Monaco, P. and **Schmertmann**, J.H. (2007). Discussion of "Accounting for Soil Aging When Assessing Liquefaction Potential" by Leon, E. et al. (in *J. Geotech. Geoenv. Engrg.*, ASCE, 2006, 132(3), 363-377). *J. Geotech. Geoenv. Engrg.*, ASCE, 133(9), 1177

Discussion of "Accounting for Soil Aging When Assessing Liquefaction Potential" by Evangelia Leon, Sarah L. Gassman, and Pradeep Talwani

March 2006, Vol. 132, No. 3, pp. 363–377.
DOI: 10.1061/(ASCE)1090-0241(2006)132:3(363)

Paola Monaco[1] and John H. Schmertmann, F.ASCE[2]
[1]Assistant Professor, Dept. of Structural, Hydraulic, and Geotechnical Engineering, Univ. of L'Aquila, 67040 Monteluco di Roio, L'Aquila, Italy. E-mail: p.monaco@ing.univaq.it
[2]Professor Emeritus, Dept. of Civil and Coastal Engineering, Univ. of Florida, Gainesville, FL 32611.

A great merit of the paper is having explicitly highlighted to the geotechnical community the importance of aging when assessing liquefaction potential. The authors have shown that accounting for aging is not a refinement but a necessity for economical design, because aging has a major influence on liquefaction behavior.

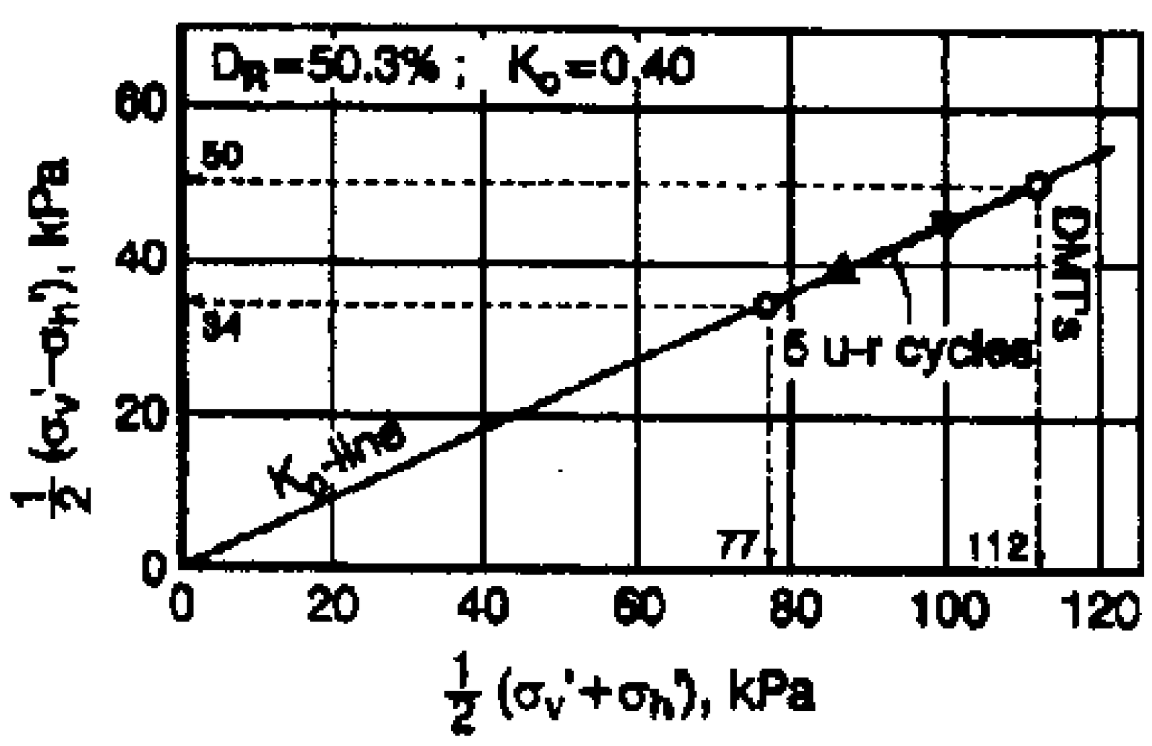
Ignoring aging effects in the sands studied by the authors and using a cyclic resistance ratio (CRR) estimated from correlations from in situ tests insensitive to aging underestimates CRR by a large 60%. Giving insufficient weight to aging or disregarding it is equivalent to omitting a primary parameter in a correlation. No wonder, then, that such an omission leads to possibly overconservative CRR values. The poor ability of SPT and CPT to poorly capture the effects of aging is due, according to a suggestion by the authors and to Fig. (5), to their insufficient sensitivity in detecting minor changes in soil fabric that can increase the liquefaction resistance of the soil. The disturbance during these tests may destroy or seriously damage the microstructure effects that result from aging.

