Least-Squares evaluation of DMT dissipation test data – some preliminary results

Emőke Imre[1*], *Diego* Marchetti[2], *Miklos* Juhasz[3], *Lachlan* Bates[4] and *Stephen* Fityus[5]

[1]*Óbuda University, Hungary* [2]*Studio Prof. Marchetti Italy* [3]*Debrecen University, Hungary* [4]*University of Newcastle, Newcastle, Australia,* [5]*Douglas Partners, Newcastle, Australia.*
** Corresponding author: imre.emoke@uni-obuda.hu*

ABSTRACT

The Flex method does not work if the DMTA total stress dissipation curve is non-monotonic or has no inflexion point. To overcome the problems, various versions of a mathematically precise DMTA total stress dissipation test evaluation method are suggested to be considered. These versions can be classified (i) on the basis of the measured data, as only total stress-based and both total stress and pore water pressure-based methods, (ii) on the basis of the dimension of the model, as oedometer, cylindrical and spherical coupled consolidation models, (iii) as linear models or models with relaxation. In this paper some DMTA dissipation tests made at test sites in Szeged and Ballina test sites are evaluated and the *c* values identified with various methods are started to be compared. According to the first results, an evaluation method, based on the oedometer relaxation test model and both total stress and pore water pressure data, provided *c* values about 3 times larger than the Flex method (and could be used to evaluate non-monotonic data). The use of pore water data – generated or measured as C readings – decreased the parameter error.

Keywords: coupled consolidation, point-symmetric, pore water dissipation, total stress dissipation.

1. Introduction

The CPT dissipation tests entailing various stress variables (u, total normal stress, f_s with a sensor of 350 cm^2 and q_c , DMT A or C pressure) are summarized in Table 1. The similar, oedometer dissipation tests are shown in Table 2. Some of them are not evaluated at present.

The phenomena taking place in the soil are as follows: the dynamic - static transition, consolidation after penetration and, during this, there is a redistribution of the equipment residual stresses, caused by penetration, being different in granular and plastic soils.

The aim of the research to implement mathematically precise methods so that more information could be drawn from the data. In this paper the DMTA dissipation test is considered and the consolidation is modelled including a time dependent constitutive law (resulting in total stress relaxation).

Since the model pile is a kinematic constraint, coupled theory is needed. All linear, pointsymmetric coupled consolidation models are similar, with analytical solution depending on the space dimension (Imre et al, 2021-2022). The boundary condition within the soil mass can be kinematic or static type, the related models are called as coupled 1 and 2 models (see 2.3).

The evaluation is based on three simulated variables: u, total normal stress, effective normal stress. These are simulated by the coupled consolidation model 1 with three subtypes (oedometer, cylindrical and spherical, the difference is very small); and various displacement domain sizes (oedometer- 2 cm, cylindrical – 63 cm, these are linked by the extended model law, see 2.3).

In this work some preliminary results are presented, using the foregoing options for DMTA and u2 tests. The identified *c* is compared at two testing sites (Szeged in Hungary and Ballina in Australia).

DMTA dissipation test means that the A pressure is measured before the standard A reading. It can be noted that the DMT A pressure is considered as a radial total stress, while it is actually not exactly a total stress rather a fluid pressure as follows (Monaco, 2021).

The concept of A reading is presented in the companion paper and also summarized here as follows. electric contact to the sensing disc and the membrane of the blade is provided by the steel spring and steel cylinder, they increase the hydraulic pressure to the membrane. When the internal oil pressure equals the external soil pressure, the membrane lifts-off from its seat and starts to expand laterally.

When the membrane has expanded of 0.05 mm at its centre, the electric contact between the membrane and the sensing disc is deactivated and the pressure is recorded and assigned to the *A*-pressure reading.

The pressurization rate is regulated so that the *A*-pressure reading is obtained in approximately 15 s after reaching the test depth (i.e. start of pressurization), with ± 5 s tolerance, according to the standards of the traditional pneumatic dilatometer (ASTM D6635-15, ISO 22476-11:2017(E)).

The B reading is at a fix displacement (typically 1.10 mm), then the membrane displaces back, and the C reading is taken similarly to the A reading. The only difference is that the hole made by the blade may stable due to silo effect and the C reading may reflect the excess pore water pressure.

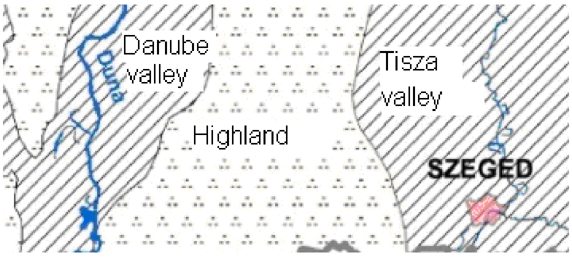


Figure 1. The Duna -Tisza river environment, with upwards (spots) and downwards (lines) seepage regimes, with the Szeged environment (pink) where upwards saline groundwater flow from lower marine clay occurs spot-like (Simon 2010).

