# QUALITY CONTROL OF EARTH CONSTRUCTION FROM ENVIRONMENTAL PROGRESSIVE MATERIALS

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The article gives special attention to codified clauses of the road construction law, the relevant clauses of standards and technical regulations to design and control the quality of earth constructions built from alternative recycled material. It is important to provide compliance between the values of relevant characteristics used within the design procedure and the subsequent quality control of earth construction and unstabilized layers of roads. The article presents the authors' suggestions to design of earth constructions of roads according to the Slovak technical standards, technical regulations and objectively determined results of research and development. Article also presents a comparison of the mechanical characteristics measurements of earth subgrade built from the recycled, slag and natural aggregate. The correlation dependence of design elastic modulus on CBR values obtained from in laboratory CBR measuring, representing the world's most widely used control method of bearing capacity of subgrade and construction layers are presented.

**KEYWORDS**

Earth construction, environment, alternative material, Californian Bearing Ratio, ferro silico manganese slag, recycled aggregate

## 1 INTRODUCTION

In evaluating the quality of 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 building process is engineering construction, representing by a majority of the range of works the highly expensive product. The standard [EN ISO 9000 2016] defined 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 reasonable price, reasonable quality, respecting the relevant requirements of users and their surrounding residents, and the principles of sustainable development during life cycle [Decky 2013]. 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 built from standard and alternative materials.

## 2 ENVIRONMENTAL PROGRESSIVE MATERIALS

The growing interest in the use of alternative materials within the area of engineering construction is derived from the tendency to conserve natural material resources as well as to reduce landfill volumes. Recycled materials (recovery of material and its use again as raw material for products that may or may not be similar to the original product), by-products (material obtained during production of another material) or waste can be used as an alternative material. Different practices (regulation, technical guidelines for engineering and environmental properties assessment and implementation into structures) exist among European countries regarding their way to handle alternative materials [Francois 2005].

An assessment of alternative materials associated with their use for engineering construction should enquire conditions related to their implementation, recommended application considering engineering properties and environmental effects. The following products can be used as alternative materials:

- *road by-product*: reclaimed asphalt pavement, reclaimed concrete pavement, reclaimed base and subbase material, mixed material,
- *by-product from the metallurgical industry*: blast furnace slag, air cooled, blast furnace slag, ground granulated, steel slag, non-ferrous slag, foundry sand,
- *by-product from other industries*: coal fly ash, coal bottom ash, mine waste rock, municipal solid waste incinerator bottom ash, scrap tyres, waste glass, building demolition materials.

OFZ a.s. as manufacturer of ferroalloys in Central Europe offers modified slag to use as aggregate. The following by-products are an example of slag use documented without negatively effect on environment:

*Grasimat* (granulometrically modified slag) is bulk material - stone aggregates of a light green colour being produced by ferrosilicomanganese slag granulation and mainly consisting of silicon, calcium, aluminium, magnesium and manganese oxides. Grasimat (Fig. 1) is bulk inert material (with density 2 900 kg.m$^{-3}$) used for underground applications such as placing and packing of non-metalic sewage, water and other pipelines, as a background material for ground cable wirings, and it is also used for winter road maintenance. Compaction is min 90 % at moisture 22.5 – 25.5 %.

*Simat* stone aggregate in the form of crushed gravel is manufactured through crushing and screening of silicomanganese slag which solidifies and is cooled down by forced cooling in layers. Simat (Fig. 2, Fig. 3) is used for foundation, protective, and drainage layers, local roads, ground completion, barriers, and for surface hardening.

**Figure 1.** Grasimat - construction product of OFZ a.s

**Figure 2.** Simat 0/16 mm, Simat 16/32 mm, Simat 32/64 mm (archive of OFZ a.s)

**Figure 3.** Application of Simat 32/64 mm in rehabilitation of landslide road (archive Viliam Hires)

### *2.1 Recycled aggregatwe*

Recycled materials according to [STN 73 6133 2010] from engineering, industrial and transport constructions (Fig. 4) 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 2008]. The standard defines recycled aggregates as aggregate resulting from the processing of inorganic or mineral material previously used in the construction. Meet the requirements in [EN 13242+A1 2008] recycled aggregates can be used in the same way as natural aggregate.

A manufacturer of 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).

As well as natural stones the recycled aggregates have to meet the geometrical, physical and chemical characteristics and be determined the portion of the constituents in the material and the water-soluble sulphates content. Legislation abroad reduces some requirements on properties of recycled aggregate compared to natural aggregate (e.g. water absorption).

