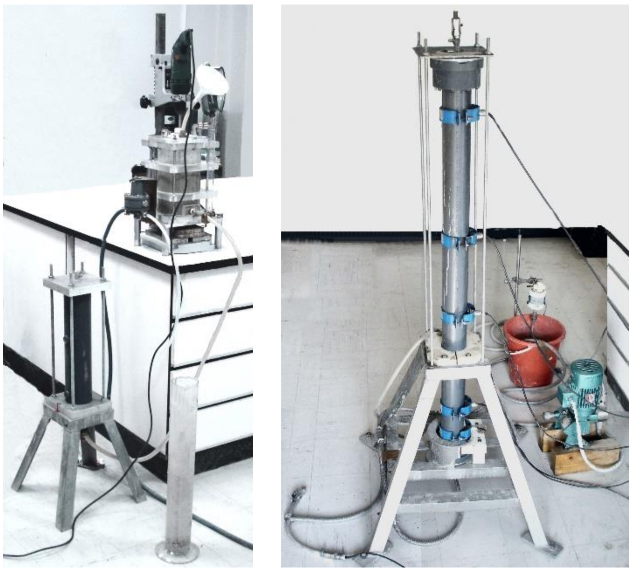
Table 3 Gradation characteristics of sand grain size fractions

Sand fraction	Specific gravity	Grain size limits (mm)	Characteristic grain sizes (mm)			Uniformity coefficients	
			d_{15}	d_{10}	$d_{2.5}$	C_u	$C_{u,25}$
5-10	2.71	4.00 – 2.00	2.25	2.15	2.04	1.40	1.10
10-14	2.72	2.00 – 1.40	1.48	1.45	1.41	1.19	1.05
14-25	2.72	1.40 – 0.71	0.80	0.77	0.72	1.43	1.11
25-50	2.70	0.71 – 0.30	0.36	0.34	0.31	1.56	1.16
50-100	2.72	0.30 – 0.15	0.166	0.160	0.152	1.43	1.09
100-200	2.72	0.15 – 0.074	0.082	0.079	0.075	1.45	1.09

of the injected grout was equal to two void volumes of the sand in the column or when the injection pressure became equal to 700 kPa. After curing for 28 days, the grouted columns were cut in alternating lengths of 16 cm and 9 cm. The resulting specimens with a length of 16 cm were tested in unconfined compression at an axial strain rate equal to 0.05 %/min. The specimens with a length of 9 cm were utilized for constant head permeability testing under water pressures ranging from 10 kPa to 200 kPa, using a specially constructed apparatus which allowed for testing of the grouted specimens in the PVC tube.



(a) (b)

Fig. 2. Laboratory equipment for (a) injectability and (b) penetrability evaluation of suspensions

4 Experimental results

4.1 Injectability

For the purposes of the experimental investigation reported herein, injectability was evaluated by conducting injection tests with the apparatus shown in Figure 2a. Groutability was characterized as "satisfactory" when the predetermined quantity of grout (two void volumes of the sand column) could be injected, as "moderate" when the volume of injected grout was approximately equal to one void volume of the sand column, and as "impossible" when the quantity of the injected grout was very small. From the results of the injection tests presented in Table 4, it can be observed that groutability was "satisfactory" in S1 and S2 (Nos. 5-10 and 10-14) sands for all combinations of suspension composition. Groutability in S3 (Nos. 14-25) sand was "moderate" or "impossible" for F0 (ordinary) cement suspensions and "satisfactory" for the finer cement suspensions. The S4 (Nos. 25-50) sand was grouted "satisfactorily" only with microfine cement F2 suspensions having W/C ratio equal to 3:1 and microfine cement F3 suspensions having W/C ratios of 2:1 and 3:1. Groutability of all suspensions with W/C ratio equal to 1:1 was "impossible" in S4 sand. Penetration in S5 (Nos. 50-100) sand was negligible for any cement suspension used. Accordingly, it can be stated that the increase of cement fineness and/or W/C ratio significantly improves the groutability of cement suspensions. On a quantitative basis, microfine cement suspensions with W/C ratios of 2:1 and 3:1 can be injected in medium to fine sands.

