den Haan, E. J. (1995). *Géotechnique* **45**, No. 3, 561–564

DISCUSSION

The formulation of virgin compression of soils

E. J. DEN HAAN (1992). *Géotechnique* **42**, No. 3, 465–483

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The Paper stimulated us to re-evaluate our own data on the compressibility of various clays which outcrop in southern Italy (Cherubini, Ramunni & Walsh, 1980; Cherubini, Giasi & Guadagno, 1986; Cherubini, 1991). In this discussion, data are reported from tests on samples of remoulded and natural blue subappennine clay. The blue subappennine clay outcrops extensively in Italy, especially in the Fossa Bradanica, southern Italy. This formation is believed to have been deposited (Del Prete & Valentine, 1971) during at least two sedimentary marine cycles—the first during the lower and medium Pliocene, and the second during the Upper Pliocene and Pleistocene (Calabriano).

The data reported here are from tests on the clay deposited during the second marine cycle. Index tests show that these are inorganic silty clays, having medium to medium high plasticity (liquid limit generally not more than 55–60%, occasionally >60%), with moderate activity. The clays are generally overconsolidated as at times there has been intense regional erosion which has affected these clays and the overlying sands and conglomerates.

The mineralogical composition of the clay fraction (which ranges from 25% to 48%) is essentially made up of illite (45–57%), kaolinite (20–25%), calcium-magnesium montmorillonite (6–15%) and chlorite (20–25%). The coarse fraction (typically 7–10% > 0·063 mm) is composed of calcite (fossil fragments and clastic grains), quartz, feldspars and muscovite, and small quantities of iron oxides, iron hydroxides, biotite, chlorite, anfiboli, piroxenes and dolomite. The carbonate content of the samples was generally found to be 20–40% by weight.

Compressibility data for the remoulded blue clays of the area of Poggiorsini and Spinazzola in Central Apulia (Cherubini *et al.*, 1980), and data for the natural blue clay from the area around Taranto (south of Apulia), and from an area between Vasto and Canosa (north of Apulia) have been obtained. The latter clays are heavily overconsolidated.

Tables 8 and 9 give values of v_1 and b for these Italian clays calculated using the author's statistical regression procedure. For the remoulded

Table 8. Data on remoulded marine blue clay

No.	Origin	Clay content: %	w_L	w_P	G_s	v_1	b	p_s
A1	Poggiorsini	33	0·44	0·24	2·72	2·72	0·082	0
A2	Poggiorsini	43	0·53	0·25	2·72	3·15	0·096	0
A3	Poggiorsini	46	0·57	0·26	2·73	3·21	0·099	0
C6	Spinazzola	34	0·48	0·25	2·69	2·85	0·086	0
C7	Spinazzola	36	0·47	0·25	2·70	2·91	0·094	0
C8	Spinazzola	37	0·46	0·25	2·72	2·89	0·088	0
C9	Spinazzola	34	0·48	0·25	2·70	2·91	0·091	0

Table 9. Data on natural marine blue clay

No.	Origin	Clay content: %	w_0	w_L	w_P	G_s	v_1	b	p_s
V1	Vasto-Canosa	40	0·26	0·53	0·24	2·71	2·34	0·064	0
V2	Vasto-Canosa	33	0·22	0·48	0·23	2·69	2·25	0·062	0
V3	Vasto-Canosa	37	0·22	0·52	0·23	2·69	2·12	0·055	0
V4	Vasto-Canosa	36	0·26	0·52	0·24	2·71	2·34	0·064	0
V5	Vasto-Canosa	31	0·19	0·47	0·22	2·69	1·95	0·046	0
V6	Vasto-Canosa	39	0·19	0·61	0·27	2·71	1·79	0·041	39
T1	Taranto	48	0·21	0·44	0·23	—	2·03	0·042	0
T2	Taranto	44	0·23	0·41	0·25	—	1·90	0·027	0

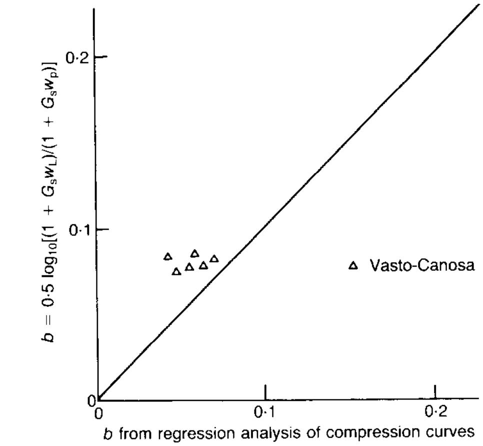


Fig. 11. Comparison of *b* values obtained from regression analysis of compression curves and from equation (14) by assuming a unique liquidity index–stress curve

