Strength and Permeability Parameters of Compacted, Partially Saturated Silty and Sandy Soils

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Summary

This Technical note summarizes some experimental results concerning the effective strength parameters (c' – φ') and the saturated coefficient of hydraulic conductivity (k) of silty and sandy soil specimens that have been compacted at different compaction degrees. The tested soils were used for the construction/refurbishment of existing levees. The effective strength parameters were obtained from conventional triaxial loading compression tests. Specimens were compacted at different percentages of the maximum (optimum) dry density and at the optimum water content. The maximum dry density and optimum water content were determined according to the Modified Proctor method. Specimens with different percentages of the maximum dry density at the optimum water content were obtained in the Proctor mold by using different compaction energy. Levees (and more generally any type of earthworks) can increase their water content because of intense rainfall or repeated floods. Therefore the strength parameters of fully saturated specimens have also been experimentally determined.

The saturated coefficient of hydraulic conductivity has been inferred from variable head permeability measurements that were performed in specially equipped oedometers. This coefficient has been measured in the case of specimens compacted at different compaction degrees and at different initial water contents (i.e. saturation degrees).

The effect of compaction degree on strength and permeability parameters has been shown. As for the strength parameters, the effect of partial saturation (suction) has also been shown.

1. Introduction

In common practice, at least in Italy, the construction of any type of earthwork is based on the prescription of a given construction material (generally referring to AASTHO M145, 1991) and of compaction method (equipment, number of passes, layer height). As for the control, it is usually prescribed to obtain at least a compaction degree of 90 % of the maximum dry density (modified Proctor method, ASTM D1557, 2012). Such an approach is essentially the same as the one adopted for the construction of road embankments. On the Author experience, a compaction degree of 90 % is hardly obtained in case of soils containing fines, when using conventional compaction machines. Usually, in various field works, we observed compaction degrees in between 80 and 90%.

On the other hand, the geotechnical design/assessment of earthworks should refer to the expected performance of given work. In particular, the design/assessment of both new and existing levees should require, at least, the knowledge of strength and permeability parameters of the construction materials in the compacted state.

Since the pioneering works of Rosenquist [1955], Seed and Chan [1959], Seed et al. [1961] it is accepted that strength parameters of compacted and unsaturated soils are mainly controlled by the structure formed during the compaction process as well as suction (capillary effects). Many papers give information about strength of compacted unsaturated soils. These studies concern the effect of different mix (sand and clay) and types of soils and give information on the unconfined compression strength or (to a less extent) on the effective strength parameters. It is worth mentioning as examples the works by Cocka et al. [2004], Cetin et al. [2007] and Tatsuoka [2015].

Based on the most recent experimental evidences, the strength parameters as well as the saturated hydraulic conductivity mainly depend on the degree of compaction and the degree of saturation at the end of compaction (see as an example Tatsuoka [2015]).

This study aims at experimentally determining the effective strength parameters and saturated permeability of two different soils with different compaction degrees.

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Tab. 1 – Soil classification.
Tab. 1 – Classificazione dei terreni.

Soil Name	LL (%)	LP (%)	IP (%)	AGI (1997)	USCS	AASHTO	Gs (-)	Modified Proctor (Scalped)	
								$g_{d,opt}$ kN/m^3	w_{opt} (%)
TC	25.1	5.8	19.3	Clayey Silt with Sand (gravel < 10%)	CL	A6	2.67	19.80	11.5
808I	-	-	-	Clayey Sand with Silt	SM	A4	2.74	18.86	11.5

AGI (1997), AASHTO M 145 (1991), ASTM 2487 (2011), ASTM D1557 (2012)

2. Tested Materials

Two different types of soils were used, TC and 808I. Soil classification is summarised in table I [GIUSTI 2017; CARRAI, 2016 ; MATTEUCCI, 2016]. Figure 1a shows the grain size distribution curves. The maximum dry density and optimum water content were determined according to the modified Proctor method. The maximum dry unit weight and optimum water content are also reported in table I. Atterberg limits were determined according to ASTM D4318 [2010]. The TC soil was used to construct a levee few hundreds of meters long and with a height ranging between 2 to 4 meters. From the crest of the bank two block samples were retrieved for control purposes. The grain size distribution curves of these two samples are also shown in figure 1a. From block samples a dry density in between 80 and 90 % of the optimum was inferred. Block samples were not retrieved immediately after the levee construction. Therefore, the water content does not correspond to that during levee formation.

It is worth noting that TC soil was sieved in order to eliminate the fraction with a diameter greater than 2 mm. As for the 808I soil the fraction greater than 0.2 mm was eliminated. Laboratory testing refer to these materials. Only the tests on specimens from block samples refer to the original TC soil. In figure 1a the grain size distribution curves of the original soil and of the same soil after elimination of the coarser fraction (scalped) are shown.

Figure 1b shows the compaction curves (Modified Proctor Method) of scalped 808I and TC soils as well as that of TC soil from block samples (not scalped).

In the following the term "compacted specimens" is used to identify those that have been compacted in the Proctor mold. "Undisturbed specimens" are those obtained from block samples.

3. Oedometer Test Results and Experimental Determination of the Coefficient of Permeability

The permeability of the two soils was obtained from oedometer tests: a) indirectly, by the estimate of Cv (according to the TAYLOR, 1948 method); b)
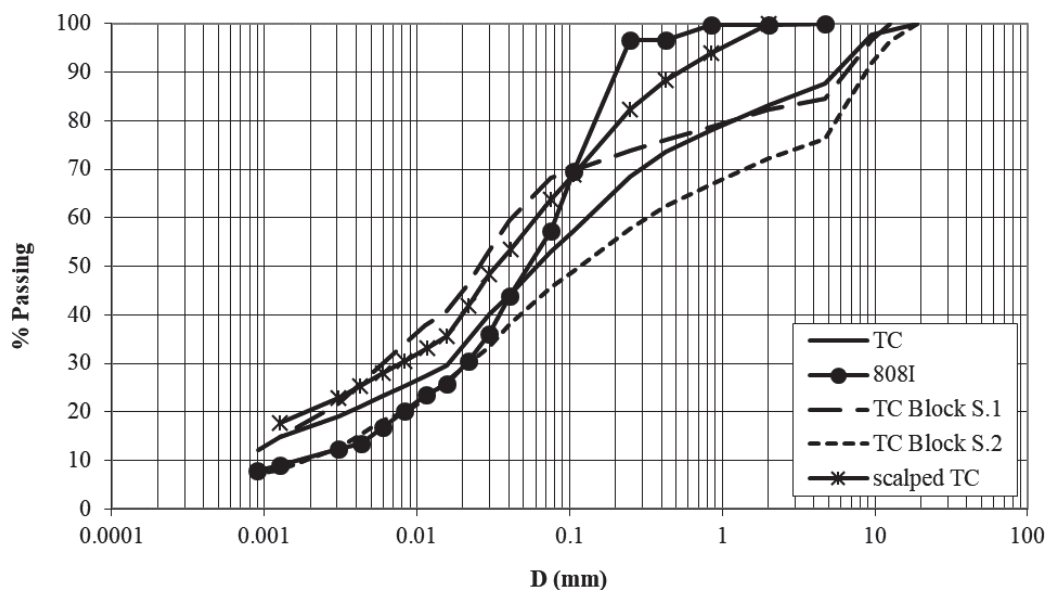