4.2 Penetrability

The term "penetrability" describes the maximum length from the injection site that a particular suspension can penetrate a specific sandy soil under a specified maximum injection pressure. According to the results of the injections performed to determine the injectability, in the second stage, an attempt was made to more accurately determine the maximum penetration length of the suspensions into the soil columns with the help of the laboratory device shown in Fig. 2b. Table 5 summarizes the results obtained from these injections. In order to have some escalation in terms of ease or difficulty of compressing the suspensions, the following penetration characterizations were adopted. In particular, the penetration of the suspension is characterized as "optimal" when the entire amount of suspension penetrates (volume of compressed suspension equal to twice the volume of sand voids

Table 4. Injectability - Experimental results.

Cement	Sand	W/C ratio	Injection result *
F0	S1	1:1–3:1	S
	S2	1:1–3:1	S
	S3	1:1	I
		2:1	M
		3:1	M
	S4	1:1–3:1	I
	S5	1:1–3:1	I
F1	S1	1:1–3:1	S
	S2	1:1–3:1	S
	S3	1:1–3:1	S
	S4	1:1	I
		2:1	I
		3:1	I
	S5	1:1–3:1	I
F2	S1	1:1–3:1	S
	S2	1:1–3:1	S
	S3	1:1–3:1	S
	S4	1:1	I
		2:1	M
		3:1	S
	S5	1:1–3:1	I
F3	S1	1:1–3:1	S
	S2	1:1–3:1	S
	S3	1:1–3:1	S
	S4	1:1	I
		2:1	S
		3:1	S
	S5	1:1–3:1	I

* S: satisfactory, M: moderate, I: impossible

in the column) with low injection pressure, as "satisfactory" when penetrating all or almost all amount of suspension with increasing injection pressure, as "marginal" when the column is grouted to a length of more than 60 cm with a maximum pressure of 700 kPa and as "small" when the column is impregnated to a length of less than 60 cm with a maximum impregnation pressure of 700 kPa. From the experimental results of the injections presented in Table 5, it appears that the suspensions of all cements (common and microfine) easily penetrate the sands 5-10 and 10-14. The suspensions based on fine-grained cements F2 and F3 showed optimal penetration into the soil columns of sand 14-25, while the satisfactory penetration of the suspensions of common cement F0 with W/C ratios of 1:1 and 2:1 in the specific sand, was accompanied by increase of injection pressure. The suspensions of common cement F0 show impossibility of compression in sand columns 25-50, while satisfactory penetration in the specific sand, present the suspensions of only fine-grained cements (F2 and F3) with W/C ratios equal to 2:1 and 3:1.

Table 5. Penetrability of Suspensions – Experimental Results

Cement	Sand	W/C Ratio	Result*	PL$ (cm)
F0	S1	1:1-3:1	B	>134
	S2	1:1-3:1	B	>134
	S3	1:1	I	>134
		2:1	I	>134
		3:1	B	>134
	S4	3:1	M	16.2
	S5	1:1-3:1	M	-
F2	S1	1:1-3:1	B	>134
	S2	1:1-3:1	B	>134
	S3	1:1-3:1	B	>134
	S4	1:1	M	10.7
		2:1	I	>134
		3:1	B	>134
	S5	3:1	M	13.4
F3	S1	1:1-3:1	B	>134
	S2	1:1-3:1	B	>134
	S3	1:1-3:1	B	>134
	S4	1:1	O	92.7
		2:1	O	83.0
		3:1	I	>134
	S5	3:1	M	22.8

* B: Optimal, I: Satisfactory, O: Marginal, M: Small
$ PL: Penetration Length

The better behavior of these F2 cement suspensions compared to those of the finer F3 cement is attributed to the lower viscosity values of the former compared to the latter. Also, the sand 25-50 was grouted with a length of about 90 cm from the suspension of the finest available cement F3 with W/C ratio equal to 1:1. The penetration of all the examined suspensions in soil sand columns 50-100 is significantly reduced as the penetration lengths determined range from 13 cm to 23 cm (Table 5). The above observation leads to the conclusion that the sand 50-100 is the upper penetration limit of the suspensions of fine-grained cements. This finding is also consistent with the results concerning the suspensions injectability (Table 4).

