Complementarity of PMT and MWD tests

Complémentarité des sondages PMT et MWD

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ABSTRACT

The measurement of drilling parameters during the creation of the cavity for the Ménard pre-bored pressuremeter test is an important source of information. These measurements cannot generally be interpreted in their raw state. Several compound parameter relationships have been proposed to minimize the influence of certain error factors. Among these relationships, the Somerton relationship proposes a drilling index that is undoubtedly the one with the most potential for comparison with the Ménard pressuremeter limit pressure. This paper presents an analysis of multiple sites and shows the good correlation between these two parameters.

RESUME

La mesure des paramètres de forage lors de la création d'une cavité pour le pressiomètre de Menard est une source importante d'information sur le terrain. Ces mesures ne peuvent pas être interprétées dans leur état brut. Plusieurs paramètres composés ont été proposés afin de minimiser l'influence de certains facteurs d'erreur. Parmi ces relations mathématiques, l'indice de Somerton propose une relation qui est sans doute celle qui a le plus de potentiel de comparaison avec la pression limite du pressiomètre de Ménard. Cet article présente une analyse de multiples campagnes géotechniques et montre une bonne corrélation entre ces deux paramètres.

Keywords: Measurement while drilling; Somerton index; Ménard pressuremeter test

1. Introduction

The Ménard pressuremeter test is a simple and reliable geotechnical investigation method commonly used throughout the francophone world that establishes a relation between a force applied on a soil and its deformation, represented in Figure 1.

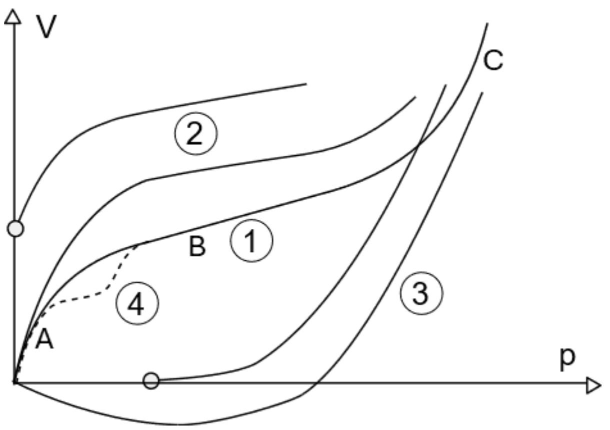

Figure 1. Typical pressuremeter curves

In the curve 1 of Figure 1, three different phases can be identified. Phase A has no significance to the investigation, as the probe is only expanding to occupy the empty space in the cavity and make contact with the soil. In phase B, a linear correlation can be seen, and the deformation is called pseudo-elastic. In phase C the curve becomes steeper, and the soil is considered to deform plastically (Cassan, 1988).

From this curve, 3 distinct parameters can be defined: the limit pressure p_{LM}, creep pressure p_{fM} and the Ménard elastic modulus E_M. The creep pressure separates the pseudo-elastic and plastic phases, while the limit pressure is determined by the pressure needed to achieve a given volume and the elastic modulus is derived from the slope of the curve in the pseudo-elastic phase (Cassan, 1988; AFNOR, 2021).

However, some problems may arise during the test that could make the test unusable, as shown by the curves 2, 3 and 4 in Figure 1. In the curve 2, the borehole is too wide, and too much volume is needed to make contact between the probe and the soil. This could lead to an underestimation of the Ménard modulus (Baguelin et al, 1978; Cassan, 1988).

Curve 3 results from the opposite problem: the borehole was too small. In this case the evaluation of the pseudo-elastic phase is also compromised, as the insertion of the probe already deformed the soil. This could also happen in cases of ground swelling, which would be indicated by a decrease in volume in the early stages of the test (Baguelin et al, 1978).

Finally, curve 4 represents the cases where the soil partially collapses into the borehole during the test. When this happens, a step can be seen in the final curve, as the probe needs to reestablish contact with the walls. This could also happen if the stabilizing mud starts to flow or in reworked clays (Baguelin et al, 1978).