The authors also point out, as many before (e.g., Pyke 2003), that the commonly used correlations for estimating CRR (based on SPT, CPT, and V_S) were derived mostly for young or freshly deposited sands, where the aging effect is negligible or small, anyway smaller than in older soils. The methodology developed by the authors for older soils utilizes correction factors based on sand sites in South Carolina. Their method, using such factors, rightly yields less conservative CRR predictions. However, for other deposits, specific factors should in general be developed because the CRR gain due to aging can depend on many ambient factors and thus can vary widely from site to site.

A desirable alternative would be to use a testing tool significantly more sensitive to aging—in addition to being sensitive to the other factors that are known to increase CRR. A testing tool seemingly satisfying such a requirement is the flat dilatometer DMT (Marchetti 1980). The higher sensitivity of this tool to aging was demonstrated by the large calibration chamber research work by M. Jamiolkowski and D. C. F. Lo Presti ("DMT research in sand. What can be learned from calibration chamber tests." 1st Int. Conf. on Site Characterization, ISC'98, oral presentation, unpublished, 1998).. They showed (Fig. 1) that K_D (DMT horizontal stress index) is much more sensitive to cyclic prestraining than the bearing penetration resistance q_D of the DMT blade and presumably also of the CPT cone. The increase in K_D caused by prestraining was found ≈3 to 7 times the increase in q_D. The two calibration chamber experiments involved stage testing and an extrapolation, as follows: (1) filling and K_0 pressurization of the chamber; (2) blade penetration and measuring q_D and K_D every 100 mm penetration to midchamber depth; (3) five cycles of prestressing/prestraining the sand in the chamber; (4) repeating (5) for the remaining depth of the chamber; (6) down and up extrapolation for the q_D and K_D values at middepth; and (7) comparing the values before and after the prestraining.

The prestraining consisted of increasing both the vertical and horizontal stress according to the stress paths shown in Fig. 1, then removing both increases, thereby returning to the same initial stress state before the DMT testing. Cycles of prestrain may be viewed as a type of "simulated aging" (at least for the me-