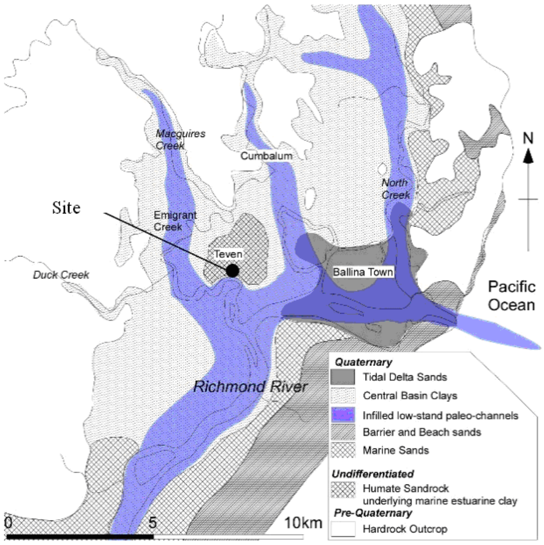


Figure 2. Ballina test site, Site Plan and Engineering Geology.

Table 1. Types of dissipation tests made with CPT

Measured variable	Notation
Pore water pressure	CPTu
Total stress	CPT-PSL, DMTA or DMTC
Shaft and tip resistance	CPT-fs and CPT-q_c

Table 2. Oedometer dissipation tests, boundary condition

Test	boundary condition
(Multistage) relaxation test (MRT)	displacement
(Multistage) compression test (MCT)	total stress

2. Materials and Methods

2.1 Szeged test site, Hungary

In Szeged City, on the western part of the Tisza river (Fig. 1), the following layers can be found: upper yellow lacustrine clay (crust), silty inclusion, lower yellow lacustrine ~NC clay and a blueish fresh-water lightly OC deposit, which then extends to several hundred meters. Statistically analysis of the data of 2000 earlier geotechnical laboratory tests by Rétháti and Ungár 1978, confirmed by a second statistical analysis with new tests (Imre 1995), indicating some local saline alteration spots. Later a specific site (ELI) was investigated down to 70 m, the data of which are used here. The lists of previous *u2* and new DMTA dissipation test data used here are shown in Tables 3, 4.

2.2 Ballina site, Australia

At the tested Australian estuary site (Table 5), a sand layer separates the normally consolidated (NC) upper Holocene from the over consolidated (OC) lower Pleistocene estuarine and deeper alluvial clays (Bishop 2009). The previous *u2* tests used here are listed in Table 5, and these are compared with a DMTA dissipation test made at 7 m depth.

Table 3. *u2* dissipation tests Szeged (Imre et al. 2016)

Depth [m]	likely soil type	~t_{50} [min]	~t_{90} [min]
50	sand	0.05	4
40	silt	1.97	7
22	uppersaline clay	0.78	22.5
30	lower clay	20.05	122

Table 4. Newly measured DMTA dissipation tests in Szeged. (Marchetti, 2020)

Depth [m]	t_{diss} [s]	Penetrometer
5	105	not released
11.00	105	not released
14.00	105	not released
17.00	480	not released
17.20	900	not released
21.00	105	not released
24.00	6120	Released

Table 5. *u2* dissipation tests Ballina (Imre et al. 2022)

test	Depth [m]	soil type	~t_{50} [min]
1	4	clay	>100
2	5	clay	>100
3	6	clay	>100
4	7	clay	>100
5	8	clay	>100
6	9	clay	>100
7	10	clay	>100
8	11	quick clay	~5
9	12	granular	~0.5
10	13	quick clay	5
11	14	Granular	<10

2.3 Models

2.3.1 General

The general solution of the coupled cylindrical consolidation model is well-known (see eg., Randolph *et al*, 1979 or Imre *et al*, 2010) and, from this, two solutions can be determined by inserting two different boundary conditions Imre et al. (2021-2022). The "coupled 1" (Imre *et al*, 2010) and "coupled 2" (Randolph *et al*, 1979) cylindrical consolidation models have constant displacement and constant total stress boundary conditions at r_1, resp.; the common boundary condition is the zero displacement at r_0, zero pore water pressure at r_1, and impermeable boundary at r_0.).

The solution of the coupled 1, cylindrical consolidation model at r_0 for the transient part of the radial total stress and pore water pressure is as follows:

$$\sigma^t(t,r_0)=\sum_{k=0}^{\infty}\lambda_k C_k e^{-\gamma_k^2 \cdot c_h \cdot t}\left\{-[I_0(\lambda_k r_1)+\mu_k Y_0(\lambda_k r_1)]\right\} \tag{1}$$

$$u(t,r_0)=\sum_{k=0}^{\infty}\lambda_k C_k e^{-\gamma_k^2 \cdot c_h \cdot t}\left\{\begin{matrix}[I_0(\lambda_k r_0)+\mu_k Y_0(\lambda_k r_0)] \\ -[I_0(\lambda_k r_1)+\mu_k Y_0(\lambda_k r_1)]\end{matrix}\right\} \tag{2}$$

where I_0 and Y_0 are Bessel functions of the first and second kind, λ_k, μ_k are the roots of the boundary condition equations (depending on r_1 and r_0); C_k (k=1, ∞) coefficients are determinable from the initial displacement distribution, and c_h is coefficient of consolidation. The coupled 2, cylindrical consolidation model has zero solution for the transient total stress at r_0 and, as a result, in the pore water pressure solution second term in the bracket in Eq 1 is zero

$$u(t,r_0)=\sum_{k=0}^{\infty}\lambda_k C_k e^{-\gamma_k^2 \cdot c_h \cdot t}[I_0(\lambda_k r)+\mu_k Y_0(\lambda_k r)] \tag{3}$$

The solution of the oedometer model differ in the index of Bessel function only (Imre et al, 2021):

$$\sigma(t)=-\sum_{i=1}^{\infty}\varphi_i e^{-i^2\pi^2 T}+\sigma_\infty \tag{4}$$

$$u(t,y)=-\sum_{i=1}^{\infty}\varphi_i[\cos(y(i\pi/H)-1]\ e^{-i^2\pi^2 T} \tag{5}$$

where $T = ct/H^2$ is the time factor, c is the coefficient of consolidation, ϕ_i are Fourier coefficients related to the initial condition, H is the half-width of a double-drained sample (length between the boundaries of the model).

