10.2478/sggw-2018-0008

Annals of Warsaw University of Life Sciences – SGGW
Land Reclamation No 50 (2), 2018: 99–108
(Ann. Warsaw Univ. of Life Sci. – SGGW, Land Reclam. 50 (2), 2018)

Analysis of compaction parameters of the exemplary non-cohesive soil determined by Proctor methods and vibrating table tests

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Abstract: *Analysis of compaction parameters of the exemplary non-cohesive soil determined by Proctor methods and vibrating table tests.* The purpose of the work is to analyze compaction parameters of non-cohesive uniformly graded soil – optimum moisture content (w_{opt}) and maximum dry density ($\rho_{d\max}$), obtained from Proctor tests and using vibrating table. The research was conducted on even-graded medium sand (Sa$\underline{\text{fgr}}$), of uniformity coefficient $C_U = 3.10$ and coefficient of curvature $C_C = 0.99$. Compaction parameters were examined by using Proctor tests – standard Proctor tests (I and II) and modified Proctor tests (III and IV) in compliance with PN-B-04481:1988, and also standard (A+A and A+B) and modified (B+A and B+B) according to PN-EN 13286-2:2010, and by using a vibrating table in compliance with PN-EN 13286-5:2006 at four sample loading attempts. The moisture content of the samples increased by 1–2% in the range of about 0% to about 10%. On the basis of the analysis of data from soil studies with uniform grain size (poorly compactable soil), it can be concluded that the values of test results $\rho_{d\max}$ of medium sand with standard (or modified) Proctor tests according to PN-B-04481:1988 and PN-EN 13286-2:2010 are close to each other. It can be concluded that in the case of $\rho_{d\max}$, the vibrating table method (with the assumed test conditions) allows to achieve results comparable to those of Proctor (mean relative difference 1.88%). Using the vibrating table the w_{opt} values were lower than those obtained by Proctor tests (mean relative difference of 18.84%).

Key words: study of non-cohesive soil, compaction parameters, optimum moisture content, maximum dry density, Proctor tests, vibrating table

INTRODUCTION

As a result of the improvement of soil by artificial compaction, the soil particles are the most tightly laid, as possible in the given soil and under given compaction conditions. The factors that have a major impact on the values of compaction parameters include: soil moisture content (Proctor 1933a, 1933b), grain size and soil type (Pisarczyk 2004, Majer 2009, Sulewska 2009), energy expenditure and the method of its transmission (Proctor 1933a, b, Gurtug and Sridharan 2004, Sivrikaya et al. 2008, Dąbska and Pisarczyk 2011, Szajna and Lechocka 2016), the power of the impulse (Wiłun 2005), characteristics of the shape and surface of grains (Kolbuszewski 1967).

The parameters of soil compaction are the maximum dry density – $\rho_{d\max}$ (in Poland the ρ_{ds} symbol is used) and the optimum water content – w_{opt}. Among the methods of testing the parameters of compaction of non-cohesive and cohesive soils, compaction by using Proctor test, in compliance with PN-B-04481:1988, is most commonly applied in Poland. In the year 2005 in road construction, the European standard PN-EN 13286-2:2005 was introduced; at present the English version of the standard is in force PN-EN 13286-2:2010 with the change of PN-EN

13286-2:2010/AC:2014. This standard applies to tests of unbound or hydraulically bound mixtures used in road construction or civil engineering. It does not refer to soils used in earthworks. A comparison of the results of the examination of compaction parameters according to the above standards is provided in the work by Tymosiak and Sulewska (2016). In road engineering, the method of compaction using a vibrating table according to PN-EN 13286-5:2006 is also used to test mixtures of aggregates used in the construction of road pavements.

Maximum dry density values are determined in order to control the compaction of cohesive and non-cohesive made soils artificially compacted, based on the calculated degree of compaction (I_S), e.g. according to PN-S-02205:1998. Only the density of non-cohesive soils embedded in embankments of water-drainage devices, e.g. in dams and embankments, should be controlled on the basis of density index (I_D) according to PN-B-12095:1997. The I_D can also be used to determine the states of naturally compacted non-cohesive soils.