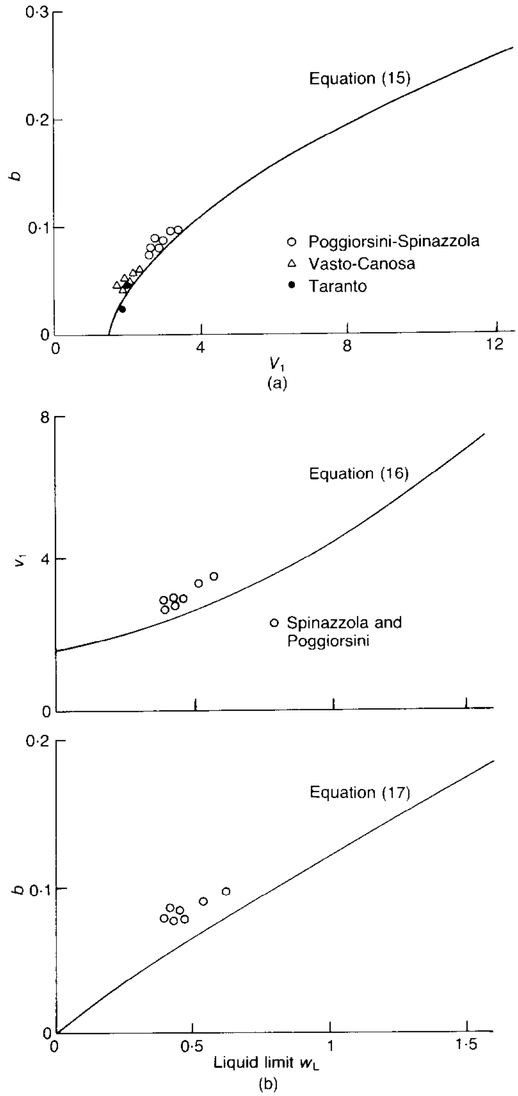
clays b has also been calculated using equation (16). Fig. 11 shows the relationship between the values of b calculated using the two methods.

For the remoulded clays, the values of b calculated using equation (14) are greater than those evaluated using the regression techniques.

The values of b and v_1 are shown in Fig. 12. The values of v_1, evaluated for the two clay groups (remoulded and natural clay) are towards the lower end of the range of the data given by the author and are in general smaller than values calculated from equation (16) for undisturbed clays, and higher for remoulded clays. The values of b are higher than those calculated using equation (17) for remoulded clays, and slightly lower for undisturbed clays.

The Atterberg limits and natural water content of these clays are among the lowest when these data are compared with the data in Tables 3 and 4. Indeed, the natural clays of the Vasto-Canosa area have a much lower natural water content than any of the clays reported in Table 4. The clay fraction for these Italian clays is also not particularly high.

The values of p_s for the samples examined of natural Italian clays were always found to be



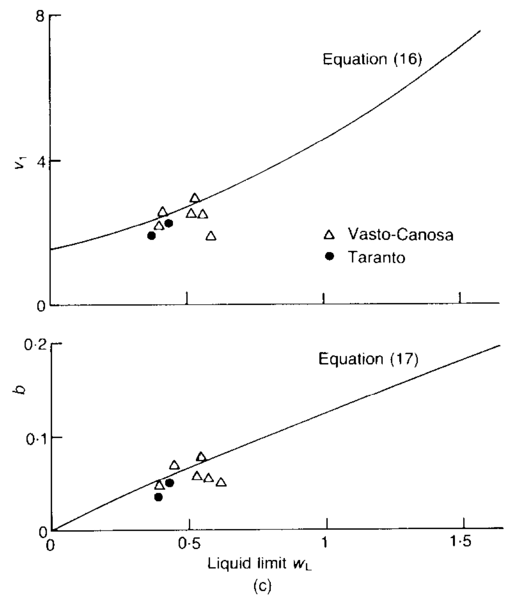


Fig. 12. Correlation of v_1, *b* and w_L, for Italian clays: (a) v_1 against *b* for natural and remoulded blue clays; (b) v_1 and *b* against w_L for remoulded blue clays; (c) v_1 and *b* against w_L for natural blue clays

zero. Only in one case is p_s equal to 39 kPa. The reasons for this are not clear, but it is probably because these clays do not have a marked concavity as shown in Fig. 2(a) (which may be for slightly disturbed samples?).

