Δελτίο Ελληνικής Γεωλογικής Εταιρείας τομ. XXV/4. 317-325. 1991
Πρακτικά 5ου Επιστημονικού Συνεδρίου, Θεσσαλονίκη, Μάϊος 1990

Bulletin of the Geological Society of Greece vol. XXV/4. 317-325. 1991
Proceedings of the 5th Congress, Thessaloniki, May 1990

PARTICLE SIZE GRADING AS A FACTOR OF COMPACTION RESULT, IN SOILS

B. Christaras* and G. Dimopoulos*

ABSTRACT

Samples of sand from Kassandra-Chalkidiki peninsula are studied in relation to the influence of their particle size distribution on the change of their plysico-mechanical characteristics after compaction. For this purpose ten samples of artificially different particle size grading are studied and correlation diagrams between particle size, compaction optimum moisture content, max. dry density and ultra sonic velocity are given; the mathematic expressions of the observed correlations are determined too.

ΣΥΝΟΨΗ

Δείγματα άμμου από την περιοχή της Κασσάνδρας Χαλκιδικής εξετάστηκαν ως προς την επίδραση της κοκκομετρικής τους διαβάθμισης επί της μεταβολής των φυσικομηχανικών χαρακτηριστικών μετά από συμπύκνωση.

Για το σκοπό αυτό δέκα δείγματα με τεχνητά διαφορετική κοκκομετρική διαβάθμιση εξετάστηκαν ως προς την υφιστάμενη σχέση μεταξύ της κοκκομετρίας, της βέλτιστης υγρασίας συμπύκνωσης, της μέγιστης ξηρής πυκνότητας και της ταχύτητας υπερήχων. Η σχέση αυτή εκφράστηκε με μαθηματικές σχέσεις και δόθηκαν τα αντίστοιχα διαγράμματα.

INTRODUCTION

Sandy soil is used in the construction, either as construction material or as foundation base. In both cases soil must be resistant in volume changes, caused by moisture fluctuation or loading. The shear strength of soils is related to their angle of internal friction and their cohesion which are directly related to their void ratio. COnsequently particle size can also related to the stability and resistance of soils. Compaction activities can ameliorate the mechanical characteristics of a soil by strength increasing and compressibility and

---

Β. ΧΡΗΣΤΑΡΑΣ & Γ. ΔΗΜΟΠΟΥΛΟΣ. Η κοκκομετρική διαβάθμιση ως παράγοντας που επηρεάζει την συμπύκνωση των εδαφών.

* Aristotle University of Thessaloniki. Department of Geology. 540 06 THESSALONIKI, Greece.

porosity decreasing; erosion resistance increases too.

The use of compacted fills and the techniques for construction of compacted fills, have developed rapidly over the past 40 years. The development of larger and more powerfull excavation and hauling equipment has made grading operations more economical. This had led to the development of many kinds of compaction machines and the use of compacted soils for many purposes. Previous studies in this field give us informations such as the dependence of soil aggregation on changes in moisture content (Andrzejeszczak, 1981) or the use of lateritic soils as fill material in embankment and dam construction (Malomo, 1981, Ogunsanwo, 1989).

The purpose of our investigation is to determine the probably existing relationship between the particle size, the optimum moisture of compaction, the maximum dry density of compaction and the ultra sonic velocity, of sandy soils so that to use them for engineering purposes.

SAMPLE DESCRIPTION

The studied samples are collected from Kassandra-Chalkidiki peninsula near Polychrono village (fig.1). The material cover almost entirely the southern Kassandra peninsula and is composed of yellow-brown cross bedding fine sand. (Sample 1 in Table I and fig. 2). According to the 1:50.000 geological map of IGME (1969) this formation is of medium-upper Miocene age while according to Marinos et al. (1970) is of Plio-pleistocene.

Mineralogically, the samples are studied by RXD method (Cuka radiation $\lambda = 1,54$ Å with Ni-filter), with the use of the Plilips RX diffractometer of the Mineralogical Department of the University of Thessaloniki (fig. 1). A semi-quantitative mineralogical composition, of the material is given too (fig. 1). The material is composed of 26% quartz, 24% micas + montmorilonite, 9% a-cristobalite, 6% k-feldspar, 32% plagioclase and 3% calcite and according to this composition it can be classified as granitic or granodioritic origin.