In the design of road embankment from recycled materials, in addition to the climatic conditions of a water and temperature flow, the specific characteristics of these materials and construction processes shall be consider to avoid segregation or voids and consequent excessive earth consolidation [STN 73 6133 2010].

## 3 BEARING CAPACITY RATIO TEST OF RECYCLED AGGREGATE

At present, in Slovakia there is lack a relevant regulation that would define the essential characteristics of the recycled material according to end uses, respectively would recommend recycled aggregate using according to source into subgrade and construction layers of roads. It would also define the control quality tests of mixtures and layers being built. Within the frame of possibilities of waste recovery in earth subgrade of engineering construction, the test of the quality of the recycled aggregate were performed in laboratory.

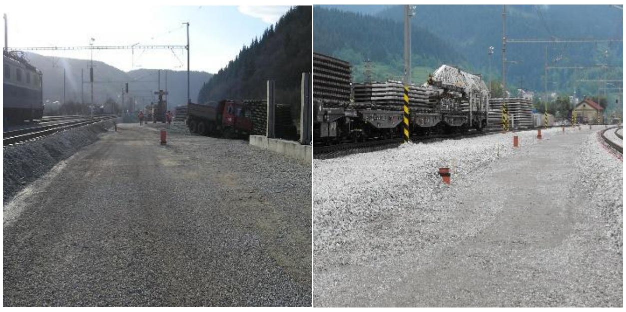

**Figure 4.** Use of recycled aggregates in road and railway construction

Fig. 5 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 course shall conform to the requirement of grading category GC and protective layer the grading category GC (for high traffic load roads) respectively grading category GP (for middle and low traffic load roads).

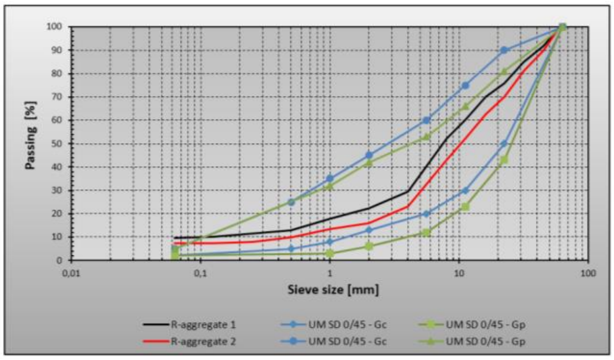


**Figure 5.** Grading curve of recycled aggregate

For the two samples from construction layers of pavement built from recycled aggregates the CBR test were performed according to [STN 72 1016 1992] with graphic findings showed in Fig.6.

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. 6) , divided by standard forces *Fs* 13.2 kN and 20 .0 kN and multiplied by 100 quantify the value of CBR in %:

$$CBR = \frac{F}{F_S} 100 \qquad (1)$$

California Bearing Ratio (CBR) is usually the ratio appertain 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 mmm, 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 CBR rounding

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

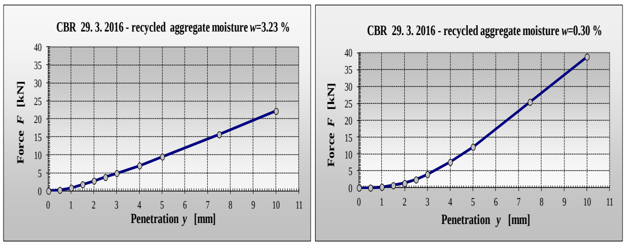


**Figure 6.** Graphic solution of CBR test according to STN 721016 – sample 1 (left), sample 2 (right)

Following values have been evaluated for repeated CBR tests:

- at moisture 3.23 %:

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

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

- at moisture 0.30 % :

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

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

## 4 IN SITU MEASURING OF CBR VALUES

One possibility for in situ measurements of CBR is to use the Clegg Impact Soil Tester [Clegg 2012]. Clegg Impact Soil Tester model CIST/882 (Fig. 7) is a device for simple method to measure the quality of structure, properties of surface and underlying layers, it allows to control earthworks and to ensures uniform compaction of large areas.

**Figure 7.** 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. 7) 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. 7 (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 we can evaluate the degree of compaction in the form of CBR value. This device gives us almost immediately 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 [Decky 2015 a] following value CBR and CIV there were founded for:

- clayey gravel

$$CBR_{STN721016} = 0.52CIV^{1.31} \quad (6)$$

- clayey sand

$$CBR_{STN721016} = 0.0773CIV^{1.93} \quad (7)$$

In Fig. 8 is presented a comparison of the objectified transformation of CIV to CBR values of different materials with the findings of foreign authors [Decky 2015 b, c].

