sciendo

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2022; 32 (3): 0116-0132
DOI: 10.2478/ceer-2022-0031
Original Research Article

INVESTIGATIONS OF PROPERTIES OF SOIL-AGGREGATE MIXTURES

Izabela SKRZYPCZAK[1]
Rzeszow University of Technology, Rzeszów, Poland

A b s t r a c t

The subject of this paper is the evaluation of the use of waste material, which is the native soil. On the example of the base ground taken from the village of Lipie (Podkarpackie voivodeship), soil-aggregate mixtures were prepared with a different degree of addition of natural aggregate. The study analysed the quantitative and qualitative parameters of the prepared mixtures and assessed their physical and mechanical properties to determine their suitability for the construction of nfrastructural facilities. It should be noted that most specifications recommend the use of primarily aggregate mixtures. The paper presents the results of a study analysing the effect of aggregate admixture to the native soil on selected physical and strength properties of the mixtures developed. The obtained results confirmed the validity of research on the use of soil-aggregate mixtures for construction purposes.

Keywords: soil-aggregate mixtures, strength parameters, grain-size distribution, optimum moisture

1. INTRODUCTION

With the increase in new construction projects, the demand for optimisation of infrastructure projects has also increased. One of the many infrastructure elements subject to optimisation is road embankments, among others. However,

[1] Corresponding author: Rzeszow University of Technology, Faculty of Civil and Environmental Engineering and Architecture, Powstańców Warszawy av. 12, 35-959 Rzeszów, e-mail: izas@prz.edu.pl, tel.+48178651013.

optimisation should not consist in reducing the quality of the materials used, but in changing the construction technology by implementing and disseminating new design methods through the use of suitable soil mixtures based on native soil instead of classic solutions and graded aggregate mixtures, which seems to be the ideal solution to take cost and sustainability criteria into account. In the case of embankment material, local surplus soil (waste) can be managed by mixing the aggregate with soil waste from earthworks [1-4]. Waste management and reuse is one of the elements to reduce the use of natural resources [5-8]. Efficient waste management is regulated by Directive 2006/12/EC [9]. It refers to the prevention and reduction of waste production, carrying out recycling and reclamation, or the obligation to create infrastructural networks for waste disposal (storage of construction debris and its recycling to obtain a substitute for aggregate). Excavation soil should be considered as waste; and thus the impact of Directive 2008/98/EC [9] is increased in the life cycle of the product, the building and its surroundings.

An important EU initiative related to the Sustainable Development Strategy is the EU Regulation 305/2011 [10] of the European Parliament and of the Council establishing harmonised conditions for the marketing of construction products. According to this regulation, "Construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and ensures recycling of construction works and their materials and parts after demolition, durability of construction works, use of environmentally compatible raw and secondary materials in construction works", of course, while ensuring the appropriate quality of design and construction works [11-13], including measurement works [14,15], at every stage of the construction process. The subject matter of the article undertaken is part of the EU horizontal policy on environmental protection, and the results of the conducted research meet the requirements of EU Regulation No 305/2011 [10].

2. AIM AND SCOPE OF THE STUDY

The study concerns the development of soil mixtures based on native soil and aggregate (sand) admixtures to improve the physical and mechanical properties of the soil medium, especially the strength parameter which is the angle of internal friction. For the purposes of this study, soil mixtures containing admixtures of various fractions in appropriate proportions were prepared and prepared on the basis of non-cohesive native soil in order to assess the influence of granulometric composition on strength parameters. Based on the literature it can be concluded that the value of the angle of internal friction is mainly influenced by the content of individual fractions, different grain size, compaction and moisture [16-19].
The scope of laboratory testing included the following determinations:

- optimum moisture content measured with a Proctor apparatus,
- sieve analysis,
- determination of the angle of internal friction in the direct shear apparatus.

3. LABORATORY TESTS

3.1. Description of the underlying soils and soil mixtures adopted

The native-base soils that were tested and modified come from the Lipie Aggregate Exploitation Plant (Fig. 1). The company deals with the extraction of natural aggregates and the processing and production of construction aggregate, as well as the production of sand.

