First experiences with flat dilatometer test in Slovenia

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ABSTRACT: In Slovenia first DMT tests were performed in the beginning of 2003. Slovenia is a small country, covering only 20 500 km^2, but with very complex geology. The assessment of ground properties is therefore a demanding task and methods that provide profiles of material properties rather than individual material data are very important. A CPT test with pore pressure measurements has been extensively used in the past. Ménard pressuremeter tests have also been used to complement CPT. Marchetti flat dilatometer tests have proven to be a fast and reliable tool when material properties are required for the assessment of stability and settlements for different geotechnical structures. The paper presents some first comparisons of DMT results with other soil investigation techniques, including laboratory and in situ tests, such as vane test, CPT and Ménard pressuremeter. Measured and predicted settlements are compared at three locations. During the first three years of the use of DMT test in Slovenia, it has become highly popular and is regularly used to test soft soil deposits.

1 INTRODUCTION

In geologically heterogeneous Slovenia, in-situ ground testing gained popularity during intensive motorway construction that began in 1994. Traditionally only SPT and vane tests had been used. The CPT(U) was first introduced in the mid 1980s and was not readily accepted by the local geotechnical community. Ménard pressuremeter followed in 1996 and Marchetti flat dilatometer in 2003. These two in-situ test methods were soon accepted due to their versatility, rapid evaluation of test results, and high reliability of evaluated soil parameters. Papers by Logar et al (2001), Kuder and Robas (2003), Robas et al (2005), Gaberc et al (2004) presented some comparative analysis of geotechnical predictions with DMT and PMT, which contributed to the wide acceptance of both tests in Slovenian geotechnical practice.

There are two DMTs operating in Slovenia. Only the results obtained and analyzed by the Geotechnical department of the University of Ljubljana are presented in the paper. The University performed 1511 m of dilatometer soundings between 2003 and 2005. At most locations DMT tests were complemented with other in-situ and/or laboratory tests. The results of selected flat dilatometer tests performed at different locations in Slovenia with different soil types are presented with other available test results at the same locations. Figure 1 shows the map of Slovenia with locations where most of DMT tests were performed. The numbers indicate the quantity of DMT tests in meters performed at those locations.

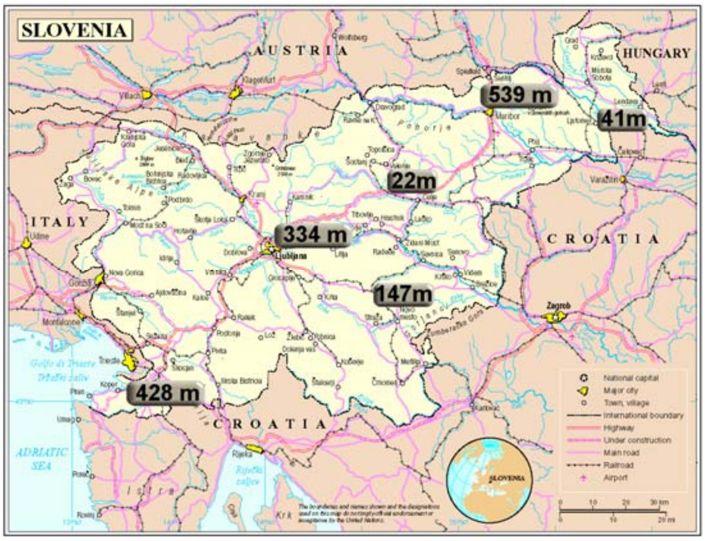

Figure 1. Map of Slovenia with the quantity of DMT tests performed from 2003 to 2005

2 SOIL CLASSIFICATION

Generally a fairly good insight into soil classification is provided from material index, I_d. Three selected profiles are plotted in Fig. 2 together with borehole logs. The main discrepancy in the classification is regularly observed in dry clayey or silty crust layers where the material index is normally greater than 1.8 indicating sandy soils (e.g. Fig 2c). The important benefit of material index obtained from DMT results is in identifying thin layers of different soil types within the tested formations (e.g. Fig. 2a).

