Original scientific paper
10.7251/AGRENG1703092Z
UDC: 624.131.1:625

A GEOTECHNICAL ASSESSMENT OF USABILITY OF A ROCK-SOIL MIXTURE FOR EARTH STRUCTURES

Eugeniusz ZAWISZA*, Andrzej GRUCHOT

Department of Hydraulic Engineering and Geotechnics, University of Agriculture in Kraków, Poland
*Corresponding author: kiwig@ur.krakow.pl

ABSTRACT
The subject-matter of the work is a mixture of rock and soil from the Lafarge Dubie mine in Rudawa, southern Poland. The conducted tests aimed at the determination of the geotechnical characteristics of this mixture and the evaluation of its suitability for the construction of earth embankments, in particular road ones. The range of the tests comprised determination of parameters characterising physical properties, such as granulometric composition, natural moisture content, density of solid particles, optimum moisture content and maximum dry density of solid particles, as well as mechanical ones, like shear strength. The obtained results show that the tested mixture is suitable for the construction of road embankments, since as coarse-grained soil, it has a high value of the uniformity coefficient (C_u = 1913). Therefore, this is very well graded soil, which provides a good compaction when it is built into the embankment. The natural moisture content (on average w_n = 9.5%) is close to the optimum one (w_{opt} = 8.5%). The maximum dry density of solid particles (ρ_{ds} = 2.16 g·cm^{-3}) is much higher than the minimum required ($\rho_d \geq$ 1.6 g·cm^{-3}). The values of the angle of internal friction (on average ϕ = 36°) and cohesion (c = 42 kPa) indicate great shear strength, therefore this soil can be subjected to considerable mechanical stresses.

Key words: *earth structures, rock-soil mixture, geotechnical properties, road embankment.*

INTRODUCTION
For the construction of road and railway embankments, it is necessary to obtain massive amounts of earth materials to form embankment bodies and load-bearing structural layers. These materials are mainly taken from native mineral deposits (natural aggregates), and, to a lesser extent, from industrial landfills – coal mining waste, steel slag, coal ash (artificial aggregates) (Kozioł and Kawalec, 2008; Pyssa, 2010; Zawisza, 2001; Zawisza, 2012). According to Kozioł (2017), the natural aggregates constitute the largest group of the extracted minerals and produced from them mineral raw materials. In Poland, in the last 25 years (1991–2015), there was

a nearly 4-fold increase in the aggregate extraction – from about 63 million tonnes per year to 232 million tonnes per year (in 2011 – 333 million tonnes per year). Mostly, there are produced gravel-sand aggregates, which accounts for about 2/3 of the production. They are mainly used in civil engineering for the production of various concretes and concrete products, as well as in other sectors such as power industry, mining, agriculture and road engineering. The possibilities of using the aggregates or, in general, materials from natural mineral deposits for various applications depend on their physical and mechanical properties. In the case of using them for the construction of traffic embankments, mainly roads, it is necessary to determine their geotechnical characteristics. The paper presents the results of investigations of the geotechnical properties of the selected rock-soil mixture and evaluation of its suitability for the construction of road embankments.

MATERIALS AND METHODS

The rock-soil mixture from the Lafarge Dubie mine in Rudawa, southern Poland, was the subject-matter of the study. The tested material was delivered to the geotechnical laboratory of the Department of Hydraulic Engineering and Geotechnics UR in Krakow in two batches. The scope of the study included determination of parameters characterising the physical properties, i.e. granulometric composition, natural moisture content, density of solid particles, as well as the mechanical ones, i.e. shear strength. Due to the coarse nature of the material, the tests were performed using a medium-sized apparatus for determining compactibility and shear strength. In these cases, fractions of thicknesses greater than 63 mm were screened to meet the condition required for coarse-grained soil in accordance with the formula (Pisarczyk, 2004):

$$\frac{D}{d_{\max}} \geq (4 \div 6)$$

where:
D – side or diameter of the sample,
d_{max} – diameter of the maximum grain.

