Closure to "Settlement of the Kansai International Airport Islands" by G. Mesri and J. R. Funk

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The Discussion by Yoichi Watabe of the Port and Harbour/Port and Airport Research Institute (PARI) of "Settlement of Kansai International Airport Islands" is most fitting because PARI conceived, designed, and constructed the airport islands. Although the authors were not directly involved in the project, the first author has been intimately aware of the island construction in Osaka Bay (Mesri 1991). The writers are not aware of the discusser's experiences using the *ILLICON* procedure, and in the absence of any references, the discusser's claims are discarded in light of excellent agreement between the observed and computed surface and subsurface settlements.

A relationship between the preconsolidation pressure and the vertical strain rate was first introduced by Mesri and Choi (1979) in terms of C_α/C_c and later refined to include other parameters (Mesri and Choi 1980, 1984; Mesri 1987). These empirical relationships, based on the C_α/C_c law of compressibility, correctly predict the data in Figs. 1–3 of the Discussion (e.g., Fig. 8 in Mesri 1987). These preconsolidation pressure $[\sigma'_p]_j$ versus vertical strain rate $[\dot{\varepsilon}_v]_j$ data, in the slow strain rate range, are a manifestation of secondary compression after the end-of-primary (EOP) consolidation (e.g., Fig. 9 in Mesri and Funk 2015) and in the fast strain rate range the result of a problematic interpretation of very nonuniform vertical strain, ε_v, and effective vertical stress, σ'_v, either during primary consolidation in an incremental loading oedometer specimen (Suklje 1957) or in a constant-rate-of-deformation specimen subjected to vertical strain rates much faster than EOP $\dot{\varepsilon}_v = \dot{\varepsilon}_p$ (Mesri and Feng 1992; Mesri et al. 1994).

It was previously explained by Mesri (2013) that the Watabe et al. (2012) interpretation of the C_α/C_c law of compressibility in terms of their measurements of preconsolidation pressure as a function of the strain rate is entirely questionable and is definitely not recommended. The C_α/C_c law of compressibility was developed by Mesri and coworkers using the decrease in void ratio as a function of time in oedometer tests, from vertical compression, whose precise measurement is entirely possible for a variety of materials, from granular soils, including rock fill, to amorphous and fibrous peats (Mesri 1987, 2001), whereas determining a strain rate–dependent preconsolidation pressure is sensitive to details of testing procedure and interpretation. On the other hand, Watabe admits that a constant $C_\alpha/C_c = 0.04$ successfully explains part of the $[\sigma'_p]_j$ versus $[\dot{\varepsilon}_v]_j$ data in the Discussion Figs. 1–3. Considering that preconsolidation pressure versus vertical strain rate is not solely a function of C_α/C_c and that C_α/C_c is equal to 0.04 ± 0.01 only for inorganic soft clay and silt deposits, the discusser's endorsement is not crucial (e.g., Terzaghi et al. 1996, Table 16.1). For example, the preconsolidation pressure–strain rate relationship may also be influenced by thixotropic hardening (Mesri 1993).

It is important, however, to recognize that the preconsolidation pressures corresponding to vertical strain rates slower or faster than $\dot{\varepsilon}_p$ are not the EOP σ'_p that turns out to be independent of the duration of primary consolidation. There is a fundamental difference, overlooked by the discusser, of the influence of elapsed time during which preconsolidation pressure develops (age, strain rate, secondary compression, thixotropic hardening, possible interparticle cementation) and elapsed time during which a preconsolidation pressure is mobilized during increases in the effective vertical stress (primary recompression). The aging time during which a preconsolidation pressure develops leads to $[\sigma'_p]_{\dot{\varepsilon}_j}$, whereas the primary recompression time mobilizes EOP σ'_p. This very significant implication of Hypothesis A is illustrated by the preconsolidation pressure data in Table 1 and Fig. 1 from over 70 separate field and laboratory measurements on 25 soft clay and silt deposits (Sällfors 1975; Leroueil et al. 1978; Mesri et al. 1995; Mesri 2001). The σ'_p (field) was determined from pore water pressure measurements in the ground, and EOP σ'_p is the preconsolidation pressure from the EOP e-log σ'_v curves of 20 mm thick undisturbed oedometer specimens. This is a most fortunate soil behavior because strain rate–independent EOP σ'_p values are used every day by geotechnical engineers throughout the world to compute settlement and evaluate undrained shear strength for stability analyses of soft clay and silt deposits and organic soils (Terzaghi et al. 1996).