Fig. 1. Lipie Aggregate Exploitation Plant - ZEK Lipie

For the purpose of the investigations two base - soil samples named and designated as natural deposit sand - native soil (Z) and rinsed sand (P) were taken (Fig. 2). The base soils were tested and analysed in detail for granulometric composition, physical and mechanical parameters. Twelve different mixtures were then prepared, six for each base soil. The mixtures consisted of the base soil with the addition of dried quartz sands in appropriate proportions, obtained from the *Kruszgeo SA* plant (Table 1). The mixtures used sand of fraction 0,4 ÷ 1,2 (described as fine) and sand of fraction 1 ÷ 2 (described as coarse) was used.

a) b)

Fig. 2. Base soils collected to test: a) rinsed sand (P), b) natural deposit sand (Z)

Table 1. Soil mixtures accepted for testing and their symbols

Mixture type		Mixture composition	Symbol
Base soils	rinsed sand (P)	base + 25% coarse sand	PG25
		base + 33% coarse sand	PG33
		base + 50% coarse sand	PG50
		base + 25% fine sand	PD25
		base + 33% fine sand	PD33
		base + 50% fine sand	PD50
	natural deposit sand (Z)	base + 25% coarse sand	ZG25
		base + 33% coarse sand	ZG33
		base + 50% coarse sand	ZG50
		base + 25% fine sand	ZD25
		base + 33% fine sand	ZD33
		base + 50% fine sand	ZD50

3.2. Materials and method

The tests carried out included the determination of basic physical and mechanical parameters of both the base soils and soil-aggregate mixtures made on their basis in accordance with standard recommendations and literature [19-24].

3.2.1. Sieve analysis

Sieve analysis was carried out in accordance with the recommendations of Eurocode 7 [22] for both the base soils and the prepared mixtures. On the basis of the sieve analysis data obtained for each soil sample, graphs of grain-size distribution curves were generated with the *Labor Tech 2 PRO* program. Figures 3, 4 and Tables 2, 3 show examples of the results of sieve analysis carried out for the native soils.

Table 1. Results of sieve analysis for the base soil - rinsed sand (P)

Particle size [mm]	**Retained**		**Cumulative percentage passing [%]**
	[g]	**[%]**	
63.000	0.000	0.000	100.000
20.000	0.000	0.000	100.000
6.300	0.000	0.000	100.000
2.000	20.000	1.333	98.667
0.630	94.000	6.267	92.400
0.200	1304.000	86.933	5.467
0.063	78.000	5.200	0.267
< 0.063	4.000	0.267	0.000
-	**1500.000**	**100.000**	**-**

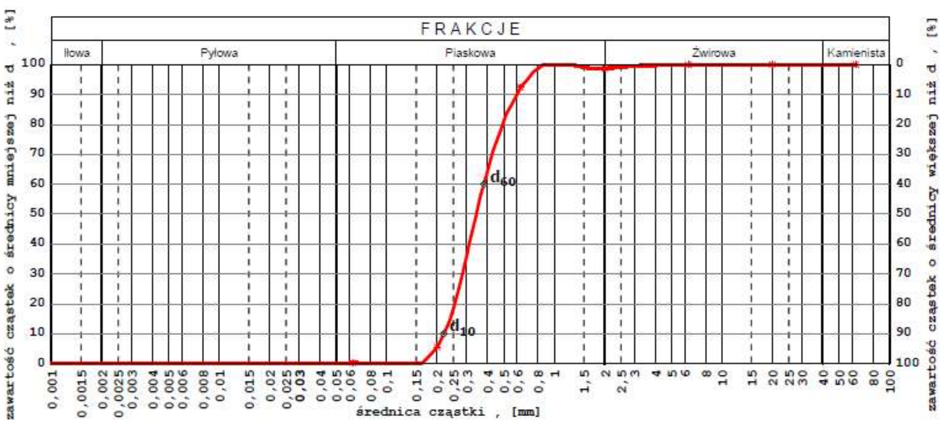


Fig. 3. Graph of grain size distribution curve for base soil - rinsed sand (P)

Table 2. Results of sieve analysis for the base soil - sand from the deposit (Z)

Particle size [mm]	Retained		Cumulative percentage passing [%]
	[g]	[%]	
63.000	0.000	0.000	100.000
20.000	0.000	0.000	100.000
6.300	0.000	0.000	100.000
2.000	90.000	6.000	94.000
0.630	148.000	9.867	84.133
0.200	1062.000	70.800	13.333
0.063	170.000	11.333	2.000
< 0.063	30.000	2.000	0.000
-	**1500.000**	**100.000**	**-**