2 notes can be made. Due to the zero total stress drop, the coupled 2 model does not describes even qualitatively the total stress dissipation test result. The time factor of the oedometer model was extended to larger dimensions using $T = ct/(r_1^2 - r_0^2)$.

2.3.2 Suggested evaluation models

The approximate solution of the model with time dependent constitutive law at the shaft consists of the solution of the linear consolidation model plus an empirical relaxation equation as follows:

$$\sigma_r(r_0,t)=\sigma_r^c(r_0,t)+\Delta\sigma_r^r(r_0,t) \tag{5}$$

where superscript c and r indicate consolidation and relaxation, respectively. It is assumed that the relaxation term can be described as follows:

$$\Delta\sigma^r(t)=-s\,\sigma(0)\frac{1}{1-s\,b}\log\left[\frac{t+t_1}{t_1+t_3}\right];t>t_1+t_3 \tag{6}$$

where s is the coefficient of relaxation, t_1 the delay time, t_3 and b=log((t_1+t_3)/t_1) are parameters describing the pause of relaxation in case of partial unloading at the displacement boundary (Imre et al. 2009). Value of t_3 and b are zero if no partial unloading takes place.

(Partial unloading may occur since the diameter may decrease due to the elastic displacement increment of the equipment during the stress release).

The qualitative behaviour is as follows. The solution of the suggested coupled 1 consolidation model changes by the initial value of the transient component until infinite elapsed time (Imre *et al*, 2010). The transient part of the total stress at the pile shaft is equal to the initial span-wise averaged pore water pressure (mean on the displacement domain).

For a positive value of this mean, the total stress will decrease by this value. The relaxation may cause further total stress decrease.

Being similar, within the coupled 1 model family the analytical solutions of the coupled consolidation models can be interchanged (ie., solutions for m = 1, m = 2 and m = 3 can be interchanged) in the Least Squares model fitting algorithm, and the extended time factor can be used $T = ct/(r_1^2 - r_0^2)$.

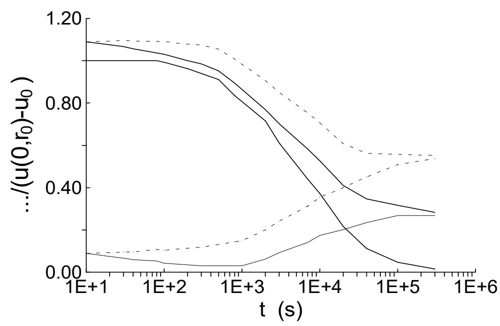


Figure 3. Precise total stress model response (dashed lines: consolidation, dashed line: consolidation and relaxation.

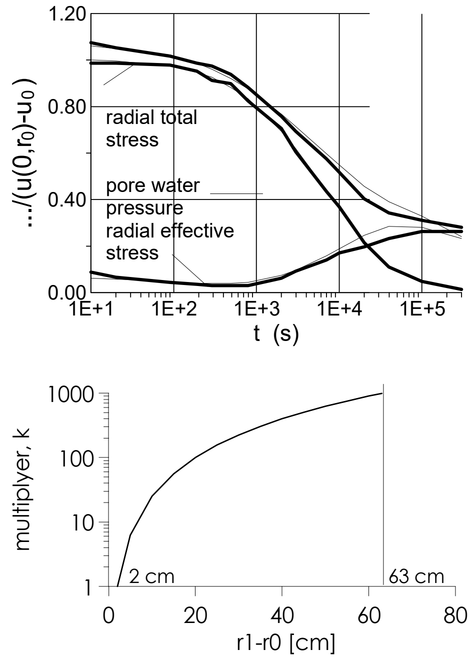


Figure 4. (a) Evaluation of the piezo-lateral stress cell test data with the oedometer model including relaxation modeling. (b) The (Terzaghi's) model law constant k law for the coefficient of consolidation $c_{cyl} = k\,c_{oed}$ (with oedometer model r_1-r_0=2cm, with cylindrical model where r_1-r_0=63cm).

2.4 Least Squares evaluation methods

The LS evaluation methods are described in Imre et al. (2013) and in Imre et al. (2021). The main considerations are the uniqueness and error of the solution. The non-linear model part may control the numerical work.

2.4.1 Pore water pressure dissipation test

The pore water pressure dissipation tests were evaluated using Methods I and II (slow and fast methods), which were Least Squares fittings of the solution of the cylindrical coupled 1 consolidation model (Eq 1, see Imre et al. 2010 to 2022). The two methods (slow and fast) do not need Ir and have built-in displacement domains. Method I, has 200 built-in coefficients for each of the parametric shape function of the initial pore pressure distribution.

The composite initial condition shape functions have four integer, non-linearly dependent parameters (s, n_1, n_2, *sign*) to describe both the negativity and the widths of the shear zone (with parameters n_1 and s, resp.), and the positivity outside the interface shear zone (with parameter n_2). The shape functions vary over a wide range; the mirror images are related to the negative multipliers, while c is identified.

