Work criterion to assess rate effects on pressuremeter testing: stress- vs strain-controlled procedures

Critère de travail pour évaluer les effets du taux sur les essais pressiométriques : Procédures contrôlées par contrainte ou par déformation

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ABSTRACT

This paper evaluates differences between rates of loading for stress- and strain-controlled test procedures. Menard and Texam Pressuremeter systems expand the pressuremeter probes using pressure-control and volume-control, respectively. The effects of different loading procedures on the soil responses to pressuremeter loading are evaluated by using a work criterion, comparing external work generated during these two loading procedures. The actual in-situ test data used in this evaluation was obtained by drilling and PMT testing two companion boreholes, one for Menard equipment and the other for Texam equipment.

RESUME

Cet article présente une évaluation des différences provenant des taux de chargement pour les procédures d'essais pressiométriques contrôlées par contrainte et par déformation. Les sondes Ménard et Texam sont pressurisées en contrôlant respectivement la pression et le volume. Les effets des différentes procédures sur les réponses du sol au chargement pressiométrique sont évalués en utilisant un critère de travail, soit en comparant le travail externe généré au cours de ces deux procédures de chargement. Les données des essais in situ utilisées dans cette évaluation ont été obtenues à partir d'essais réalisés dans des forages voisins à l'aide d'équipement Ménard et Texam.

Keywords: In-situ testing; Menard and Texam Pressuremeters; Rate of loading; Stress- and Strain-controlled loading; Pressuremeter data interpretation.

1. Introduction

Current Prebored Pressuremeter testing practice in North America are being implemented in general accordance with Procedures A or B of the ASTM-D 4719-07 standard.

These two alternative methods utilize Pressure-Controlled (A) or Volume-Controlled (B) loading procedures, corresponding to Menard and Texam, respectively. The soil mass being tested under PMT loading conditions will have a specific response whether pressure or volume is maintained at each load step.

Like many in-situ testing practitioners, the authors here ask themselves if the test data obtained via these two approaches lead to similar, comparable results or otherwise. And if they are not similar, how much more different test results could be.

In this paper, the authors explore the differences between A or B loading procedures from a rate-of-loading point of view. Specifically, the pressure-volume responses from actual PMT testing using Menard and Texam equipment are compared using the principle of strain energy or work imparted by the respective control units into the soil mass being tested.

1.1. Background

Texam Pressuremeter is one of the preferred testing equipment in Canada and USA. The equipment, manufactured by Roctest Ltée, in Montreal, Canada, has proven to be reliable, robust to work in the glacial till deposits typically encountered in the region. Often, these glacial tills are very stiff, dense deposits, with gravel or rocky intrusions, which are difficult or not amenable for other type of in-situ testing such as CPT, Flat Plate Dilatometer, field vane testing, etc (Baguelin, et.al; Briaud; Clarke, and others).

Roctest equipment uses a mono-cell probe, and the control unit implements a volume-controlled procedure.

Texam control unit also allows for pressure-controlled loading although in an approximate manner.

On a different consideration, interpretation of Pressuremeter data has undergone important developments worldwide in the past decade. The introduction of the Pressiorama charts by Baud & Gambin and others (Baud, et.al, 2013; Baud, 2016; Reiffsteck, et.al. 2013) provides a reliable framework to obtain inferred soil parameter including the Menard's α parameter, estimates of shear strength parameters, and a soil index to identify soil behaviour types. The research leading to the development of the Pressiorama correlations is, strictly speaking, based on test data obtained with the Menard's equipment, pressure-controlled system with guard cells (tri-cell probes).

For Texam users, as in case of the present authors, the possibility of using Pressiorama correlations is highly desirable, but it remains to be considered whether the Pressiorama empirical correlations can be applied to Texam test data, based on volume-controlled loading.

Comparisons of Menard- versus Texam-produced test data have been completed by the present authors Marcil, et.al, 2015; Marcil, 2020; and Marcil et.al., 2024). The basis for these comparisons were the pressure-volume curves obtained for each one of these Menard and Texam loading procedures. The similarities and differences of these two loading procedures are discussed in these references. Also, a set of PMT tests were performed on special flexible tubes (faux-sol) to generate responses in the quasi-linear range of deformations as an attempt to isolate the effects of the diameter-to-length ratios, different for the Menard (tri-cell) and Texam (mono-cell) probes (Marcil, et.al, 2015).