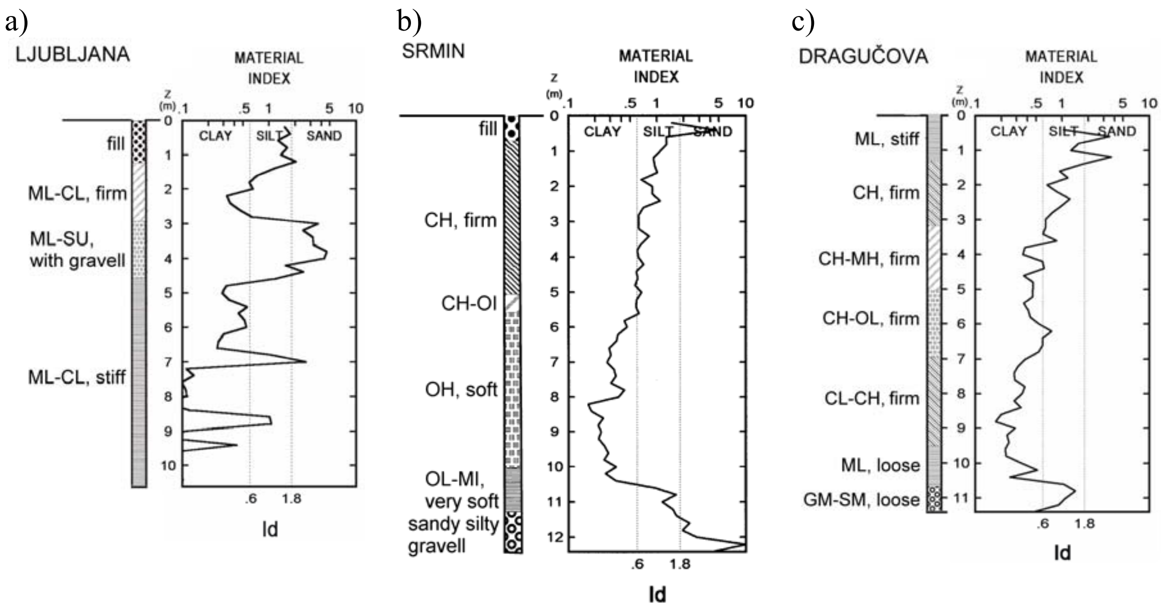

Figure 2. Comparison of selected borehole logs with DMT profiles for three different locations

3 OEDOMETER MODULI

The first analyses compared oedometer (constrained) moduli and undrained shear strength. Oedometer moduli (E_{oed}) were traditionally measured only in laboratories. CPT results were rarely used for settlement predictions or were used with caution and possibly together with laboratory results. The following examples show that constrained moduli obtained from flat dilatometer tests are comparable to the laboratory results. Comparisons with CPT results show that moduli derived from cone resistance can be either too large or too small. Moreover, we observed that thin layers of sand found in soft soil deposits do not provide significantly increased cone resistance and hence give similar moduli as soft cohesive soils. Due to different directions of penetration and membrane expansion, DMT provides reliable moduli estimates for such soil deposits (Figures 5 and 6).

Figures 3 to 9 show comparisons of oedometer moduli obtained by DMT, CPT and/or by laboratory oedometer tests in. Figure 8 shows the results for a site with up to 6 m thick layer of unsaturated clay on the top of soil profile. All other profiles are obtained within saturated soil layers, except for thin dry crust. DMT gives unusually high moduli for the unsaturated layer from Fig. 8, predominantly over 30 MPa. This value is significantly greater than laboratory values. Also the settlement measurements at the same location (see paragraph 5) indicate that moduli obtained within unsaturated soil layer are probably too high. Such cases are regularly observed for relatively thin (and therefore less significant) dry crust layers on the top of many soil profiles (see Figures 3, 5, 6, 7).