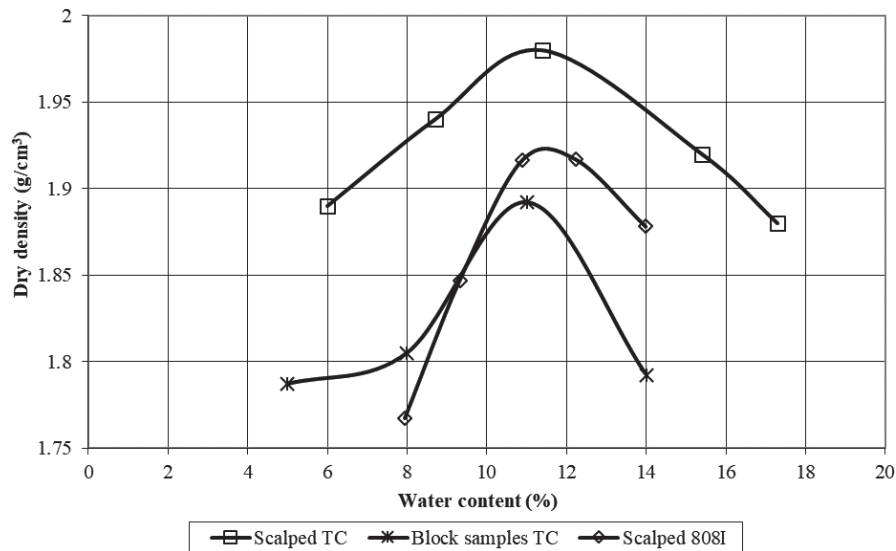Fig. 1a – Grain size distribution curves.
Fig. 1a – Curve granulometriche.

Fig. 1b – Compaction curves.
Fig. 1b – Curve di compattazione.

directly, by using the oedometer as a rigid wall permeameter. More specifically, variable head permeability tests were carried out. The test setup is shown in figure 2. The standard oedometer - test equipment was ad - hoc modified. The hydraulic load was applied at the bottom of the oedometer cell through the lower porous filter. The water could flow only throw the soil sample thanks to o-rings located between the two metal rings and between the outer metal ring and the base of the oedometer cell. Samples were compacted in the Proctor mold according to the modified Proctor method (ASTM D1557-12. 2012). Different initial water contents led to different dry densities. After compaction, the samples were extracted from the Proctor mold and specimens were trimmed and transferred into the oedometer cell according to the usual procedures. Such operations caused a certain disturbance and the initial void ratio of the specimen does not coincide with that of the sample. As for TC soil the test conditions are summarized in table IIa. Table IIb summarizes the test conditions as for 808I soil.

A graduated glass burette was connected to the lower porous stone. It was possible to appreci-

Tab. 2a – Summary of oedometer test conditions (TC soil).
Tab. 2a – *Tabella riassuntiva dei parametri delle prove edometriche (terreno TC).*

Oedometer No. (Sample)	1	2	3	4	5
Dry unit weight γ_d (kN/m^3)	17.36	18.54	18.64	17.76	17.46
Total (initial) unit weight γ_{tot} (kN/m^3)	18.96	20.63	21.00	20.33	20.40
Final water content w_f (%)	15.5	14.7	14.1	15.6	18.7
Initial water content w_i (%)	9.2	11.0	12.9	14.4	16.8
Initial void ratio e_0	0.509	0.409	0.408	0.474	0.497
Initial saturation degree S_{ri} (%)	48	72	84	81	90

Tab. 2b – Summary of oedometer test conditions (808I soil).
Tab. 2b – *Tabella riassuntiva dei parametri delle prove edometriche (terreno 808I).*

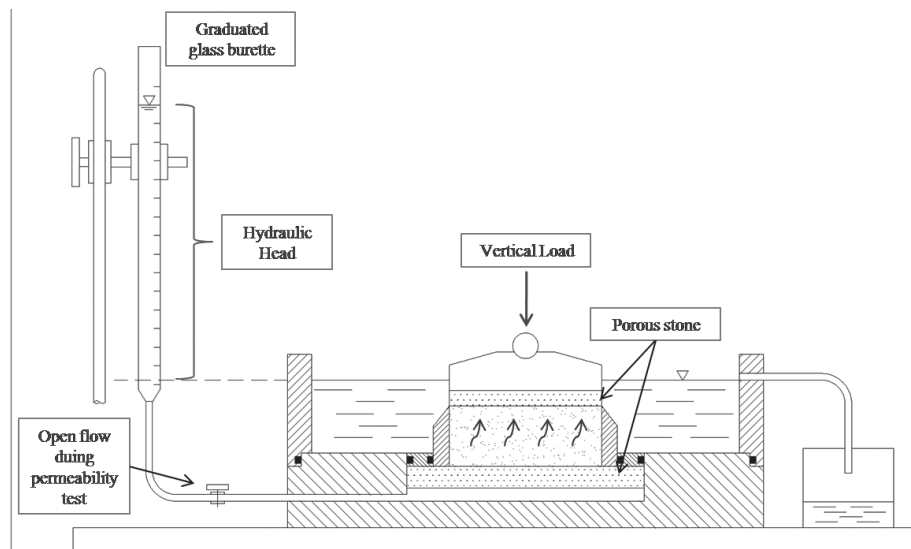| Oedometer No. (Sample)	1	2	3	4	5
Dry unit weight γ_d (kN/m^3)	17.33	18.12	18.80	18.81	18.42
Total (initial) unit weight γ_{tot} (kN/m^3)	18.80	19.88	20.89	21.14	21.13
Final water content w_f (%)	19.6	18.2	16.8	15.3	15.4
Initial water content w_i (%)	8.5	9.7	11.1	12.4	14.7
Initial void ratio e_0	0.571	0.544	0.488	0.445	0.526
Initial saturation degree S_{ri} (%)	41	49	63	77	76