The question of the different rates of loading between Menard and Texam systems however should be evaluate, and this is the focus for this paper.

1.2. Scope of present study

Using existing PMT soil data, we evaluate the rate of loading conditions for the Menard and Texam procedures by comparing the work per unit volume generated by the respective control units. This is to say that comparisons of pressure-volume responses, or stress-strain curves, are not clear enough to identify differences in the soil responses due to different loading rates.

The list below summarizes the content of this evaluation, as follows:

Section 1 describes a geotechnical concern with pressuremeters and introduces a work-based approach to analyze rate of loadings.

Section 2 lists some details of the in-situ testing work, including site conditions, test depth intervals, and relevant field information.

Section 3 discusses the loading methods used for Menard and Texam equipment, with descriptions of time-delayed readings.

Section 4 introduces the general definition of external work completed by the respective loading units. The use of incremental and cumulative work per unit volume is discussed, and the corresponding expressions to calculate work per unit volume are presented.

Section 5 summarizes findings and conclusions following from this study.

2. Field testing work

The comparisons of soil responses to PMT loading analyzed here use actual testing data. In the months of May, June and August 2022, three boreholes were advanced in a geotechnical site. Each borehole was dedicated to ***a)*** Menard testing (G-AM model, tri-cell probe), ***b)*** Texam testing (Vulcolan rings, mono-cell probe), and ***c)*** Texam testing with steel rings (also monocell).

This drilling-testing program was carried out along the shorelines of Lake Erie, near Port Rowan, Ontario, Canada. As of today, no proper site characterization has been completed at this location, but it remains a necessary task to be completed. In terms of general geotechnical site descriptions, the Ontario Geological Survey (Barnett, 1983) indicates that bedrock has not been identified above the 50 to 100 m depths. The soils in this location consist of silty Clay-clayey Silt TILL of the Wentworth formation. Local ground water was identified at 1.8 m below ground surface.

For test comparison purposes, drilling and testing were completed at 1.5 m depth intervals, from 1.6 m to 23.3 m depths. These boreholes were 3 m apart to avoid drilling disturbance. Mud-rotary drilling technique was used to advance the test sections of the borehole.

While the corresponding test depths are approximately 0.1 m higher or lower, the two main difficulties associated with these data sets are the diameter of the test section affected by drilling, and soil variability between borehole location. These difficulties could be minimized with careful drilling, but it remains as the main difficulty for any in-situ testing programs. As such, we selected for analyses those tests that exhibit close similarities in their responses.

2.1. PMT test results: field data

A total of fifteen tests have been completed in each of the three boreholes. These data sets can be made available upon request. The main outcome of the tests, based on corrected pressure versus corrected volumes, have been published by Marcil, et.al, 2024. Main conclusions from interpreted data by Menard testing (pressure-controlled) and Texam Testing (volume-controlled) are:

p_o values were 5 to 13% higher for the former than the latter. (estimates of the in-situ total horizontal stresses).

E_M values were 2 to 17% higher for the former than the latter. (Menard or pressuremeter modulus).

p_y values could be 8% higher or lower for Menard and Texam (yield pressure).

p_L values were 11 to 22% higher for the former than the latter (limit pressure).

In terms of PMT field data, the following parameters were captured for each load step during testing:

- Pressure and volume readings at 30- and 60-second time-delays, for the Menard equipment.

- Volume and pressure readings at 15- and 30-second time-delays, for the Texam unit.

It is noted that zero-sec time-delay readings were not taken for either unit. The practical reason why these readings were not taken is that the zero-sec readings drift very fast at the end of active loading, and it is difficult to catch by the operator. While these zero-sec readings are not necessary to interpret soil parameters in typical site investigations, it constitutes a limitation of the present analysis.

3. PMT loading procedures

Typical PMT tests include multiple cycles of unload-reload. For the comparison of Menard and Texam results, the fieldwork for the present investigation omitted the use of U-R cycles. Pressuremeter testing in this series considered monotonic uploading in a stepwise manner.