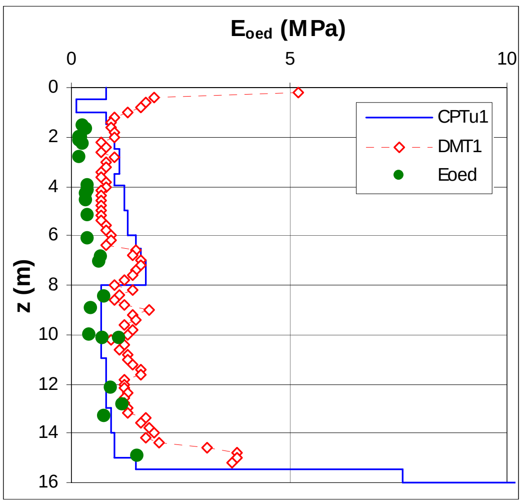

Figure 3. E_{oed} at crossover Peruzzijeva, Ljubljana

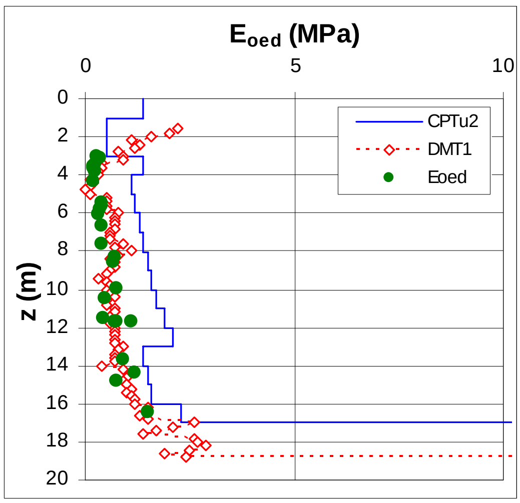

Figure 4. E_{oed} at Lidl, Ljubljana

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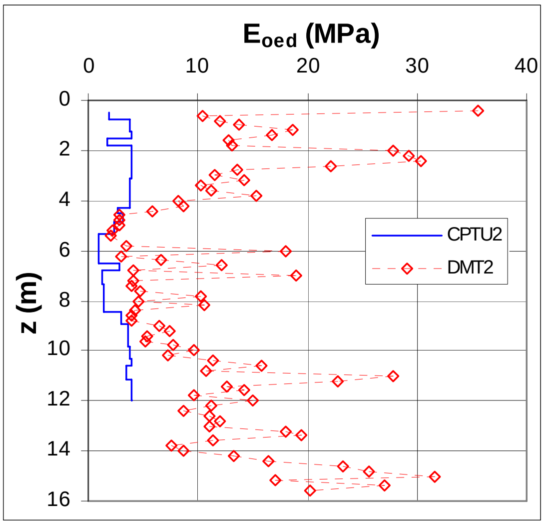

