A [LOG(PLM) , LOG(EM/PLM)] DIAGRAM FOR SPECTRAL ANALYSIS© OF MÉNARD PRESSUREMETER TESTS RESULTS. APPLICATIONS TO GEOTECHNICAL SITE SURVEYS.

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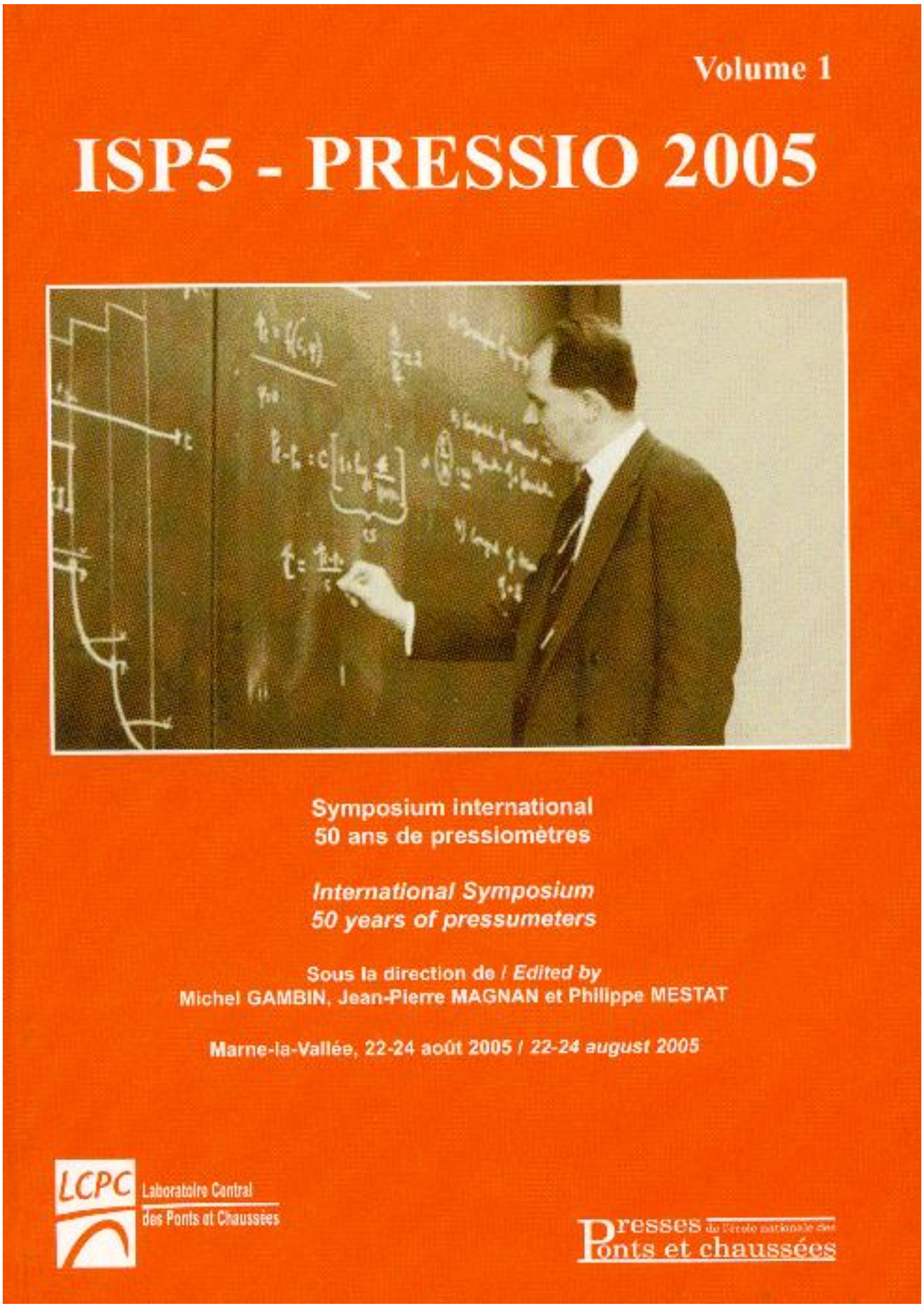

Cover photo: Louis Ménard lecturing about the Pressuremeter, circa 1975.

A [LOG(P_{LM}) , LOG(E_M/P_{LM})] DIAGRAM FOR SPECTRAL ANALYSIS© OF MÉNARD PRESSUREMETER TESTS RESULTS. APPLICATIONS TO GEOTECHNICAL SITE SURVEYS.