METHODOLOGY

The purpose of our investigation was to study the influence of the particle size distribution on the compaction result of a fine grained sand. Thus ten samples of the same mineralogical composition are tested after having (artificially)chanaged their particle grading in the given range (fig. 2). These ten samples are studied concerning their compaction result by the standard Proctor method (ASTMD 698). In this method, soil samplesd were compacted into a special mould using a 5.5 lb rammer with a 12 in drop at various moisture contents. The resulting densities (γd) were plotted against moisture contents (w%) from which

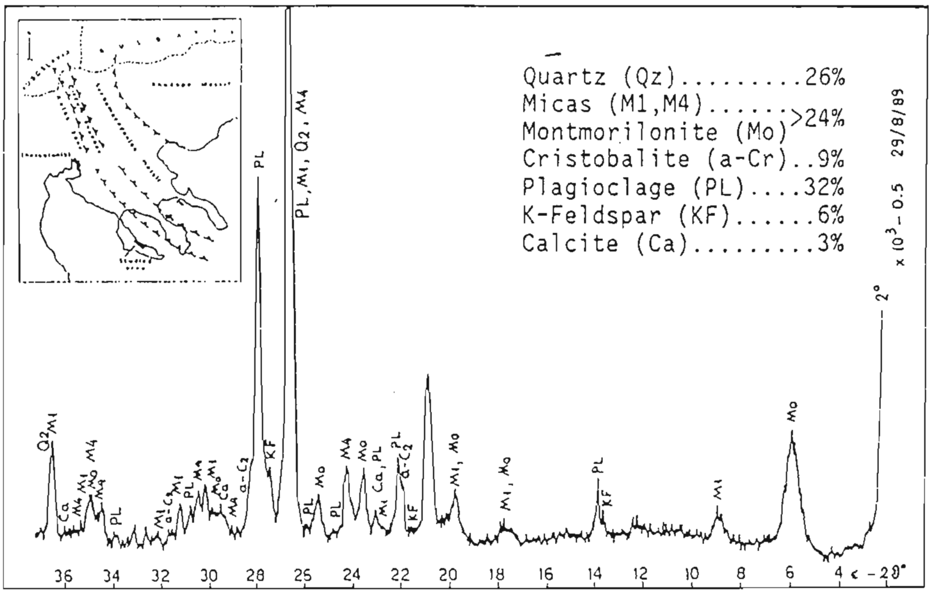

Fig. 1. RXD mineralogical and semi-quantitative composition of the studied material (in original grain size grading). A skech indicating the studied area is inlaid.

Εικ. 1. Ακτινογραφική ορυκτολογική και ημι-ποσοτική σύνθεση του μελετούμενου υλικού (στην αρχική κοκκομετρική διαβάθμιση). Σε ένθετο σκαρίφημα σημειώνεται η περιοχή μελέτης.