The entire procedure is then repeated at multiple depths to create a soil profile at the investigation point, which will allow the foundation designer to understand how the material properties change with depth at that location. The use of multiple profiles creates a model representing the soil in the studied area.

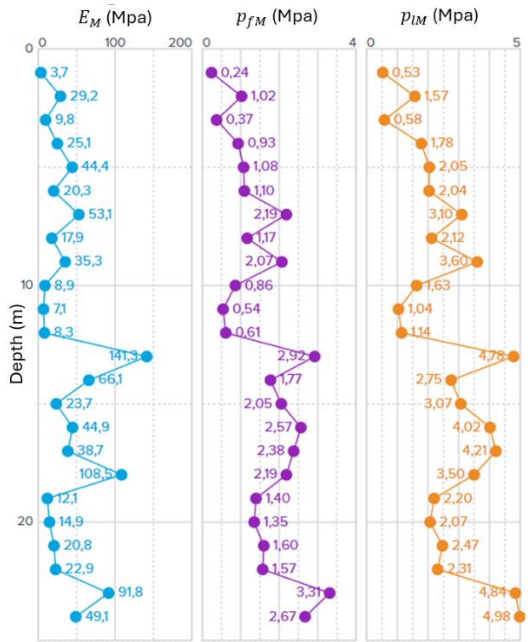

Figure 2. Example of a pressuremeter profile

However, due to the length of the probe, the information in this profile isn't continuous. Pressuremeter tests are typically done every 1,0 to 1,5 meters. More data from the soil can be collected during the drilling process, a technique called Measurement While Drilling (MWD). This technique registers various machine parameters while drilling the hole in which the pressuremeter tests will be executed to create a continuous, more detailed, profile.

Multiple parameters can be monitored in this manner, with the most common being the drill bit's advance rate, downthrust, holdback pressure, torque and rotation speed, and the drilling fluid's injection pressure and volumetric flow. While not directly describing the soil's characteristics, it is considered that all these parameters can be used to infer the soil's response to the drilling and its nature. Certain patterns are empirically associated with certain soil types, such as high fluid injection pressure in clayey soils, and changes in soil lithology usually results in a sudden change in one or multiple drilling parameters, which can facilitate the construction of soil profiles (Cardu et al., 2013; Moussouteguy, 2002).

This interpretation can be made simpler with the use of what is called a compound parameter, a mathematical relation between the raw parameters. There are multiple compound parameters suggested in the literature and one of the most commonly used is the Somerton index (1959), an empirical formula that represents the material's resistance to drilling calculated from the machine's advance rate and downthrust.

At the present moment, however, the interpretation of drilling parameters is only qualitative rather than quantitative, and no engineering parameters can be extracted from all the data collected. This happens because of the huge variability in drill rig architecture, drill bit design and drilling techniques employed. Concurrently, as most projects only employ MWD in a limited number of investigations, no wide-scale correlations have been established (Reiffsteck, 2010; Moussouteguy, 2002)

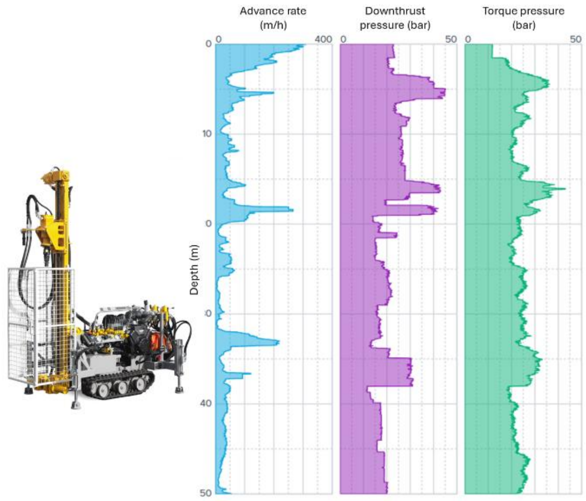

Figure 3. Geotechnical drill rig and MWD logs

For this reason, this article will analyze multiple MWD and pressuremeter essays performed throughout France to seek a correlation between the Somerton index corrected as suggested by Yalcinkaya and Okyay (2024) and the pressuremeter's limit pressure.