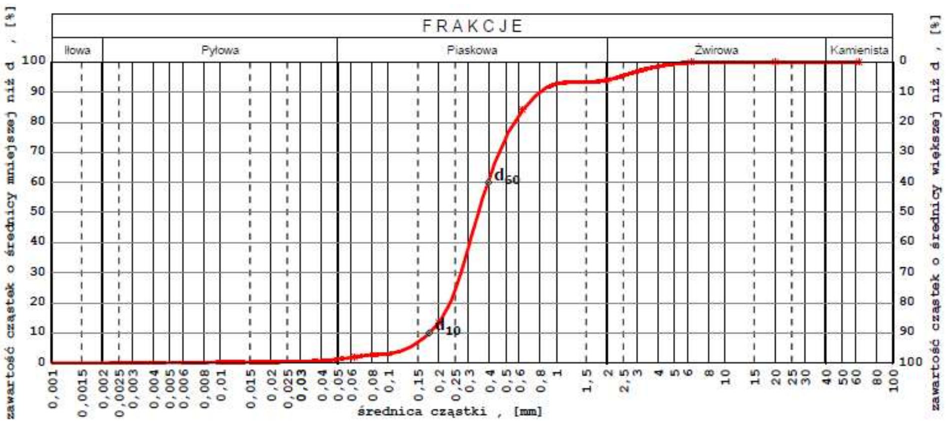


Fig. 4. Graph of grain size curve for the base soil - sand from the deposit (Z)

A summary of the sieve analysis results for the base soils and individual mixtures (group 1 and 2 soils) is given in Tables 4 and 5.

Table 4. Summary of results from sieve analysis test for group 1

Symbol	Fraction content [%]					C_u [-]	C_C [-]	Classification by [15]
	gravel	sand Sa			silt & clay			
		coarse	medium	fine				
P	1.33	6.27	86.93	5.20	0.27	1.74	0.97	fine sand FSa
PG25	1.07	29.47	64.13	5.20	0.13	2.21	0.85	fine sand FSa
PG33	0.80	36.80	56.07	5.33	0.00	2.57	0.78	fine sand FSa
PG50	0.53	53.60	40.53	4.93	0.40	3.44	0.80	coarse sand CSa
PD25	0.93	4.80	88.27	5.73	0.27	1.73	0.97	fine sand FSa
PD33	0.79	3.86	88.27	6.80	0.27	1.74	1.00	fine sand FSa
PD50	0.66	3.07	90.67	5.47	0.13	1.68	0.97	fine sand FSa

Explanations: C_u - coefficient of uniformity; C_C - coefficient of curvature

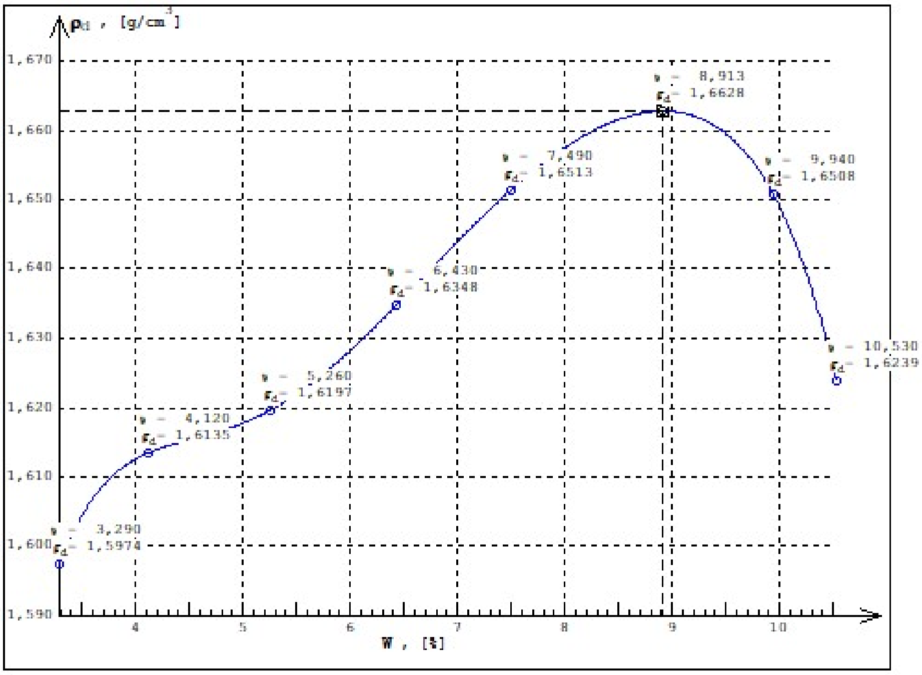
Table 5. Summary of results from sieve analysis test for group 2