ANALYSE DES RESULTATS PRESSIOMETRIQUES MÉNARD DANS UN DIAGRAMME SPECTRAL© [LOG(P_{LM}), LOG(E_M/P_{LM})] ET UTILISATION DES REGROUPEMENTS STATISTIQUES DANS LA MODELISATION D'UN SITE.

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ABSTRACT – The Ménard rules regarding how to use the E_M modulus and the limit pressure p^*_{LM} in the pressure measurement direct design method require the user to take the E_M/p^*_{LM} into consideration in order to classify soils and, among other points, set the value of the rheological coefficient α. This choice is critical for the forecasting the settling of structures and other deformations. A graphical representation which can be helpful is proposed, having been successfully used for more than ten years.

1. Fundamental nature of the ratio between E_M and p_{LM} and the rheological coefficient α.

Louis Ménard chose to define the deformation modulus which now bears his name based on the pressure measurement test instead of the shear modulus which is the direct result of the equation for the expansion of a cylindrical cavity in an elastic medium (Lamé, 1852):

$$\frac{\Delta R}{R} = \frac{1}{2G}\Delta p \qquad (1)$$

where

- G is the shear modulus for the range of strains caused,
- R is the radius of the hole's cross-section,
- ΔR stands for the increase in this radius as a function of an increase in pressure Δp on the cavity's wall,

whilst opting for the conventional fixed value of ν =1/3 for Poisson's coefficient, which interlinks the orthogonal deformations.

He also stressed the importance of the link that exists between the deformation speed and the breaking strength of a given soil, which reduction of the pressure measurement test to measuring its two parameters E_M and p_{LM} ran the risk of neglecting. Using the dimensionless ratio E_M/p_{LM} placed in relation with rheological coefficient α, so that $\alpha = E_M/Ey$, he defined the soil's behaviour type in a decision-making table regarding the value of α as a function of E_M/p_{LM} and the nature of the soil (Ménard & Rousseau, 1962).

To date, no more precise method of determining α has been proposed. For example, that of systematic comparisons between measurements of pressure measurement and oedometric moduluses might have been expected, a subject regarding which publications of experimental results continue to be sporadic, not forgetting that the oedometric modulus varies depending on the range of pressures for which it is defined.

The range of values that the E_M/p_{LM} ratio can assume for standard pressure measurement tests is relatively limited: the extreme values in Ménard's original table range from 6 (normally consolidated sand and gravel) to 16 (overconsolidated clay), and the idea that the average is 10 is sufficiently well substantiated to enable tests that deviate too far from this average to sometimes be judged dubious. And, as a matter of fact, remoulding of a ring of soil around the borehole does tend to cause a major drop in the E_M/p_{LM} ratio, while excessive sinking of the probe into clay soil raises the interstitial pressure and artificially increases the E_M/p_{LM} ratio, which may reach high or very high values.

In other words, apart from these detectable cases in relation to conducting a test, and particularly drilling the borehole, often there remains a strong correlation between E_M and p_{LM}.

2. The uses of a graphical representation

2.1. Graph of E_M as a function of p_{LM}

The graphical representation of E_M as ordinates as a function of p_{LM} as abscissas for a large number of tests in soils and altered rocks (Figure 1a) is not very useful for differentiating between tests, but does show this concentration of representative points.