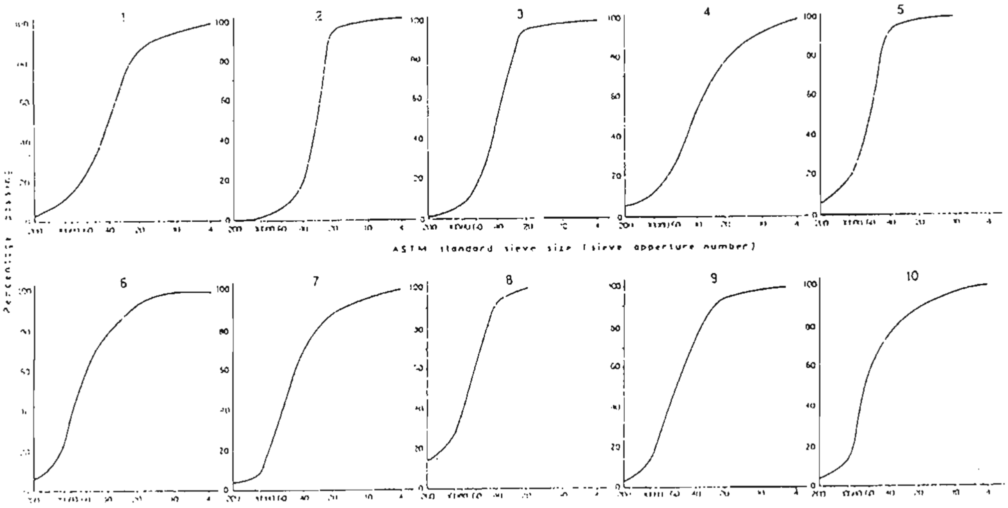

Fig. 2. Grading curves of the studied samples, according to Table 1 (sample No 1 in original grain size grading).

Εικ. 2. Κοκκομετρικές καμπύλες των μελετηθέντων δειγμάτων, σύμφωνα με τον πίνακα 1 (δείγμα No 1 σε αρχική κοκκομετρική διαβάθμιση).

Table 1. Particle size grading of the studied samples.
Πίνακας 1. Κοκκομετρική διαβάθμιση των μελετηθέντων δειγμάτων.

ASTM sieve size number	Sieve apperture (mm)	Weight percentage passing (%)									
		1	2	3	4	5	6	7	8	9	10
4	4.760	100.00	100.00	100.00	100.00		100.00	100.00		100.00	100.00
10	2.000	95.92	98.84	98.83	94.42	100.00	99.42	95.55		98.70	97.01
20	0.850	84.85	94.15	96.20	79.93	99.26	95.36	87.97	100.00	95.41	89.59
40	0.425	53.71	19.49	51.70	53.09	93.35	78.78	67.82	93.39	70.68	76.27
60	0.250	24.05	6.12	19.18	26.98	47.24	62.43	37.93	60.45	45.30	54.72
80	0.180	14.66	2.44	8.46	17.13	26.94	39.65	20.10	39.90	28.36	22.55
100	0.150	10.99	1.35	5.46	12.86	19.15	20.72	8.95	26.91	13.12	12.69
200	0.075	2.99	0.27	1.46	5.67	6.96	5.63	3.83	14.43	3.42	4.58

Table II. Compaction test; experimental results of the studied samples.
Πίνακας II.Δοκιμή συμπύκνωσης· πειραματικά αποτελέσματα των μελετηθέντων δειγμάτων.

Sample	Dry density γd (Kg/m^3)	Moisture content W%	Max dry density γd (kg/m^3)	Optimum moisture content (Wo%)	Sample	Dry density γd (Kg/m^3)	Moisture content W%	Max dry density γd (kg/m^3)	Optimum moisture content (Wo%)
1a	1545	17.91	1566	19.28	6a	1510	19.05	1552	20.58
1b	1564	18.95			6b	1554	20.38		
1c	1558	20.08			6c	1550	21.09		
1d	1502	21.79			6d	1529	22.00		
1e	1426	23.91			6e	1482	23.59		
2a	1707	13.09	1735	15.50	7a	1540	18.23	1585	19.24
2b	1720	14.02			7b	1567	18.61		
2c	1730	14.81			7c	1582	19.03		
2d	1713	17.56			7d	1575	19.59		
2e	1545	2.83			7e	1417	21.12		
3a	1661	15.11	1688	16.27	8a	1490	20.37	1520	21.18
3b	1683	15.70			8b	1514	21.01		
3c	1676	16.85			8c	1511	21.69		
3d	1620	17.88			8d	1505	21.95		
3e	1518	19.53			8e	1483	22.70		
4a	1602	18.27	1612	19.78	9a	1551	18.29	1613	19.13
4b	1609	10.08			9b	1604	18.57		
4c	1606	20.04			9c	1609	18.97		
4d	1571	21.17			9d	1606	19.52		
4e	1550	21.74			9e	1547	20.77		
5a	1509	19.83	1530	20.80	10a	1525	19.32	1560	20.05
5b	1526	20.41			10b	1544	19.57		
5c	1516	21.87			10c	1553	19.83		
5d	1439	24.50			10d	1550	20.52		
5e	1368	26.72			10e	1513	22.27		

plot the optimum moisture content (Wo%) and max dry density were obtained (fig. 3). This pair of values will be used to design a stable foundation ground for a structure.