Symbol	Fraction content [%]					C_u [-]	C_C [-] [-]	Classification by [15]
	gravel	sand Sa			silt & clay			
		coarse	medium	fine				
Z	6.00	9.87	70.80	11.33	2.00	2.25	1.06	fine sand FSa
ZG25	4.00	29.20	54.53	11.07	1.20	2.89	0.95	fine sand FSa
ZG33	4.67	41.20	43.73	9.20	1.20	3.83	0.78	coarse sand CSa
ZG50	3.73	58.53	29.60	7.33	0.80	4.21	1.11	coarse sand CSa
ZD25	4.79	13.47	70.28	10.40	1.07	2.15	1.00	fine sand FSa
ZD33	4.13	7.20	73.73	13.20	1.73	2.23	1.11	fine sand FSa
ZD50	5.20	9.47	73.73	10.67	0.93	2.08	1.03	fine sand FSa

Explanations: C_u - coefficient of uniformity; C_C - coefficient of curvature

3.2.2. Optimum humidity

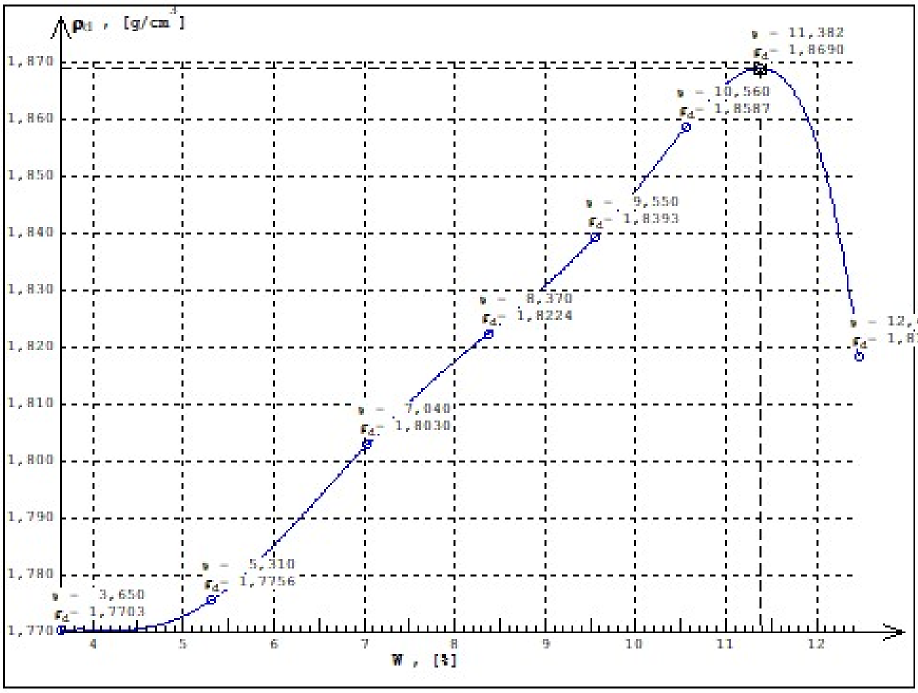
The optimum moisture content was determined only for the base soils, i.e. rinsed sand (P) and natural deposit sand (Z). According to the charts of optimum moisture contents (Fig. 5, 6), the optimum moisture contents W_{opt} for rinsed sand is 8,91 %, whereas the optimum moisture contents W_{opt} for natural deposit sand is 11,38 %.



Wilgotność optymalna	W_{opt}	=	8,913 %
Max. gęstość szkieletu gruntowego	$\rho_{d\ max}$	=	1,6628 g/cm^3
Współczynniki korekcyjne	x	=	1,000
	ρ_s	=	2,650

Niepewność standardowa	$u_{W_{opt}}$ =	± 0,192	$u_{\rho_{d\ max}}$ =	± 0,00354
Niepewność rozszerzona	$U_{W_{opt}}$ =	± 0,384	$U_{\rho_{d\ max}}$ =	± 0,00709

Fig. 5. Optimum moisture content plot generated with Labor Tech 1 PRO for rinsed sand



Wilgotność optymalna	W_{opt}	=	11,382 %
Max. gęstość szkieletu gruntowego	$\rho_{d\,max}$	=	1,8690 g/cm^3
Współczynniki korekcyjne	x	=	1,000
	ρ_s	=	2,650

Niepewność standardowa	$u_{W_{opt}}$	=	± 0,169	$u_{\rho_{d\,max}}$	=	± 0,00358
Niepewność rozszerzona	$U_{W_{opt}}$	=	± 0,338	$U_{\rho_{d\,max}}$	=	± 0,00717

Fig. 6. Optimum moisture content plot generated with Labor Tech 1 PRO for rinsed sand

3.2.3. Strength parameters

Tables 6 and 7 show the results of strength parameters tests carried out for soil mixtures developed from two base soils (group 1 and group 2). On the other hand, Figs. 7 and 8 show examples of normal stress vs. σ_n shear stress τ_f for the base soils: rinsed sand (P) and natural deposit sand (Z).