4.3 Results Evaluation

Summarizing the results (Tables 4 and 5) concerning the scaling of the injectability and penetrability of cement suspensions into uniform sands, it appears, as expected, that the reduction in the grain size of the soil formation leads to an increase in the degree of difficulty of penetration sand columns. This is due to the fact that the reduction of the grain size of the soil formation also regulates the size of its voids. The reduction of the size of the gaps, consequently, differentiates their geometric correlation with the size of the cement grains of the suspension, as a result of which additional obstacles are placed in the flow through the soil formation. Increasing the water-to-cement ratio also contributes substantially to improving the injectability and increasing the penetration length of the suspensions. In addition, the increase in the fineness of the cement has a positive effect on the injectability and penetrability of the suspensions, thus highlighting the usefulness of the fine-grained cements and the effort to develop new materials. Increasing the injection pressure improves the injection effect only in marginal cases in terms of the geometric relationship between cement grain sizes and sand voids. In contrast, in cases where this relationship does not allow penetration of the suspension, increasing the impregnation pressure does not affect the outcome of the injection. In conclusion, it is found that the suspensions of the fine-grained cements used (F2 and F3) with water to cement ratios of 2:1 and 3:1 by weight can penetrate to a sufficient length into formations with medium to fine-grained sand.

5 Efficiency of “groutability criteria”

Groutability prediction of cement suspensions can lead to the proper design of grouting materials as well as to the rational determination of the distance and sequence of grouting boreholes, minimizing, in this manner, the uncertainties in the design and execution of grouting operations. A preliminary evaluation of groutability can be made using available criteria, such as the “groutability ratios” [39, 51] which are defined as $N_1=(D_{15})soil:(D_{85})grout$ and $N_2=(D_{10})soil:(D_{95})grout$. D_{10}, D_{15}, D_{85}, and D_{95} are characteristic grain sizes of soil and grout. Grouting is considered possible for $N_1>25$ or $N_2>11$ and not possible for $N_1<11$ or $N_2<6$. $N_1>20$ is considered the minimum condition necessary for penetration and, if $N_1\geq50$, satisfactory permeation should be achieved. The characteristic grain sizes d_{10}, and d_{15} of soil correspond to the grain diameter at which 10% and 15% of the weight of the specimen is finer, respectively. Likewise, the characteristic grain sizes d_{85}, d_{90} and d_{95} of grout correspond to the particle diameter at which 85%, 90% and 95% of the weight of the specimen is finer, respectively. The conditions that must be satisfied for considering grouting as possible or not possible in accordance with each groutability criterion, are also given in Table 6. Groutability can also be estimated using the empirical formula presented by Akbulut & Saglamer (2002) [18] (Table 6) where N is groutability (if N>28 soil can be grouted sufficiently by cement-based grouts), d_{10} and d_{90} are characteristic grain sizes of soil and grout, w/c is water to cement ratio of grout, FC is the finer content of soil passing through a 0.6 mm sieve, P is the grouting pressure, D_r is relative density of soil and k_1, k_2 are constants. Values of N_1 and N_2 for the materials used in this investigation are presented in Table 7. Although the values used, were not always between the limits given by Akbulut & Saglamer (2002), groutability was computed by applying the empirical formula for the injection tests conducted in this investigation and the results obtained, are shown in Table 7.

Table 6 Criteria for the estimation of soil groutability

Reference	Equation(s)		Grouting possible	Grouting not possible
Mitchell (1981)	$N_1=\frac{(d_{15})_{soil}}{(d_{85})_{grout}}$	$N_2=\frac{(d_{10})_{soil}}{(d_{95})_{grout}}$	$N_1>25$ $N_2>11$	$N_1<11$ $N_2<6$
Krizek, Liao and Borden (1992)	$N_1=\frac{(d_{15})_{soil}}{(d_{85})_{grout}}$	$N_2=\frac{(d_{10})_{soil}}{(d_{95})_{grout}}$	$N_1>15$ and $N_2>8$	---------
Akbulut and Saglamer (2002)	$N_3=\frac{(d_{10})_{soil}}{(d_{90})_{grout}}+0.5\frac{W/C}{FC}+0.01\frac{P}{D_r}$ [a]		$N_3>28$	$N_3<28$

[a] It gives reasonable values when: 0% < FC < 6%, 0.8 < W/C < 2 and 50 kPa < P < 200 kPa.

Table 7 Groutability predictions and experimental results.

