

# Design of Road Pavement Using Recycled Aggregate

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**Abstract.** The presented article gives special attention to codified clauses of the road construction law, the relevant clauses of the standards and technical regulations to design and control the quality of recycled aggregate constructions. The article also presents the authors' suggestions to design of earth constructions and pavements of roads according to the Slovak technical standards, technical regulations and objectively determined results of research and development of road infrastructure. The article presents a comparison of the mechanical characteristics measurements of the structural layers of road pavements built from the recycled and natural aggregate. It also presents correlation functions of results obtained from in situ and in laboratory CBR (Californian Bearing Ratio) measuring, representing the world's most widely used control method of bearing capacity of mentioned construction layers.

## 1. Introduction

In evaluation the quality of an engineering construction in civil engineering, similarly as in other types of constructions, it is necessary to apply a systemic approach. The quality in previous international standard ISO 8402 was defined as the sum of characteristics of the product or service that reflect their ability to meet the stated and implied needs of the customers. The product or the construction product of a building process is the engineering construction representative the highly expensive product from a majority of the range of works. The standard EN ISO 9000 [1] defines a quality as the degree to which a set of inherent characteristics fulfils requirements.

Pavement roads required to be designed, built, maintained and disposed of at a reasonable price, reasonable quality, respecting the relevant requirements of users and their surrounding residents, and the principles of sustainable development during life cycle. Therefore, it is important to provide compliance between the values of the relevant characteristics used within the design and the subsequent quality control of the earth construction and unstabilized layers of engineering structures [2].

## 2. Recycled materials

Recycled materials according to STN 73 6133 [3] from engineering, industrial and transport structures to be used in construction must not contain undesirable organic substances and substances which in contact with water and climatic influences vary excessively in volume, strength and shape, and/or chemical changes occur (wood, gypsum, masonry unit and plaster, metal waste, etc.). Recycled material used for the earth construction, application of unbound and bound layers must meet the requirements



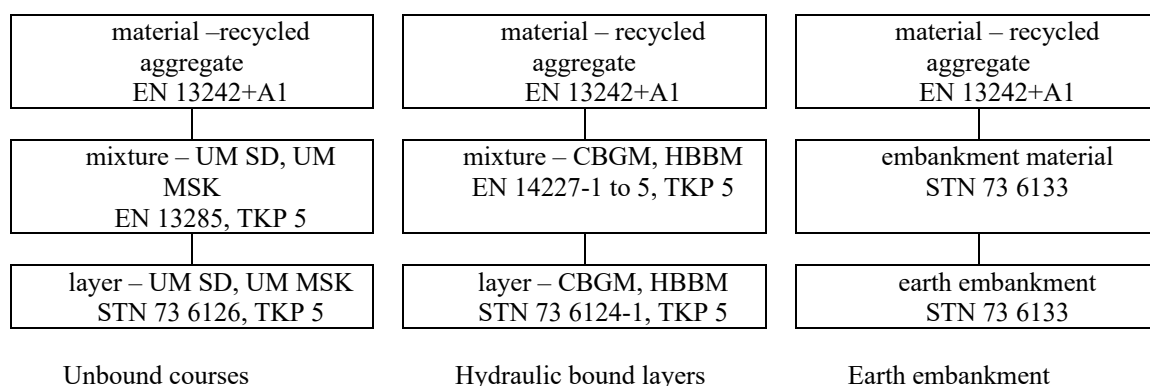
specified in EN 13242+A1 [4]. The standard defines recycled aggregates as the aggregate resulting from the processing of inorganic or mineral material previously used in the construction. If the requirements in [4] are satisfied the recycled aggregates can be used in the same way as natural aggregate.

The tests given in [4] are divided into three groups to test the geometrical, physical and chemical properties. Properties of the recycled aggregate are influenced mainly by its composition and own processing, which takes place on the recycling line.

A manufacturer of the recycled aggregate shall document the basic information as an input control by defining the type of material, description of source, provider or transporter. It is necessary to identify and establish the proportions of the constituent materials in all-in recycled aggregates in classifications:

- concrete, concrete product, mortar, concrete masonry units,
- unbound aggregate, natural stone, hydraulic bound aggregate,
- clay masonry unit, calcium silicate masonry units, aerated non-floating concrete,
- bituminous materials,
- glass,
- floating material,
- other material (clay and soil, metals, wood, plastic and rubber).