Figure 5. E_{oed} at Dolenjska

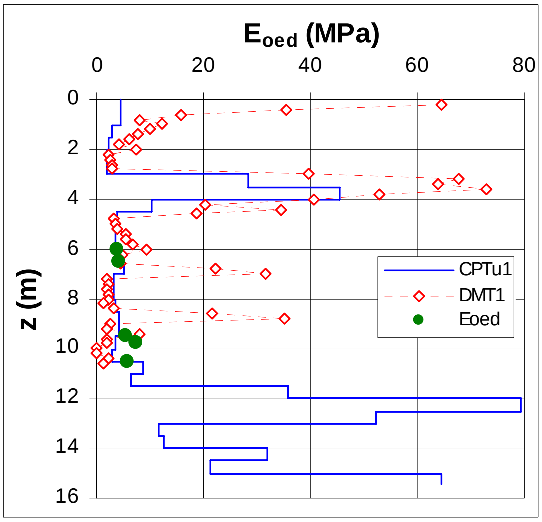

Figure 6. E_{oed} at veterinary faculty, Ljubljana

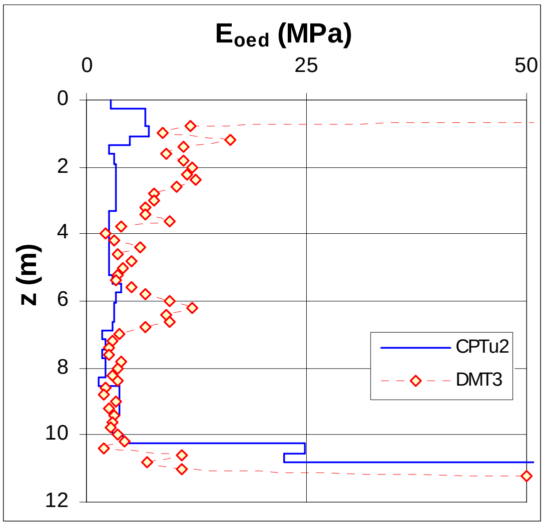

Figure 7. E_{oed} at Dragučova

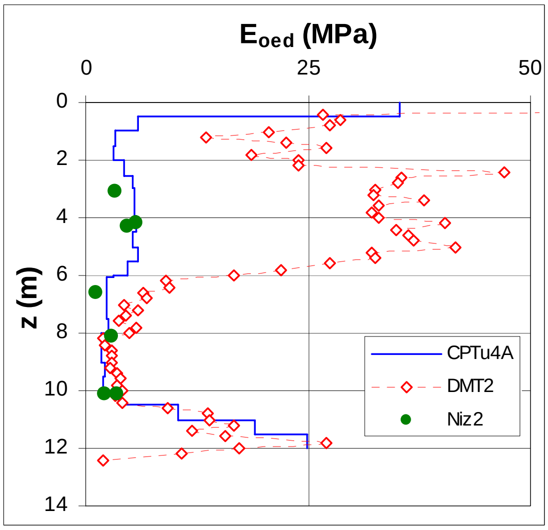

Figure 8. E_{oed} at Srmin

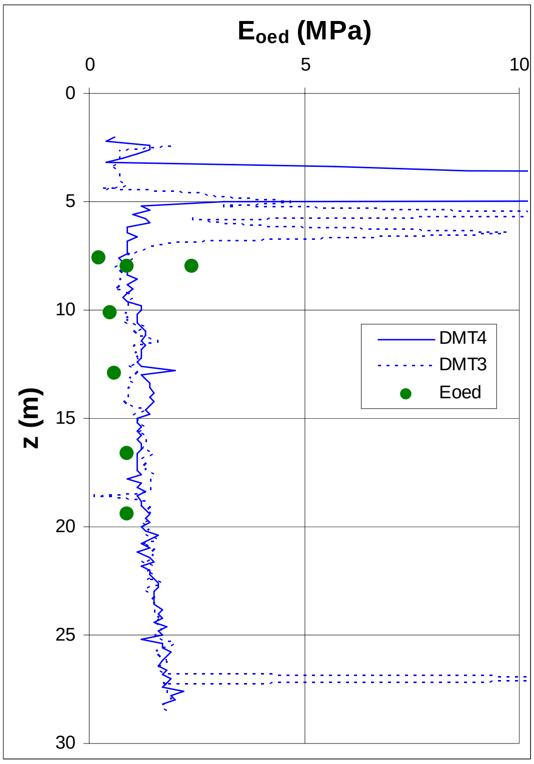

Figure 9. E_{oed} at Port of Koper

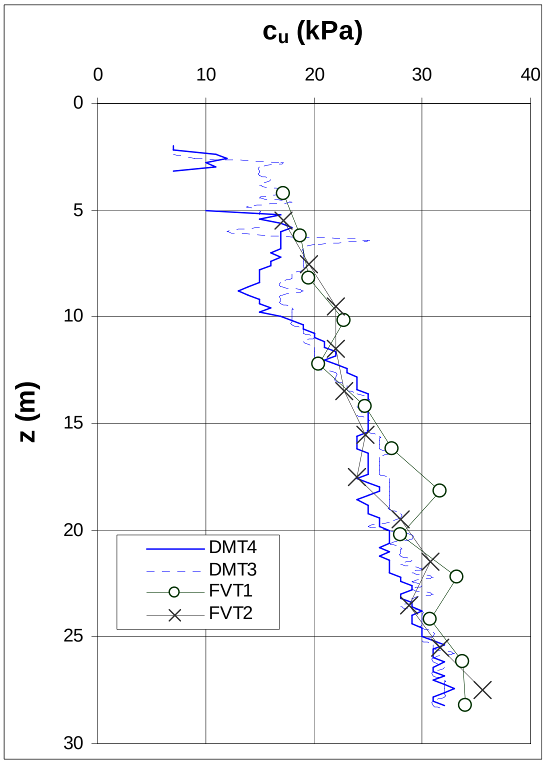

Figure 10. c_u at Port of Koper

BACK

4 UNDRAINED SHEAR STRENGTH

Undrained shear strength was measured or derived from field vane test, CPT test and Ménard pressuremeter test and compared to values obtained by the interpretation of DMT results.