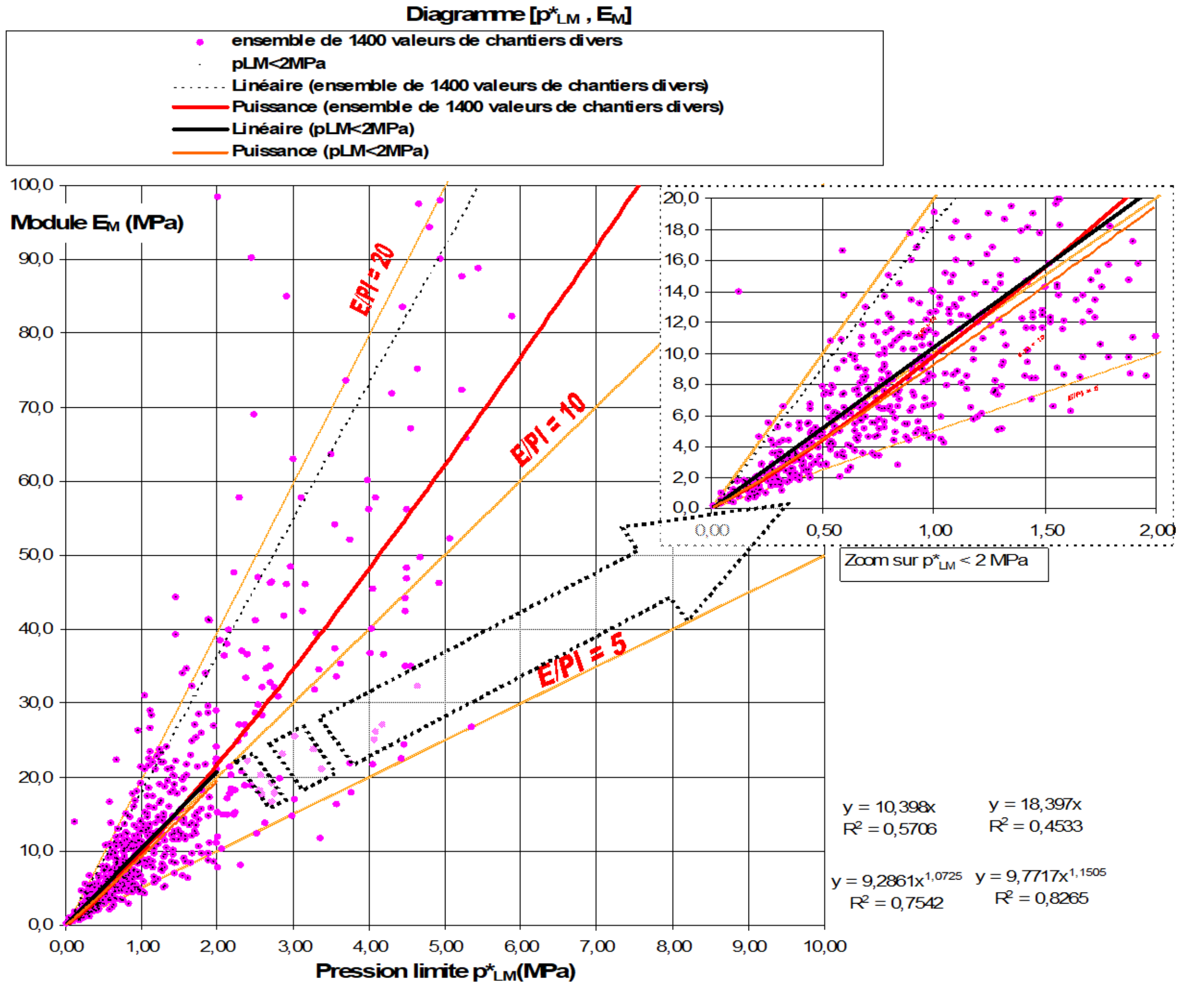

Figure 1a. Representation of E_M as a function of p^*_{LM} as arithmetic scales.

A [log(p_{LM}), log(E_M)] representation provides a slightly better differentiation of the representative points (Figure 1b), which do however remain grouped within the narrow band between E_M/p^*_{LM} = 5 and E_M/p^*_{LM} = 20, which become parallel lines in this bi-logarithmic reference.

Diagramme [log(p^*_{LM}) , log(E_M)]

La représentation log(E_M) / log(p^*_{LM}) visualise, mieux que la représentation arithmétique, la relation $E_M = 10\ [-5\ ,\ +10]\ p^*_{LM}$, mais ce groupement dans une bande étroite ne favorise pas la différenciation des points représentatifs des essais