Cement	Sand	N_1	N_2	W/C ratio	N	Injection result *
F0	S1	70	47	1:1–3:1	58	S
	S2	46	32	1:1–3:1	39	S
	S3	25	17	1:1	23	I
				2:1	23	M
				3:1	23	M
	S4	11	7	1:1–3:1	12	I
	S5	5	3	1:1–3:1	7	I
F1	S1	119	85	1:1–3:1	101	S
	S2	78	57	1:1–3:1	68	S
	S3	42	30	1:1–3:1	36	S
	S4	19	13	1:1	19	I
				2:1	19	I
				3:1	20	I
	S5	9	6	1:1–3:1	10	I
F2	S1	210	161	1:1–3:1	183	S
	S2	138	108	1:1–3:1	123	S
	S3	75	58	1:1–3:1	66	S
	S4	34	25	1:1	32	I
				2:1	32	M
				3:1	31	S
	S5	15	12	1:1–3:1	16	I
F3	S1	297	236	1:1–3:1	260	S
	S2	195	159	1:1–3:1	175	S
	S3	106	85	1:1–3:1	93	S
	S4	47	37	1:1	44	I
				2:1	43	S
				3:1	43	S
	S5	22	18	1:1–3:1	23	I

* S: satisfactory, M: moderate, I: impossible

According to the values of the ratio N_1 (Table 7) and the relevant criteria, it appears that the sands S1 and S2 can be satisfactorily injected with the suspensions of all the examined cements. In S3 sand, injection with suspensions of cements F0 and F1 is feasible while a satisfactory penetration length can be achieved with suspensions of cements F2 and F3. In S4 sand, injection is not feasible with F0 and F1 cement suspensions, it is feasible with F2 cement suspensions and satisfactory penetration length can probably be achieved with F3 cement suspensions. Finally, the injection with the suspensions of all the examined cements in the S5 sand is not possible or impracticable. The criteria based on the N_2 ratio provide even more optimistic predictions which deviate significantly from the experimental ones. In terms of the empirical formula proposed by Akbulut et al. (2002) [18], if the water to cement ratio is less than 0.8:1, satisfactory soil groutability is not possible, even if the injection pressure increases above 200 kPa. Conversely, in cases where the W/C ratio of the suspension is greater than 2:1, the value of N may be greater than 28 (satisfactory injection), but the suspension is filtered (hence not sufficient penetration) especially in cases where the injection pressure has increased significantly. Also, even if the injection pressure and the water-to-cement ratio of a suspension increase, it does not appear that this will penetrate the soil if the percentage of fine components is greater than 6%. Despite the limitations regarding the application of this empirical relationship, an attempt was made to evaluate its reliability in comparison with the findings resulting from the injections carried out in the present study. It can be observed that, predictions of groutability using the empirical formula proposed by Akbulut et al. (2002) [18] are "closer" to the experimental results than the predictions based on groutability ratios, due to the fact that a larger number of factors affecting groutability is taken into consideration in this formula [52].

6 Conclusions

Based on the results obtained and the observations made during this experimental investigation and within the limitations of the range of parameters investigated, the following conclusions can be advanced:

1) The use of microfine cements, produced by grinding of common cements, improves the penetrability of cement suspensions rendering them effective for grouting of medium-to-fine sands.
2) Cement suspension penetrability is also improved by increasing W/C ratio, decreasing viscosity, reducing sand relative density or saturating the sand prior to grouting and is affected by sand gradation.
3) Predictions of injectability based on most of the available groutability criteria, are rather optimistic and are often not confirmed experimentally. This prediction inefficiency can be attributed to the fact that the effect of significant factors, such as W/C ratio, viscosity and composition of the finer portion of the sand gradation, is not considered adequately. The implementation limitations and the material differences are also responsible for the reduced prediction efficiency of groutability criteria.

References:

[1] Philotheos Lokkas, Emmanouil Papadimitriou, Nikolaos Alamanis, Grigorios Papageorgiou, Dimitrios Christodoulou, and Theodoros Chrisanidis: "Significant Foundation Techniques for Education: A Critical Analysis", *Wseas Transactions on Advances in Engineering Education* doi: 10.37394/232010.2021.18.2., E-ISSN: 2224-3410, Volume 18, 2021, pp. 7-26.

[2] Nicolaos Alamanis, "Failure of Slopes and Embankments under Static and Seismic Loading", *American Scientific Research Journal for Engineering, Technology and Sciences (ASRJETS)*, Volume 35, No.1, 2017, pp. 95-126.

[3] Papageorgiou G.P., Alamanis N. and Xafoulis N., "Acceptable movements of road embankments", *Electronic Journal of Structural Engineering*, 20(1), 2020, pp 30-32, Melbourne, Australia.