Figures 10 to 16 show comparisons of undrained shear strength profiles for the same locations where oedometer moduli were previously studied.

Generally, fair to good agreement can be seen. The differences are partly due to variations in natural ground and partly due to different test methods and tools.

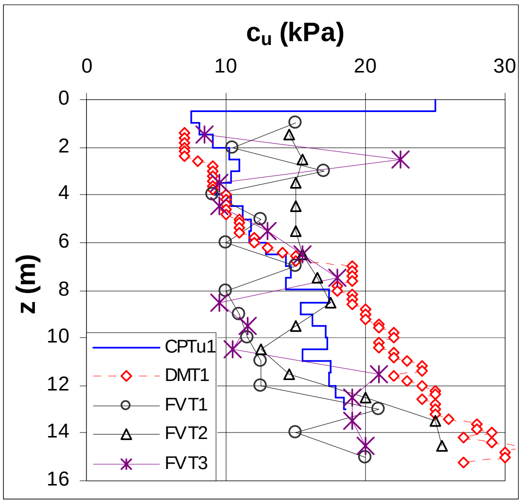

Figure 11. c_u at crossover Peruzzijeva, LJ.

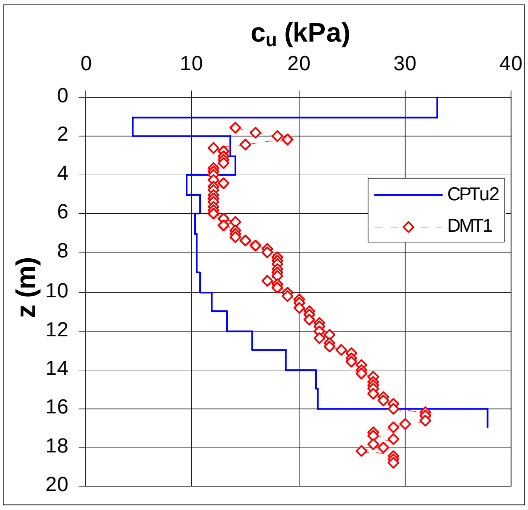

Figure 12. c_u at Lidl, Ljubljana

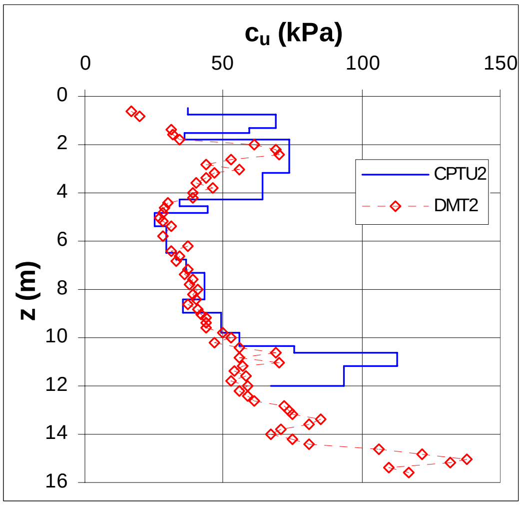

Figure 13. c_u at Dolenjska

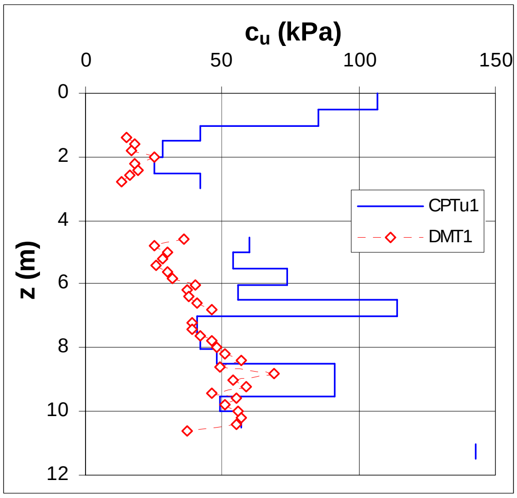

Figure 14. c_u at veterinary faculty, Ljubljana

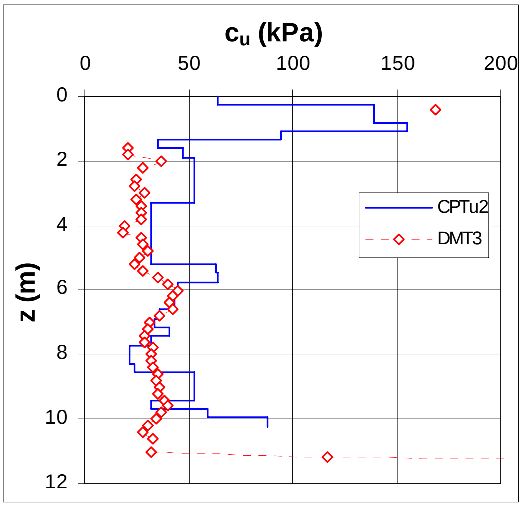

Figure 15. c_u at Dragučova