It should be emphasized that according to Pisarczyk (1977) the parameters determined for the material finer than 60 mm do not differ from the parameters specified for the soil of the full granulation by more than 1–2%, hence the results obtained can be considered representative for the whole material. The granulometric composition was determined by a combined method, i.e. sieve and areometric analyses. Part of the sieve analysis on the samples weighing several dozen kilograms was made dry with manual cleaning thick crumbs from fine fractions, and then the sieve analysis with washing with water was performed on fractions finer than 16 mm. For fractions finer than 0.063 mm, the areometric analysis was done. Grain size distribution is a leading property having a significant impact on a number of basic geotechnical parameters of the soil. It was determined for the first batch of the materials and for the material averaged out from both supplied samples. The density of solid particles was determined for the grains finer than 0.063 mm by means of a volumetric flask in distilled water, for the materials as given above. The natural moisture content was determined by a dryer method at 105°C for the materials as described above. The optimum moisture content and the maximum dry density of solid particles were determined in a Proctor medium-sized apparatus with a cylinder volume of 9.8 dm^3 (h = 20 cm, d = 25 cm), on a material averaged out from both batches with a particle size finer than 63 mm, using standard compaction energy E_z = 0.59 $J \cdot cm^{-3}$. The values of the parameters characterising the shear strength, i.e. the angle of internal friction and cohesion were determined in a medium-sized shear apparatus in a box of dimensions of 30 x 30 x 20 cm, with intermediate frames forming a shearing zone 3.0 cm thick, on two samples of the material averaged out from both batches with a particle size less than 63 mm. Using the intermediate frames enables zone shearing, limiting the impact of wedging and intermeshing grains on the value of cohesion (so called apparent cohesion). The tests were performed on the material with the grains finer than 63 mm at the optimum moisture content and the degree of compaction I_S = 0.95.

RESULTS AND DISCUSSION

The values of the geotechnical parameters of the tested material are presented in the Table 1. The granulometric composition of the material provided in the first batch was dominated by coarser fractions – gravel (about 47%) and cobbles (about 25%), a total of over 71%. The finer fraction content was as follows: sand – about 8%, silt – above 17% and clay below 4%. According to the standard PN-EN ISO 14688-2:2006, this material can be classified as a clayey gravel with a large amount of cobbles (Fig. 1). Effective grain sizes were equal: d_{10} – 0.015 mm, d_{60} – 35.0 mm, which gives the uniformity coefficient C_u = 2333.3. It means, that this soil is very well graded (multi-fractional).

Table 1. Basic geotechnical parameters of the rock-soil mixture

Parameter	Value	
	Sample number:	
	1	2
Fraction content [%]: cobbles (> 63 mm) gravel (2–63 mm) sand (0.063–2 mm) silt (0.002–0.063 mm) clay (< 0.002 mm)	 24.6 46.49 7.84 17.48 3.59	 14.03 51.48 14.64 16.5 3.35
Name of the soil acc. to PN-EN ISO 14688-2:2006	clGr+Co	clGr+Co
Uniformity coefficient [–]	2333.3	1913.0
Coefficient of curvature [–]	23.33	3.42
Density of solid particles [$g \cdot cm^{-3}$] (for d < 0.063 mm)	2.75	2.77
Natural moisture content [%]	7.31	10.66
Maximum dry density of solid particles [$g \cdot cm^{-3}$]	2.165	
Optimum moisture content [%]	8.5	
Angle of internal friction [°] at I_S = 0.97	36.5	35.6

Cohesion [kPa] at I_S = 0.97	40.1	43.3

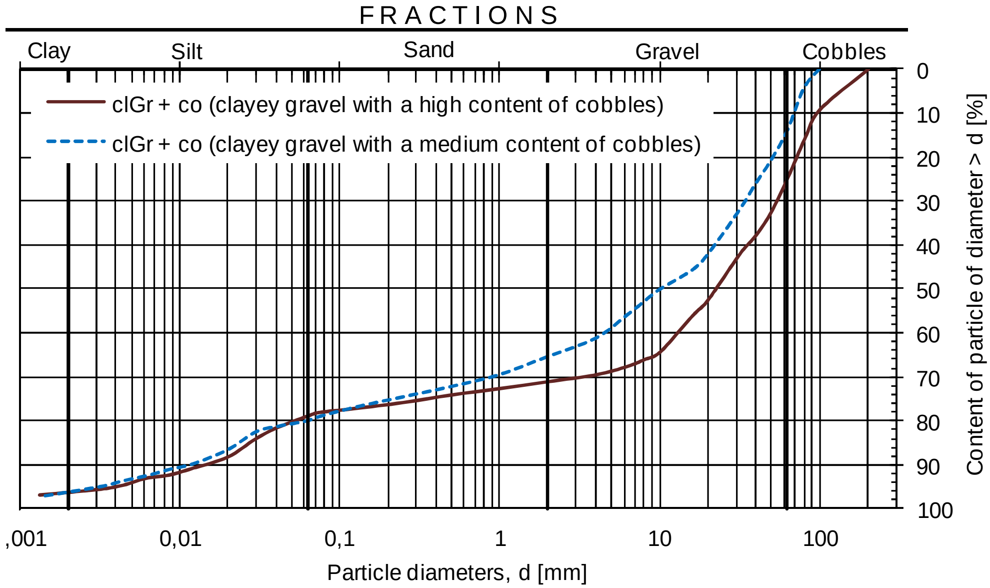

Figure 1. Granulation curve for the rock-soil mixture

In the sample averaged out from both batches of the delivered material, the content of the gravel fraction was over 51%, cobbles over 14% – a total of more than 65%. The content of the sand fraction was about 15%, silt more than 16%, and clay over 3%. This material can also be classified as a very well graded clayey gravel with a medium content of cobbles (Fig. 1), but with a greater content of finer fractions (sand and silt – by about 5%), and smaller content of coarser fractions (gravel and cobbles – by about 6%).