MATERIAL AND METHODS

The research was carried out on Pleistocene fluvioglacial quartz sand from around Białystok, which according to PN-B-02480:1986 was classified as medium sand Ps. According to PN-EN ISO 14688-2:2006 + PN-EN ISO 14688-2:2006/Ap2:2012, it was sand interbedded with fine gravel (Safgr). The results of the soil particle size distribution study were made using the sieve method according to PN-B-04481:1988 and are presented in the form of particle size distribution curve in Figure 1. According to the grain size distribution indexes: $C_U = 3.10$; $C_C = 0.99$, it was a uniformly grained soil (even-graded according to PN-EN ISO 14688-2:2006/Ap2:2012).

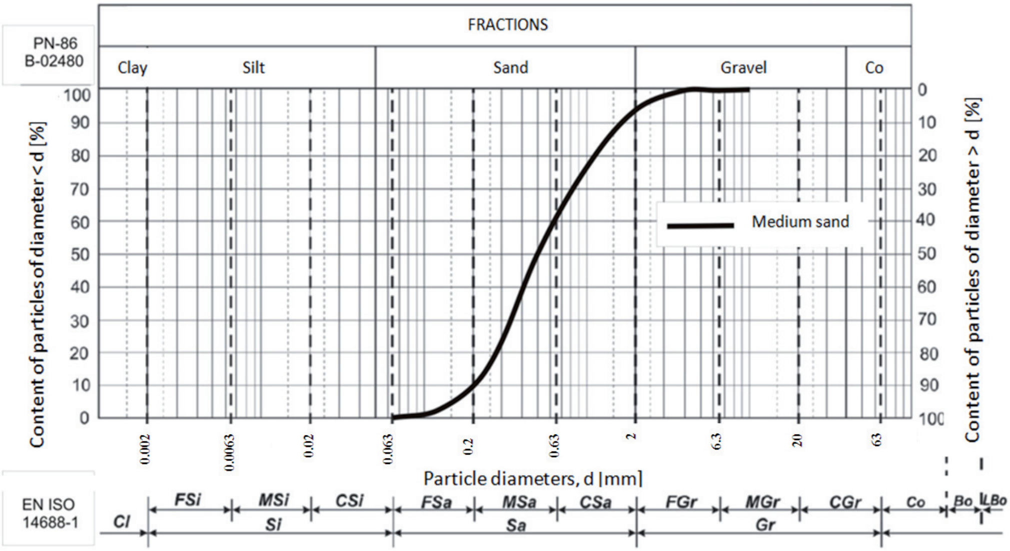

FIGURE 1. Particle size distribution curve of studied soil

Kolbuszewski’s research (1967) on sands compaction using vibrations suggests that with the increase in the grain size uniformity coefficient (C_U) of sands (the study was carried out on two groups of sands in the C_U range: from 1.7 to 3.3 for first group and from 1.6 to 2.95 for second group), the minimum porosity is reduced $n_{\min}$ (from 0.38 to 0.31 for first group and from 0.44 to 0.35 for second group), i.e. the higher the C_U value, the better the compaction of a soil. It is assumed that the non-cohesive soil is well grained (easily compactable and thus useful for the construction of embankments), if $C_U > 4$ for gravels and $C_U > 6$ for sands, with $C_C = 1–3$ (Czyżewski et al. 1973, Arquié 1980). According to this criterion, the examined sand was one of the poorly compactable soils.

The compaction parameters were investigated using the following methods:

- according to PN-B-04481:1988 tests: standard (I and II) and modified (III and IV), with the use of Proctor mechanical compactor – Figure 2 (Tymosiak and Sulewska 2016),
- according to PN-EN 13286-2:2010 tests: standard (rammer + mould: A+A and A+B) and modified (B+A and B+B), with the use of Proctor manual compactors – Figure 3 (Tymosiak and Sulewska 2016);
- according to PN-EN 13286-5:2006 using vibrating table (Fig. 4) with four loadings of the sample with the total weights m_1–m_4.