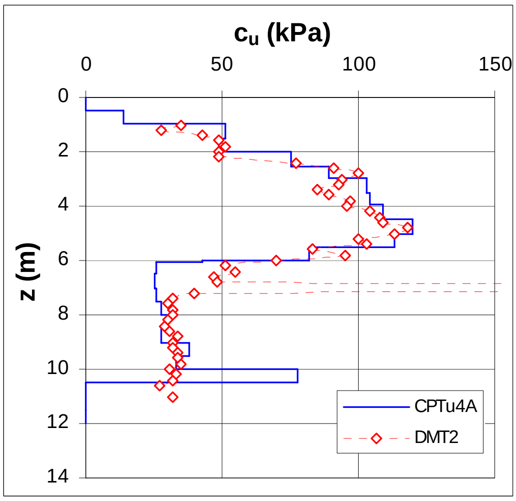

Figure 16. c_u at Srmin

BACK

Figure 17 presents the comparison of undrained shear strength for soft marine clay made after the extensive site investigation program at Pier II of Port of Koper. 4 DMT and 3 CPTU profiles were recorded. Only average values are presented in Fig. 17 together with the results of field vane test and pressuremeter results.

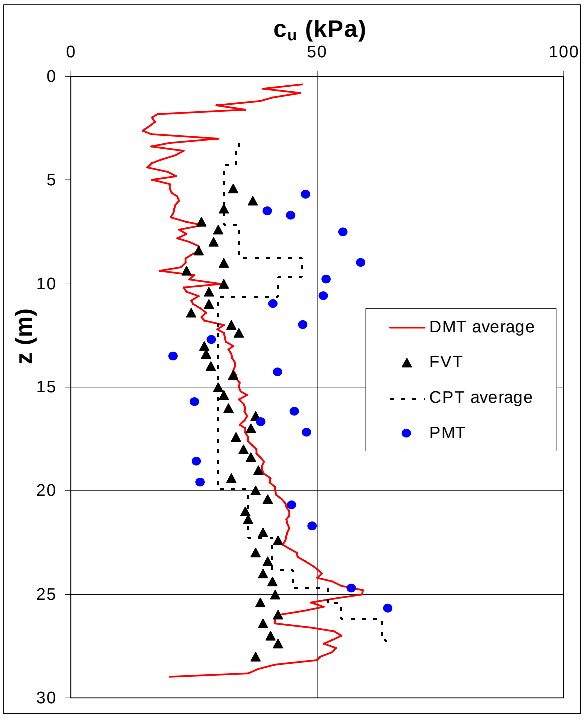

Figure 17. c_u at Pier II, Port of Koper

5 SETTLEMENTS

Three cases with settlement prediction based on DMT results and subsequent settlement measurements have been are documented so far. In all cases the settlements are caused by motorway embankments.