Each load step consists of two stages, namely ***a)*** active loading, and ***b)*** hold-load for a time delay. The time delays are specific to Menard or Texam loading procedures.

Menard pressure-controlled loading step consists of an active pressure loading increments, which take about 30 seconds. During the hold-load stage, the applied pressure becomes stabilized and volume readings are taken at 30- and 60-sec time-delays. As mentioned above, zero-sec readings are not usually taken as the volume changes very rapidly during this stage.

Texam volume-controlled step consists of an active loading of a 40 cm^3 volume increment, which take about 10 seconds to apply. During the hold-load stage, pressure readings are taken at 15- and 30-sec time-delays. As for Menard method, zero-sec readings of pressure are not taken, due to fast changing nature of the pressure drop.

Using 30- and 60 sec readings for Menard has been a standard practice since the original implementation of test procedures by L. Menard, as reported by Sols-SOILS No. 26 issue in 1975 (*D.60.AN General Notice: Interpretation and Application of Pressuremeter Test Results)*.

On the other hand, the 15- and 30-sec readings used in Texam respond to need to have a time duration comparable to that of the Menard test.

In other words, a typical Menard PMT test may be completed in about 18 to 24 minutes (no U-R cycles) with a total of 12 to 16 data points (about 90 sec per load step).

A Texam PMT test may be completed in a similar time window with 22 to 28 data points (50 sec per load step). It is considered that Texam tests, by having more data points in the pressure-volume curve, provide a slightly better resolution than Menard for the stress-strain response of the soil.

Customarily, pressure-volume data is showed as two curves, one for the first time-delay reading, and a second curve showing the pressure-volume variations for the second time-delay reading. Moreover, the curve representing second readings are used to interpret PMT data into deformation and shear strength properties of the tested soils.

In reality however, the pressure-volume evolution cannot be separated in two individual curves.

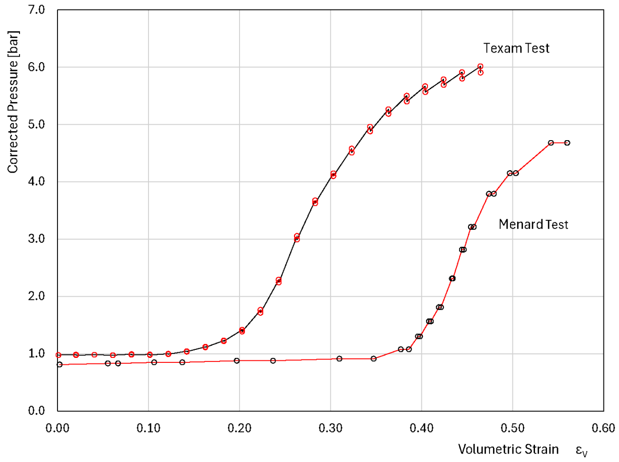

Figure 1: Menard and Texam actual pressure-volume curves.

Fig.1 illustrates the changes in volumetric strains and pressure for each load step corresponding to Menard and Texam, respectively.

The test curves shown in Fig. 1 above, correspond to companion tests at the depth of $z = 6.43$ m below grade.

The initial flat responses correspond to the probes expanding inside the boreholes before stablishing full contact with the cavity walls. It can be observed that the Menard test was carried out on a borehole section somewhat bigger than the Texam test section. The Menard test reached a lower maximum pressure than the Texam test.

It must be noted that the Texam and Menard probes have different inflatable length, and thereby different initial volumes. The G-AM probe has an initial volume of $v^M{}_0 = 725\ cm^3$, while the Texam NX probe has an initial volume of $v^T{}_0 = 1968\ cm^3$. For comparison of response purposes is necessary to display test results in terms of corrected pressure vs volumetric strains ε_V, as suggested in eq. 1, with V_i representing the volume at the current load step *i*.

$$\varepsilon_v = \frac{V_i}{V_0} \qquad (1)$$

3.1. Menard pressure-controlled loading

Since the work performed by the control units into their respective probes is essentially the area under the P- ε_V curve, the evolution of pressure and ε_V during the active stage and the subsequent hold-load stage are illustrated in Fig. 2 and Fig. 3, for Menard and Texam, respectively.