Fig. 2 – Permeability - Test setup (Giusti 2017).
Fig. 2 – Schema dell'apparecchiatura utilizzata per la misura della permeabilità (Giusti 2017).

ate a head variation of 0.5 mm corresponding to a volume variation as small as 48 mm^3. After checking the burette verticality, it was filled with distilled water and the hydraulic circuit was saturated. The specimens were subject to the conventional load sequence (25 – 50 -100 – 200 – 400 – 800 – 1600 – 3200 – 6400 – 1600 – 400 – 100 – 25 kPa). Each loading step was kept for about 24 hours. At the end of each loading step, the burette was filled with distilled water in order to have an initial head of 50 cm. The head was evaluated with respect to the water level inside the oedometer cell. After that, the bottom drainage was opened and a variable head permeability test was performed. Permeability tests were not performed during the unloading stage. Head variation with time was manually recorded together with ambient temperature and variation of the specimen height, if any. The test was continued until the achievement of a stationary condition as shown in figure 3. In other words, we assume that after the first loading step and subsequent flow for the first k determination, the specimens are fully saturated.
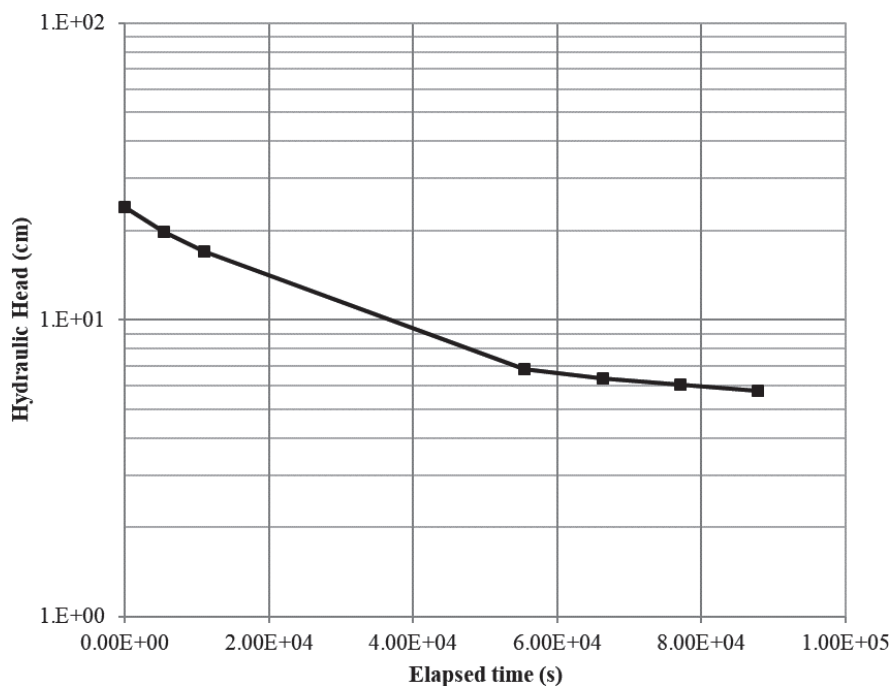

Fig. 3 – Interpretation of permeability tests (808I soil – Giusti 2017).
Fig. 3 – Interpretazione delle prove di permeabilità (terreno 808I – Giusti 2017).
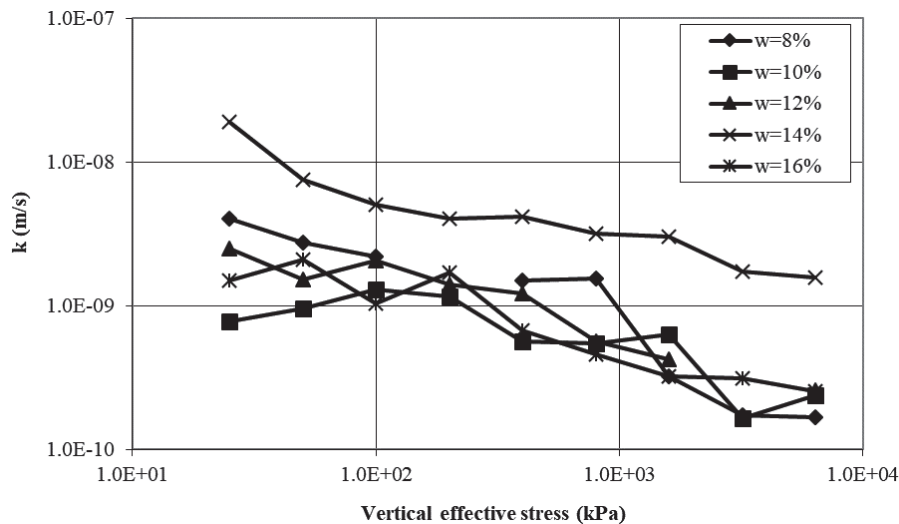
Fig. 4a – Variation of k with the effective vertical stress for the various initial water contents for TC soil (Carrai 2016).
Fig. 4a – Variazione di k con la tensione verticale efficace per i diversi valori del contenuto di acqua iniziale, terreno TC (Carrai 2016).
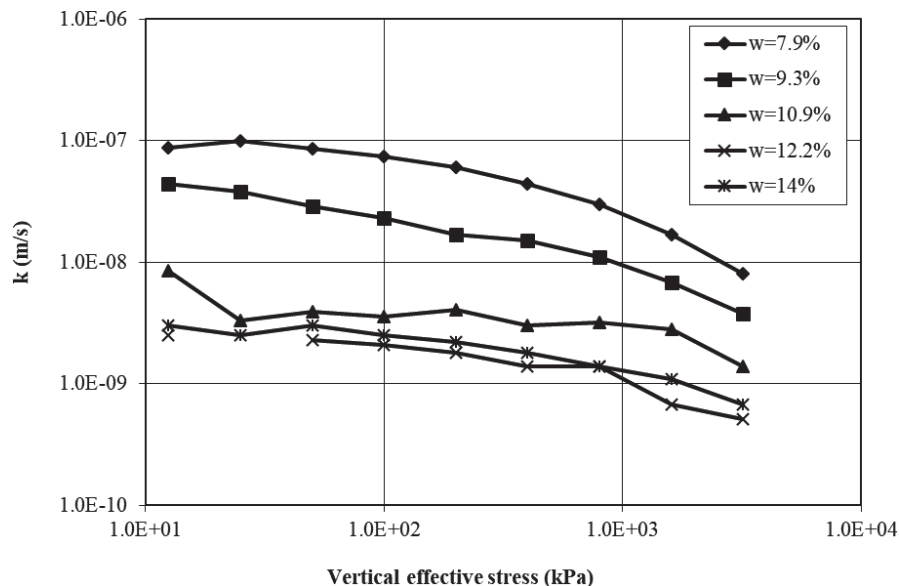

Fig. 4b – Variation of k with the effective vertical stress for the various initial water contents for 808I soil (Giusti 2017).
Fig. 4b – Variazione di k con la tensione verticale efficace per i diversi valori del contenuto di acqua iniziale, terreno 808I (Giusti 2017).