The choice of the test method for compaction parameters (Proctor standard or modified test) depends on the grain size of the soil and the use of the material in the embankment and the expected embankment load (e.g. on the road traffic category according to PN-S-02205:1998). It can be assumed that the energy of compaction in Proctor standard method corresponds to the compaction of the soil in the embankment with light compacting equipment (light road rollers, pneumatic rollers weighing up to 10 t, and light compactors). Compaction energy in modified Proctor method corresponds to the work of heavy compacting equipment: road

TABLE 1. Characteristics and terms of use of compaction by Proctor methods

Method	Mass of rammer (kg)	Volume of mould (dm^3)	Compaction energy (kN·m^{-1}·dm^{-3})	Terms of use: sieve (D) size (mm)
I	2.5	1.00	0.59	$D < 6.0$
II	2.5	2.20	0.59	$D < 10.0$
III	4.5	1.00	2.65	$D < 6.0$
IV	4.5	2.20	2.65	$D < 10.0$
A+A	$A = 2.5$	$A = 0.94$	0.60	Mould A: when 100% of grains’ diameter is $D < 16.0$ Mould B: – when 100% or 75–100% of grains’ diameter is $D < 16.0$ – when 100% or 75–100% of grains’ diameter is $D < 31.5$ – when 100% of grains’ diameter is $D < 63.0$
A+B	$A = 2.5$	$B = 2.12$	0.59	
B+A	$B = 4.5$	$A = 0.94$	2.68	
B+B	$B = 4.5$	$B = 2.12$	2.67	

FIGURE 2. Proctor mechanical compactor

FIGURE 3. Proctor manual compactors and cylinders (on the left: A+A, on the right: B+B)

FIGURE 4. Vibrating table with weights: guide with lid 2.906, 5.017, 7.085, 10.092 kg

rollers weighing 20–30 t, heavy vibratory rollers weighing more than 4 t, heavy compactors weighing more than 2 t (Majer 2013).

For vibrating tests of the soil, the researchers used a cylinder with a diameter $d_c = 16.20$ cm and a height $h_c = 19.08$ cm and a volume $V_c = 3.93$ dm^3, attached to a vibrating table, which was a slightly modified Vebe table according to PN-EN 12350-3:2011. The vibration parameters of the vibrating table (with empty cylinder and without weights) approximately corresponded to the method of testing w_{opt} and $\rho_{d\max}$ of road aggregates using a vibrating table according to PN-EN 13286-5:2006 and amounted to: vibration frequency $f = 49.75$ Hz, vertical displacement amplitude $d = 0.25$ mm, vibration acceleration $a = 27.11$ m·s^{-2} (2.76 g). For the tests on the vibrating table, six separate ground samples of 6.00 kg were prepared each time. Five samples were flooded with a suitable amount of water to obtain a moisture contents of approximately 2, 4, 6, 8, 10%. One sample was left in the air-dry state. Each of the five samples was soaked for 48 h in sealed containers. After the wetting period, the test soil sample was mixed in a container for several minutes. Next, the cylinder was filled with soil with the assumed moisture content to almost the entire height, the surface of the sample was leveled, the cylinder was weighed with soil, the cover was placed and the initial height of the sample in the cylinder was measured. Soil moisture content was determined by drying according to PN-B-04481:1988.

One sample of a given moisture content was loaded with a mass of m_1 and compacted by $t_1 = 20$ min, measuring every minute the height of the sample in the cylinder at four places around the circumpherence. After 20 min of sample compaction, a load of m_2 was applied and compacted for a further $t_2 = 20$ min, measuring every minute the height of the sample in the cylinder, after which a load of m_3 was applied, followed by m_4, proceeding similarly. In total, the time of compaction of one sample was 80 min. The unit loads of the sample surface were: 1.35, 3.70, 7.01, 9.38 kPa.