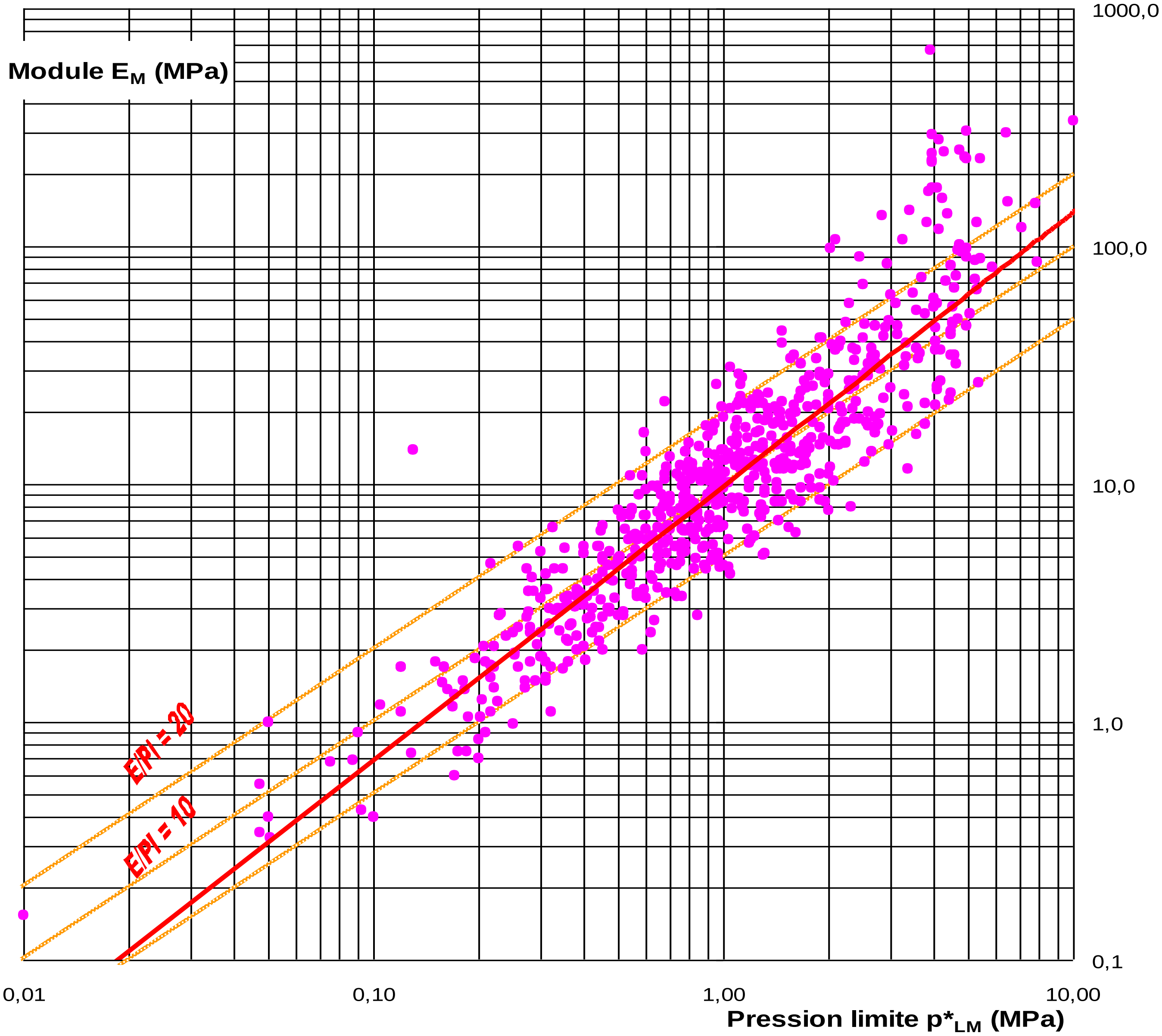

Figure1b. Representation of E_M as a function of p^*_{LM} as bi-logarithmic scales.

2.2. Graph of E_M/ p^*_{LM} as a function of p^*_{LM}

In order to visually distinguish between the representative points for pressure measurement tests in a diagram that is better "laid out", I propose systematically recording the representative points for pressure measurement tests for the same soil, borehole or site in a [log(E_M/p^*_{LM}) , log(p^*_{LM})] bi-logarithmic diagram, which I shall call the pressure measurement spectral analysis© diagram. This diagram (Figure 2) does in fact enable good representation of the wide range of values that these two parameters can assume:

- One that is dimensionless, E_M/p^*_{LM}, the soil's consolidation index;
- The other in strain units, net limit pressure p^*_{LM} .