In the first case a 11.5 m high embankment was constructed on the soil profile presented above in Figures 8 and 16. Complete DMT results are given in Fig. 18. The main characteristics of this profile are the unsaturated top clayey layer, which is up to 6 m thick, and a soft layer below the first one having undrained shear strength c_u=20 kPa and even lower local values. Due to high load imposed by the embankment, the ground was improved by the installation of stone columns 60 cm in diameter at a spacing of 2.25 m. The estimated settlement reduction factor for such pattern of stone columns was β=0.8.

Table 1 shows the predicted and the measured values of settlements. Three DMT soundings were made and all three gave essentially the same settlement prediction, even though the profiles of the moduli were not equal.

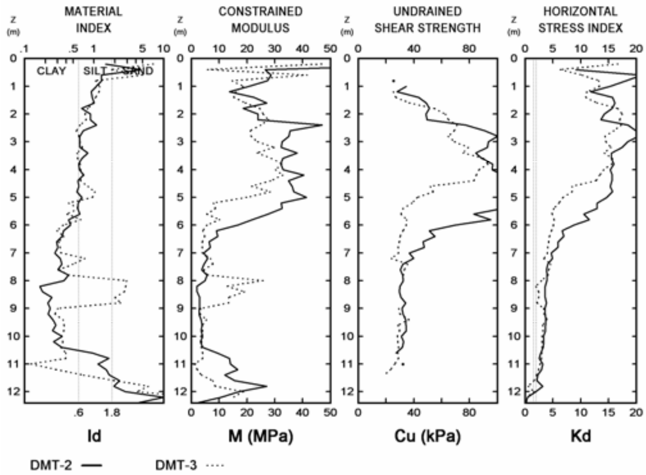

Figure 18. DMT results for the Srmin embankment

Table 1. Predicted and measured settlements for the Srmin motorway embankment (first case history)

	u_z
DMT prediction without stone columns	40 cm
DMT prediction with stone columns	32 cm
Measured total settlement	68 cm

The significant difference between the predicted and the measured values can be attributed to several reasons:

- DMT tests were performed at the toe of the embankment when the embankment was nearly completed and the ground was partly consolidated. One test was made farther away, but a thick layer of sand was encountered, again leading to lower settlements.
- Part of the settlement was deviatoric settlement.
- The moduli determined from DMT results for the upper unsaturated layer were too high.

In the second case a 7 m high motorway embankment near Smednik was constructed over 15 m thick deposit of soft soil resting on a stiffer sandy layer. The profile of oedometer modulus is given in Fig. 19. Table 2 gives the predicted and the measured settlement. In this case, the class A prediction of settlements under the embankment is in excellent agreement with later measurements.

Table 2. Comparison of the measured settlements with class A prediction based on DMT results (second case history)

Settlement at	Center	Edge
Class A DMT prediction	23.5 cm	13.6 cm
Last measured	20.6 cm	11.6 cm
Estimated end settlement by the Asaoka method	23.6 cm	13.5 cm

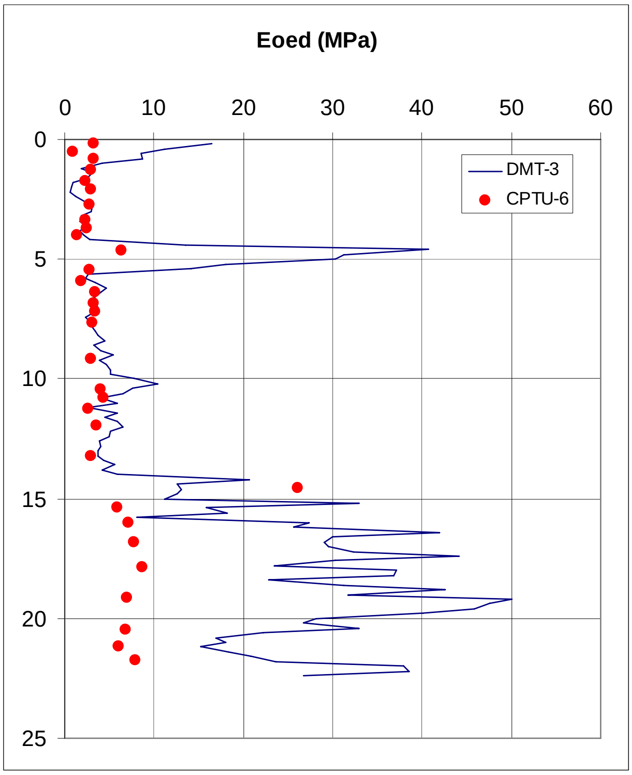

Figure 19. Profile of oedometer modulus (2nd case history)