The experimental data of the particle size analysis are given in Table I while the experimental data of the Standard-Proctor test are given in Table II. It must be mentioned that the data of sample 1, in Table I and fig. 2, refer to the original particle grading of the formation.

The ultrasonic velocity (SV, ASTM- C597) is a good index characteristic of the physico-mechanical behaviour of soils and rocks, related to their porosity, strain, specific gravity and weatherability. Measurements have been done on cylindric compacted specimens (diameter 38 mm and high 76 mm) taken from the Proctor machine, after drying for 24h at 110° C. For this purpose, a portable PUNDIT machine, of the Thessaloniki, Faculty of Technology was used (Table III). It must be mentioned that drying didn´t provoke cracking phenomena, which could change the awaited result, because of the following reasons a) fines were in lower percentage than 15% making the creation of important colloidal masses almost insignificant, b) drying of each specimen was done with slow progressive increase of the temperature, in order to prevent cracking phenomena caused by a rapid change of temperature.

Table III. Experimental results of the studied samples.
Πίνακας III. Εργαστηριακά αποτελέσματα των μελετηθέντων δειγμάτων.

Sample	Compaction max dry density γd (kg/m^3)	Compaction optimum moisture content (Wo%)	Sonic velority SV (mm/μs)	a % < 75 μ (No 200)	b % < 425 μ (No 40)
1	1566	19.28	0.82	2.99	53.71
2	1735	15.50	0.48	0.27	19.49
3	1688	16.27	0.58	1.46	51.60
4	1612	19.78	0.69	5.67	53.09
5	1530	20.80	0.85	6.96	93.35
6	1552	20.58	0.80	5.63	78.78
7	1585	19.24	0.78	3.83	67.82
8	1520	21.18	0.90	14.43	93.39
9	1613	19.13	0.73	3.42	70.68
10	1560	20.05	0.77	4.58	76.27

INTERPRETATION OF TEST RESULTS

The test results were interpreted statistically. The influence of the particle size on the change of the measured compaction result was determined in relation to the ultra sonic velocity; this relationship was expressed mathematically, by either linear or logarithmic regressions, with a significant correlation coefficient, given in Table IV.

In order to verify the significance of the measured correlation, the

Table IV. Mathematic expression between the studied properties.
Πίνακας IV. Μαθηματικές σχέσεις μεταξύ των μελετηθέντων ιδιοτήτων.

	Mathematic expression	Correlation Coefficient
1	% < 75 μ(a) - Optimum moisture content (Wo%) $Wo = 17.15 + 1.65 \ln a$	$r = 0.943$
2	% < 425 μ(b) - Optimum moisture content (Wo%) $Wo = 14.33 + 0.074\, b$	$r = 0.874$
3	Optim. moisture cont. (Wo%) - Ultra-sonic velocity (SV, mm/μs) $SV = -0.47 + 0.063\, Wo$	$r = 0.935$
4	Optim. moisture cont. (Wo%) - max density (γd, kg/m^3) $\gamma d = 2276 - 35.5\, Wo$	$r = -0.967$

coefficient $t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$ was calculated with the aid of the Student Tables, according to which the correlation coefficient must be higher than 0.7646 ($n-2 = 8$, n : number of specimens), for a critical region size 0.01.

According to our correlation study the max dry density after compaction, presents, in the range of the present measurements, a significant negative correlation with the optimum moisture content (fig. 3), which is related to the percentage of fine grained particles (<0.075 mm), by positive logarithmic regression