SOIL TESTING

Proctor testing

Dependency graphs $\rho_d = f(w)$ from Proctor testing have been shown in Figure 5 (Tymosiak and Sulewska 2016). Two groups of curves were obtained: the upper group of diagrams marked with dashed lines, with clearly higher $\rho_{d\max}$ values corresponds to the results of tests with modified methods (except for B+B method), the lower group of diagrams marked with continuous lines with lower $\rho_{d\max}$ values represents the results of tests with standard methods. Values of parameters w_{opt} and $\rho_{d\max}$ have been summarised in Table 2.

According to Wiłun (2005) for gravels and sands, the approximate ranges of w_{opt} and $\rho_{d\max}$ values from tests according to PN-B-04481:1988 are: for methods I and II w_{opt} = 8–12% and $\rho_{d\max}$ = 2.00–1.80 g·cm^{-3} and for methods III and IV w_{opt} = = 6–8% and $\rho_{d\max}$ = 2.10–1.90 g·cm^{-3}. According to Pisarczyk's research (2004), for sands: w_{opt} = 8–13.5%, $\rho_{d\max}$ = = 1.65–2.10 g·cm^{-3}, and $\rho_{d\max}$ at w_{opt} essentially corresponds to the saturation degree S_r = 0.4–0.7.

On the basis of the authors' medium sand tests, it can be concluded that the majority of received values $\rho_{d\max}$ are in the range S_r = 0.6–0.7 (Fig. 5). Exceptionally, the greatest value of $\rho_{d\max}$ from the

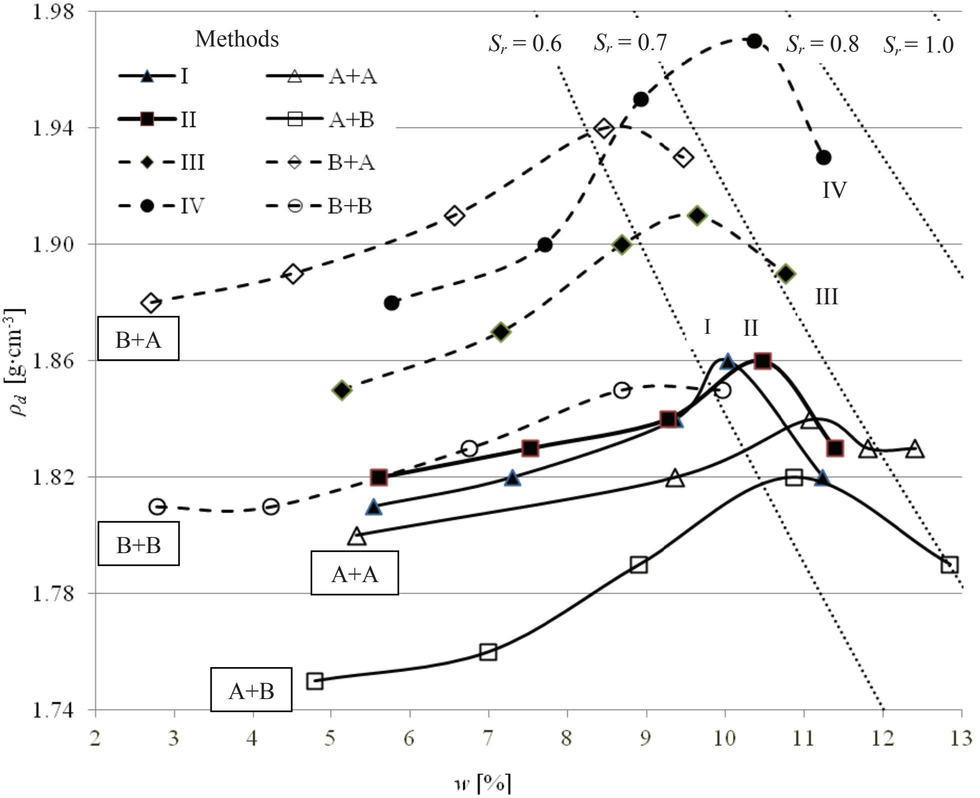

FIGURE 5. Curvatures of medium sand compaction obtained by Proctor tests

TABLE 2. Values of medium sand compaction parameters depending on a method of study (Tymosiak and Sulewska 2016)