[4] Alamanis Nikolaos, Zografos Christos, Papageorgiou Grigorios, Xafoulis Nikolaos and Chouliaras Ioannis, "Risk of retaining systems for deep excavations in urban road infrastructure with respect to work staff perception", *International Journal of Scientific & Technology Research*, Vol. 9, Issue 2, 2020, pp. 4168-4175, ISSN 2277-8616.

[5] Dimos Zachos, Georgios Bakalis, Konstantinos Bakalis, Nikolaos Alamanis, Grigorios Papageorgiou, Nikolaos Xafoulis, "A methodology for selecting the required cross‐section of a self‐supporting retaining bulkhead, on a vertical excavation front, of an energy conduit passage trench", *Energy Systems*, Springer https://doi.org/10.1007/s12667-021-00429-9. Received: 3 Jan. 2021 / Accepted: 20 February 2021 / Published on line: 06 March 2021, © Springer-Verlag GmbH Germany.

[6] Alamanis N., Dakoulas P., "Simulation of random soil properties by the Local Average Subdivision method and engineering applications", *Energy Systems*, Springer. https://doi.org/10.1007/s12667-019-00362-y. Print ISSN 1868-3967, Online ISSN1868-3975 p.p 1-21. Received: 6 March 2019 / Accepted: 2 October 2019, Published on line: 07 November 2019, © Springer-Verlag GmbH Germany.

[7] Alamanis N., Dakoulas P. (20, "Effect of spatial variability of soil properties on the stability and permanent seismic displacements of highway slopes", *The 17th European Conference on Soil Mechanics and Geotechnical Engineering*, 1st - 6th September 2019, Reykjavik Iceland. XVII ECSMGE Reykjavik Iceland 2019.

[8] Alamanis N., Dakoulas P., "Effect of spatial variability of soil properties on permanent seismic displacements of slopes with uniform load", *14th Baltic Sea Geotechnical Conference* 18-19 Jan 2021, Helsinki, Finland.

[9] Markou IN, Christodoulou DN, Papadopoulos BK, "Penetrability of microfine cement grouts: experimental investigation and fuzzy regression modeling", *Canadian Geotechnical Journal* 52(7), 2015, pp. 868–882.

[10] Zebovitz S, Krizek RJ, Atmatzidis DK, "Injection of fine sands with very fine cement grout", *Journal of Geotechnical Engineering* 115(12), 1989, pp. 1717-1733.

[11] De Paoli B, Bosco B, Granata R, Bruce DA (1992a), "Fundamental observations on cement based grouts (1): traditional material", In: *Proceedings of the conference on grouting, soil improvement and geosynthetics*, New Orleans, ASCE GSP 30, vol 1, 1992a, pp. 474-485.

[12] De Paoli B, Bosco B, Granata R, Bruce DA, "Fundamental observations on cement based

grouts (2): microfine cements and the CemillR process", *In: Proceedings of the conference on grouting, soil improvement and geosynthetics*, New Orleans, ASCE GSP 30, Vol. 1, 1992b, pp. 486-499.

[13] Sano M, Shimoda M, Matsuo O, Koseki J, "Microfine cement grouting as a countermeasure against liquefaction", *In: Proceedings of the conference on grouting and deep mixing*, Tokyo, Balkema, Rotterdam, Vol 1, 1996, pp. 65-70.

[14] Santagata M.C., Collepardi M., "Selection of cement-based grouts for soil treatment", *In: Proceedings of the geo*-congress'98, Boston, ASCE GSP 80, 1998, pp. 177-195.

[15] Schwarz LG, Krizek RJ, "Hydrocarbon residuals and containment in microfine cement grouted sand", J Mater Civ Eng 18(2), 2006, pp. 214-228.

[16] Axelsson M, Gustafson G, Fransson A, "Stop mechanism for cementitious grouts at different water-to-cement ratios", *Tunn Undergr Sp Technol* 24(4), 2009, pp. 390-397.

[17] Legendre Y, Hery P, Vattement H, "Microsol grouting, a method for grouting fine alluvium", *In: Proceedings of the 6th international offshore mechanics and arctic engineering symposium*, Houston, ASME, Vol. 1, 1987, pp. 433-440.

[18] Akbulut S., and Saglamer A., "Estimating the groutability of granular soils: a new approach", Tunnelling and Underground Space Technology, Elsevier Science Ltd., Vol. 17, 2002, pp. 371-380.