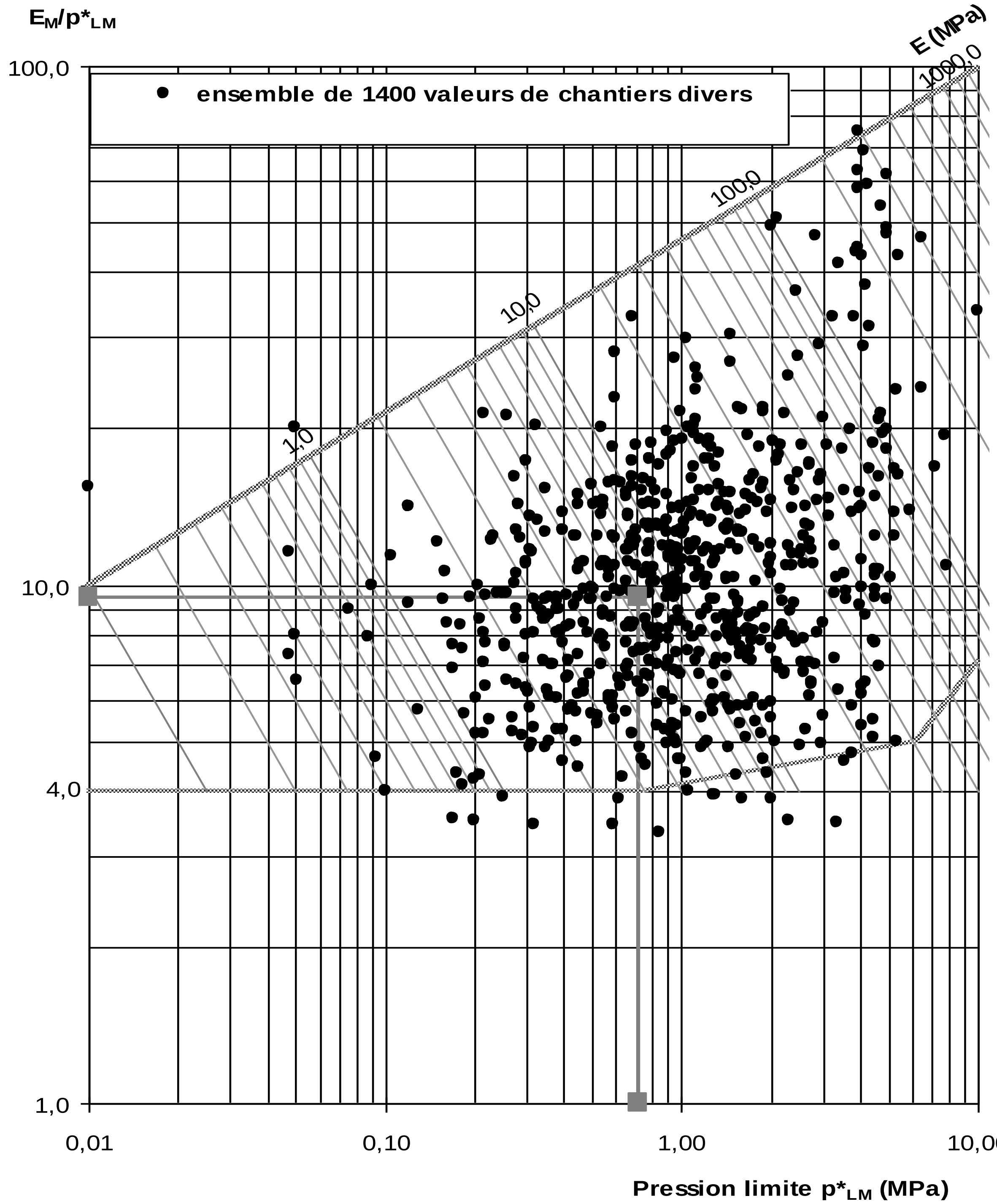

Figure 2. Example of a [log(p^*_{LM}), log(E_M/p^*_{LM})] pressure measurement spectral analysis© diagram

This new form of diagram represents the same points from a large number of different tests, if not disparate from the perspective of the natures of the soils, with the following graphical semiological conventions linked to the logarithmic scales, compatibility with standard paper or screen formats (using the conventional “portrait” or “landscape” formats), and taking care to place the range of usual values for soils and altered rocks in the centre of the graph:

- Vertically; 2 logarithmic moduluses for E_M/p^*_{LM} from 1 to 100
- Horizontally; 3 logarithmic moduluses for p^*_{LM} from 0.01 MPa to 10 MPa;
- At the top, near the high values for E_M/p^*_{LM}, the straight line [10/0.01MPa, 100/10MPa] forms a “natural” boundary which should not normally be crossed by standard pressure measurement tests;
- At the bottom, near the low values, the physical boundary is $E_M/p^*_{LM} = 4$;
- To the left, near the low p^*_{LM} values, values lower than 0.01MPa are difficult to measure and representation of them serves no further purpose;
- To the right, extension of the graph by 1 logarithmic modulus (p^*_{LM} up to 100 MPa) or even 2 moduluses can be envisaged but the diagram then enters the field of the mechanical properties of rocks;
- The convention is for the graph to adopt a proportion of 1.15/1 ($2/\sqrt{3}$ for 1);
- The indexing lines for the pressure measurement moduluses are parallel lines with logarithmic spacing and, visually, are perpendicular to the graph’s upper boundary in the agreed configuration.