2. Methodology

In this article, the limit pressure and creep pressure as calculated by the Ménard pressuremeter test will be compared to the Somerton index calculated from the connected MWD parameters for the same hole.

In the Ménard pressuremeter test, the limit pressure p_{LM} is conventionally defined as the pressure needed to double the initial volume of the soil cavity. The initial volume is identified at the start of the pseudo-elastic phase and if the doubling of the volume couldn't be achieved during the test, the pressure can be extrapolated by extending the plastic phase trendline (AFNOR, 2021)

The Somerton index is a compound parameter derived from the MWD parameters collected while drilling for the pressuremeter test. The adimensional index intended to represent the soil's resistance the drilling and is calculated by Equation 1. For this, Somerton (1959) takes into account the drilling's advance rate (u), rotation speed (N) and downthrust (F), but if the rotation speed is considered to be relatively constant only F and u are needed.

$$S_d = \frac{N}{\sqrt{u}}F \cong \frac{F}{\sqrt{u}} \quad (1)$$

Following the methodology proposed by Yalcinkaya and Okyay (2024), the drilling parameters were also registered for a section that had already been drilled with the intend of using these logs for correction. The Somerton index was also calculated for these logs and used to correct the index calculated for the actual drilling. This is done to approach the index's values to those of the pressures calculated in the pressuremeter test while also accounting for the inefficiencies in the drill rig and the friction between the drill string and the walls of the hole.

As explained in the original paper, the Somerton index that is supposed to represent the soil's strength should be 0 for every calibration drilling made on a prebored hole. However, this is not the case as some downthrust pressure is needed to move the drill rig, and eventual contact between the drill string and the hole's wall introduces a bit more resistance that needs to be counterbalanced by slightly increasing the pressure in the rotation and translation circuits.

The corrected Somerton index is calculated by Equation 2.

$$S_{d,corrected} = \frac{S_d}{S_{d,calibration}} - 1 \qquad (2)$$

This normalized Somerton index $S_{d,corrected}$ and the Ménard limit pressure p_{LM} of multiple geotechnical investigations were compared, considering the lithology encountered by each investigation, to establish a correlation between both variables.

A total of twenty investigations from 4 different campaigns in the northwest of Paris, France that performed pressuremeter tests and collected MWD data were analyzed. To reduce the variability of the MWD data, all drillings analyzed were of the same diameter (64 mm) and made with similar sized machines. Their MWD results were corrected by the Yalcinkaya and Okyay (2024) method and visually compared to the pressuremeter profiles from the same investigations. The values were also statistically analyzed while considering the reported stratigraphy in the search for correlations between corrected Somerton index and soil type.

3. Results and discussion

Five drillings were selected as representatives of the analyses and have their stratigraphy is shown in Figure 4. When analyzing the limit pressure and the Somerton index curves together, it can be seen that the two curves resemble each other, but they are not aligned. As both parameters indirectly measure the soil's resistance, it would be logical that they both present similar trends, as can be seen in Figure 5.

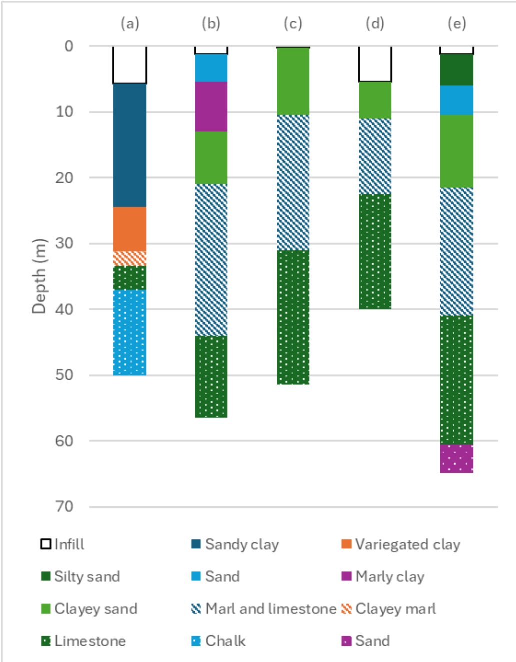

Figure 4. Stratigraphy for the drillings presented in Figure 5 and 6.