[19] Mittag J., Savvidis S., "The groutability of sands – Results from one-dimensional and spherical tests", *In: Proceedings of the 3rd international conference on grouting and ground treatment*, New Orleans, ASCE GSP 120, Vol. 2, 2003, pp. 1372-1382.

[20] Tamura M., Goto T., Ogino T., Shimizu K., "Injection with ultrafine cement into fine sand layer", *In: Proceedings of the 4th international offshore and polar engineering conference*, Osaka, International Society of Offshore and Polar Engineers, Vol. 1, 1994, pp. 567-571.

[21] Mollamahmutoglu M., "Treatment of medium to coarse grained sands by fine grained Portland cement (FGPC) as an alternative grouting material to silicate-ester grouts", *Cement, Concrete and Aggregates* 25(1), 2003, pp. 1-6.

[22] Paillere AM, Buil M, Miltiadou A, Guinez R, Serrano JJ, "Use of silica fume and superplasticizers in cement grouts for injection of fine cracks", *In: Proceedings of the 3rd international conference on fly ash, silica fume, slag and natural pozzolans in concrete*, Trondheim, Norway, ACI, Vol. 2, 1989, pp. 1131-1157.

[23] Ziming W., Daneng H., Yaosheng X., "Investigation of the rheological properties and groutability of fresh cement pastes", *In: Proceedings of the international conference on rheology of fresh cement and concrete*, Liverpool, E.&F.N. Spon, London, 1990, pp. 207-213.

[24] Eklund D., Stille H., "Penetrability due to filtration tendency of cement-based grouts", *Tunn Undergr Sp Technol* 23(4), 2008, pp. 389-398.

[25] Warner J., "Soil solidification with ultrafine cement grout", *Proceedings of the 3rd International Conference on Grouting and Ground Treatment*, Johnsen F.L., Bruce A.D. and Byle J.M., Editors, New Orleans, La., U.S.A., ASCE, New York, U.S.A., Geotechnical Special Publication No. 120, Vol. 2, 2003, pp. 1360-1371.

[26] Henn R., Davenport R., "Ultrafine cement: a critical component of a grouting program", *Tunnels and Tunnelling International*, April: 2005, pp. 27-29.

[27] Bremen R., "The use of additives in cement grouts", *International Journal of Hydropower and Dams*, 4(1), 1997, pp. 71-76.

[28] Eriksson M., Friedrich M., Vorschulze C., "Variations in the rheology and penetrability of cement-based grouts – an experimental study", *Cem Concr Res* 34(7), 2004, pp. 1111-1119.

[29] Saada Z., Canou J., Dormieux L., Dupla J.C., "Evaluation of elementary filtration properties of a cement grout injected in a sand", *Canadian Geotechnical Journal*, 43(12), 2006, pp. 1273-1289.

[30] Arenzana L., Krizek R.J., Pepper S.F., "Injection of dilute microfine cement suspensions into fine sands", *In: Proceedings of the 12th international conference on soil mechanics and foundation engineering*, Rio de Janeiro, Brazil, Vol. 2, 1989, pp. 1331-1334.

[31] Perret S., Ballivy G., Khayat K., Mnif T., "Injectability of fine sand with cement-based grout", *In: Proceedings of the conference on grouting: compaction – remediation – testing*, Logan, ASCE GSP 66, 1997, pp. 289-305.

[32] Eriksson M., Stille H., Anderson J., "Numerical calculations for prediction of grout spread with account for filtration and varying aperture", *Tunn Undergr Sp Technol* 15(4), 2000, pp. 353-364.