For any load step, see inset plot in Fig. 2, for example, the loading stage starts on a straight line by adjusting a pressure regulator (active loading). The regulator is sluggish in nature and take some time to stabilize. We assumed the uploading as a straight line without introducing any significant error. During the hold-load stage pressure remains constant while the volume expands. Readings are taken at 30- and 60-sec time-delays, as shown in Fig. 2 below.

The volume changes at this initial stage varies fast and would be difficult to capture unless a computer-based datalogger and instruments are used.

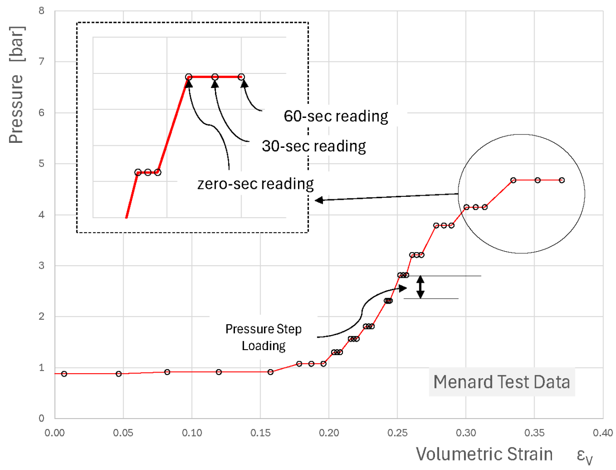

Figure 2: Menard loading procedure

3.2. Texam volume-controlled loading

During the active loading stage, the volume step is represented by assumed straight line, and for the hold-load stage the pressure drops or relaxes. As in the case for Menard loading path, we do not measure or capture the zero-sec reading, as pressure drops fast and is difficult to capture a reliable reading.

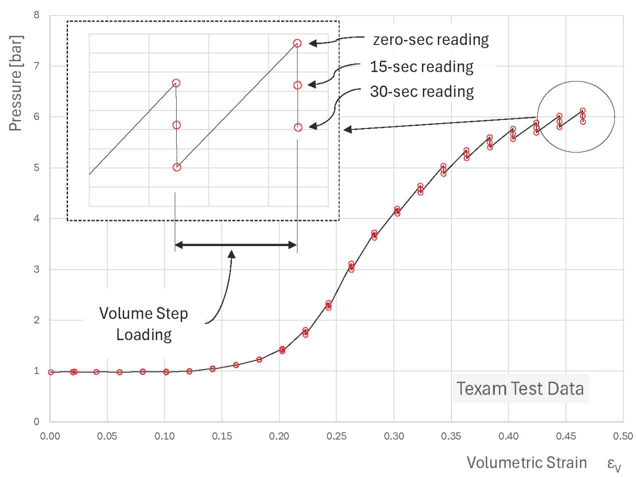

Figure 3: Texam loading procedure

The next Section will introduce the concept of external work per unit volume as the area below the P- ε_V curves for these two paths.

4. Work criterion to assess rate effects

Rate effects have a significant impact in the response of soils to loading. For a saturated soil mass on one hand, if the rate of loading is faster than the rate of pore pressure dissipation, a corresponding increase of excess of pore pressure will ensue, with reduction of effective stresses. On the hand, when the rate of pore pressure dissipation keeps up with the rate of loading, no significant excess of pore pressure would develop, and the soil response to loading occurs essentially under drained conditions, and the shear strength of the soil mass will be dominated by effective stresses.

In this paper we seek to determine if rates of loadings for Menard and Texam equipment are similar. In which case the generation and dissipation of excess pore pressure may be compatible or similar. And if the rates of loadings are not similar, then the question is how much different they might be.

The work criterion per unit volume has been introduced by Becker, et.al, 1987, as the basis for a better estimation of preconsolidation pressure p'_c from 1D consolidation testing data. This approach is effective in enhancing meaningful trends existing in any given set of data points.

We use this approach, namely, the work per unit volume criterion to capture rates of loading effects on soil's response at each load step.