Of course we can determine only the initial and final water contents.

The saturated coefficient of hydraulic conductivity was computed by means of the following formula:

$$k = H \frac{a}{A} \frac{ln(h1/h2)}{t2 - t1} \qquad (1)$$

where:
– H=current height of the specimen
– *a* and *A* = cross areas of the burette and specimen respectively
– the term *ln(h1/h2)/(t2-t1)* represents the slope of the best – fit line of the experimental data (Fig. 3).

Figures 4a and 4b show the variation of k with the effective vertical stress in a log-log scale, for the various initial densities. Figure 4a refers to TC soil, while figure 4b shows the results for 808I soil. TC soil exhibits values of k (direct measurements) that are about one order of magnitude lower than those of 808I soil. More specifically, k of TC soil ranges in between 10^{-8} and 10^{-10} m/s, while the permeability of 808I soil ranges in between 10^{-7} and 10^{-9} m/s.

The grain size effects on k can be evaluated by using the HAZEN [1911] or PRUGH [1959] approaches. These empirical equations are in principle applicable only to sandy soils and only consid-
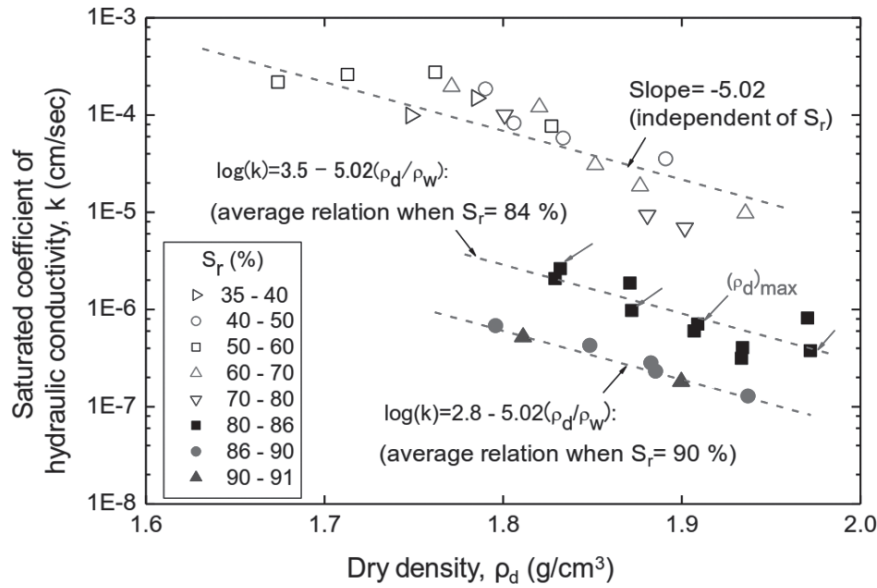
Fig. 5a – Dependence of k on the Saturation degree and Dry density (Tatsuoka 2015).
Fig. 5a – Dipendenza di k dal grado di saturazione e dalla densità secca (Tatsuoka 2015).
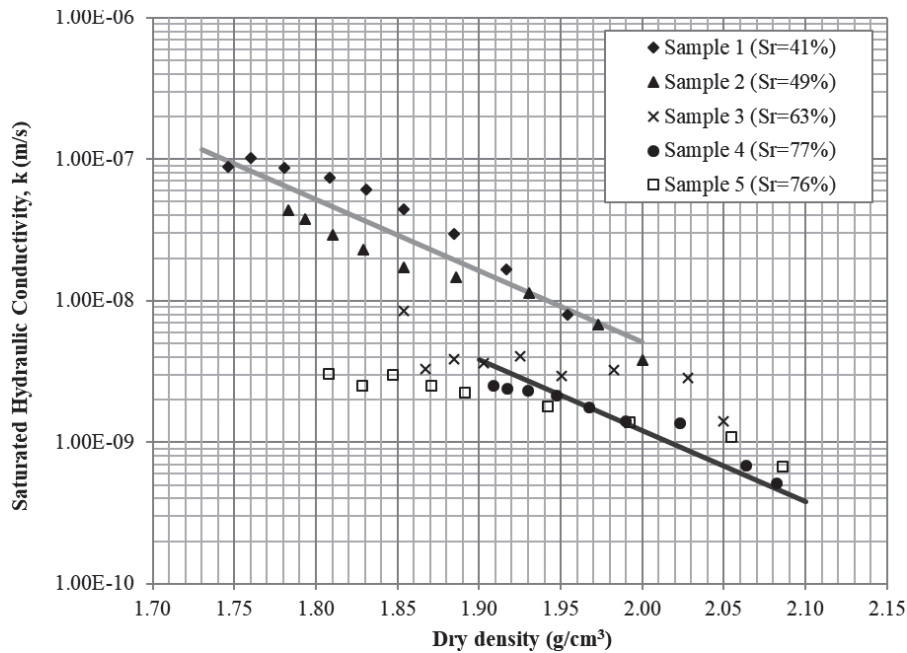

Fig. 5b – Dependence of k on the initial degree of saturation and dry density for 808I soil (Giusti 2017 – data).
Fig. 5b – Dipendenza di k dal grado di saturazione e dalla densità secca per il terreno 808I (Giusti 2017 - dati).

er the grain size characteristics of the soil (*i.e.* D_{50} and coefficient of uniformity or D_{10}). However, the differences in terms of k values between the two types of soils could be explained by considering the different clay percentage. Indeed, the clay fraction of TC soil (scalped) is twice that of 808I soil (scalped).