In the Method II, the k coefficients of the first k terms of the infinite series analytical solution are identified.

The resulting initial condition is limited by the number of terms in the set (for $k=1$, it is monotonic; for $k>1$ it is non-monotonic). Less than about 5 terms are used in practice since numerical problems occur otherwise. The C_i (i=1..k) coefficients are identified, as linear model parameters. If the slow method has a non-unique solution, the fast $k=1$ method can help to select the good solution.

2.4.2 DMTA total stress dissipation test

According to the previous research results, there are some issues with the parameter error; the inverse problem may generally be well-defined only on the condition that both total stress and pore water pressure data are used for the model fitting (Imre et al 2021-2022).

Since the analytical solutions can be interchanged, it was reasonable to us the simplest oedometer relaxation test model to evaluate the DMTA dissipation tests (method M1). Method M1, suggested for the evaluation of DMTA dissipation tests, was as follows.

- at first some pore water pressure data were derived from the DMTA total stress data using the analytical relationship of Eqs 6, 7 (Imre et al. 2011).
- then the oedometer relaxation test model was fitted simultaneously on the total stress and pore water pressure data mathematically precisely and
- the identified c was modified by the model law (Eqs 3 to 4, Figs 3,4).

The initial condition was identified using the following parametric shape function:

$$u(0,y)=A\,y^3+B\,y^2+C\,y \qquad (8)$$

where A, B and C are real valued initial condition parameters, with linear dependence.

The model was linear in the simplest form. The non-linear behavior was approximated by applying a relaxation part-model (Eqs 5 to 6, Figs 3, 4). The so-estimated pore water pressure data were also evaluated with the cylindrical consolidation model.

It can be noted that the cylindrical model can also be used to evaluate the total stress data alone, but the inverse problem has generally non-reliable solution with large parameter error (Imre et al. 2021-2022).

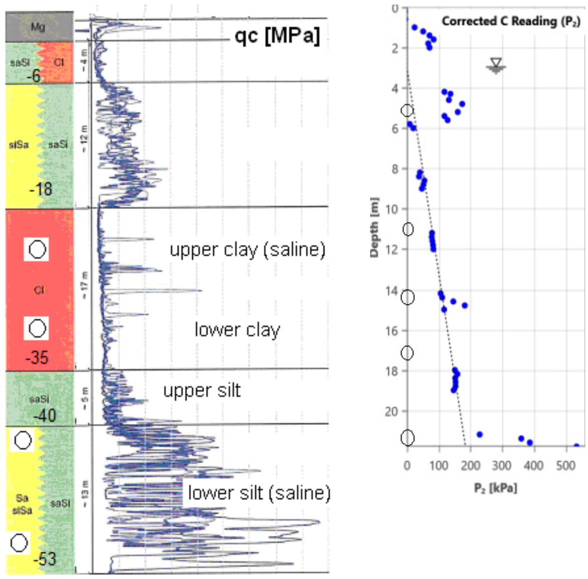


Figure 5. (a) Mean Szeged CPT profile indicating location of the *u2* dissipation tests. (b) DMT estimation of u_0 at Szeged, indicating DMTA locations.

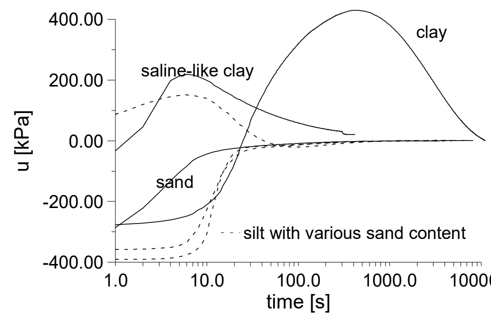


Figure 6. Pore water pressure dissipation curves at Szeged.

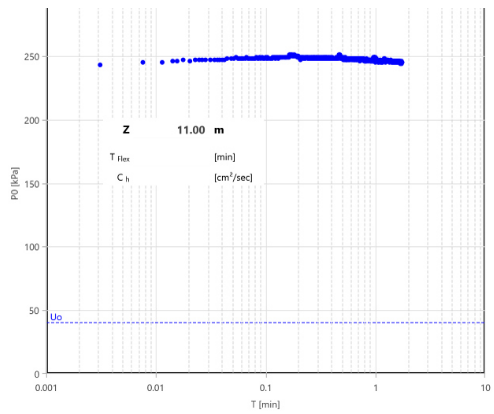


Figure 7. DMTA dissipation curve at Szeged, sand.