The recycled aggregates, as well as natural stone aggregates, have to meet the geometrical, physical and chemical characteristics, and the portion of the constituents in the material and the water-soluble sulphates content have to be determined. Legislation abroad reduces some requirements on properties of the recycled aggregate compared to the natural aggregate (e.g. water absorption). In the design of road embankment from recycled materials, in addition to the climatic conditions of water and temperature flow, the specific characteristics of these materials and construction processes shall be considered to avoid segregation or voids and consequent excessive earth consolidation [3].



**Figure 1.** Regulations for using recycled aggregate in construction layers and subgrade.

Recycled aggregates can be used in the construction of unbound and bound layers of road pavements. Quality control of the recycled mixture without a binder and requirements specification are based on the current European standards for unbound mixtures according to EN 13285 [5] and national requirements defined in [6]. Designed mixture depending on the construction layer and the traffic loading must meet criteria on grading, the proportion of oversize aggregate, fines content and bearing capacity at optimal moisture (index IBI).

### 3. Laboratory test of the bearing capacity ratio of the recycled aggregate

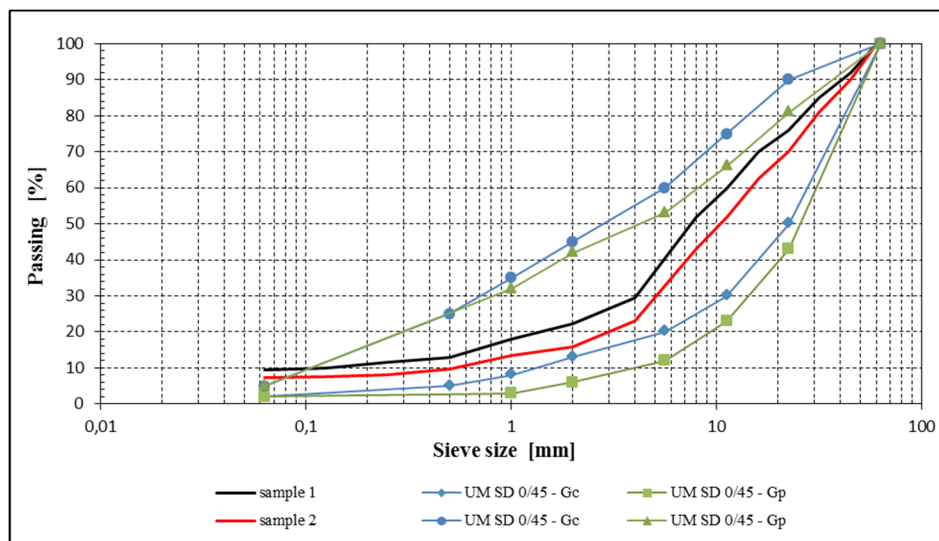
The view of the layer of asphalt pavement built from recycled aggregate is presented in Figure 2. Within the frame of possibilities of waste recovery in earth subgrade of engineering construction, laboratory testing of the quality of the recycled aggregate was performed. Presently in Slovakia, there is a lack of relevant regulations that would define the essential characteristics of the recycled material according to end uses, or that would recommend the application of recycled aggregate according to its source into

subgrade and construction layers of roads. Also the control quality tests of mixtures and layers being built are not defined.



**Figure 2.** Views of the construction layer built from recycled aggregate and the sample of recycled aggregate

Fig. 3 shows the grading curve of two samples of recycled aggregate and grading limits for unbound mixtures UM SD 0/45. The grading of the unbound mixture UM SD for use into sub-base and base courses and protective layer must conform to the requirement of grading category G<sub>C</sub> (for high traffic load roads) or grading category G<sub>P</sub> (for middle and low traffic load roads).



**Figure 3.** Grading curve of recycled aggregate

For the two samples from construction layers of pavement built from recycled aggregates (Fig. 2), the CBR tests were performed according to [7] with graphic findings displayed in Fig. 4 and Fig. 5.