Watabe does not accept the concept of an EOP compression independent of duration of primary consolidation (Mesri 2001), preferring Hypothesis B. Note that geotechnical engineers have been successfully using the EOP e-log σ'_v relationship from 20 mm thick oedometer specimens for settlement analyses of ground both without (long duration of primary consolidation) and with (short duration of primary consolidation) vertical drains. Notwithstanding the discusser's incorrect definition of Hypothesis A, it is here asserted that in the entire geotechnical engineering literature there are no reliable observed laboratory or field data that directly support Hypothesis B as it is defined in Fig. 40 of Ladd et al. (1977).

It is unfortunate that Watabe and his colleagues at PARI do not present an alternative settlement prediction for Kansai International Airport islands based on their "viscoplastic creep model with overstress viscoplastic theory . . . and large number of long-term consolidation tests for worldwide clays with various characteristics." For example, a preconsolidation pressure decreasing with decreases in the strain rate can be expected to predict settlements larger than those by the *ILLICON* procedure based on the uniqueness of the EOP e-log σ'_v relationship and the C_α/C_c law of compressibility. Watabe's comments on observed and predicted pore water pressures are somewhat confused. The pore water pressure increase in the seabed under Island I adjacent to Island II construction could have resulted either from the increase in total stress or from pore water pressure redistribution. Either effect could have been included in the *ILLICON* settlement analyses. However, this factor was considered to be of minor significance, which was confirmed by the observed settlements. The continued presence of excess pore water pressure in some of the clay layers is entirely expected, as shown by the degree of primary consolidation in

Table 1. Preconsolidation Pressure Mobilized in Full-Scale Field Situation, Deduced from Pore Water Pressure Measurements during Embankment Loading of Soft Clay Deposits, Compared with EOP σ'_p from 20 mm Thick Oedometer Specimens