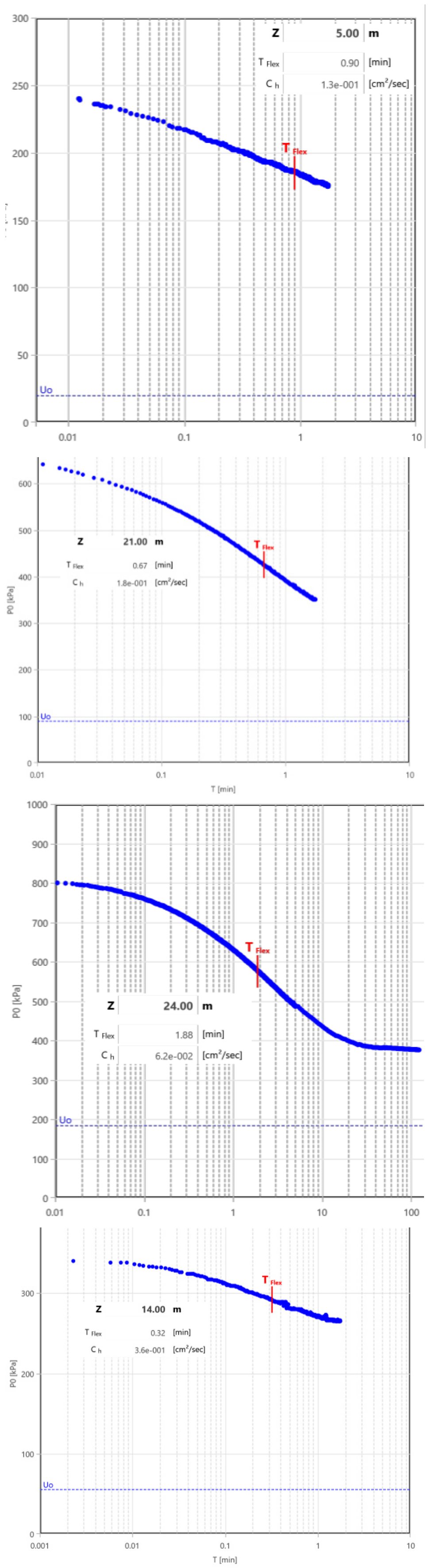


Figure 8. DMTA dissipation curves at Szeged, plastic soils.

An oedometer relaxation test model was fitted simultaneously on DMTA total stress and some estimated pore water pressure data. Then the identified c was modified on the basis of the different sizes of the oedometer sample and the displacement domain of the in situ test, by using a model law (with multiplier of $k=(R_1-R_0)^2/(r_1-r_0)^2$, with oedometer model constant $r_1-r_0=2$ cm, with cylindrical model constant $R_1-R_0=63$ cm). The estimated u data was determined approximately since the final total stress parameter was not identified.

2.5 One-point evaluation

2.5.1 Flex method

Using total stress data measured in DMT, the coefficient of consolidation c is determined with the following one-point fitting equation (Method IV):

$$c_{DMT} = \frac{F}{t_{50}} \tag{9}$$

where F is between 7 and 12 cm^2 (Totani et al. 1998).

2.5.2 Teh-Houlsby method

Method III (the one of Teh et al. 1988) was based on a two-dimensional model and a fitting at the t_{50} determined according to Sully et al. (1997).

The measured and the theoretical dissipation curves are fitted in one point. The coefficient of consolidation c_{T-H} is determined by Lunne et al. (1997):

$$c_{T-H} = \frac{T_{50}^{T-H}}{t_{50}} r_0^2 \quad I_r^{\,1/2} \tag{10}$$

where r_0 is radius of the rod, t_{50} is measured time for 50% dissipation, I_r is rigidity index, T^{T-H}_{50} is a time factor. The initial pore pressure distribution is determined by the strain path method for undrained penetration).

The evaluation with this is non-straightforward and does not work when t_{50} is less than about 50 s (ie. partial drainage influences the initial condition), if the dissipation curve is non-monotonic and if the dissipation curve is partly negative. The method has embedded initial conditions (undrained penetration). The t_{50} determined according to Sully et al. (1999). It is difficult to assign a value of Ir since the shear modulus decreases with strains by a factor of 20 or 30 (Mayne, 2007).

3. Results

3.1 Soil profile, dissipation tests, Szeged

The mean CPT and DMT profiles are shown in Fig. 5. The dissipation tests are shown in Figs. 6 to 8. The $u2$ dissipation curves (Fig. 6) were non-monotonic in the NC clays (type III and IV). Comparing the various interpretations of the $u2$ and DMTA dissipation tests, results are as follows (Tables 6 to 8 and Figs. 9 and 10).

Table 6. Results of evaluation of u_2 dissipation tests, Method I

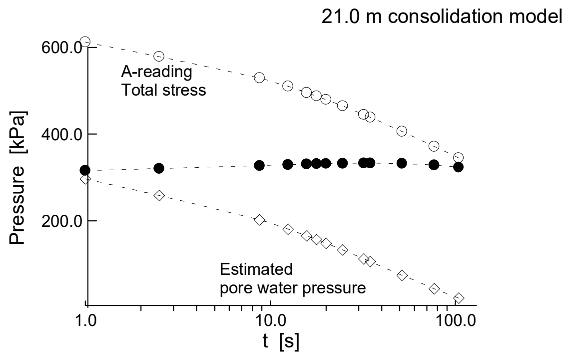
	Method I parameters			
	negativity	mean	width	c[cm^2/s]
sand	3	4		40
upper clay	1	2	7	0.5
lower clay	1	5	5	0.1
silt	1	5	7	20

Table 7. Evaluation of u_2 dissipation tests, Methods II, III

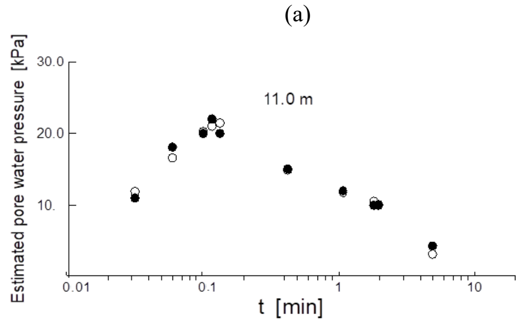
	Method II	Method III
layer	c [cm²/s]	c [cm²/s]
sand		
upper saline clay	3	0.5
lower clay	0.1	0.02
silt	20	-