The value of CBR is determined according to equation (1), the forces  $F$  at a penetration of 2.5 mm and 5.0 mm specified from adjusted curve (Fig. 4 and Fig. 5), divided by standard forces  $F_s$  13.2 kN and 20.0 kN and multiplied by 100 quantify the value of CBR in %:

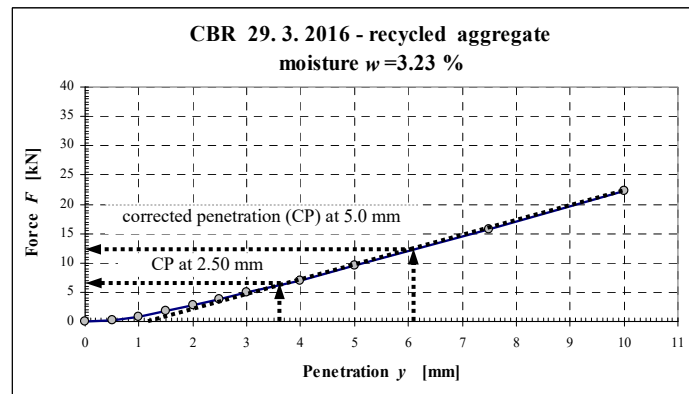
$$CBR = \frac{F}{F_s} \times 100 \quad (1)$$

California Bearing Ratio (CBR) is usually the ratio appertaining to penetration of 2.5 mm. If the bearing capacity ratio at penetration 5.0 mm is greater than ratio at a penetration of 2.5 mm, the test must be repeated. When repeating the test, the ratio at penetration 5.0 mm is greater, this ratio is

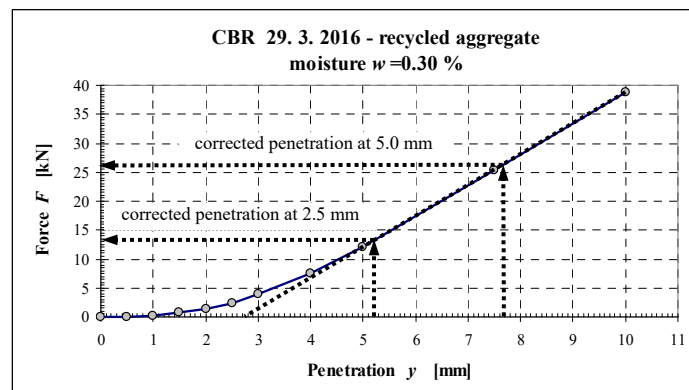
considered as the test result, and the resulting value is the average of two determinations rounded according to Table 1.

**Table 1.** The rules of resulting values of CBR rounding

Range of CBR values	< 30	30 to 100	>100
Rounding off to nearest value	1 %	5 %	10 %



**Figure 4.** Graphic solution of CBR test according to [7] – sample 1.



**Figure 5.** Graphic solution of CBR test according to [7] – sample 2.

Following values have been evaluated for repeated CBR tests:

- moisture 3.23 %:

$$CBR_{2.5mm} = \frac{F}{F_s} \times 100 = \frac{6.0}{13.2} \times 100 \doteq 45\% \quad (2)$$

$$CBR_{5.0mm} = \frac{F}{F_s} \times 100 = \frac{12.0}{20.0} \times 100 \doteq 60\% \quad (3)$$

- moisture 0.30 %:

$$CBR_{2.5mm} = \frac{F}{F_s} \times 100 = \frac{13.5}{13.2} \times 100 \doteq 100\% \quad (4)$$

$$CBR_{5.0mm} = \frac{F}{F_s} \times 100 = \frac{27.0}{20.0} \times 100 \doteq 130\% \quad (5)$$

#### 4. In situ CBR tests

One possibility for in situ measurements of CBR is to use the Clegg Impact Soil Tester. Clegg Impact Soil Tester model CIST/882 (Fig. 6) is a device for a simple method for measuring the quality of structure, properties of surface and underlying layers, while it allows controlling earthworks and ensures uniform compaction of large areas.