Site	Reference	Depth (m)	σ'_{vo} (kPa)	σ'^{a}_{p} (kPa)	σ'^{b}_{p} (kPa)	σ'_p (field) (kPa)	σ'_p/σ'_{vo}
Asrum I	Hoeg et al. (1969)	3	10	24	26	24	2.64
Drammen II	Engesgaar (1970)	4.4	49	63	69	60	1.41
Mastemyr	Clausen (1970)	3.5	16	24	26	22	1.65
		6	32	48	53	41	1.65
Interstate 95	D'Appolonia et al. (1971)	16.8	168	268	295	234	1.75
		24.5	240	240	264	320	1.10
		32.1	300	300	330	375	1.10
Lanester	Pilot et al. (1973)	3	12	22	24.2	22	2.02
Narbonne	Mieussens and Ducasse (1973)	5	48	58	64	78	1.32
		10	100	110	121	110	1.21
Palavas-les-Flots	Bourges et al. (1973)	7	41	50	55	66	1.34
		14	73	93	102	86	1.40
Plaine de l'Aude	Mieussens (1973)	10	90	95	105	110	1.16
		12	105	110	121	121	1.15
		14	120	120	132	139	1.10
		16	134	134	147	154	1.10
		18	148	156	172	168	1.16
		20	160	160	176	193	1.10
		11.5	103	108	119	119	1.15
		15.1	128	130	143	149	1.12
		18.6	152	165	182	182	1.19
Porto Tolle	Croce et al. (1973)	15-18	140	140	154	140	1.10
		27-29	225	225	248	250	1.10
St. Alban A	Trak (1974)	1.5	16	50	55	40	3.44
Backebol	Sällfors (1975)	2.7	21	—	45	46	2.15
		3	24	—	44	46	1.84
		3.6	26	—	42	44	1.60
		4	28	—	53	49	1.87
		4.6	31	—	47	43	1.50
		5.5	37	—	49	48	1.32
		7.1	46	—	64	57	1.38
		10	62	—	65	62	1.06
Valen	Sällfors (1975)	1.5	17	—	47	50	2.76
		2	16	—	26	33	1.64
		2.5	15	—	22	25	1.47
		3	14	—	19	22	1.32
		4	17	—	17	17	1.00
		5	27	—	32	27	1.19
Kristianstad	Sällfors (1975)	3.2	29	—	86	85	2.97
		4.2	36	—	104	93	2.89
		5.2	44	—	112	116	2.54
		6.3	51	—	135	140	2.63
St. Alban B	Chapeau (1975)	2.5	19	46	51	44	2.66
		5	32	73	80	66	2.50
St. Alban C	Chapeau (1975)	2.5	19	46	51	44	2.66
St. Alban D	Chapeau (1975)	2.5	19	46	51	43	2.66
Cubzac-les-Ponts A	Vogien (1975)	2	18	53	58	50	3.23
		4	28	53	58	53	2.08
		6	38	55	61	54	1.59
		6	38	78	86	72	2.25
		8	48	62	68	72	1.42
Rupert A	Dascal and Tournier (1975)	7.5	51	133	146	77	2.87
		10.7	78	148	163	141	2.09
Arles	Brigando and Simon (1976)	4.5	35	100	110	68	3.14
		7.5	50	100	110	74	2.20
Cubzac-les-Ponts B	Magnan et al. (1977)	2	21	34	37	33	1.78
		4	30	42	46	40	1.54
		6	38	48	53	49	1.38
		8	46	62	68	59	1.48
Rang de la Concession	Tavenas et al. (1978)	9	86	103	113	116	1.32
Rang du Brulé	Tavenas et al. (1978)	9	80	92	101	115	1.27
Rang Saint Georges	Tavenas et al. (1978)	9	72	72	79	104	1.10
Rang du Fleuve	Tavenas et al. (1978)	9.2	68	68	75	80	1.10

Table 1. (*Continued.*)

Site	Reference	Depth (m)	σ'_{vo} (kPa)	σ'^{a}_{p} (kPa)	σ'^{b}_{p} (kPa)	σ'_p (field) (kPa)	σ'_p/σ'_{vo}
Fluminense Plains	Ramalho-Ortigão et al. (1983)	2	6	20	22	19	3.40
		3	10	22	24	23	2.54
		4	13	26	29	26	2.24
		5	16	30	33	24	2.06
		8	26	42	46	34	1.80
Joliette	Morin et al. (1983)	3.5	23	95	105	94	4.50
		5.9	37	123	135	108	3.60

[a] Preconsolidation pressure from so-called conventional 24-h IL oedometer test.

[b] End-of-primary (EOP) preconsolidation pressure from 20 mm thick oedometer specimen.

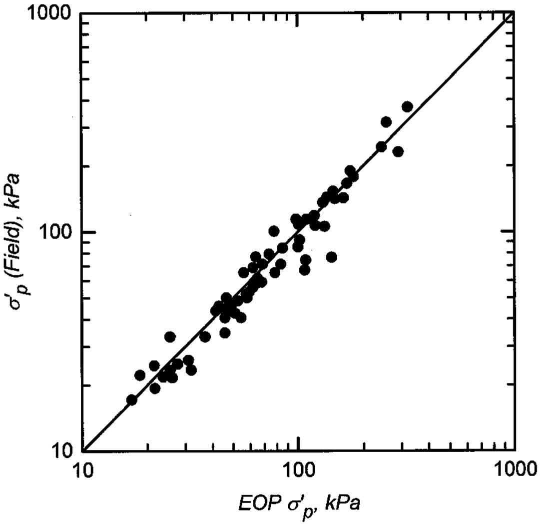

Fig. 1. Preconsolidation pressure mobilized in field compared with EOP σ'_p from 20 mm thick oedometer specimens (reprinted from Mesri et al. 1995, with permission)

