Excerpt from paper :
Failmezger R.A. & Bullock P.J.(2011)
"Owner Involvement - Choosing Risk Factors for Shallow Foundations".
Proceedings GeoRisk 2011 - ASCE

SITE INVESTIGATION TO QUANTIFY RISK

The engineer needs reasonably accurate deformation tests to accurately predict settlement of shallow foundations. The oedometer test, standard penetration test (SPT), cone penetrometer test (CPT), pressuremeter test (PMT), and dilatometer test (DMT) are commonly used for shallow foundation design. The applicability of these tests to quantify the risk of undesirable settlement is discussed below.

Oedometer Test: Sampling, followed by consolidation testing in an oedometer in the lab, provides an accurate test of deformation properties. However, testing is time-consuming and is typically performed at depth intervals exceeding 10 ft (3 m) or more. Sampling and handling disturbance may also significantly reduce the accuracy of the results. In general, the authors believe that in-situ testing provides more information, more quickly, with less cost.

Standard Penetration Test (SPT): Tests are commonly performed on 5-foot (1.5-meter) depth intervals at several borehole locations on a site. Because each boring could serve as a settlement prediction, there are usually enough data for numeric probability analyses. The test measures the number of hammer blows (N value) to drive a sampler 1 ft (0.30 m) into the soil. There are several acceptable hammer types, but these different hammer systems deliver different energies to the sampler. Unfortunately, the energy is rarely measured in the United States. (The new standard in Europe requires energy measurement.) The hammer energy transferred to the rods, when measured, varies from 30 to 95% of the theoretical potential energy of 4200 in-lb (475 N-m). The hammer type, while a critical factor for the energy, is often omitted from the boring log. If the geotechnical engineer does not know the energy used to drive the sampler, this significantly reduces the accuracy of any N-value interpretation.