Table 6. Summary of results for group 1

Summary of the results for group 1			
Symbol	**angle of internal friction**	**cohesion**	**mean standard deviation**
	φ_u [°]	c_u [kPa]	$S\tau_f$ [kPa]
P	32.162	3.699	5.939
PG25	33.201	2.465	2.699
PG33	34.259	1.067	1.941
PG50	35.791	1.662	3.319
PD25	30.970	4.078	3.004
PD33	29.833	5.467	3.510
PD50	29.254	12.743	2.491

Table 7. Summary of results for group 2

Summary of the results for group 2			
Symbol	**angle of internal friction**	**cohesion**	**mean standard deviation**
	φ_u [°]	c_u [kPa]	$S\tau_f$ [kPa]
Z	32.108	5.209	3.947
ZG25	33.187	5.157	2.566
ZG33	34.745	5.753	2.642
ZG50	35.274	2.361	1.797
ZD25	33.175	6.504	4.279
ZD33	33.201	2.465	2.699
ZD50	32.091	1.334	6.239

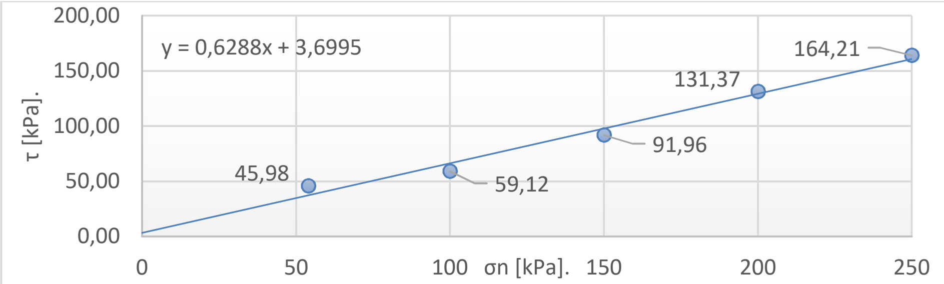


Fig. 7. Plot of normal stress $\boldsymbol{\sigma_n}$ shear stress $\boldsymbol{\tau_f}$ for rinsed sand (P)

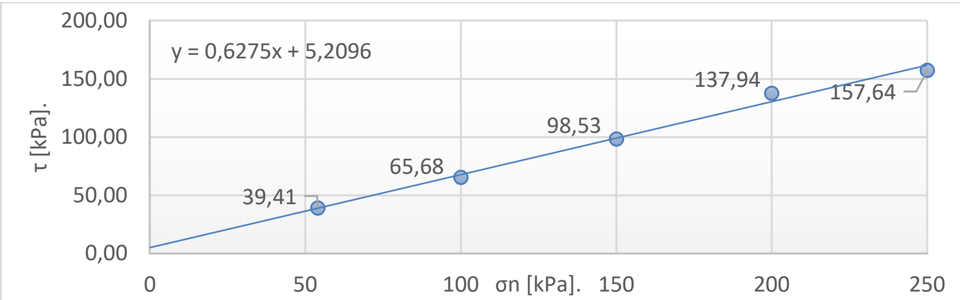


Fig. 8. Plot of normal stress $\boldsymbol{\sigma_n}$ shear stress $\boldsymbol{\tau_f}$ for natural deposit sand (Z)

4. DISCUSSION

Granulometric analysis and strength parameters were carried out for two soil samples which were taken from one testing ground (Lipie Aggregate Exploitation Plant). Twelve mixtures containing 25, 33, 50 % quartz sand of finer and coarser fractions were prepared on the basis of the base soil samples.

Granulometric analysis of soil mixtures as well as base soils was performed using the sieve method in accordance with the recommendations of the PN-EN 1997-1:2009 code [22]. Based on the results obtained, the granulometric composition was determined. Next, using the Labor Tech 2 PRO program, grain-size distribution curves were prepared. The obtained results of the granulometric composition for individual soil mixtures and base soils are presented in Tables 4 and 5.

