavebni-odpad`.

[6] M. Luňáček. Pokročilé technologie zřízení a obnovy konstrukčních vrstev tělesa železničního spodku s efektivním využitím materiálů z druhotných surovin. Roční zpráva o řešení projektu v programu TRIO v roce 2021: Evidenční číslo projektu FV40081, Brno, 2021.

[7] M. Luňáček. Pokročilé technologie zřízení a obnovy konstrukčních vrstev tělesa železničního spodku s efektivním využitím materiálů z druhotných surovin. Roční zpráva o řešení projektu v programu TRIO v roce 2020: Evidenční číslo projektu FV40081, Brno, 2020.

[8] Úřad pro technickou normalizaci, metrologii a státní zkušebnictví. ČSN EN 933-1. Zkoušení geometrických vlastností kameniva – Část 1: Stanovení zrnitosti – Sítový rozbor. Prague, 2012.

[9] Úřad pro technickou normalizaci, metrologii a státní zkušebnictví. ČSN EN 13286-2. Nestmelené směsi a směsi stmelené hydraulickými pojivy – Část 2: Zkušební metody pro stanovení laboratorní srovnávací hmotnosti a vlhkosti – Proctorova zkouška. Prague, 2011.

[10] Úřad pro technickou normalizaci, metrologii a státní zkušebnictví. ČSN EN 13286-47. Nestmelené směsi a směsi stmelené hydraulickými pojivy – Část 47: Zkušební metoda pro stanovení kalifornského poměru únosnosti, okamžitého indexu únosnosti a lineárního bobtnání. Prague, 2012.