Proctor standard test	w_{opt} (%)	Average w_{opt} (%)	$\rho_{d\,max}$ (g·cm^{-3})	Average $\rho_{d\,max}$ (g·cm^{-3})	Proctor modified test	w_{opt} (%)	Average w_{opt} (%)	$\rho_{d\max}$ (g·cm^{-3})	Average $\rho_{d\max}$ (g·cm^{-3})
I	10.03	10.25	1.863	1.859	III	9.64	10.01	1.913	1.939
II	10.47		1.855		IV	10.37		1.965	
A+A	11.08	10.98	1.843	1.832	B+A	8.46	8.57	1.935	1.895
A+B	10.87		1. 821		B+B	8.68		1.855	

IV method is in the range of S_r = 0.7–0.8, and from the B+B method S_r < 0.6. As presented in Table 2, the average values of $\rho_{d\max}$ of the investigated medium sand determined by standard methods and modified methods according to PN-B-04481:1988 are slightly higher than $\rho_{d\max}$ according to PN-EN 13286-2:2010 + PN-EN 13286-2:2010/AC:2014: their differences are respectively: $\Delta\rho_{d\max}$ = 0.027 and 0.044 g·cm^{-3} and the relative differences are 1.45 and 2.27%. It follows that the $\rho_{d\max}$ values examined with the Proctor tests according to PN-B-04481:1988 and PN-EN 13286-2:2010 + PN-EN 13286-2: 2010/AC:2014 are similar. In the case of the optimal moisture content of the w_{opt}, no clear regularities were found: Δw_{opt} = |–0.73| and 1.44%, relative differences are as follows: |–7.12| and 14.39%. It should be noted that the procedures according to the "old" standard are simpler and require field sampling of five times smaller sample for testing. According to the "new" standard, one sample can be compacted once, and according to the "old" one, sample can be compacted five times, which in the case of quartz sands has no significant impact on grain crumbling (Patakiewicz and Zabielska-Adamska 2017).

Studies with vibrating table

Dependency graphs $\rho_d = f(w)$ from testing on vibrating table have been shown in Figure 6. The obtained compactability curves are similar to the compaction curvatures typical of sands obtained from Proctor test, where, often at low moisture content close to 0% higher values of volumetric densities than at optimal moisture are obtained (Pisarczyk 2004). This phenomenon is of no practical significance in our climate, because in Poland, sands usually have natural moisture content w_n = 3–5%. Moreover, with such a low humidity, the sands have a low bearing capacity (Majer 2013).

Table 3 presents the values of moisture content and the dry density. In the majority of tests, the highest dry density values were obtained after vibrations time 10 min. Vibratory compaction exceeding 10 min did not cause a significant increase of volumetric density.

Studied soil on the vibrating table is best compacted in the air-dry state (w = 0.45%) or at the moisture content w = 8.00%. Optimal moisture content of 8.00% was found to be optimal. At compaction of the sample at moisture content greater than 8.00%, it was observed that