The cluster of representative points from various tests is in fact shown centred near the “pivot” value [p^*_{LM} =1 MPa , E_M/p^*_{LM}= 10], and the deviation between the points around this value is easy to ascertain visually.

Tests with E_M/p^*_{LM} values less than 10 are not to be ruled out without exercising discernment; firstly, granular soils that have no cohesion do in fact give pressure measurement curves with low concavity, for which a secant modulus of about half of the pressure range corresponds to low values for the ratio, and secondly for such tests which do now show a pseudo-linear part, there are major differences in interpretation of the modulus, with a tendency to make an artificial increase in the modulus to make it comply with a higher value sought.

The limit indicated $E_M/p^*_{LM} = 4$ may seem low, or even lax. What is demonstrated is simply that it is the lower limit set by definition in relation to a loose granular soil with a maximum void index, the reaction of which is linear from p_0 to p_{LM}; such cases apply to clean sand discharged as a result of stormwater, or granulates piled underwater for example. Whatever the limit pressure, which is then a function of the mass of the soil above the test, the E_M/p^*_{LM} ratio is such that $G_M = (V_p+V_p/2) \cdot p_{LM}/V_p$ or $G_M = 1.5\ p_{LM}$ and since $E_M=8/3G_M$, $E_M = 4\ p_{LM}$ (Baud & Gambin, 2005). Lastly E_M/p^*_{LM} is still a bit, or even a lot, lower than E_M/p_{LM}.

3. The uses of the pressure measurement spectral analysis© diagram

Representation of the results of pressure measurement tests using points in a diagram does not provide any new elements in relation to those contained in pressure measurement drilling logs, in which the ratio E_M/p^*_{LM} is explicit or implicit. But collating results on the same support enables a display which helps with synthesis.

3.1. Educational uses

The diagram was initially put together to explain the range of values that may be assumed by the E_M moduluses and pressure measurement limit pressures p^*_{LM} in soils and rocks (Baud, 1991) to geology students who were beginners in the field of geotechnics.

Figure 3 illustrates presentation in this diagram, extended to cover the field of rocks (p^*_{LM} of up to 100MPa), with classification concepts for soils and rocks with clay or sandy behaviour, the pressure measurement response, qualification of the compressibility or stiffness of the soils (soft, crumb, stiff, rocky) in standard language, and assessment of the degree of consolidation using E_M and p^*_{LM}.