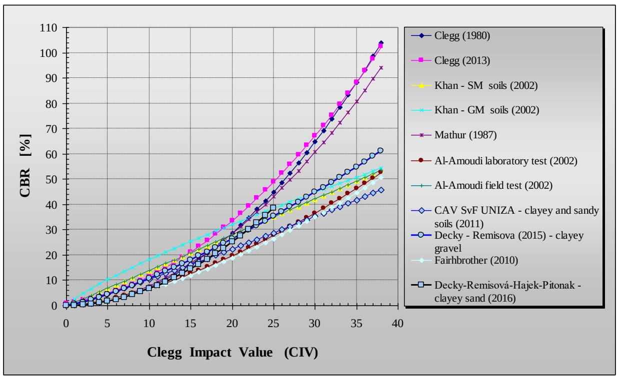


**Figure 8.** Correlation dependence of the CBR on the CIV value

## 5 CONVERSION OF CBR VALUES TO ELASTIC MODULUS

In Slovakia regulation [TP 3/2009] the design procedure of asphalt pavements of roads was codified. In this relevant rule, which is also applicable to the dimensioning of roads using construction layers built from recycled aggregate, it must be known the elastic modulus of objective construction layers and subgrade. The design value of elastic modulus is determined according to dependence of the elastic modulus on CBR values by Fig. 9.

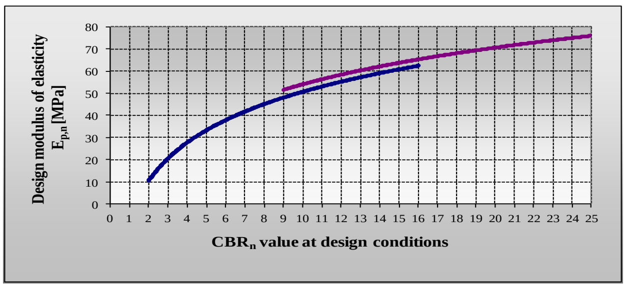


**Figure 9.** Dependence of the elastic modulus of the soil on the CBR values according to [TP 3/2009].

This dependence considers only the CBR values up to 25 %. The extrapolation of graphic dependence of $E_n$ on the CBR for incoherent soils (Fig. 9) up to the CBR value 150 % is shown in Fig. 10. Then the design value of the elasticity modulus of recycled aggregate is 140 MPa at moisture 3.23 % and value of elasticity modulus 260 MPa at moisture 0.30 %.

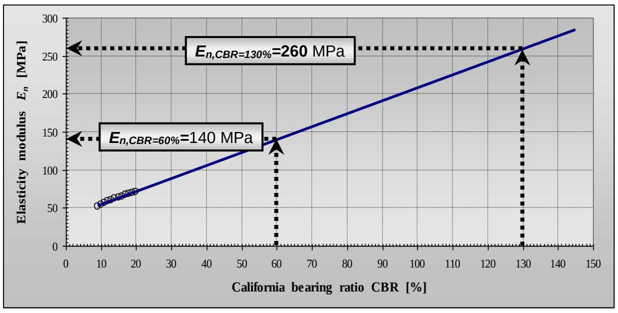


**Figure 10.** Linear extrapolation of dependence of En on the CBR for incoherent soil

According to the Czech supplement [TP 170 2004], the design elastic modulus of the subgrade is determined according to the Tab. 2, with intermediate values being determined by linear interpolation. Extrapolation of values for the CBR > 50 % from the table is not possible.

**Table 2.** Determination of the design elastic modulus for the subsoil of the CBR = 15-50% [TP 170, 2004]

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

## 6 CONCLUSIONS

The growing interest in the use of alternative materials (recycled materials, by-products, waste) within the area of engineering construction is derived from the tendency to conserve natural material resources. At present, our country lacks a relevant regulation that would define the essential characteristics of the recycled material according to end uses, respectively it would recommend to use of recycled aggregates according to their source into the subgrade and construction layers of roads. It would also define the control tests of mixtures and layers built from them.

The paper presents the possibility of quality control of engineering construction layers of recycled aggregate by CBR test and 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 laboratory tests.


## ACKNOWLEDGMENTS

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