The conclusions that can be drawn are only partial. The data concerning some samples of Pleistocenic blue clays are in some cases in good agreement with the models proposed by the Author; in other cases there is a minor discrepancy.

Author's reply

Figure 13 shows e–log p plots for some of the tests reported by the writers; the data were kindly supplied by Professor Cherubini. The remoulded clays in Fig. 13(a) have values of v_1 and b which plot within the range of scatter in Figs 11, 12(a) and 12(b).

Figure 13(b) shows that the natural blue subappennine clays are strongly overconsolidated. Only one test passes from initial concavity to convexity. Even though stresses of up to 25 bar were applied, much higher stresses would apparently be necessary to obtain convexity. The formulations given in the Paper describe the post-yield convexity, and applying them to early post-yield behaviour will give too low values of v_1 and b. This may explain the deviations found by the writers for their natural samples.

In Fig. 13(b), the curve for V6 apparently exhibits sufficient convexity for reliable determination of v_1 and b. The curve is much lower than that of the remoulded test A3 at a comparable liquid limit. The Paper demonstrates the opposite behaviour: remoulded clays generally have lower curves than natural clays at the same liquid limit, and few curves of natural clays fall below that of the average remoulded clay.

The preconsolidation pressure of V6 appears to be 50–60 kPa, which seems very low for a clay of such high density. A rough estimate of the preconsolidation pressure is obtained from the pressure on the virgin curve at initial density. Taking the virgin curve as the remoulded curve given by equations (16) and (17) at $w_L = 0{\cdot}61$, and taking $v_0 = 1{\cdot}52$ as for test V6, one would expect p_c to be about 6200 kPa. However, the curve of V6 in its general form does not differ greatly from the other tests on natural clays. Perhaps therefore the convex section is not virginal after all.

Test V6 appears to exhibit some brittle structure with $p_s = 39$ kPa. This in itself is not unlikely. No significance should be given to the fact that this test alone was found to have $p_s > 0$, as the curves of the remaining natural clays seem to be insufficiently developed to determine v_1, b and p_s.

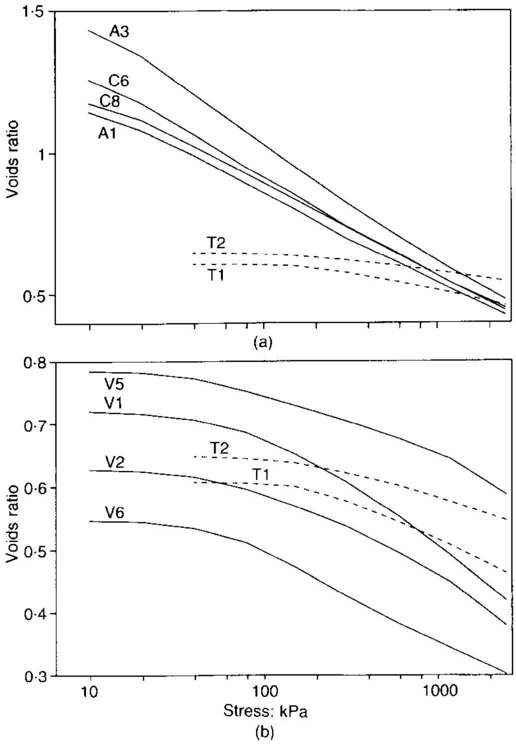


Fig. 13. Compression curves of Blue Subappennine clay

The writers rightly remark that their natural clays have much lower natural water contents than any of the clays in Table 4. It may be concluded that the concepts developed in the paper are not applicable to very stiff natural clays—at least not within the range of stresses of interest to engineering.

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No.	Reference	w_L	w_P	G_s	p_s: kPa	v_1	b
1	Rutledge (1944)				27	72·2	0·382
2	Rutledge (1944)				40	52·6	0·353
3	Girault (1960)				3	116·5	0·507
4	Leonards & Girault (1961)	3·58	1·25	2·4	87	35·6	0·331
5	Mesri *et al.* (1975)	5·0	1·5	2·35	38	74·3	0·400
6	Mesri *et al.* (1975)	5·0	1·5	2·35	42	46·5	0·349
7	Zeevaert (1991)				110	26·9	0·282
8	Zeevaert (1991) (Lake Texcoco)				14	60·3	0·391

CORRIGENDA

In Table 1 a value has been omitted. The average volume estimation error for cemented clay, when using equation (2) with $v_\infty = 1$ and $p_s > 0$, is 0·40%.

In Table 7, the values of v_1 and b for tests 1–6 are erroneous. The correct table is as shown here.

Figure 5 is affected by the errors in Table 7. The correct Fig. 5 is as shown here.