Table 8. Results of evaluation of DMT dissipation tests

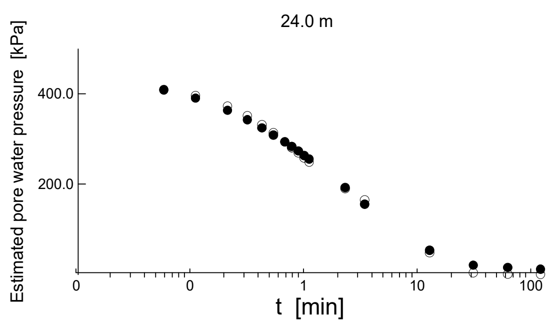
Test Method	DMTA M1	estimated u Method II	DMTA Flex
depth	c [cm²/s]	c [cm²/s]	c [cm²/s]
5 m	0.9	10	0.13
11 m		4	
14 m	1	10	0.36
21 m	0.5	7	0.18
24 m	0,1	0.7	0.062



(a)

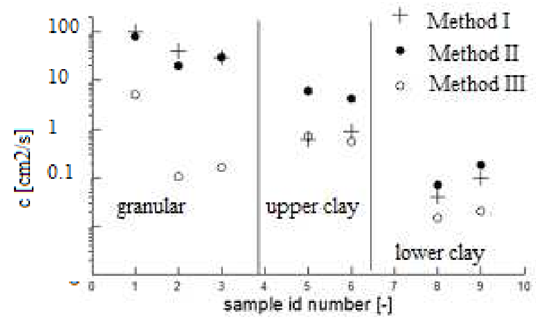


(b)

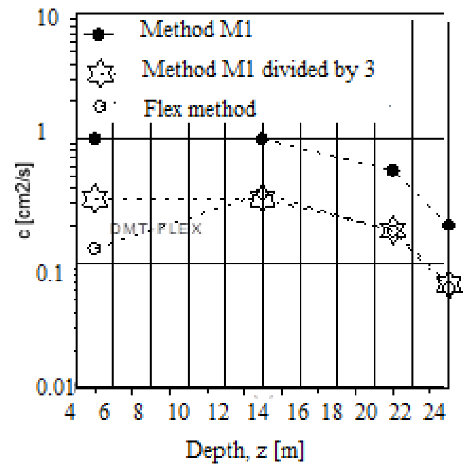


(c)

Figure 9. DMTA dissipation curve evaluation at Szeged, measured, estimated and fitted data. (a) 21 m, plastic soil, Method M1. (b) and (c) cylindrical model evaluation of the pore pressure u estimated by the M1 method.



(a)



(b)

Figure 10. Szeged (a) *u2*, comparing the results of Methods I, II and III. (b) DMTA, Comparing the result of M1 in plastic soil, there is about a factor 3 difference.

Concerning the *u2* pore water pressure dissipation test data, the coefficient of consolidation (c) result of the three methods in Szeged showed similar pattern in terms of soil type here and in the previous research (Fig. 10(a), Tables 6 to 8). The Flex gave slightly smaller values than Method I with *u2* data and similar values as Method III.

The M1 evaluation of DMTA was made in such a way that the model was fitted on DMTA total stress and estimated u data simultaneously, using oedometer relaxation test model. The u data were generated from A data such that the last total stress value was considered as the final total stress parameter. Then the model law was applied for the identified c. The u data were approximate in this preliminary work and were also evaluated by Method II. The estimated u data gave about 7 to 10 times larger c than Method M1.

According to the results shown in Fig. 10(b) and Table 8, the Flex method values were smaller than the M1 values by a factor of about 3. This result indicates that the M1 method can be used as an reliable method to substitute the Flex method.

3.2 Soil profile, dissipation tests, Ballina

The mean Ballina profile is shown in Fig. 11. From a geotechnical perspective, highly sensitive upper clays occur in locations where clays have remained saturated and normally consolidated but have been flushed by fresh water (Bishop, 2009).

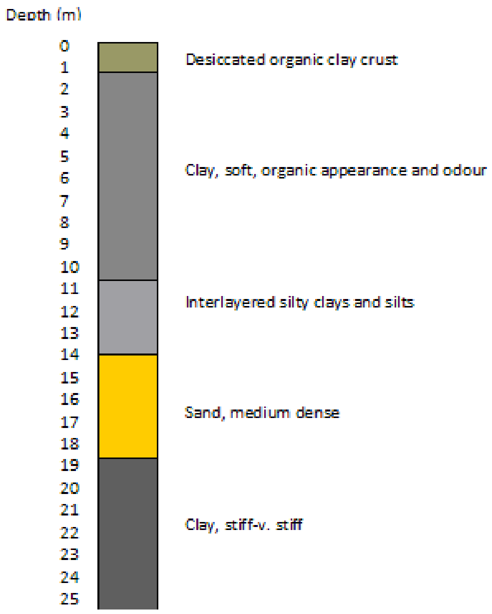


Figure 11. Typical Ballina profile.