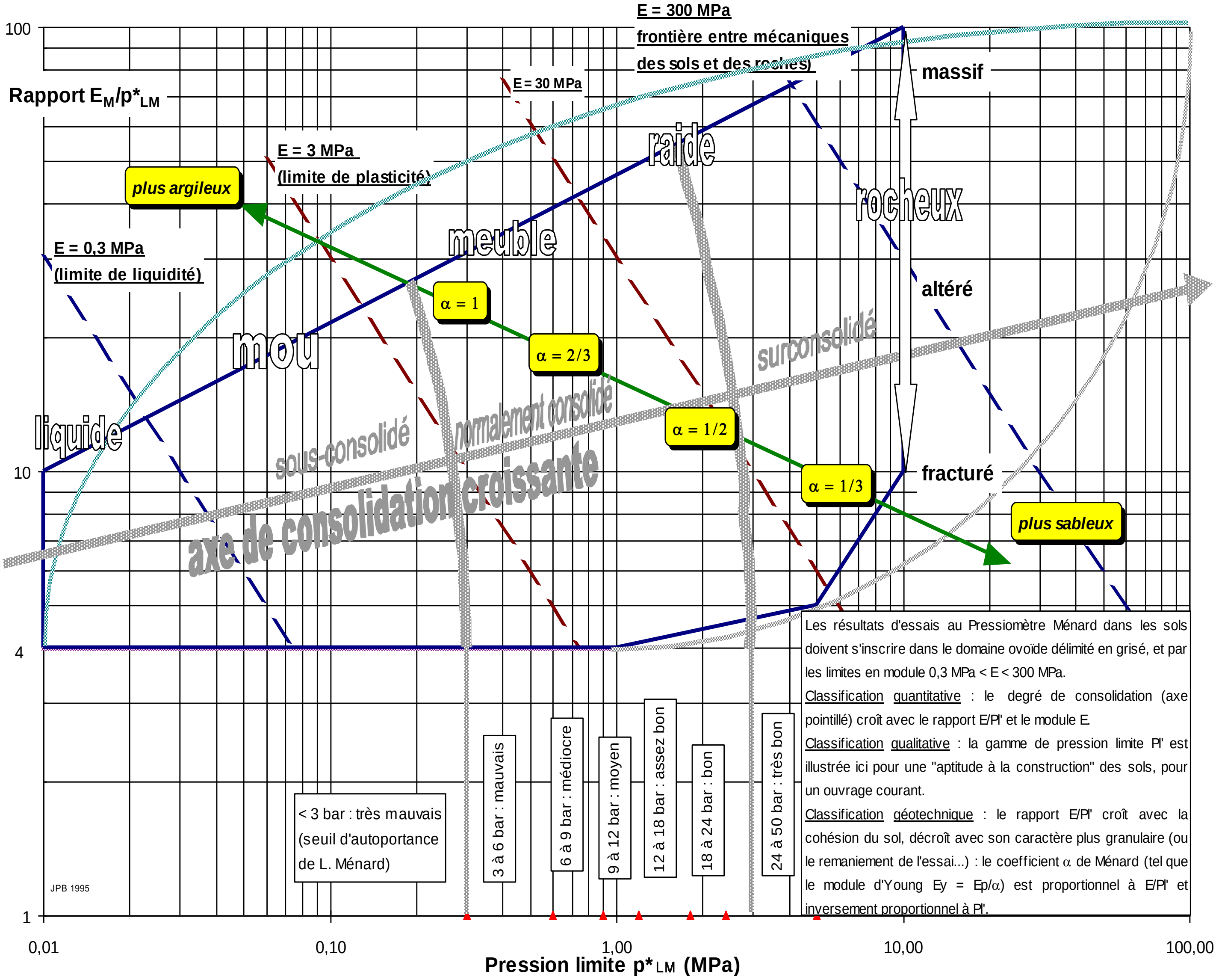

Figure 3: Use of the spectral analysis© diagram for pressure measurement characteristics for a schematic qualification of soils and rocks.

3.2. The role of the “regulatory” categories for soils in the diagram

For engineers, the rules for using pressure measurement results with a view to sizing surface foundations and deep foundations (AFNOR 1993; MELT 1993) entail choosing the classification of values for the parameters measured in very simplified soil categories, defined based on the LCPC (French National Civil Engineering School Central Laboratory) classification on the one hand, and on the pressure measurement values obtained (mainly p_{LM}) themselves on the other hand. Although the E_M modulus is not used explicitly for this categorisation, examination of the results in the spectral analysis© diagram can assist with decision-making. Figure 4 is an attempt to go further in terms of this categorisation, in accordance with Table 3 in Appendix E1 of Part 62, Section V.