Subsequently, soil classification was carried out in accordance with PN-EN ISO 14688-2 [21]. The tested soils were mostly fine sands with the exception of mixtures (PG50 and ZG50), which contained 50% coarser quartz sand. The classification shows that the mixtures based on rinsed sand and natural deposit sand are identically classified. The differential grain size index for all soils in both

groups is similar and does not exceed the value of 6, and the curvature index is within the range of 0.78-1.11, so the tested mixtures are monofractured soils.
On the basis of the performed tests, it can be observed that the granulometric composition has a very strong influence on the strength parameters. The angle of internal friction φ_u depends on the value of the different grain size index C_u , as shown in the following diagrams (Figs. 9 and 10); the higher the different grain size index C_u the higher the angle of friction φ_u .

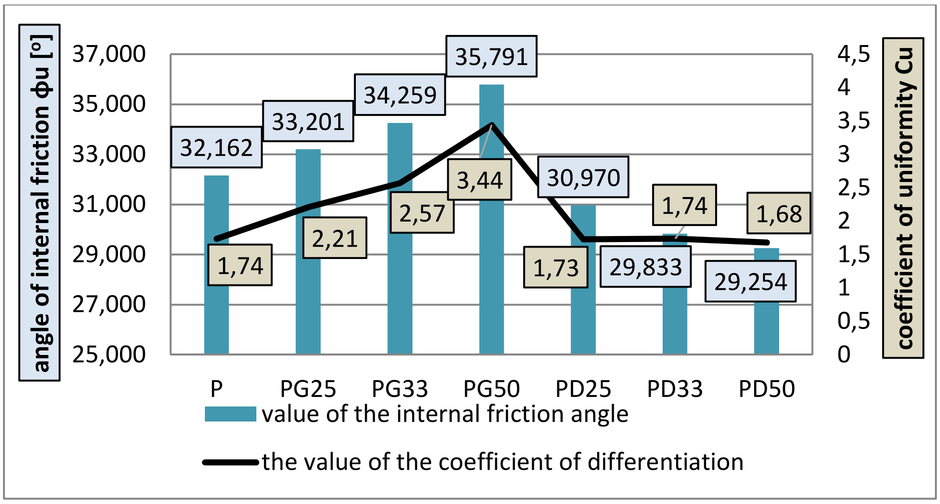


Fig. 9. Dependence of the friction angle on the different grain size index for group 1 of the tested mixtures

On the basis of a comparison of results from granulometric analysis and strength parameters, it can also be concluded that the value of the angle of internal friction is affected by the content of larger fractions such as coarse sand or gravel. The prepared mixtures differ mainly in the content of the gravel fraction. For mixtures in group 1, the gravel content ranged from 0.66 to 1.33 % and for group 2 from 5.20 to 6.00%. Although the total sand fraction content for both groups is similar, for group 1 mixtures it ranges from 98.20 to 99.21% and for group 2 from 92.00 to 95.46%. However, in the sand fraction there are clear differences between the proportion of subfractions. These differences concern the sub-fractions: coarse, medium and fine sand.

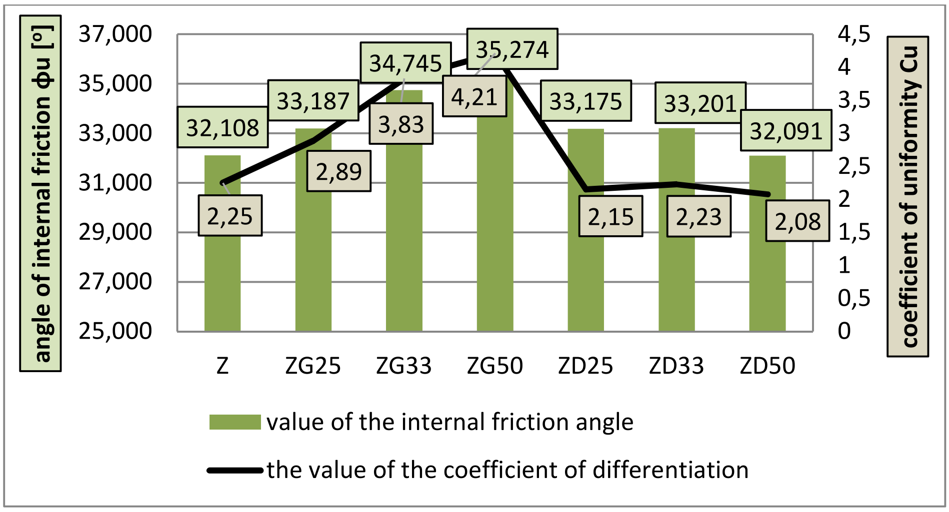


Fig. 10. Dependence of the friction angle on the different grain size index for group 2 of the tested mixtures

The participation of fractions starting with coarse sand determines the obtaining of higher values of the angle of internal friction. This can be observed in mixtures such as PG33, PG50, ZG33 or ZG50, where the coarser grains of the base sample and the coarse quartz sand admixture were dominant (Tables 8 and 9).