Table 9. Ballina, results of evaluation of u_2 dissipation tests.

test	*h* [m]	Method II	Method I
		c [cm^2/s]	*c* [cm^2/s]
1	4	0.05	0.03
2	5	0.1	
3	6	0.03	
4	7	0.007	0.0005
5	8	0.05	
6	9	0.02	0.02
7	10	0.03	0.0007
8	11	0.9	0.009
9	12	20	4
10	13	0.8	0.009
11	14	1	

Table 10 Identified parameters. u_2 dissipation tests, Method I. Ballina

test	h [m]	negativity	mean	width	c [cm^2/s]
1	4	0	9	1	0.03
2	5	0	1	4	
3	6	1	0	5	
4	7	1	2	1	0.0005
5	8	0	1	1	
6	9	1	0	7	0.02
7	10	0	2	1	0.0007
8	11	0	1	4	0.009
9	12	1	2	2	4
10	13	1	1	4	0.009
11	14	1	1	7	

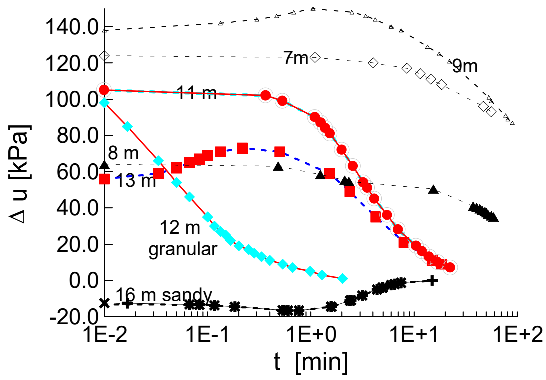


Figure 12. Measured *u2* dissipation curves.

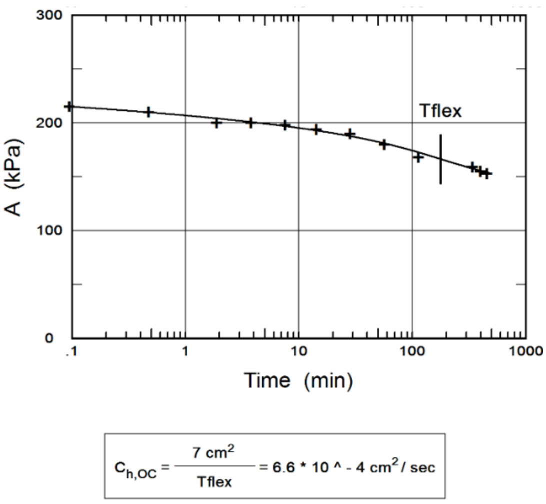


Figure 13. DMTA dissipation curves at Ballina, 7m depth.

The upper clay is sensitive, with a liquid limit of around 100 %, a plastic limit of 40 % and a natural water content of 80 % with a unit weight of around 14.2 kN/m^3. The shear vane strength is low, around 25 kPa. The lower clay is not sensitive, has a liquid limit of around 80 %, a plastic limit of 25 % and a natural water content of 60 % with a unit weight of around 16.4 kN/m^3. The shear vane strengths are higher, at around 70 kPa.

Fig. 12 shows typical pore pressure dissipation curves for the Ballina site. In a sandy layer between 12 m and 13 m the soil exhibits a larger stress drop than the layers above.

Fig. 13 shows a DMTA dissipation curve and its Flex evaluation. Method M1 gave practically the same result. Comparing Fig. 13 with Tables 9 and 10, the main finding is that the Flex on DMTA data gave about the same results as Method 1 with *u2* data.

4. Discussion and conclusions

There is a good agreement between the coefficient of consolidation (*c*) results of the mathematically-precise, (slow *u2*) Method 1 and the DMTA Flex method in data from Szeged and in Ballina.

The coefficient of consolidation (*c*) result of the three published *u2* pore water pressure dissipation test evaluation methods showed the same pattern (i.e., Fig. 10(b) and Tables 6-10) as in case of other projects (Imre et al. 2014 to 2022).

It can be concluded that the DMTA total stress dissipation data, being considerably simpler to obtain than involving the measurement of pore water pressure, gave valuable information. However, the interpretation was not easy since pore water pressure data were needed to reduce the parameter error. In the ideal case, both DMTA and DMTC dissipation tests are available at about the same depth.

Concerning the newly suggested Method M1 to evaluate DMTA, it gave about 3 times larger *c* values than the Flex *c* for Szeged site data. This indicates an agreement with the results of the DMT Flex and the M1 methods even though that estimated *u* data were used. In other words, the suggested M1 method seems to be a good alternative to the Flex method.

It can be noted that when the estimated *u* data were evaluated as pore water pressure data with with the Method II, then the identified *c* was about 7 to 10 times larger than *c* from the M1 method.

The suggested M1 total stress dissipation evaluation method is very useful in two cases: (i) if the DMTA dissipation curve has no inflexion point or (ii) if the DMTA dissipation curve is non-monotonic (see eg., Lim at al. 2019).

The short DMTA dissipation results presented in the companion paper (Imre at al. 2023), and here, indicated non-monotonic curves in sand. The suggested evaluation method can be used when the dissipation curve is non-monotonic, as illustrated in Fig. 9(b) and Table 8.

Further research is suggested on several aspects of the suggested DMTA dissipation test evaluation methods. A more precise estimation can be made if *u* data are available (see eg., Imre et al. 2011), for example if DMTA and DMTC data are evaluated together.

References

Bishop, D. 2009. “Eng. Geol. Of Richmond River Estuary.” *PhD Thesis*, The University of Newcastle. (unpub).

Imre, E. 1995. “Statistical evaluation of simple rheological CPT data.” *Proc. of XI. ECSMFE*, 1. 155-161.