**Figure 6.** Testing the degree of compaction of earth plane by Clegg Impact Soil Tester with indicating the CIV reading

Apparatus for measuring compaction can also be used to detect insufficiently compacted locations. The device (Fig. 6) consists of:

- falling hammer with in-built compaction sensor,
- guiding cylinder with integrated base plate and auxiliary handle,
- measuring instrument with digital display and connecting cable.

These parts can be easily assembled as a lightweight handset. Special compaction hammer weighing 4.5 kg moves in a vertical guiding roller. After releasing the hammer from a height, it falls in the cylinder and drops onto the surface of the base plate. The breaking rate is determined by a force dependent on compaction of the material at the location of compaction. Precision accelerometer signal which records the maximum reduction of the speed of hammer, situated in a falling hammer is transmitted through the connecting cable to the digital display. The value obtained after the fourth fall of the hammer is recorded as the value of compaction of tested material - see Fig. 6 (019 IV 4). The first three figures represent the value of compaction **CIV (Clegg Impact Value)**. The letters IV stand for Impact Value; last number represents the number of falls of hammer since switching on the device. Based on this information, the degree of compaction in the form of CBR value can be evaluated. The fourth value of compaction is possible to convert according to the manual of the device to CBR equivalent using the following equation:

$$CBR_{Clegg} = (0.24 \times CIV + 1)^2 \quad (6)$$

where  $CBR_{Clegg}$  is CBR value according to Clegg [%]. In the assessed case applies the following:

$$CBR_{Clegg} = (0.24 \times CIV + 1)^2 = (0.24 \times 19 + 1)^2 \quad CBR_{Clegg} \doteq 31\% \quad (7)$$

This device provides almost immediately the results for the degree of compaction of assessed soil, thus removes the greatest disadvantage of other methods to control the quality of compaction (determination of bulk density, static load tests, geodetic control method). Operating the device is very simple and it is easy to carry.

As a part of research activities, the following values CBR and CIV were founded for:

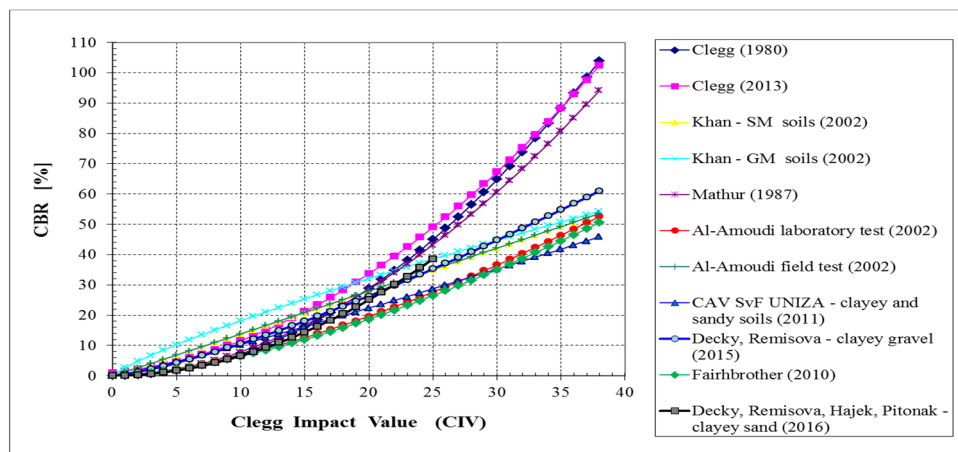
- clayey gravel

$$CBR_{STN721016} = 0.52 \times CIV^{1.31} \quad (8)$$

- clayey sand

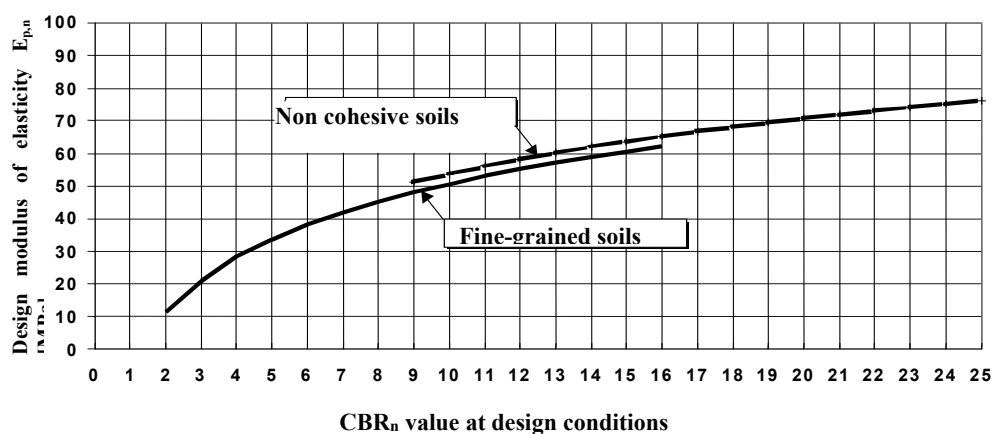
$$CBR_{STN721016} = 0.0773 \times CIV^{1.93} \quad (9)$$

Figure 7 presents a comparison of the objectified transformation of CIV to CBR values from authors measuring [8, 9] with the findings of foreign authors.



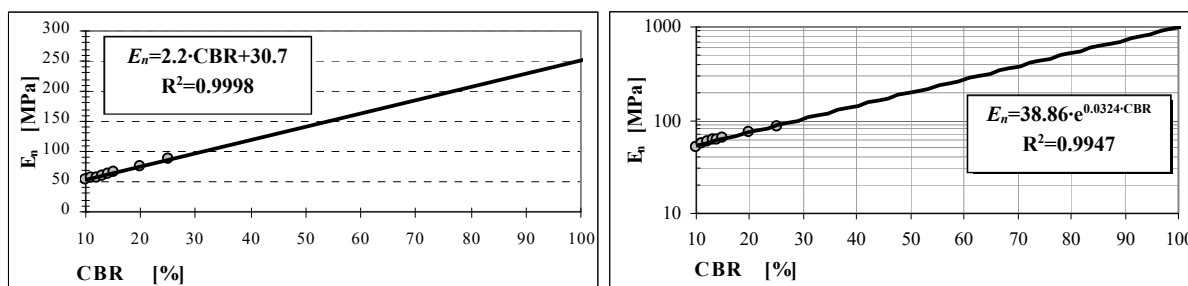
**Figure 7.** Correlation dependence of the CBR on the CIV value

In Slovakia the design procedure of asphalt pavements of roads is codified in regulation [10]. In this relevant rule, which is also applicable to the dimensioning of roads using construction layers of recycled aggregate, the dependence of the elastic modulus of the soil on CBR values was determined in Fig. 8.



**Figure 8.** Dependence of the elastic modulus of the soil on the CBR values according to [10]

Presented figure and dependence do not consider the design values of elastic modulus of soils with higher CBR values. Calculated extrapolations of graphic dependence of  $E_n$  on the CBR (Fig. 8) to the CBR value of 100% are shown in Fig. 9.



**Figure 9.** Linear and exponential extrapolation of dependence of  $E_n$  on the CBR for non-cohesive soil, [11]

According to the supplement [12], the design elastic modulus of the subsoil is determined according to the Table 2, with intermediate values determination by linear interpolation. Extrapolation of CBR values greater than 50% from the table is not possible.

**Table 2.** Determination of the design elastic modulus for the subsoil of the CBR = 15-50% [12]

CBR	Design elasticity modulus $E_d$ [MPa]	The coefficient of transverse deformation
15 %	50	0.40
30 %	80	0.35
50 %	120	0.30

## 5. Conclusions

At present, Slovakia lacks a relevant regulation that would define the essential characteristics of the recycled material according to end uses, or that would recommend to use of recycled aggregates according to their source into the subgrade and construction layers of roads. Also the control tests of mixtures and layers built from them are not defined.

The authors of the paper present the possibility of quality control of engineering construction layers of recycled aggregate by CBR test, especially in the case of roads, and also specify problems in the design of roads using recycled aggregates. Due to the absence of separate design values of mechanical properties of construction layers of recycled aggregates, their use directly in the construction of the road is very difficult and it requires a range of time-consuming in laboratory tests.

## Acknowledgement(s)

The research is supported by the European Regional Development Fund and the Slovak state budget for the project “Research Centre of University of Žilina”, ITMS 26220220183.

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