It follows from the above that the studied soil is coarse-grained, clayish, because the dominant fractions are cobbles and gravel (on average about 70%) and the content of clay fraction is slightly higher than 2% (on average 3.5%).

The natural moisture content determined for the sample delivered in the first batch was 7.31%, and in the second – 9.24 and 12.07%. It follows that the moisture content of the tested material was in the range of 7.3 to 12.1%. The differences of the moisture content values occurring in the individual batches of the material result from the different locations of collection points and atmospheric conditions. The average value was 9.5% and was typical for that type of soil.

The density of solid particles, determined for the clay-silt fraction (d < 0.063 mm) on the samples from both batches, was relatively high and equalled 2.75–2.77 $g \cdot cm^{-3}$.

The optimum moisture content and the maximum dry density of solid particles were respectively: w_{opt} = 8.5%, ρ_{ds} = 2.165 $g \cdot cm^{-3}$ (Fig. 2), and these values should be accepted as reliable in earthwork design.

The values of the angle of internal friction and cohesion were equal respectively: sample 1 – ϕ = 36.5°, c = 40.1 kPa; sample 2 – ϕ = 35.6°, c = 43.3 kPa (Fig. 3). The average values of these parameters equalled: ϕ = 36°, c = 42 kPa. These are relatively high values and indicate a great shear strength of the tested materials.

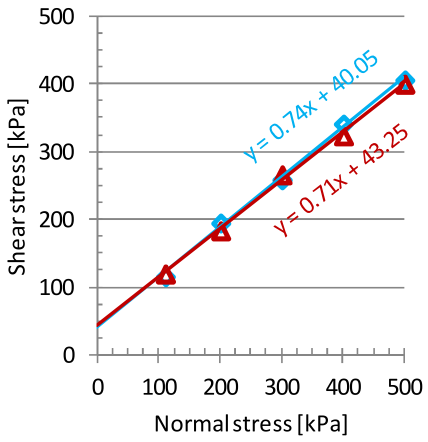

Fig. 2. Shear stress versus normal stress

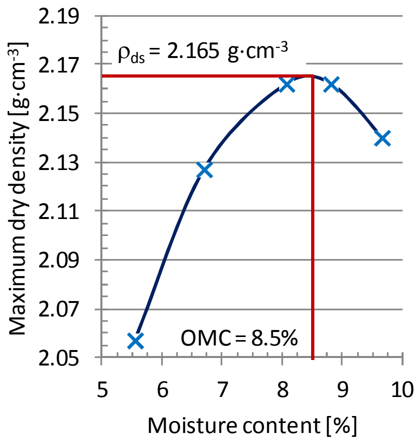

Fig. 3. Maximum dry density versus moisture content

Assessment of the tested soil for erecting road embankments

The usability of the tested rock-soil mixture for the construction of road embankments was determined on the basis of the PN-S-02205:1998 standard, which provide the requirements that should be met by the soil used to make the earth embankments. They relate to the granulation and parameters characterising the frost-heave, compactibility, consistency, organic matter content and bearing capacity. In terms of grain size distribution, the rock-soil mixture corresponds to clayey gravels with the average content of cobbles. The above cited standard describes such soils as usable for bottom layers of embankments below the freezing zone. The standard also allows this type of soil to be used for the top layers of embankments in the ground freezing zone, provided that they are improved with the binder, e.g. cement, lime or active ashes. The values of the individual geotechnical parameters of the tested mixtures and the relevant standard requirements are summarized in the Table 2. The rock-soil mixture meets most of the required criteria.

Based on the results of the study, it can be concluded that the mixture in question is suitable for the construction of road embankments because:

As the coarse-grained soil, it has a high value of the uniformity coefficient (C_u = 2333.3). Thus, it is a very well graded soil (multi-fractional), which forecasts good compactibility of the material when incorporated into the embankment.