Permeability values, for the same type of soil, also depend on the initial compaction degree and on the applied effective stress. The influence of vertical effective stress on k is well known and stated in any textbook of soil mechanics (see, as an example, LANCELLOTTA, 1993). It is supposed that the increase of the vertical stress and consequent reduction of the void ratio lead to a reduction of k. For the tested soils, an almost linear relationship between log(k) and log(σ'_v) can be seen in both figures 4a and 4b (as expected).

The influence of the compaction degree on k, in the case of compacted soils, is not so well documented in literature. Experimental results shown in figures 4a and 4b suggest that, for a given soil, the
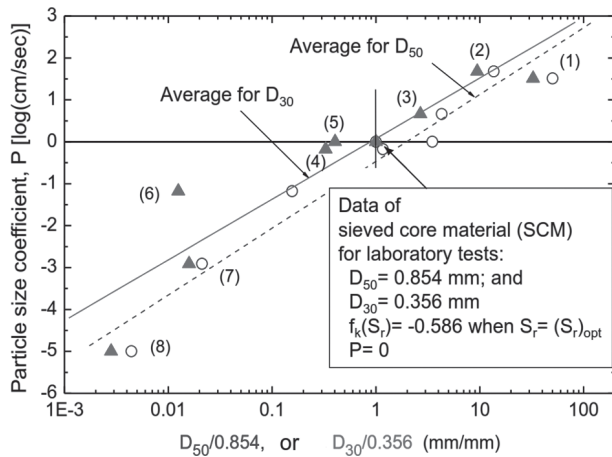
Fig. 6 – Particle size coefficient, P (Tatsuoka 2015).
Fig. 6 – Coefficiente P della dimensione delle particelle (Tatsuoka 2015).

Fig. 7 – Function representing the dependence of k on the saturation degree (Tatsuoka 2015, SCM Miboro Dam)).
Fig. 7 – Funzione che rappresenta la dipendenza di k dal grado di saturazione (Tatsuoka 2015, SCM Miboro Dam).

specimens with a compaction degree very close to the optimum value exhibit the lowest permeability. At the same time the permeability decreases with an increase of the compaction degree. More specifically, these observations are true for the whole range of applied stresses in the case of 808I soil (w_{opt} = 11.5 %). As for the TC soil (w_{opt} = 10.2 %) the above mentioned effects are evident mainly at low consolidation stresses. Apart the above observations, the effect of compaction degree (and consequently of initial water content) on k seems more complicated and needs additional considerations.

A comprehensive predictive model for k of compacted soils was proposed by Tatsuoka [2015]. The Tastuoka's model is based on the experience of more than forty years in Japan and worldwide. More specifically, it is based on the following experimental observations:

– the saturated coefficient of hydraulic conductivity (k) for a given soil and a given range of the saturation degree linearly decreases with the dry density in a semi – log scale (Fig. 5a);

– the slope of the above relationship between log(k) and r_d is constant and equal to -5.02. The saturation degree during compaction does not affect such a constant (Fig. 5a);

– the effect of the saturation degree during compaction on k is very small or insignificant when Sr < 80% (Fig. 5a);

– the data presented in figure 5a are those of SCM soil (Sieved Core Material of Miboro dam) ;

– data shown in figure 5b [Giusti, 2017] confirms the Tatuoka's observations and refers to 808I soil. It is worth noting to remark that the figure shows the saturated permeability as a function of the dry density. Different symbols are used for different initial degrees of saturation.
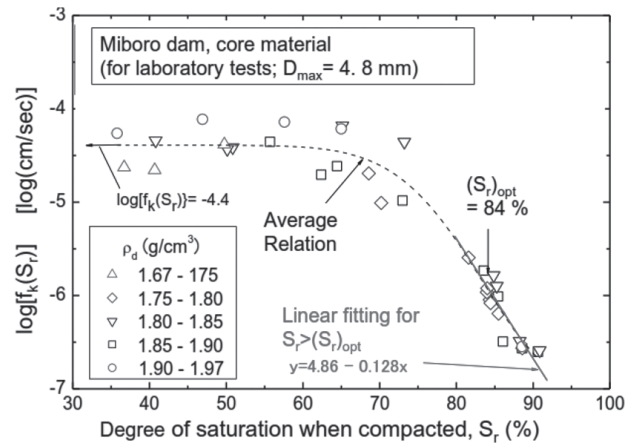
Based on the above observations, Tatsuoka [2015] proposed the following equation to predict the permeability:

$$Log(k)=Logf_k(S_r)+5.02\cdot(1.872-\mathrm{r}_d/\mathrm{r}_w) \qquad (2)$$

where: $Logf_k(S_r)$ represents the dependence of k on the degree of saturation at the end of compaction; the term $5.02\cdot(1.872-\mathrm{r}_d/\mathrm{r}_w)$ represents the dependence of k on the dry density.

Tatsuoka [2015], thanks to a huge amount of experimental data, proposed the following relationship for the term $Logf_k(S_r)$ (Eq. 2):

$$Logf_k(S_r)= P+Log[f_k(S_r)]_{SCM} \qquad (3)$$

where: the particle size coefficient P can be obtained from data shown in figure 6 and the function $Log[f_k(S_r)]_{SCM}$ is shown in figure 7.