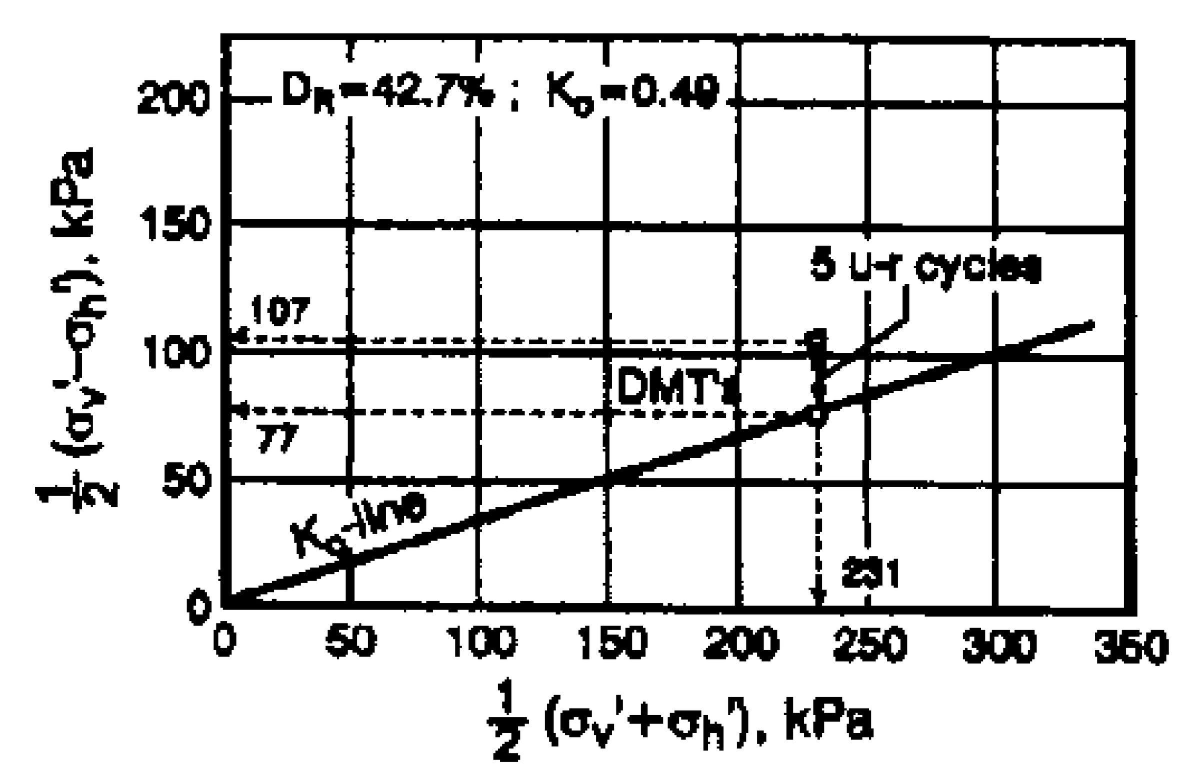
CC TEST N. 216 IN TICINO SAND



	I_D (-)	K_D (-)	E_D (MPa)	M_D (MPa)	q_D (MPa)
Before	2.62	1.98	29.0	30.3	16.0
After	2.41	2.38	31.8	37.8	16.4

K_D increase +20%
q_D increase +3%

CC TEST N. 241 IN TICINO SAND



	I_D (-)	K_D (-)	E_D (MPa)	M_D (MPa)	q_D (MPa)
Before	2.50	1.03	27.6	23.5	14.5
After	2.50	1.43	33.4	28.5	16.1

K_D increase +39%
q_D increase +11%

Fig. 1. Calibration chamber test results (prestraining cycles) showing the higher sensitivity of K_D to prestraining than penetration resistance q_D (Jamiolkowski and Lo Presti 1998, with permission)

chanical "nonchemical" mechanism responsible for aging, consisting of grains gradually slipping into a more stable configuration). Prestraining just speeds the slippage of particles versus that which would otherwise take place over long periods of time. It is also well known that cyclic prestrain, just as aging, increases the liquefaction resistance due to the similarity of the mechanism (e.g., Triantafyllidis et al. 2004).

The sensitivity of K_D to prestrain/aging combined with the recognized sensitivity of K_D to a number of other factors that are known to increase liquefaction resistance has stimulated considerable DMT research work in the past 2 decades. A summary of the available knowledge on the subject and the latest version of the CRR-K_D correlation based on all previous data, can be found in Monaco et al. (2005). The aptness of the K_D parameter to evaluate liquefaction potential has been reinforced by the experience gained from a large number of tests performed in recent years with the seismic dilatometer (SDMT). Tests by SDMT routinely provide pairs of profiles of K_D and V_S, from which two independent estimates of CRR can be compared and evaluated.

A clear feature emerging from the comparisons of the K_D and V_S profiles (one example is shown in Fig. 2, representative of many similar ones) is the clarity with which "aging crusts" (which are not relative density crusts, see Maugeri and Monaco 2006) are evidenced by K_D, while such crusts are barely recognizable in the V_S profiles. Such capability of K_D to reflect stress history is important. In fact, while the original paper is focused on the influence of aging on liquefaction resistance, the evaluation of any alternative method would be incomplete without also checking its ability to account for other stress history effects, as clearly recommended in the following quotes.

Jamiolkowski et al. (1985) pointed out that "reliable predictions of liquefaction resistance of sand deposits having complex stress-strain history would require the development of some new in situ device [other than CPT or SPT], more sensitive to the effects of past stress-strain histories."

Pyke (2003) observed that "overconsolidation and aging are likely to have a much greater effect on increasing liquefaction resistance than they do on penetration resistance. Thus soils that are even lightly OC or more than several decades old may have a greater resistance to liquefaction than indicated by the current correlations, which are heavily weighted by data from hydraulic fills and very recent streambed deposits."

In conclusion, it is possible that the current CRR correlations based on K_D, or future refined versions, will not need the introduction of age correction factors because part of the aging effects are already "incorporated" in K_D. On the other hand, K_D is, at the same time, sensitive to factors such as stress history and cementation, long recognized as important to liquefaction behavior. Using an in situ test also more sensitive to aging effects, such as the DMT, should lead to better correlations to obtain CRR.

References

Jamiolkowski, M., Baldi, G., Bellotti, R., Ghionna, V., and Pasqualini, E. (1985). "Penetration resistance and liquefaction of sands." *Proc., XI ICSMFE*, Balkema, Rotterdam, The Netherlands, 1891–1896.

Marchetti, S. (1980). "In situ tests by flat dilatometer." *J. Geotech. Engrg. Div.*, 106(3), 299–321.

Maugeri, M., and Monaco, P. (2006). "Liquefaction potential evaluation by SDMT—Flat dilatometer testing." *Proc., 2nd Int. Conf. on the Flat Dilatometer*, R. A. Failmezer and J. B. Anderson, eds., 295–305.