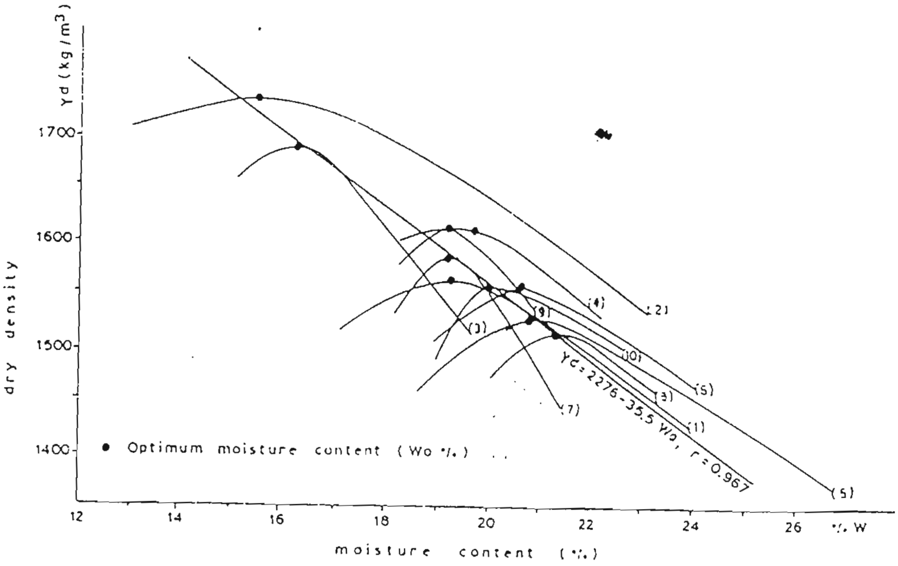

Fig. 3. Compaction curves of the studied samples and correlation line Wo-γd.
Εικ. 3. Καμπύλες δοκιμών συμπύκνωσης των μελετηθέντων δειγμάτων και ευθεία συσχέτισης Wo-γd.

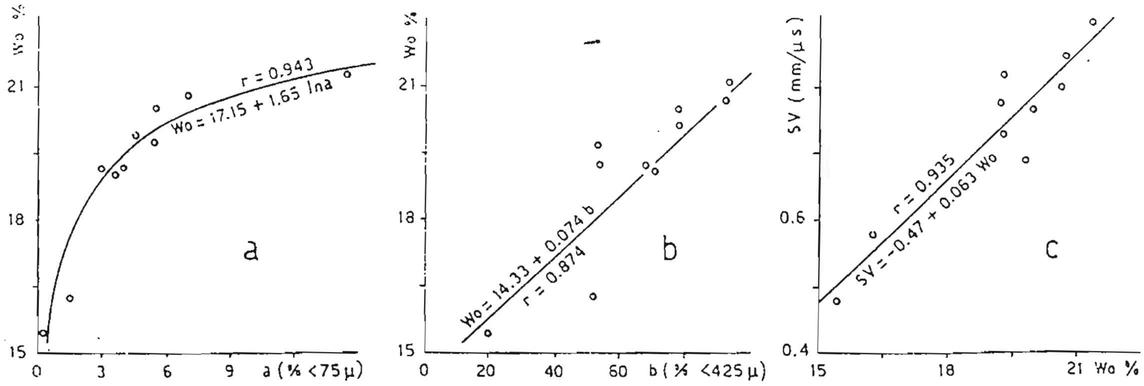

Fig. 4. Correlation diagrams between the studied properties.
Εικ. 4. Διαγράμματα συσχέτισης μεταξύ των μελετηθέντων ιδιοτήτων.

(fig. 4a). It must be mentioned that according to the calculated "Wo-lna" regression the optimum moisture content (which presents a theoretical maximum value of 24.7% for material with particle size 100% < 75 μ) presents a short range of values 23.7-24.7% for material with 50-100% fine grained particles (<75 μ). According to Atlan and Feller (1980) and Ola (1981) the relationship between the percentage of fine particles (<75μ) and dry density and optimum moisture content of compaction, for fine soils in Senegal and Nigeria, presents a peak which approximately correspondes to a maximum dry density and a minimum optimum moisture content, for 15-20% fine particles content. For higher percentages of fines (<75 μ) the dry density decreases whereas the optimum moisture content increases. The compaction result, expressed by the optimum moisture content, is also related to the percentage of particles passing through the sieve No 40 (<425 μ) with a significant positive linear correlation. This significance is presented quite well in fig. 4b, taking in mind that Y-axis (Wo%) is magnified.