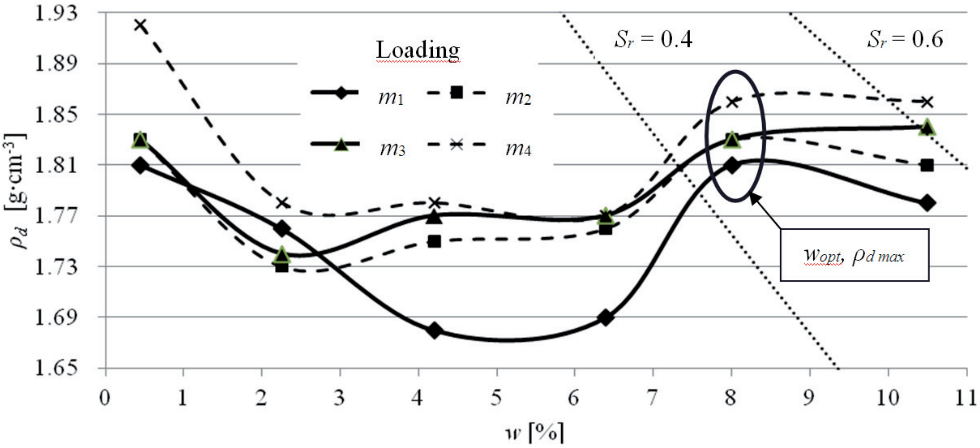

FIGURE 6. Curvatures of medium sand compaction obtained from tests on vibrating table

TABLE 3. Values of compaction parameters of medium sand on the vibrating table depending on the load

Loading	Weight (kg)	Unit loading (kPa)	w_{opt} (%)	$\rho_{d\max}$ (g·cm^{-3})
m_1	2.906	1.35	8.00	1.808
m_2	7.923	3.70	8.00	1.828
m_3	15.008	7.01	8.00	1.834
m_4	20.083	9.38	8.00	1.860

water flows to the surface of the sample and spills out of the cylinder (sprays up and out) during vibration.

Essentially, in the moisture content range 0.45% < w < 8.00%, lower values of the soil dry density were observed than at moisture content w = 8.00%, and at 8.00% < w < 10.50%.

A slight decrease of ρ_d value was observed in relation to ρ_d with w = = 8.00%. The higher the surface loads of a sample being compacted, the higher the ρ_d values are obtained. The values of $\rho_{d\max}$ increase from 1.808 g·cm^{-3} with the increase of sample surface load from m_1 to m_4, successively: 0.020, 0.006, 0.026 g·cm^{-3}, and the relative differences are respectively: 1.11, 0.33, 1.42%.

Eventually, the compaction parameters of medium sand compacted on the vibrating table were adopted for 10 min: w_{opt} = 8.00% and $\rho_{d\max}$ = 1.860 g·cm^{-3}. Comparing the value of $\rho_{d\max}$ obtained from the tests on the vibrating table with the mean values obtained by Proctor tests, according to the "old" and "new" standards (Table 2), we obtain differences from standard and modified tests: respectively: |–0.001| and 0.079 g·cm^{-3} or |–0.028| and 0.035 g·cm^{-3}, which gives relative differences of |–0.05| and 4.07% and |–1.53| and 1.85%, respectively; an average of 1.88%. The optimum moisture content determined by the vibrating table method is lower than the moisture contents obtained by Proctor tests, according to the "old" and "new" standards by 2.25, 2.01, 2.98, 0.57%, which gives relative differences of 21.95, 19.61, 27.14, 6.65%; average 18.84%.

Finally, it can be concluded that in the case of $\rho_{d\max}$ the vibrating table method (with the accepted test conditions) allows to achieve results comparable with Proctor tests (mean relative difference of 1.88%). Using the vibrating table resulted in values w_{opt} lower than those obtained by Proctor test (mean relative difference of 18.84%).

CONCLUSIONS

On the basis of the analysis of data from the studies on medium sand with uniform grain size, it can be concluded that:

1. Results of studies of the values of compaction parameters (w_{opt} and $\rho_{d\max}$) investigated using the Proctor tests according to PN-B-04481:1988 and PN-EN 13286-2:2010 + PN-EN 13286-2:2010/AC:2014 are comparable.
2. Results of tests of $\rho_{d\max}$ values determined with the use of a vibrating table (with a unit sample surface load of 9.38 kPa and a compaction time of 10 min) are comparable to the Proctor test results, and w_{opt} is much lower – an average of about 19%.
3. Applied method of testing the compaction parameters using a vibrating table is useful for testing the compaction parameters (w_{opt} and $\rho_{d\max}$) of medium sand with uniform grain size distribution.
4. Research will be continued on other types of non-cohesive soils, in particular on uniform-grained soils (poorly compactable).