Figure 8 compares the experimental results (808I soil) with the proposed model [Giusti 2017]; the factor P has been evaluated considering D_{30} = 0.02 mm, therefore P = -1.6 (Fig. 6). The Tatsuoka's predictive model fits very well the experimental results that were obtained for 808I soil during the present research. The variability, for each sample, in figure 8 is due to the effect of the vertical consolidation stress during oedometer tests. More specifically, the Figure shows the saturated permeability vs. the initial degree of saturation. The final degree of saturation is also known and equal to 100%. On the other hand, the empirical assessment of the degree of saturation during the various consolidation steps is not possible. It was assumed a complete saturation after the first measurement of k at a vertical consolidation stress of 12.5 kPa.
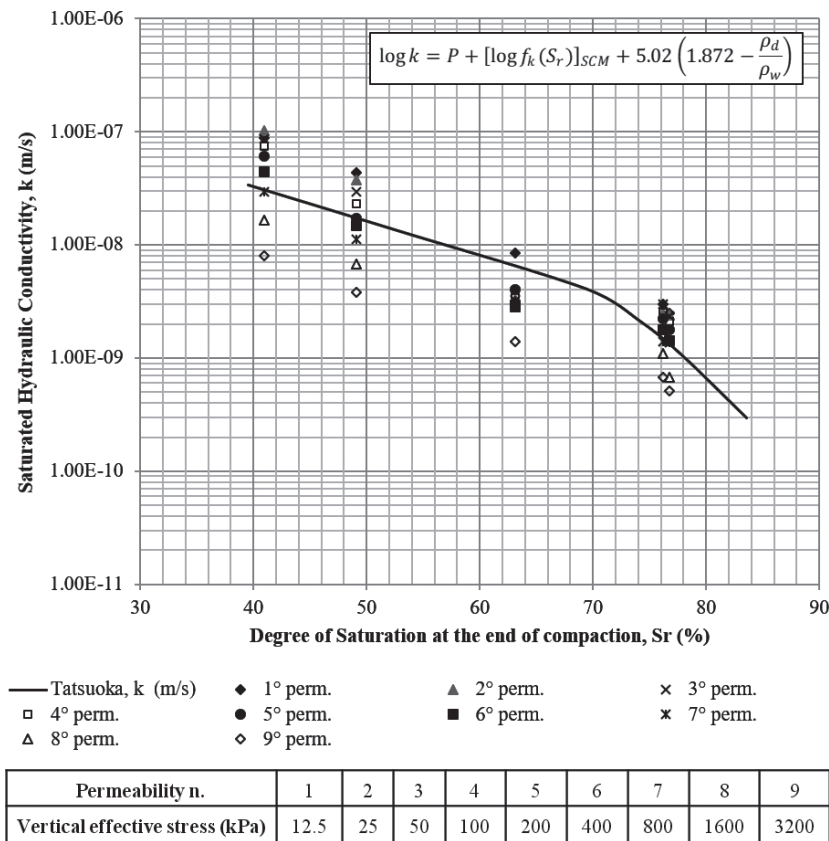
$$\log k = P + [\log f_k(S_r)]_{SCM} + 5.02\left(1.872 - \frac{\rho_d}{\rho_w}\right)$$

—— Tatsuoka, k (m/s)	◆ 1° perm.	▲ 2° perm.	✕ 3° perm.
□ 4° perm.	● 5° perm.	■ 6° perm.	✱ 7° perm.
△ 8° perm.	◇ 9° perm.		

Permeability n.	1	2	3	4	5	6	7	8	9
Vertical effective stress (kPa)	12.5	25	50	100	200	400	800	1600	3200

Fig. 8 – Comparison between the experimental k values (808I soil) and the Tatsuoka's model (Giusti 2017).
Fig. 8 – Confronto tra i valori sperimentali di k (terreno 808I) e le previsioni ottenute con il modello di Tatsuoka (Giusti 2017).

4. Triaxial Test Results and Effective Strength Parameters

The effect of suction on the effective strength parameters of soils is well documented in literature by experimental results. Alonso *et al.* [2010] (see also Alonso *et al.* [1990]) developed a predictive model for the effective strength parameters of partially saturated soils. On the other hand limited evidences are available in the case of compacted partially saturated soils (see as an example Varsei *et al.* [2016]). In the present work, triaxial tests were performed on specimens compacted at different compaction degree and at the optimum water content. The compaction degree is defined as the ratio of the dry density to the maximum dry density. Different compaction degrees at the same water content were obtained by controlling the density of each layer and using different compaction energy. Therefore the w-r_d data do not lie on the same compaction curve. After compaction, the samples were extracted from the Proctor mold and specimens were trimmed and transferred into the triaxial cell according to the usual procedures. Such operations caused a certain disturbance and the initial void ratio of the specimen does not coincide with that of the sample.

As far as the TC soil was concerned, three different types of triaxial tests were performed:

– compression loading triaxial tests on specimens compacted in the Proctor mould at different compaction degrees (about 80 and 90%). The porous stones and filter paper were dry and the specimens had a water content of about 11-12% (i.e the optimum water content). Specimens were isotropically consolidated and sheared under compression loading with free drainage (CID);

– compression loading triaxial tests on specimens reconstituted in the proctor mould at different compaction degrees (about 80 and 90%). The specimens and testing apparatus were saturated with check of B parameter as usually and then sheared in compression loading with closed drainage (CIU);

– compression loading triaxial tests on specimens obtained from block samples. Two block samples were retrieved from the first metre of a levee that had been constructed by using TC soil. The porous stones and filter paper were dry and the specimens had a variable water content. Specimens were isotropically consolidated and sheared under compression loading with free drainage (CID). Other specimens, from block samples, were saturated, with check of the B parameter as usually, and then sheared in compression loading with closed drainage (CID).

Tab. 3 – TC samples compacted at 80 and 90 % of the optimum dry density. Compression loading TX CID test results (partial saturation).

Tab. 3 – *Campioni TC compattati all'80% e al 90% della densità ottima. Risultati della prova di compressione per carico TXCID (parziale saturazione).*

γ (kN/m³)	Wi (%)	σ'₁F (kPa)	σ'₃F (kPa)	s' (kPa)	t (kPa)
17.54	11.04	43.96	0	21.98	21.98
16.97	11.47	115.36	40	77.68	37.68
17.51	11.49	267.01	80	173.505	93.505
17.13	11.46	59.11	0	29.555	29.555
17.04	11.47	135.81	40	87.905	47.905
17.23	10.94	294.58	80	187.29	107.29
19.46	11.46	86.82	0	43.41	43.41
19.33	11.46	242.2	40	141.1	101.1
19.12	11.34	350.3	80	215.15	135.15

Tab. 4 – TC samples compacted at 80 and 90 % of the optimum dry density. Compression loading TX CIU test results (saturated condition).

Tab. 4 – *Campioni TC compattati all'80% e al 90% della densità ottima. Risultati della prova di compressione per carico TXCIU (condizione di saturazione).*

γ (kN/m³)	Wi (%)	σ'₁F (kPa)	σ'₃F (kPa)	s' (kPa)	t (kPa)
16.58	11.82	110.3	23.8	67.05	43.25
16.97	11.7	160.6	50.1	105.35	55.25
17.04	11.8	277.4	87.5	182.45	94.95
19.7	12.3	68.3	16.5	42.4	25.9
20	12.05	101.1	25.1	63.1	38
20	12.01	195.6	53.9	124.75	70.85

Tab. 5 – TC block samples. Compression loading TX CIU and TX CID test results.