The third case consists of two embankments constructed at two opposite ends of a motorway viaduct. The ground consists mainly of clayey and silty soils and was investigated by CPT and laboratory tests. The northern embankment was 6.6 m high and the southern 4.3 m high. Shortly before the construction began, the dilatometer had become available and two tests were made, one within the area of each embankment. The results are given in Figures 20 and 21.

The design prediction of settlement was based on previously available results. The settlements were measured by horizontal inclinometers and settlement plates. The comparison of the calculated and the measured settlement is given in Table 3. The measured settlements are given in a range, since slightly different values were obtained at individual measuring points.

Table 3. Comparison of the measured and the calculated settlements (third case history)

	Northern embankment	Southern embankment
Design prediction	39 cm	40 cm
DMT prediction	27 cm	17 cm
Last measured	41 cm	19 cm

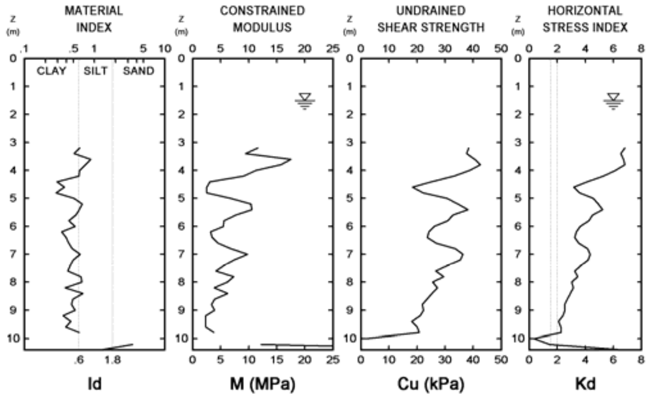

Figure 20. The DMT results for the northern embankment (third case history)

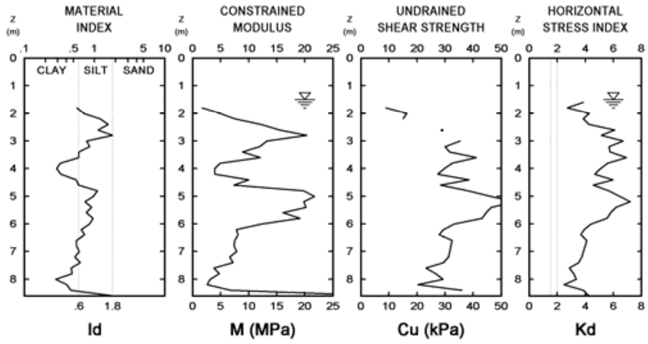

Figure 21. The DMT results for the southern embankment (third case history)

It is evident that the calculated settlements do not agree very well with the measurements. However, much more consistent agreement with the measured values is obtained by DMT prediction.

6 CONCLUSIONS

First experiences with flat dilatometer test in Slovenia were presented. This easy to use and versatile tool has proven to be competitive with other in-situ test procedures. Until now, it has mainly been used for the analysis of safety and settlements of ground under fills and embankments. Reliable results for undrained shear strength were obtained. The main advantage of DMT was found to be in stiffness data. The profile of constrained modulus is much more realistic compared with CPT moduli, and the resulting settlements are in fairly good agreement with the measured settlements.

The differences between the DMT predictions and the observed behavior were mainly found in cases where layers of unsaturated soil layers were present.

DMT has been well accepted in Slovenia. In three years University of Ljubljana has carried out over 1500 m of DMT soundings. Many projects where DMT was used are still in preparatory stage or under construction. Further research is in progress.

BACK

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