Acknowledgements

This work, carried out Bialystok University of Technology, was supported by Polish Ministry of Science and Higher Education (project S/WBiIŚ/2/2018).

REFERENCES

ARQUIÉ G. 1980: Zagęszczanie. Drogi i pasy startowe. Wydawnictwa Komunikacji i Łączności, Warszawa.

CZYŻEWSKI K., WOLSKI W., WÓJCICKI S., ŻBIKOWSKI A. 1973: Zapory ziemne. Arkady, Warszawa.

DĄBSKA A., PISARCZYK S. 2011: Wpływ energii zagęszczania na zagęszczenie gruntów i parametry zagęszczalności [The energy compaction influence on soil compaction and soil compaction parameters]. Inż. i Bud. 1: 21–23 [Engl. summ.].

GURTUG Y., SRIDHARAN A. 2004: Compaction behaviour and prediction of its characteristics of fine grained soils with particular reference to compaction energy. Soils Found. 44 (5): 27–36.

KOLBUSZEWSKI J. 1967: Specjalne własności piasków. Porowatość graniczna [Some special properties of sand materials. Porosity]. Wykład 1. SGGW, Warszawa [Engl. summ.].

MAJER S. 2009: Zagęszczalność gruntów niespoistych a wskaźnik jednorodności uziarnienia [Compactibility of non-cohesive soils versus uniformity coefficient]. In: Materiały IV Międzynarodowej Konferencji Naukowo-Technicznej „Nowoczesne technologie w budownictwie drogowym", Poznań: 446–455 [Engl. summ.].

MAJER S. 2013: Zagęszczalność gruntów niespoistych [Non-cohesive soil compactibility]. Izolacje 2: 72–76 [Engl. summ.].

PATAKIEWICZ M.A., ZABIELSKA-ADAMSKA K. 2017: Crushing of non-cohesive soil grains under dynamic loading. Proc. Eng. 189: 80–85.

PISARCZYK S. 2004: Grunty nasypowe. Właściwości geotechniczne i metody ich badania. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa.

PN-B-02480:1986. Grunty budowlane. Określenia, symbole, podział i opis gruntów [Building soils. Terminology, symbols, classification and descrition of soil].

PN-B-04481:1988. Grunty budowlane. Badania próbek gruntu [Building soils. Laboratory tests].

PN-B-12095:1997. Urządzenia wodno-melioracyjne. Nasypy. Wymagania i badania przy odbiorze [Amelioration and water equipment. Embankments. Requirements and tests on commissioning].

PN-EN 12350-3:2011. Badania mieszanki betonowej. Część 3: Badanie konsystencji metodą Vebe [Testing fresk concrete. Part 3: Vebe test].

PN-EN 13286-2:2010-11. Mieszanki niezwiązane i związane hydraulicznie. Część 2: Metody badań laboratoryjnych gęstości na sucho i zawartości wody. Zagęszczanie metodą Proctora [Unbound and hydraulically bound mixtures. Part 2: Test methods for laboratory reference density and water content. Proctor compaction] + PN-EN 13286-2:2010/AC:2014-07.

PN-EN 13286-5:2006. Mieszanki niezwiązane i związane spoiwem hydraulicznym. Część 5: Laboratoryjne metody oznaczania referencyjnej gęstości i zawartości wody. Stół wibracyjny [Unbound and hydraulically bound mixtures. Part 5: Test methods for laboratory reference density and water content Vibrating table].

PN-EN ISO 14688-2:2006. Badania geotechniczne. Oznaczanie i klasyfikowanie gruntów. Część 2: Zasady klasyfikowania [Geotechnical investigation and testing. Identification and classification of soil. Part 2: Principles for a classification] + PN-EN ISO 14688-2:2006/Ap2:2012.