Imre, E,; Móczár B,; Farkas J,. 2009 “Laboratory Creep and Relaxation after Partial Unloading.” Proceedings of the 17th ICSMGE pp. 742-745.

Imre, E, Firgi T, Juhász M, Hazay M, Hegedűs M, Bakacsi Zs, Singh V 2014. “CPTu pore water pressure dissipation tests in saline environment”. In: *3rd International Symposium on Cone Penetration Testing*: Las Vegas, pp. 675-682.

Imre, E., Juhász M., Józsa V., Hegedûs M., Bíró B., Singh V. G. 2014. “CPTu tests and CPT simple dissipation tests in saline environment”. In: *3rd International Symposium on Cone Penetration Testing* Las Vegas, pp. 683-690.

Imre, E., Rózsa, P., Bates, L., Fityus, S. 2010: “Evaluation of monotonic and non-monotonic dissipation tests.” *COGE*. 37: 885-904.

Imre, E., Bates, L., Fityus, S. 2011: “Evaluation of dilatometer dissipation test data with no inflexion point.” pp. 495-502.13th IACMAG, Melbourne, Australia (2011)

Imre, E, Schanz, T, Hegedűs, Cs. 2013. “Some thoughts in non-linear inverse problem solution”. *EURO:TUN 2013*. Bochum, Germany, 2013.04.17-04.19. pp. 357-365.

Imre, E, Bishop D, Bates L, Fityus S, Bakacsi Z, Rajkai K, Juhász M. 2016 “Dissipation tests in saline environment”. In: Leishman Associates (szerk.) ISC'5.: Hobart, Australia, 2016.09.05-2016.09.09. 2016. pp. 479-485. (ISBN:978-0-9946261-0-3).

Imre, E,;, Schanz T.; Bates L, Fityus S 2018 “Evaluation of complex and/or short CPTu dissipation tests” Cone Penetration Testing 2018 pp. 351-357. CRC Press.

Imre, E, Hegedűs M, Bates L, Fityus S 2022 “Evaluation of complex CPTu dissipation tests of B.E.S.T.” CPT’22. CRC Press. pp. 473-479. Bologna ISBN: 9781003308829

Imre E; Berzi P; Hegedűs Cs; Kovács S; Kovács L 2021 “Reducing numerical work in parameter identification”. arxiv.org/ftp/arxiv/papers/2102/2102.08210.pdf (2021)

Imre, E., Bates, L., Fityus, S; Hegedus, M., Hortobágyi, Zs., Singh V. P. 2021-2022. “Evaluation of dilatometer dissipation test data2. ISC6. https://doi.org/10.53243/ISC2020-273

Imre, E., Bates, L., Fityus, S; Hegedus, M., Singh V. P. “Coupled models for stress dissipation tests”. ISC6. 2021-2022. https://doi.org/10.53243/ISC2020-269

Imre, E., Hegedűs, M., Marchetti, D., Juhász, M., Hortobágyi, Zs; Bishop, D., Bates, L. 2022 “Comparing dissipation tests of CPTu and DMT”. 20th ICSMGE Sydney. Australian Geomechanics Society. 2022. 417-422.

Imre, E., Marchetti, D., Juhász, M. Bates, L., Fityus, “The short dissipation test” IS-Porto submitted.

Imre, E / Óbuda University “CPTu dissipation test, Imre-Rózsa model, fast method II”, [computer program] Available at: request.

Imre, E / Óbuda University “CPTu dissipation test, Imre-Rózsa model, long method I”, [computer program] Available at: request.

Imre, E / Óbuda University “Oedometer relaxation test (ORT)”, [computer program] Available at: request.

Lunne, T., Robertson, P.K. and Powell, J.J.M. 1997. “Cone Penetration Testing in Geotechnical Practice,” London: *Taylor & Francis*. ISBN 9780419237501, pp. 60-61.

Lim, Y X ; Tan, S A ; Kok-Kwang P. Interpretation of horizontal permeability from piezocone dissipation tests in soft clays *Computers and Geotechnics* 107 (2019) 189–200

Marchetti, D. 2020. “Medusa DMT tests in Szeged, ELI – Alps” Expertise. 2020.

Monaco, P 2021 “Standardization of Medusa DMT testing Medusa dilatometer test Pre-standard Reference Test” Report of UnivAQ – DICEAA. 1st March 2021.

Randolph M F & Wroth C P (1979) An analytical solution for the consolidation around displacement piles. I. J. Num. Anal. Meth. in Geomech.3:217-229.

Rétháti, L., Ungár, T. 1978: Large area’s soil physical data – statistical analyses. *Építés, Építészettudomány*, X. 1-2 In Hungarian.

Simon, Sz. 2010. “Characterization of groundwater and lake interaction in saline environment, Kelemenszék Lake, Danube-Tisza Interfluve, Hungary.” *PhD dissertation*. Eötvös Loránd University, Budapest, 167 p.

Sully, J.P., Robertson, P.K., Campanella, R.G., Woeller, D.J. 1999. “An approach to evaluation of field CPTU dissipation data in OC fine-grained soils”. *Can. Geotech. J.* 36: 369–381.

Teh, C.I. and Houlsby, G.T. 1988. *6th Int. Conf. on Num. Meth. Geomechanics*, Innsbruck

Totani, G; Clabrese, M; and Monaco, P. In situ determination of ch by flat plate dilatometer. Proceedings of ISC-1, Atlanta, Georgia, 1998. 883–888.