Natural moisture content, slightly variable in different batches of the material (on average w_n = 9.5%) is close to the optimum one (w_{opt} = 8.5%), which allows it to be incorporated into the embankment without additional treatment, e.g. drying or wetting. This material has a high value of the maximum dry density of solid particles (ρ_{ds} = 2.165 g·cm^{-3}), which is significantly greater than the minimum required ($\rho_{ds} \geq 1.60$ g·cm^{-3}). The values of the angle of internal friction (ϕ = 36°) and cohesion (c = 42 kPa) indicate great shear strength, therefore, this material can be subjected to considerable mechanical stresses. Hence, we may envisage the appropriate bearing capacity and stability of the embankments formed from this material. However, due to the excessive content of fine particles, the mixture has been classified as questionable in terms of frost heave. Given the above, the rock-soil mixture can be used for lower layers of road embankments below the freezing zone, if built in dry areas or places protected from groundwater and surface water.

Table 2. Values of geotechnical parameters of the rock-soil mixture comparing to the Polish standard requirements for road embankments

Parameter	Standard PN-S-02205:1998 requirements	Rock-soil mixture
Maximum dimension of grains, [mm]	200	lack of grains coarser than 200 mm
Uniformity coefficient, C_u	≥ 3	1913
Maximum dry density of solid particles [g·cm^{-3}]	≥ 1.6	2.165
Content of grains [%]: ≤ 0.075 mm ≤ 0.02 mm	 < 15 < 3	 21.0 13.5
Frost susceptibility group	depending on the group of soils	questionable

CONCLUSION

On the basis of the laboratory tests and analysis of the results, it can be concluded that the rock-soil mixture from the Lafarge Dubie mine in Rudawa is the coarse-grained soil that can be used as a construction material for earth structures. It is characterised by favourable geotechnical parameters. As the multi-fractional soil with the great value of the maximum dry density of solid particles, it has good compactibility. With the high degree of compaction (I_S = 0.95), it has a high shear strength. Therefore, it can be used for the construction of various types of traffic embankments – road, rail and technological ones (access roads) – for the bottom layers of the embankments below the freezing zone. In order to maintain the stability conditions, it is necessary to assure the degree of compaction suitable for the given road class at the proper soil moisture content and inclination of the embankment slope. Due to the variability of the material from different mine exploitation fragments, every time, it is indispensable to determine the geotechnical parameters necessary to assess the usability of the collected soil for the intended application. Test methods for geotechnical parameters should be appropriate for the nature of the soil, which is coarse. Therefore, research should be conducted with the use of medium-sized equipment and the results verified under conditions of construction on experimental embankments, using compacting equipment fitting to the grain size.

REFERENCES

Kozioł W. (2017). W kruszywach rok 2016 gorszy od oczekiwań. (2016 worse than expected for the aggregates industry.) Kruszywa Produkcja Transport Zastosowanie (Aggregates Production Transport Application), 1, 12–17.

Kozioł W., Kawalec P. (2008). Kruszywa alternatywne w budownictwie. (Alternative aggregates in construction.) Nowoczesne budownictwo inżynieryjne (Modern Civil Engineering), 4 (19), 34–37.

Pisarczyk S. (1977). Zagęszczalność gruntów gruboziarnistych i kamienistych. (Compactibility of coarse-grained and cobbled soils.) Warsaw University of Technology, Faculty of Civil Engineering, Institute of Roads and Bridges, pp. 114.

Pisarczyk S. (2004). Grunty nasypowe. Właściwości geotechniczne i metody ich badania. (Made soils. Geotechnical properties and methods of their investigation) Printing House of Warsaw University of Technology, pp. 238.

PN-EN ISO 14688-2:2006. Badania geotechniczne. Oznaczanie i klasyfikacja gruntów. Część 2: Zasady klasyfikowania. (Geotechnical tests. Identification and classification of soils. Part 2: Classification rules.) Polish Committee for Standardization, Warsaw.

PN-S-02205:1998. Drogi samochodowe, roboty ziemne. Wymagania i badania. (Roads, earthworks. Requirements and tests.) Polish Committee for Standardization, Warsaw.

Pyssa J. (2010). Kruszywa w Polsce – zasoby, produkcja oraz kierunki wykorzystania. (Aggregates in Poland – resources, production, and use directions.) Przegląd Górniczy (Mining Review) 5, 38–44.

Zawisza E. (2001). Geotechniczne i środowiskowe aspekty uszczelniania grubookruchowych odpadów powęglowych popiołami lotnymi. (Geotechnical and environmental aspects of sealing of coarse-grained coal mining wastes with fly ashes.) Zeszyty Naukowe AR w Krakowie (Scientific Journal of AR in Kraków) 280, Rozprawy (Dissertations), pp. 178.

Zawisza E. (2012). Odpady hutnicze jako antropogeniczne grunty budowlane. Metody badań i właściwości geotechniczne. (Furnace slag as an anthropogenic building soil. Testing methods and geotechnical properties.) Publishing house of UR in Kraków, pp. 148.