PN-S-02205:1998. Drogi samochodowe. Roboty ziemne. Wymagania i badania [Motor roads. Earthworks. Requirements and research].

PROCTOR R.R. 1933a: Fundamental principles of soil compaction. ENR 111 (9): 245–248.

PROCTOR R.R. 1933b: Description of field and laboratory methods. ENR 111 (10): 286–289.

SIVRIKAYA O., TOGROL E., KAYADELEN C. 2008: Estimating compaction behavior of fine-grained soils based on compaction energy. Can. Geotech. J. 45 (6): 877–887.

SULEWSKA M.J. 2009: Sztuczne sieci neuronowe w ocenie parametrów zagęszczenia gruntów niespoistych [Artificial neural networks in the evaluation of non-cohesive soil compaction parameters]. IPPT PAN, Studia z Zakresu Inżynierii 64 [Engl. summ.].

SZAJNA W.S., LECHOCKA P. 2016: Ocena metod badania gęstości objętościowej szkieletu gruntowego piasku wykorzystujących widełki wibracyjne i stół wibracyjny [Evaluation of the two methods of determining bulk density of sand: tapping fork test and vibrating table test]. Drogi i Mosty 15: 5–20 [Engl. Summ].

TYMOSIAK D., SULEWSKA M.J. 2016: Badania parametrów zagęszczalności gruntów niespoistych metodą Proctora [The study of compactibility parameters in non-cohesive soils by Proctor compaction test]. Acta Sci. Pol. Architectura 15 (3): 43–54 [Engl. summ.].

WIŁUN Z. 2005: Zarys geotechniki. Wydawnictwa Komunikacji i Łączności, Warszawa.

Streszczenie: *Analiza wyników badań parametrów zagęszczalności gruntu niespoistego metodami Proctora i za pomocą stołu wibracyjnego.* Celem pracy jest analiza wartości parametrów zagęszczalności gruntu niespoistego: wilgotności optymalnej (w_{opt}) i maksymalnej gęstości objętościowej szkieletu gruntowego ($\rho_{d\max}$), uzyskanych z badań metodami Proctora oraz na stole wibracyjnym. Badania zostały wykonane na piasku średnim Ps (Safgr), równoziarnistym o wskaźniku jednorodności uziarnienia $C_U = 3{,}10$ i wskaźniku krzywizny $C_C = 0{,}99$. Parametry zagęszczenia zostały zbadane metodami Proctora – standardowymi (I i II) i zmodyfikowanymi (III i IV) według PN-B-04481:1988, a także standardowymi (A+A i A+B) i zmodyfikowanymi (B+A i B+B) według PN-EN 13286-2:2010, jak również za pomocą stołu wibracyjnego według PN-EN 13286-5:2006 przy czterech obciążeniach powierzchni próbki. Wilgotność próbek wzrastała co 1–2% w zakresie 0–10%. Na podstawie analizy danych z badań gruntu o równomiernym uziarnieniu (słabo zagęszczalnego) wnioskuje się, że wartości wyników badań $\rho_{d\max}$ piasku średniego standardowymi (lub zmodyfikowanymi) metodami Proctora według norm PN-B-04481:1988 i PN-EN 13286-2:2010 są zbliżone do siebie. W przypadku $\rho_{d\max}$ metoda stołu wibracyjnego (przy przyjętych warunkach badania) pozwala na osiągnięcie wyników porównywalnych z metodami Proctora (średnia różnica względna wynosi 1,88%). Z użyciem stołu wibracyjnego uzyskuje się mniejsze wartości w_{opt} niż za pomocą metod Proctora (średnia różnica względna wynosi 18,84%).

Słowa kluczowe: badania gruntów niespoistych, parametry zagęszczalności, wilgotność optymalna, maksymalna gęstość objętościowa szkieletu gruntowego, metody Proctora, stół wibracyjny

MS received 30.01.2018

MS accepted 04.06.2018

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