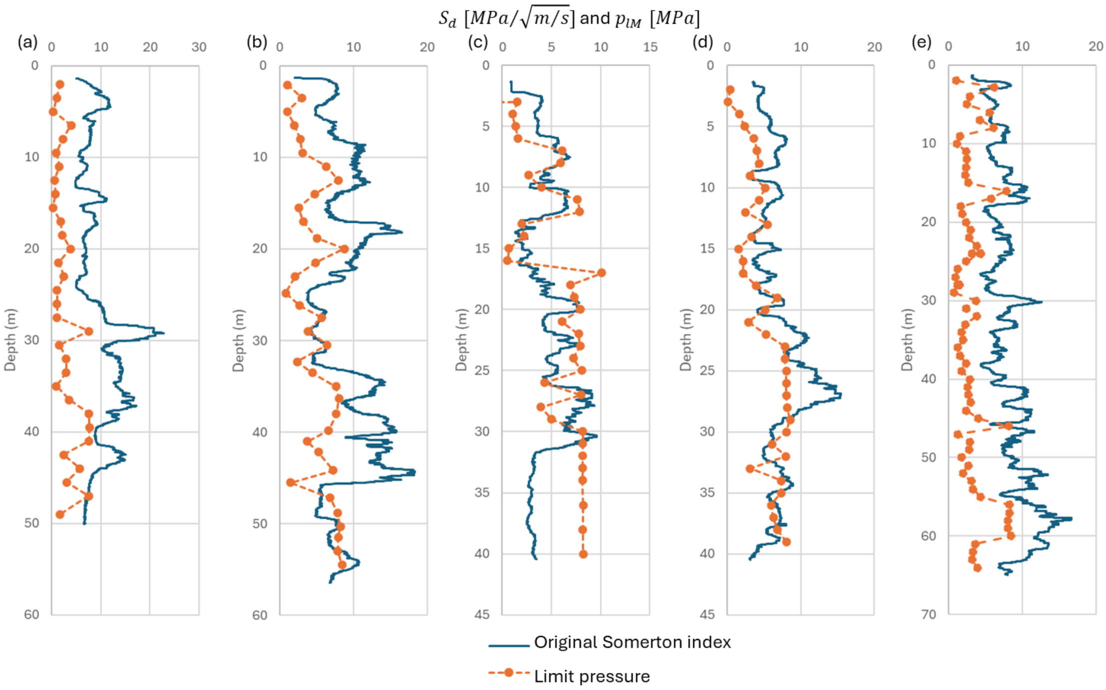

Figure 5. Comparisons of the original Somerton index S_d and limit pressure p_{lM}

Applying the correction factor for each of the investigations brings the Somerton index numerically closer to the limit pressure values, as seen in Figure 6.

In most of the profiles, the correlation tends to become worse as depth increases. This could be due to the calibration drilling not having the same length as the actual drilling, and the change in the weight of the drill string affecting the correlation. On the other hand, it could also be the result of encountering more compact and harder materials at those depths, and the soil having different resistances along the vertical axis and on the horizontal plane. In all five investigations showed in Figure 6 exept investigation (e), the correlation worsened when the drilling reached a layer of coarse limestone, so the differences seen between the two parameters could be due to heterogeneities specific to this layer.

Differences in technique between the drillers can also affect the final result of MWD investigations, as the method's standards are followed as strictly as those of the Ménard pressuremeter test. These small differences affect all of the drilling parameters logged while drilling and can greatly affect the compound parameters calculated later.