[33] Toumbakari E-E, Van Gemert D., Tassios T.P., Tenoutasse N., "Effect of mixing procedure on injectability of cementitious grouts, *Cem Concr Res* 29(6), 1999, pp. 867-872.
[34] Karol R.H., "Grout penetrability", *In: Proceedings of the conference on issues in dam grouting*, Denver, ASCE, 1985, pp. 27-33.
[35] Santagata M.C., Santagata E., "Experimental investigation of factors affecting the injectability of microcement grouts", *In: Proceedings of the 3rd international conference on grouting and ground treatment*, New Orleans, ASCE GSP 120, Vol. 2, 2003, pp. 1221-1234.
[36] Bouchelaghem F., Vulliet L., Leroy D., Laloui L., Descoeudres F., "Real-scale miscible grout injection experiment and performance of advection-dispersion-filtration model", *International Journal for Numerical and Analytical Methods in Geomechanics*, 25(12), 2001, pp. 1149-1173.
[37] Chupin O., Saiyouri N., Hicher P.-Y., "Modeling of a semi-real injection test in sand", *Computers and Geotechnics*, 36(6), 2009, pp. 1039-1048.
[38] Chupin O., Saiyouri N., Hicher P.-Y., "The effects of filtration on the injection of cement-based grouts in sand columns", *Transport in Porous Media*, 72(2), 2008, pp. 227-240.
[39] Mitchell J.K., "Soil improvement – state of the art report", *In: Proceedings of the 10th international conference on soil mechanics and foundation engineering*, Stockholm, Sweden, Vol. 4, 1981, pp. 509-565.
[40] Krizek R.J., Liao H.-J., Borden R.H., "Mechanical properties of microfine cement / sodium silicate grouted sand", *In: Proceedings of the conference on grouting, soil improvement and geosynthetics*, New Orleans, ASCE GSP 30, Vol. 1, 1992, pp. 688-699.
[41] Markou I.N., Christodoulou D.N., Petala E.S., Atmatzidis D.K., "Injectability of Microfine Cement Grouts into Limestone Sands with Different Gradations: Experimental Investigation and Prediction", *Geotechnical and Geological Engineering Journal*, Vol. 36, Issue 2, 2018, pp. 959–981.
[42] Markou I.N. and Litsiou A.E., "Efficiency of soil groutability criteria for cement suspension grouting", *The 17th European Conference on Soil Mechanics and Geotechnical Engineering*, 1st - 6th September 2019, Reykjavik Iceland, XVII ECSMGE Reykjavik Iceland, 2019.
[43] CEN (2000a) Cement – Part 1: Composition, specifications and conformity criteria for common cements. European standard EN 197-1. European Committee for Standardization, Brussels.
[44] Henn R.W., Soule N.C., "Ultrafine cement in pressure grouting", ASCE Press, Reston, 2010.
[45] Littlejohn G.S., "Design of cement based grouts", *In: Proceedings of the conference on grouting in geotechnical engineering*, New Orleans, ASCE, Vol. 1, 1982, pp. 35-48.
[46] Bruce D.A., Littlejohn S., Naudts C.A., "Grouting materials for ground treatment: a practitioner's guide", *In: Proceedings of the conference on grouting: compaction – remediation – testing*, Logan, ASCE GSP 66, 1997, pp. 306-334.
[47] Lombardi G., "Grouting of rock masses", *In: Proceedings of the 3rd international conference on grouting and ground* treatment, New Orleans, ASCE GSP 120, Vol. 1, 2003, pp. 164-197.
[48] Pantazopoulos I.A., Markou I.N., Christodoulou D.N., Droudakis A.I., Atmatzidis D.K., Antiohos S.K., Chaniotakis E., "Development of microfine cement grouts by pulverizing ordinary cements", *Cement and Concrete Composites*, 34(5), 2012, 593–603.
[49] ASTM, 2009. Standard Specification for Wire Cloth and Sieves for Testing Purposes ASTM Standard E11. American Society for Testing and Materials, West Conshohocken, PA, U.S.A.
[50] ASTM, 2007. Standard Test Method for Particle-Size Analysis of Soils ASTM Standard D422. American Society for Testing and Materials, West Conshohocken, PA, U.S.A.
[51] Verfel J., "Rock grouting and diaphragm wall construction", Amsterdam: Elsevier Science Publishers, 1989.
[52] Christodoulou D.N., Droudakis A.I., Pantazopoulos I.A., Markou I.N. and Atmatzidis D.K., "Groutability and Effectiveness of Microfine Cement Grouts", Proceedings, *17th International Conference on Soil Mechanics and Geotechnical Engineering: The Academia and Practice of Geotechnical Engineering*, Alexandria, Egypt, Hamza et al. (Editors), IOS Press, Vol. 3, 2009, pp. 2232-2235.

Contributions

D. Christodoulou had the idea of writing this article. In fact, together with I. Markou, organized the research along with the methodology of the paper and actively participated in both the translation and the submission of the text. He, also,

contributed to the execution of the experiments and to the writing of literature review.
I. Markou had the original idea of dealing with this subject and succeeded in financing the research. He also organized the research effort and carried out the literature review.
A. Droudakis contributed to the execution of the experimental tests and to the writing of literature review.

It should be noted, however, that all the authors reviewed the paper and came to the interesting conclusions of the above work.

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