Monaco, P., Marchetti, S., Totani, G., and Calabrese, M. (2005). "Sand liquefiability assessment by flat dilatometer test (DMT)." *Proc., XVI ICSMGE*, Millpress, Rotterdam, The Netherlands, 2693–2697.

Pyke, R. (2003). "Discussion of 'Liquefaction resistance of soils: Summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils' by T. L. Youd." *J. Geotech. Geoenviron. Eng.*, 129(3), 283–284.

Triantafyllidis, Th., Wichtmann, T., and Niemunis, A. (2004). "On the determination of cyclic strain history." *Proc., Int. Conf. on Cyclic Behaviour of Soils and Liquefaction Phenomena*, Balkema, Rotterdam, The Netherlands, 321–334.

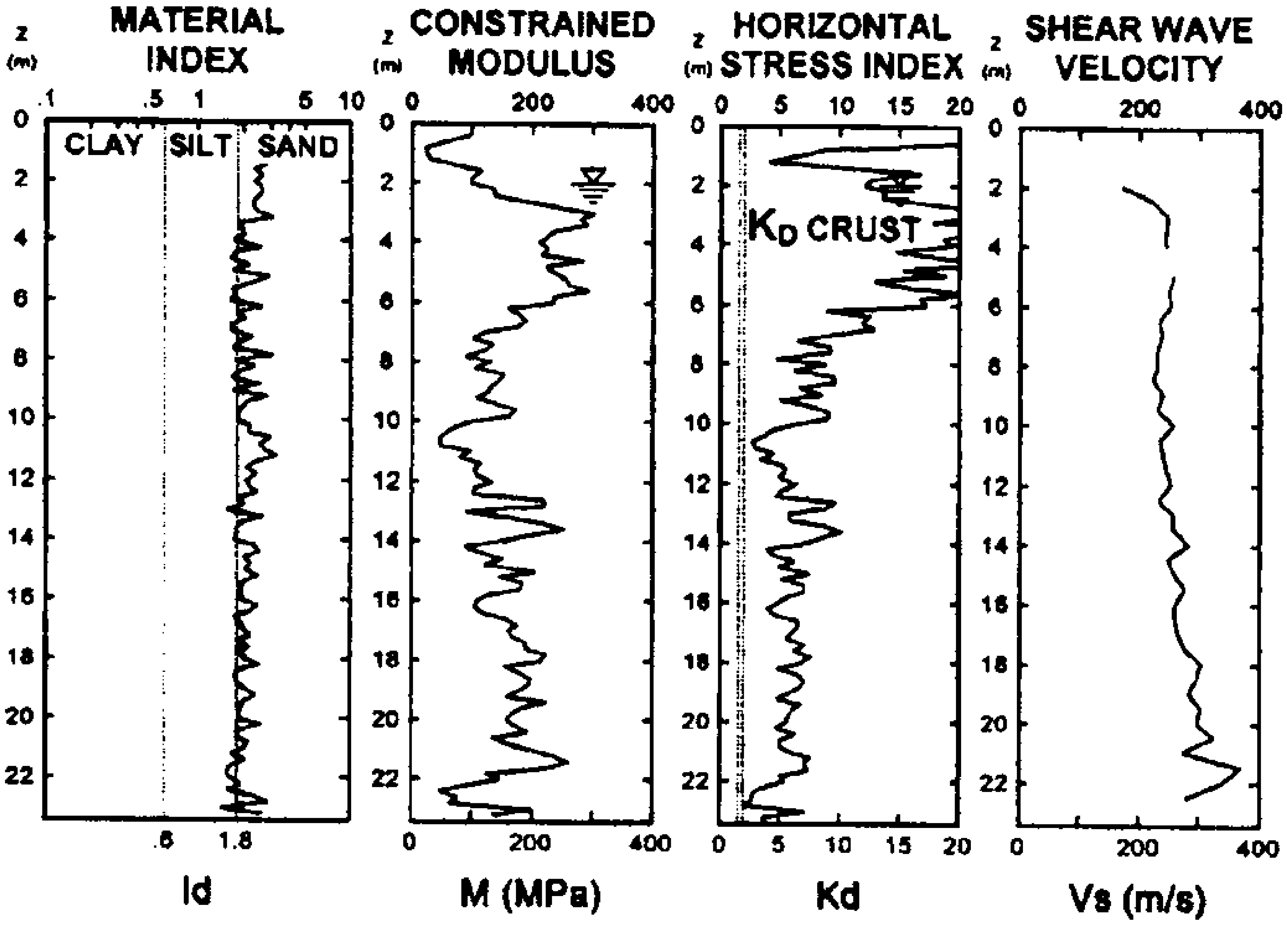


Fig. 2. Example of K_D crusts in sand: SDMT results at the site in Catania, Italy (after Maugeri and Monaco 2006)