Table 8. Comparison of strength parameters and granulometric composition for group 1

Symbol	Strength parameters		Fraction content [%]				
	angle of internal friction	cohesion	gravel	sand			Silt & clay
				coarse	medium	fine	
P	32.162	3.699	1.33	6.27	86.93	5.20	0.27
PG25	33.201	2.465	1.07	29.47	64.13	5.20	0.13
PG33	**34.259**	1.067	0.80	**36.80**	56.07	5.33	0.00
PG50	**35.791**	1.662	0.53	**53.60**	40.53	4.93	0.40
PD25	30.970	4.078	0.93	4.80	88.27	5.73	0.27
PD33	29.833	5.467	0.79	3.86	88.27	6.80	0.27
PD50	29.254	12.743	0.66	3.07	90.67	5.47	0.13

Table 9. Comparison of strength parameters and granulometric composition for group 2

Symbol	Strength parameters		Fraction content [%]				
	angle of internal friction	cohesion	gravel	sand			silt & clay
				coarse	medium	fine	
Z	32.108	5.209	6.00	9.87	70.80	11.33	2.00
ZG25	33.187	5.157	4.00	29.20	54.53	11.07	1.20
ZG33	**34.745**	5.753	4.67	**41.20**	43.73	9.20	1.20
ZG50	**35.274**	2.361	3.73	**58.53**	29.60	7.33	0.80
ZD25	33.175	6.504	4.79	13.47	70.28	10.40	1.07
ZD33	33.201	2.465	4.13	7.20	73.73	13.20	1.73
ZD50	32.091	1.334	5.20	9.47	73.73	10.67	0.93

The secondary strength parameter determined during the tests was cohesion. Due to the fact that the tested samples belong to non-cohesive soils, the cohesion has very little influence on the strength of these soils as it occurs as an apparent cohesion. Due to a very low content of the dust and clay fraction, for the group 1 mixtures it is in the range of (0-0.4) %, and for the group 2 mixtures in the range of (0.8-2.0) %, the cohesion obtained is in the range of 1.067 kPa to 12.743 kPa. The appearance of apparent cohesion is favoured by the state of optimal humidity of the samples. It occurs as a result of capillary forces and disappears when the soil dries out or becomes saturated with water.

5. CONCLUSIONS

The aim of the study was to determine the granulometric composition and its influence on the strength parameters of the investigated soils. Two basic samples of base soil were used in the study, i.e. rinsed sand and sand taken directly from the deposit. For both soil materials a granulometric analysis was performed, as well as testing of strength parameters in a direct shear apparatus. The next step was to interfere with the granulometric composition of the investigated soils. As a result of mixing the base samples with selected sands in appropriate proportions, 12 modified soil mixtures with altered granulometric composition were produced, which were also subjected to the same tests.

The analyses carried out confirm that the granulometric composition of soil media determines the strength characteristics of soils. In the case of non-cohesive soils, the value of the angle of internal friction depends on the different grain size index and the content of coarser fractions. As these characteristics increase, the angle of internal friction increases.

The use of both the native soil taken directly from the deposit and selected rinsed sand gives similar results in terms of strength and compaction parameters. From an ecological point of view, this is of considerable importance because it has been shown that for engineering purposes (embankments, substructures for linear structures etc.), by means of appropriate ginning, the local native soil can be used effectively without being limited to the use of much more expensive material purchased from aggregate manufacturers. The development of a soil mixture and the installation of properly graded soil material may prove to be very effective in terms of improving geotechnical parameters as well as economically and environmentally friendly.

Conducting research on optimal mixtures based on native soil and applying them to infrastructure construction fits in with the strategy of sustainable development and protection of geoenvironmental resources.