It must be mentioned that while the optimum moisture content is related logarithmically to the percentage of the fines (<75 μ), the relationship between optimum moisture content and percentage of particles finer than 425 μ is linear. To explain this diversity we can consider that fine grains of clay and silt size move between the grains of sand to fill the existing voids; the increase of the percentage of filler causes the increase of the optimum moisture content, but for percentage of filler higher than [illegible]% this optimum moisture content rate of rising becomes smaller. For higher percentage of filler, fine grains push and surround the grosser grains so that in practice the material behave in an approximately similar way in relation to the optimum moisture content of maximum compaction; the appearence of cohesion forces between fine grains (especially of clay) and the probable creation of colloidal masses, can also explain the decrease of this optimum moisture content rate of rising. Concerning the linear relationship of the optimum moisture content to the percentage of the finer particles than 425 μ, the situation is slightly different; in the range of sand, the decrease of particle size increases the capability of compaction with simultaneous increase of the optimum moisture content.

The ultra sonic velocity presents also a significant positive linear correlation with the optimum moisture content of compaction (fig. 4c). The reason for measuring the ultra sonic velocity through the compacted specimens, was exactly its direct relationship with the voids, the decrease of which is the purpose of the compaction method.

Finally, it could be considered that test results are only of a local importance, due to the local character of sampling; we could risk however to generalise these results for soils of similar mineralogical composition origin and particle size grating. A further investigation with a wide range sampling, could complete this study.

CONCLUSION

In the present study sandy soil material from Kassandra-Chalcidiki peninsula is investigated concerning the compaction behaviour against the particle size. For this purpose the particle size grading was changed artificially and the results are summarised as follows.

i. The material, in original grading can be characterised as a yellow-brown cross bedded fine sand of medium-upper Miocene or Plio-Plistocene age.

ii. Mineralogically the material is composed of 26% quartz, 24% micas + montmorilonite, 9% a-cristobalite, 6% k-feldspars, 32% plagioclase and 3% calcite. According to this composition it can be classified as of granitic or granodioritic origin.

iii. The statistical interpretation of the test results showed a distinct influence of the particle size distribution of the material, on the maximum dry density and the optimum moisture content of compaction; this influence is expressed also by the ultra sonic velocity through the material. It must be mentioned that the most important point in addition to the determined relationships, is that a small quintity of fines in the sand, lower than [illegible] increase the optimum moisture content of compaction. Although our sampling had a local character, test results could be probably used for sands of similar mineralogical composition, origin and particle size grading. The determined relationships are as follows:

- $Wo = 17.15 + 1.65 \ln a$ $r = 0.943$
- $Wo = 14.33 + 0.074 b$ $r = 0.874$
- $SV = -0.47 + 0.063 Wo$ $r = 0.935$
- $\gamma d = 2276 - 35.5 Wo$ $r = -0.967$

REFERENCES

ADDRZEJESZCZAK, B. (1981). Dependence of soil aggregation and reaggregation on changes in moisture content.- *Bull. IAEG*, 24, 155-161, Essen.

ATLAN, Y. & FELLER, C. (1980). Application de la gedologie ä la caracterisation geotechnique de quelque sols fins du Senegal.- *Bull. IAEG*, 22, 233-241, Krefeld.

IGME (1969). Geological map of Kassandra peninsula, scale 1:50.000.- Athens.

MALOMO, S. (1981). The compressibility characteristics of a compacted lateritic soil. *Bull. IAEG*, 24, 151-155, Essen.

MARINOS, G., SAKELLARIOU-MANE, E., SOTIRIADIS, L. & SAPOUNTZIS, H. (1970). Sur la paléogéographie de l´Egéīde du Nord dans la région de Cassandra.- *Ann. Geol. Pays Hell.*, 22, 1-27, Athens.

OGUNSANWO, O. (1989). Some properties of a sedimentary laterite soil as engineering construction material.- *Bull. IAEG*, 39, 131-137, Paris.

OLA, S.A. (1981). Stabilisation of Maiduguri Black Cotton soils of Nigeria with sand.- *Bull. IAEG*, 24, 145-151, Essen.