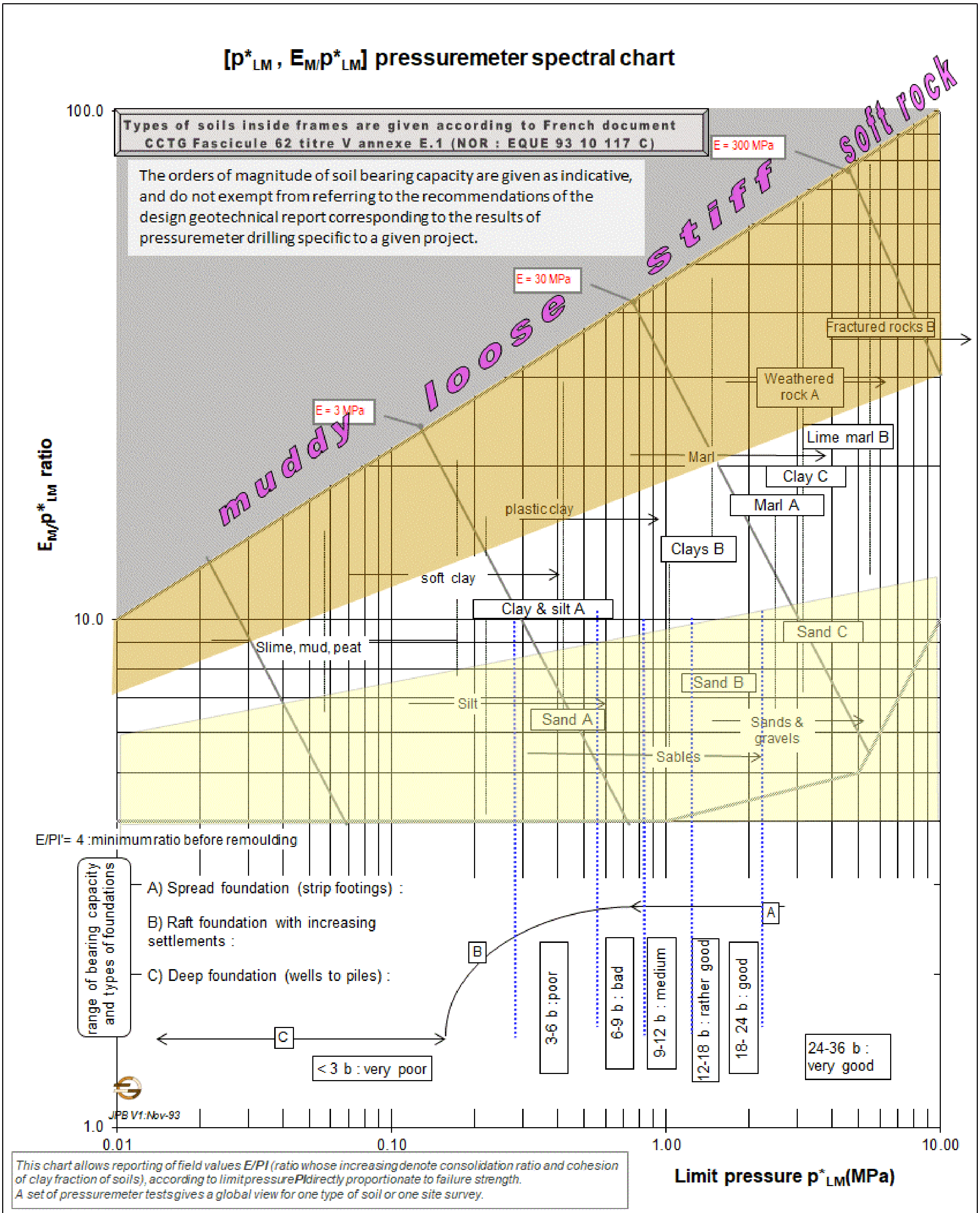

Figure 4. Identification (using the names in the boxes, followed by a characteristic letter) of "regulatory" soil categories (MELT, 1993) in the spectral analysis© diagram. The range of standard values from the publication Ménard D60 (TLM, 1965) has been added. In the bottom left-hand corner of the graph, the meaning of the letters A, B and C is provided in a key.

Using this diagram makes it possible to specify breaks in the "layers" which match groups of homogeneous values within the context of sizing piles.

3.3 Modelling a site as part of a geotechnical study

Using the pressure measurement spectral analysis© diagram has proved to be extremely useful for analysis of full pressure measurement campaigns, for which the statistical analysis of pressure measurement data and work on averages is one usual method. Grouping or spreading points in the diagram characterising formations that are deemed to be identical lithologically enables their degree of homogeneousness to be checked so that they can be broken into sufficiently homogeneous sub-sets within the apparent continuum in order to justify their simplification by representative average values.

Iterations between borehole drilling logs and the diagram are often necessary in order to refine the diagnostics. In a well-conducted pressure measurement campaign (or at least with a constant “standardised remoulding”), tests that were apparently aberrant or “outside the cluster” can thus appear and prompt a review of test reports and lithological sections in order to check whether these anomalies do not reveal elements in the sub-soil’s structure which did not appear obvious during a quick analysis of the results.

I suggest that the reader refer to professional publications in which, in the near future, I shall be presenting some very significant examples.

4. Conclusions and prospects

Analysis of the results of pressure measurement campaigns through use of the pressure measurement spectral analysis© diagram presented here just constitutes one more stone in the edifice of the pressure measurement method established by Louis Ménard, and perfected over 50 years by numerous more fundamental theoretical and experimental contributions, such as the lateral friction curves as a function of p^*_{LM} (Bustamante & Gianiselli, 1981). It casts new light on the old issue of determining or rather assessing the rheological coefficient α, for which I hope that it may serve as a support for drawing curves of isovalues for this coefficient as a function of p_{LM} and E_M/p_{LM}, with the help of feedback from instrumental work on foundations as well as theoretical research.

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The methods were developed by analysis of a large number of worksites involving pressure measurement tests from a wide range of sources, both as far as the types of soils are concerned and the drilling and testing companies are concerned. For any further information about pressure measurement methods and their applications, contact the author via e-mail: ***baud@eurogeo.fr***

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