REFERENCES

1. Dong, Y 2007. Experimental study on intensity character of rock-soil aggregate mixture. *Rock and Soil Mechanics* **28**, 1269-1274.
2. Xu, XC, Chen, SX and Jiang, LF 2015. *On Compaction Characteristics and Particle Breakage of Soil-aggregate Mixture*. 1st International Conference on Information Sciences, Machinery, Materials and Energy (ICISMME). Proceedings of the First International Conference on Information Sciences, Machinery, Materials and Energy, 126, 83-87.
3. Xu, XC, Zhou, W, (...), Li, JX 2010. Research on compaction properties of soil-aggregate mixture. *Rock and Soil Mechanics* **31**, 115-120.
4. Hopkins, TC, Beckham and TL 2000. *Influence of clay fraction and moisture on the behaviour of soil-aggregate mixtures*. 5th International Symposium on Unbound Aggregates in Road Construction (UNBAR 5). Unbound Aggregates in Road Construction, 21-28.
5. Skrzypczak, I, Kokoszka, W, Buda-Ożóg, L, Kogut and J, Słowik, M 2017. *Environmental aspects and renewable energy sources in the production of construction aggregate*. ASEE17, E3S Web of Conferences 22, 1-8.
6. Knapik, K and Bzówka, J 2017. Permeability of the mixture of fine grained soil and fly ash from fluidized bed combustion. *Sborník vědeckých prací Vysoké školy báňské - Technické Univerzity Ostrava* **17**, 25-30.
7. Kokoszka,W 2019. Impact of Water Quality on Concrete Mix and Hardened Concrete Parameters. *Civil and Environmental Engineering Reports* **29**, 174-182.
8. Bakir, N, Abbeche, K, Panczer, G and Belagraa, L 2020. Study of the effect of waste glass fibers incorporation on the collapsible soil stability behavior. *KnE Engineering* **5**, 157-166.

9. Directive 2006/12/EC of the European Parliament and of the Council of 5 April 2006 on waste. https://op.europa.eu/pl/publication-detail/-/publication/0f484039-4061-4922-9739-76d173d0d919/language-pl
10. Regulation (EU) no 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EE. https://www.itb.pl/rozporzadzenie-parlamentu-europejskiego-i-rady-ue-nr-305-2011-z-dnia-9-marca-2011-r.html
11. Skrzypczak, I, Kokoszka, W, Zientek, D, Tang, Y and Kogut, J 2021. Landslide Hazard Assessment Map as an Element Supporting Spatial Planning: The Flysch Carpathians Region Study. *Remote Sensing* **13**, 317.
12. Skrzypczak, I, Kogut, J, Kokoszka, W and Zientek, D 2017. Monitoring of landslide areas with the use of contemporary methods of measuring and mapping, *Civil and Environmental Engineering Reports* **24**, 069-082.
13. Skrzypczak, I, Kokoszka, W, Kogut, J and Oleniacz, G 2017. Methods of measuring and mapping of landslide areas, IOP Conference Series: *Earth and Environmental Science* **95**, 022013.
14. Mrówczyńska, M and Sztubecki, J 2021. The network structure evolutionary optimization to geodetic monitoring in the aspect of information entropy Measurement. *Journal of the International Measurement Confederation* **179**, 109369.
15. Mrówczyńska, M 2011. Neural networks and neuro-fuzzy systems applied to the analysis of selected problems of geodesy. *Computer Assisted Mechanics and Engineering Sciences* **18**, 161–173.
16. Pisarczyk, S 2005. *Geoengineering. Subsoil modification methods.* Warsaw: PWN Publishers.
17. Ismail, M 2008. Mathematical correlations between the effective diameter of soil and other properties. *Engineering and Technology,* 26 (10),1274-128.
18. Kokoszka, W, Skrzypczak, I and Wilk, K 2018. Analysis of Geotechnical Properties of Miocene Deposits of the Carpathian Foredeep. *Civil and Environmental Engineering Reports* **28**, 62-70.
19. Kopciuch, D 2021. Wpływ parametrów granulometrycznych na wytrzymałość ośrodka gruntowego. Praca dyplomowa. Opiekun I. Skrzypczak. In: *APD Politechnika Rzeszowska*.
20. PN-EN ISO 14688-1:2006 Geotechnical investigation. Determination and classification of soils. Part 1: Determination and description.
21. PN-EN ISO 14688-2:2006 Geotechnical investigation. Determination and classification of soils. Part 2: Principles of classification.
22. PN-EN 1997-1:2009 Eurocode 7: Geotechnical design. Part 2: Identification and investigation of subsoils.

23. Myślińska, E 2016. *Laboratory studies of soils and grounds*. Warsaw: University of Warsaw Publishers.
24. Wiłun, Z 2000. *Outline of geotechnics*. Warsaw: WKŁ Publishers.

Editor received the manuscript 03.06.2022