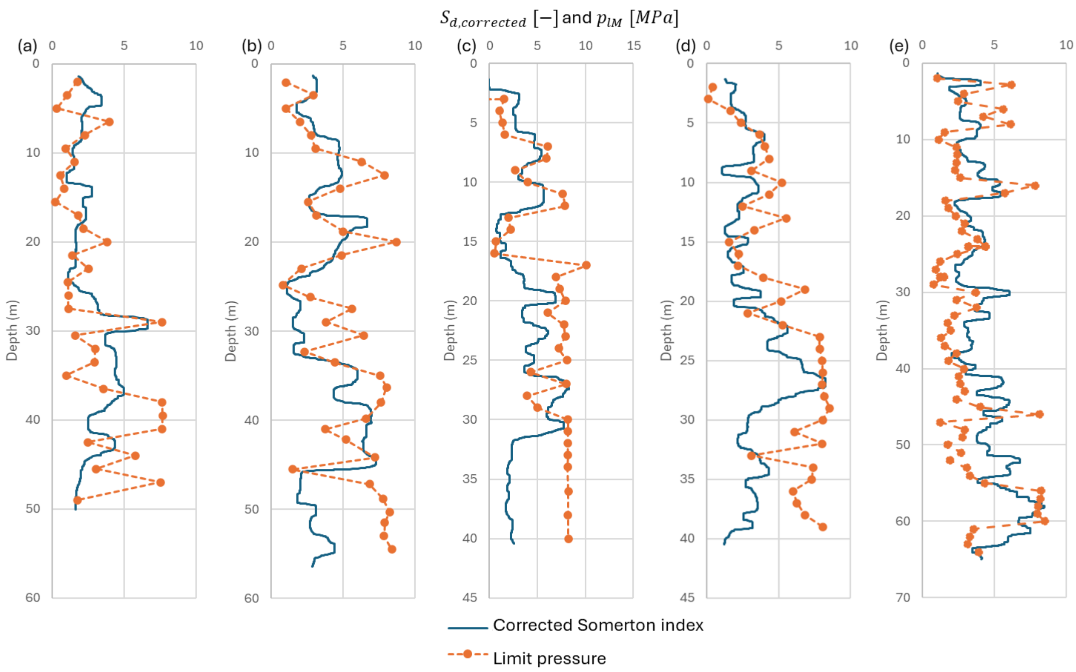

Figure 6. Comparisons of the corrected Somerton index and limit pressure

As the pressuremeter cell measures 40 cm in length, the drilling logs were smoothed by a moving average measuring 40 cm, centered at the recorded depth. These averages can then be compared with the limit pressures measured at the same depths in a scatter plot like the example shown in Figure 7. The correction applied to the Somerton index brings the values numerically closer to the limit pressure measurements, but as a single correction factor is applied to entire curve, there is no significant change in the coefficient of determination.

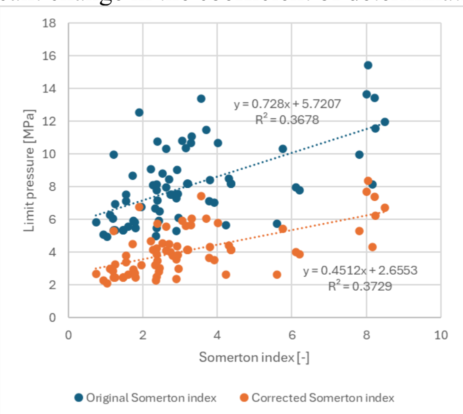

Figure 7. Comparison of limit pressures and smoothed Somerton indexes

4. Conclusion

In this paper, a correlation between the limit pressure measured by the Ménard pressuremeter and the Somerton index derived from MWD logs and later calibrated was investigated. The corrected Somerton index showed good visual correlation with the pressuremeter's limit pressure measurement, especially in shallower depths. This simple correlation could be used to inform on P_{LM} in between measurement points or even in points where the test couldn't be performed successfully. Short MWD-only investigations could also be used alongside a few investigations where both methods were employed to create a more detailed model of the underground. The use of multiple calibration factors should also be investigated, registering multiple calibration runs at different depths to account for changes in drill string weight and lateral friction.

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