Tab. 5 – *Campioni cubici TC. Risultati delle prove di compressione per carico TX CIU e TX CID.*

γ (kN/m³)	Wi (%)	σ'₁F (kPa)	σ'₃F (kPa)	s' (kPa)	t (kPa)
18.41	17.58	84.86	20.36	52.61	32.25
19.09	19.62	124.69	28.89	76.79	47.9
19.10	16.39	271.92	64.12	168.02	103.9
18.49	18.49	138.53	35.13	86.83	51.7
19.23	17.65	221.94	51.44	136.69	85.25
19.94	11.8	377.94	107.44	242.69	135.25
18.21	20.68	61.50	0	30.75	30.75
18.41	21.13	150.98	40	95.49	55.49
18.28	23.62	302.51	80	191.25	111.25
18.27	17.66	48.10	0	24.05	24.05
19.70	17.80	135.03	40	87.51	47.51
19.90	16.62	80.40	0	40.20	40.20
18.80	16.65	75.50	0	37.75	37.75
18.55	15.87	144.08	40	92.04	52.04
19.49	14.89	150.60	40	95.30	55.30

Tab. 6 – Mohr-Coulomb strength parameters.

Tab. 6 – *Parametri del criterio di resistenza di Mohr-Coulomb.*

Soil type	Test Conditions	c' (kPa)	φ' (°)
TC	Compacted 80%, Partially saturated (CID)	9.6	29.9
TC	Compacted 90%, Partially saturated (CID)	25.7	32.5
TC	Compacted 80% and 90%, fully saturated (CIU)	8.6	29.0
TC	Undisturbed specimen (block sample), 80 - 90%, (CIU and CID)	12.6	30.9
808I	Compacted 90%, fully saturated (CIU)	10.4	42.2

Figure 9 shows an example of undrained stress paths for the case of undisturbed (block samples) TC specimens. The whole test results are summarised in tables III to 6 and figures 10 to 12. The upper part of table V concerns the CID tests on undisturbed specimens (block samples), while the lower part summarizes the results of CIU tests. It is worth noting that the dry unit weight of the intact TC soil, at the Modified Proctor optimum, is equal to 18.54 kN/m³.

It is possible to comment the results in the following way (all comments refer to peak condition):
– compacted specimens with a compaction degree of 90% and a water content equal to about the optimum water content exhibit a cohesion of up to 26 kPa and a friction angle of 32.5°;
– compacted specimens with a compaction degree of 80% and a water content equal to about the optimum water content exhibit a cohesion of up to 10 kPa and a friction angle of 30°;
– compacted and saturated specimens with a compaction degree of 80 and 90 % exhibit the same strength envelope. The obtained strength parameters are the same of compacted specimens with a compaction degree of 80% but tested under the condition of partial saturation;
– as for the block samples, the strength parameters apparently exhibit some differences with respect to those of the compacted specimens, but in practice the two strength envelopes coincide. It is worth noting that block samples have a coarser fraction that has been eliminated in the case of compacted specimens and moreover also the optimum density is different;
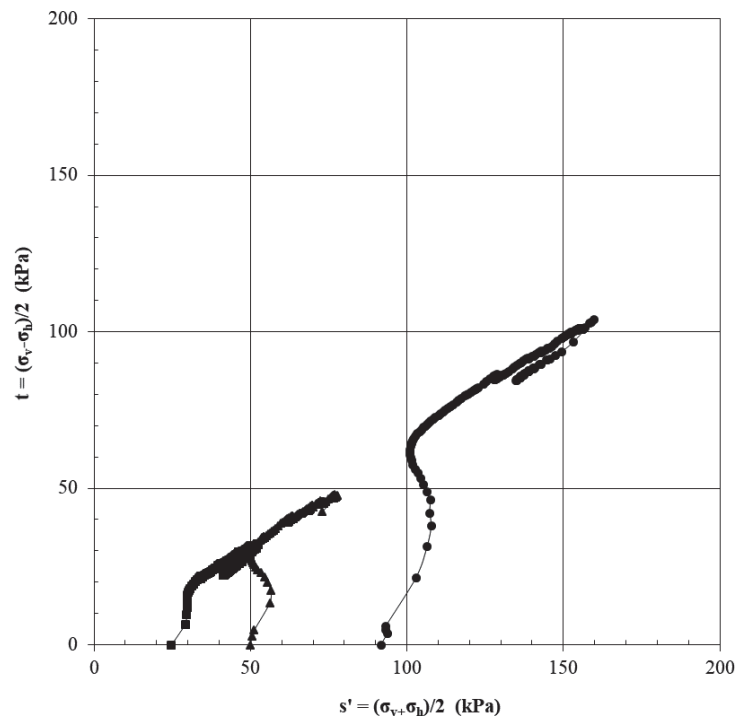
Fig. 9 – Stress-paths - Compression Loading Triaxial tests on saturated undisturbed specimens (CIU).
Fig. 9 – Percorsi di carico – Prove triassiali di compressione per carico su provini indisturbati saturi (CIU).

– as for the saturated specimens (compacted or from block samples) it would be expected a curve envelope with zero cohesion. This is not the case. Different explanations are possible: a) strength – envelope curvature appears at very low confining stresses (unfortunately with the available equipment, it is not possible to maintain very low confining stresses); b) trimming produces a very high disturbance which delete the benefit of compaction; c) compaction - induced co – action causes a permanent cohesion which cannot be deleted by the full specimen saturation as well as by disturbance during transferring and specimen trimming.

In conclusion, compacted soils (at least for a compaction degree between 80 and 90%) exhibit certain cohesion. The highest values of the cohesion are observed in the case of partially saturated
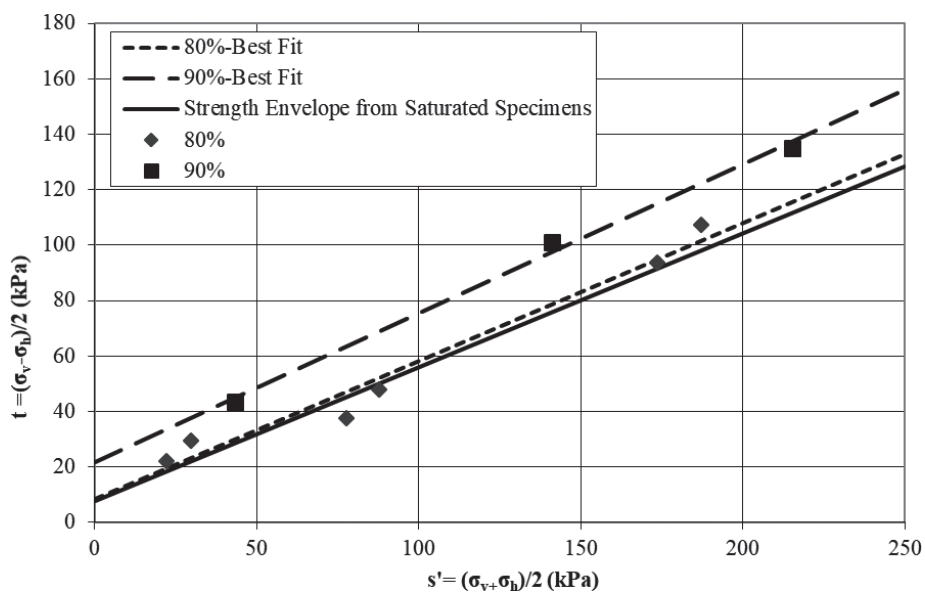