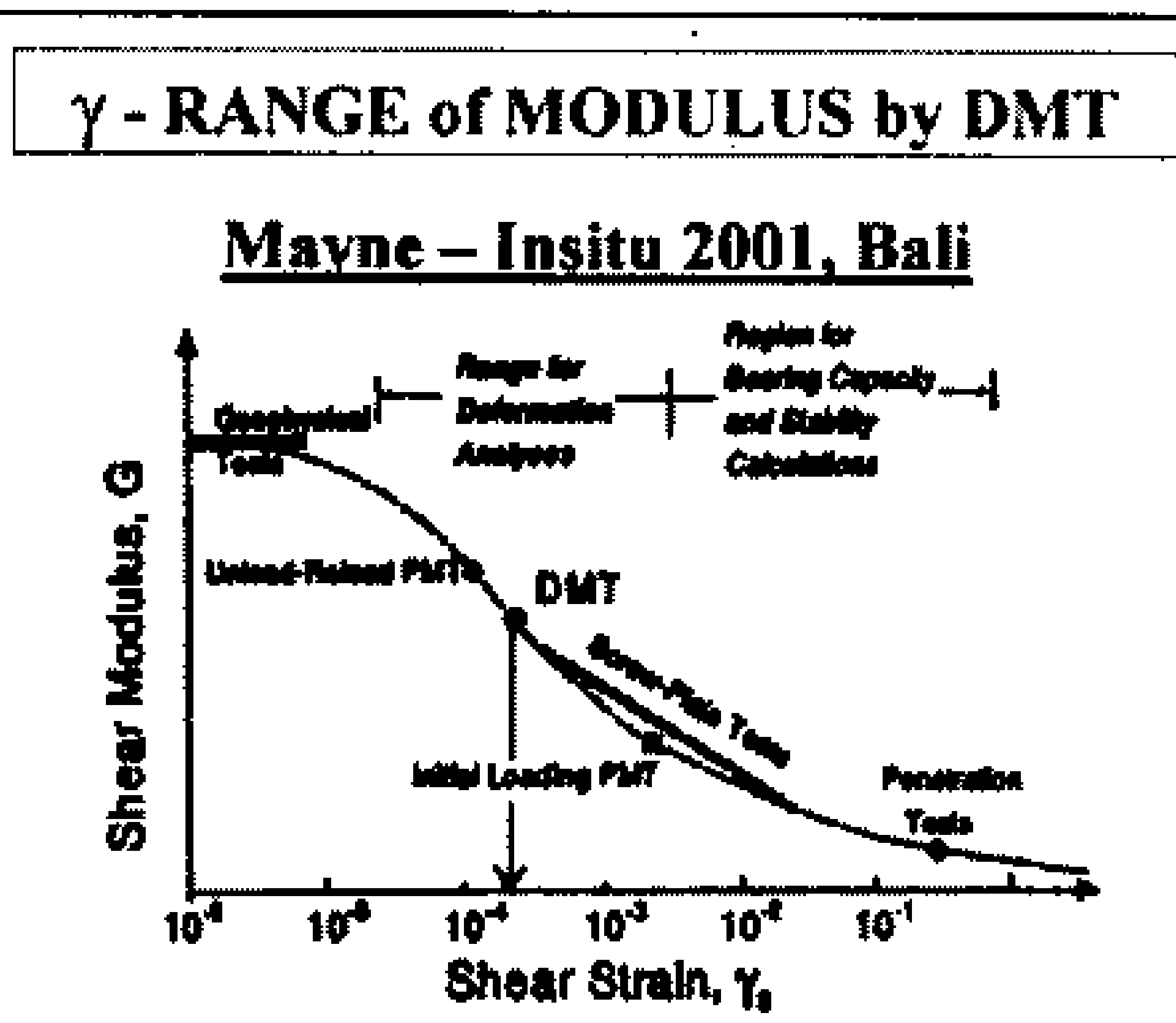

FIG. 1 Comparison of strain levels of in-situ tests and structures

The SPT is a dynamic penetration strength test and strains the soil to failure. As shown on Fig. 1, structural loads commonly strain the soil to intermediate levels. To determine the soil deformation modulus from the SPT N-value requires extrapolation from a strength parameter at failure strain to a deformation parameter at an intermediate strain, another possible source of error.

The dynamic penetration of the sampler in cohesive soil, especially sensitive soil, remolds the soil. In residual soils, the SPT destroys the latent rock structure. In both cases N-value correlations for the static deformation modulus are very poor or invalid. In sands, modulus correlations are somewhat better. Duncan (2010) suggests a relatively high coefficient of variation for the accuracy of predicting settlement in sands using N_{60} values (N-value with energy corrected for 60% of the theoretical energy) of 0.67. In a perfectly homogeneous soil, the error in the method alone would require that the average value of settlement be 0.30 in (7.6 mm) to be 95% certain that a settlement of 1.00 in (25.4 mm) would not be exceeded. Therefore, even the best case scenario for the SPT, seems much too inaccurate to predict settlement.

Cone penetrometer tests (CPT): The CPT measures the tip resistance (q_T) using calibrated strain gauges, typically providing repeatable data at 0.03 to 0.16 ft (0.01 to 0.05 m) depth intervals. Therefore, there are sufficient data to quantify risk. Like the SPT, the test strains the soil to failure. While the quasi-static tip resistance, q_T, has reasonable accuracy and repeatability, the engineer must still extrapolate to a deformation modulus at an intermediate strain level. The commonly-used equation below relates the tangent modulus, M, to q_T, using a strength parameter to predict a deformation parameter.

$$M = (\alpha)\,(q_T),$$

Depending on stress history and soil type, the value of α ranges from 1 to 8 for cohesive soil, 3 to 11 for normally-consolidated sand, and 5 to 30 for over-consolidated sand. Most engineers use conservatively low values and tend to over predict settlement. The unknown range of α reduces the accuracy of settlement prediction from the CPT.

Pressuremeter tests (PMT): The pressuremeter test strains the soil to intermediate strains in static deformation. Thus, the PMT predicts settlement relatively well, though often relying on empirical methods. However, it is a relatively slow test to perform and typically only two to six tests can be performed in one day, often at depth intervals of 10 ft (3 m) or more. The quantity and the quality of the tests are highly dependent on the driller's skill and experience. Unfortunately, there are usually not enough tests performed for a risk assessment of settlement.

Dilatometer tests (DMT): Like the pressuremeter, the dilatometer uses static deformation to strain the soil to intermediate strains. The DMT provides the one-dimensional tangent modulus (M) with tests generally performed at depth intervals of 0.66 ft (0.20 m). In thin layers of compressible soils, tests are often performed at depth intervals of 0.33 ft (0.10 m) for better definition. Tests typically take about 1 minute to perform and a sounding provides sufficient data for risk assessment of settlement with DMT. The authors recommend the dilatometer test as the best choice of in-situ tests for the settlement prediction of shallow foundations. At numerous (20+) sites in a wide variety of soils, Schmertmann (1986) and Hayes (1986) separately predicted settlement using DMT and measured actual settlement of footings/embankments. With the exception of quick silts, they found a ratio of predicted to measured settlement of 1.07 with a coefficient of variation of 0.18 (Failmezger, Bullock, 2004).