Table 2 of Mesri and Funk (2015) for clay layers at MP1-II. Closure Table 2 showing the predictions of the degree of consolidation and settlement for the Pleistocene clay layers at MP2-II was added. Table 2 shows that clay Layers Ma11L, Ma10, Ma9, Doc5, Ma8, and Ma7 will still be in the primary consolidation stage in the year 2100.

Possible solutions to the implications of large settlements of the Kansai International Airport islands require a clear interpretation of the observed and predicted behavior. The research reported by Mesri and Funk (2015) was motivated and directed toward this important practical objective.

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Table 2. Summary of Calculations for Compression of Pleistocene Clay Layers at MP2-II

Layer	L_o (m)	t_p from January 2001 (years)	Date when t_p reached	σ'_{vf}/σ'_p (November 2006)	EOP compression (m)[a]	Primary compression in 2100 (m)	Secondary compression in 2100 (m)
Ma13	23.9	5.1	January 2006	4.00–24.37	8.12	8.12	0.28
Dtc	6.2	59.8	October 2060	1.85–1.99	0.68	0.68	0.02
Ma12	16.6	59.8	October 2060	1.68–1.81	2.68	2.68	0.15
Doc1	9.8	59.8	October 2060	1.55	1.26	1.26	0.07
Ma11U	9.4	85.6	July 2086	1.38–1.42	1.05	1.05	0.01
Ma11L	10.5	$\beta_{\text{avg}} = 88\%$ in year 2100		1.32	1.11	0.98	—
Ma10	24.5	$\beta_{\text{avg}} = 54\%$ in year 2100		1.07–1.15	1.60	0.89	—
Ma9	24.7	$\beta_{\text{avg}} = 78\%$ in year 2100		1.14–1.18	1.93	1.51	—
Doc5	14.2	$\beta_{\text{avg}} = 46\%$ in year 2100		1.05–1.07	0.75	0.35	—
Ma8	11.2	$\beta_{\text{avg}} = 76\%$ in year 2100		1.05–1.06	0.52	0.32	—
Ma7	17.2	$\beta_{\text{avg}} = 78\%$ in year 2100		1.03–1.05	0.70	0.54	—
Doc6	5.3	5.5	June 2006	1.01	0.07	0.07	0.22
Ma4	7.9	5.5	June 2006	0.97	0.05	0.05	0.40
Ma3	19.0	7.5	February 2007	0.87	0.09	0.09	1.02
Ma2	7.9	7.3	November 2006	0.89	0.03	0.03	0.34
NMC-1	4.0	6.3	November 2005	0.88	0.01	0.01	0.16
NMC-2	2.8	6.2	October 2005	0.88	0.01	0.01	0.12
NMC-3	9.2	6.4	January 2006	0.87	0.04	0.04	0.37
Ma1	16.2	6.4	January 2006	0.90	0.05	0.05	0.64
NMC-4	5.2	6.4	January 2006	0.89	0.02	0.02	0.24
Ma0	13.9	6.0	August 2005	0.82	0.04	0.04	0.04
NMC-5	3.3	5.1	September 2004	0.82	0.01	0.01	0.01
				Σ	20.83	18.81	4.08

[a] EOP compression corresponds to $\beta_{\text{avg}} = 95\%$ for Ma13 thru Ma11U and Doc6 thru NMC-5. EOP compression calculated from EOP void ratio for Ma11L thru Ma7.

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