Fig. 10 – Compression Loading Triaxial tests on partially saturated compacted specimens (CID).
Fig. 10 – Prove triassiali di compressione per carico su provini compattati parzialmente saturi (CID).
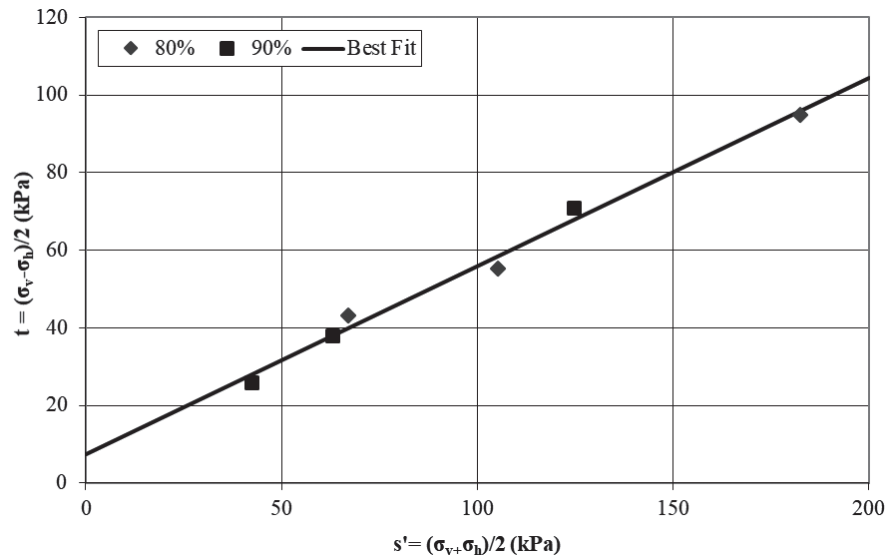
Fig. 11 – Compression Loading Triaxial tests on fully saturated compacted specimens (CIU).
Fig. 11 – Prove triassiali di compressione per carico su provini compattati saturi (CIU).
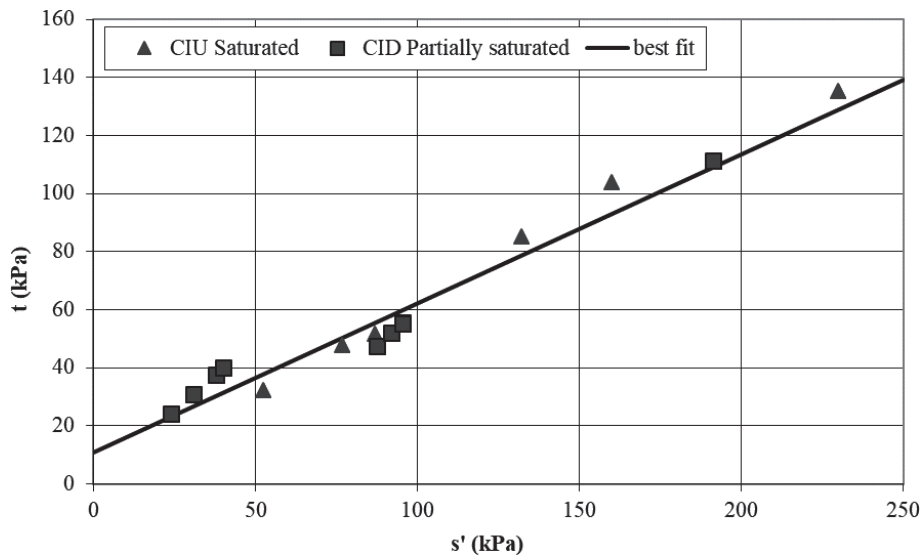

Fig. 12 – Compression Loading Triaxial tests on undisturbed specimens – Block Sample (CIU and CID).
Fig. 12 – Prove triassiali di compressione per carico su provini indisturbati – Campione Cubico (CIU e CID).

specimens (optimum water content) and compacted at 90% of the optimum. As for the friction angle, in practice it seems not too much affected by the test conditions (water content, compaction degree).

5. Conclusions

This experimental investigation has shown that both the saturated coefficient of hydraulic permeability and the apparent cohesion depend on the compaction degree and water content (or saturation degree) during compaction. Therefore, it could be possible, in principle, to infer these parameters (for a giv-

en earthwork) from the knowledge of the compaction degree and water content. It is worth noticing that the dependence of the apparent cohesion on the compaction degree is more pronounced in the case of partial saturation (suction effects). Therefore, when assessing the safety factor of any earthwork it may be of fundamental importance to evaluate (control) the compaction degree and in situ water content.

Acknoweledgements

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Parametri di Resistenza e Permeabilità di Terreni Limosi e Sabbiosi Compattati ed in Condizioni di Parziale Saturazione

Sommario

La nota tecnica illustra alcuni risultati sperimentali relativi alla determinazione dei parametri di resistenza in termini di sforzi efficaci (c' – φ') e del coefficiente di conducibilità idraulica in condizioni sature (k). I materiali sottoposti a prova sono stati utilizzati per lavori di adeguamento di argini esistenti. I parametri di resistenza sono stati ottenuti da prove triassiali di compressione per carico eseguite in celle convenzionali. I provini sono stati compattati a differenti percentuali della densità ottima e al contenuto d'acqua ottimo. I parametri di resistenza sono stati determinati anche in condizioni di completa saturazione.

Il coefficiente di conducibilità idraulica è stato ricavato nell'apparecchio edometrico sia da misure indirette (Cv) sia da misure dirette (prove a carico variabile).

Le prove hanno evidenziato la dipendenza dei parametri di resistenza e di k dal grado di compattazione e dal contenuto d'acqua (effetto della suzione).