4.1. Measurement of external work

Both measurements of volume and pressure capture the state of the membrane in contact with the cavity, at any time during the test. This is to say that we observe the loading phenomenon from the equipment standpoint and therefore we only capture the external work imparted by the test to the soil mass in contact with the membrane. Furthermore, we usually do not measure water pore pressure on the soil mass. As such, soil behavior must be inferred solely for test data.

It is important to recognize the distinctive mechanisms contributing to the deformation of a soil mass under external PMT loading, specifically under *active loading* or *hold-load* stages.

Soil deformations during the active loading stage have components from:

a. *Elasto-plastic deformations,* which are due to changes in the external loading. By nature, these deformations are time independent.
b. *Consolidation*, which results from changes in the soil's void ratio. These deformations are time dependent. Void changes are related to seepage of the interstitial fluid with an attendant dissipation of excess pore pressures. And
c. *Creep deformations*, which are both time and load-level depend. Creep deformations happen concurrently with consolidation, even after all excess of pore pressure has been dissipated.

Soil deformations during the hold-load stage, on the other hand, have contributions only from *consolidation* and *creep* mechanisms.

4.2. Work generated by Menard loading

As introduced in Section 3, the loading pattern shown in Fig. 2 will be the basis for calculations of the work generated by the Menard equipment. The external work is represented by a trapezoid area and by two rectangular areas, namely *ABGH*, *BCFG*, and *CDEF*, as illustrated in Fig. 4 below.

The trapezoid inscribed by *ABGH* area represents the work generated during the active loading stage. From now on the terms of *work* will refer to the *work per unit volume* (or volumetric strains).

Area *BCFG* represents work generated during the hold-load stage from zero- to 30-sec readings.

And area *CDEF* represents work generated during the hold-load stage from 30- to 60-sec readings.

The incremental work for these three stages is correspondingly calculated as:

$$\Delta W_M^A = \frac{1}{2}(P_i + P_{i-1})(\varepsilon_i^{0"} - \varepsilon_{i-1}^{60"}) \quad (2)$$

for the active loading stage, and

$$\Delta W_M^{30"} = P_i \, (\varepsilon_i^{30"} - \varepsilon_i^{0"}) \quad (3)$$

$$\Delta W_M^{60"} = P_i \, (\varepsilon_i^{60"} - \varepsilon_i^{30"}) \quad (4)$$

For the total hold-load stage, work is then:

$$\Delta W_M^{HL} = P_i \, (\varepsilon_i^{60"} - \varepsilon_i^{0"}) \quad (5)$$

These expressions correspond to load step *i*, the subscript M stands for Menard Test, and superscripts *A* and *HL* stand for *active* and *hold-load* stages, respectively. The cumulative work along all step loadings is then:

$$W_M^y = \sum_{i=0}^n \Delta W_{Mi}^y \quad (6)$$

Where *n* is the number of total load steps, and *y* stand either for *A*-active or *HL*-hold-load stages.

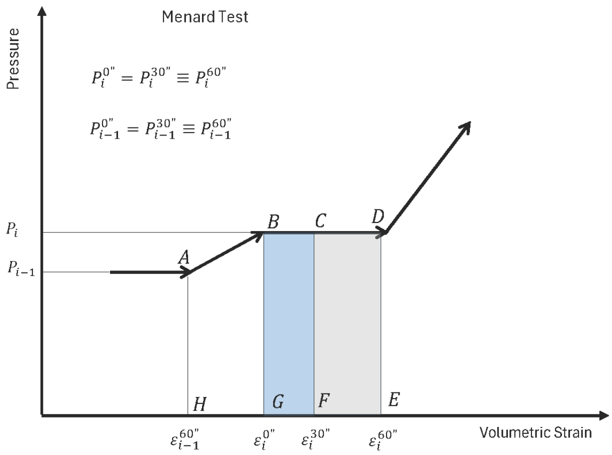

Figure 4: External work generated by the Menard unit.

It is noted that positive work is still developing by the Menard unit during the hold-load stage.

4.3. Work generated by Texam loading

Following the same approach as above, Texam loading procedure is illustrated in Fig. 5 below.

The external work is represented by a trapezoid area and by two triangular areas, namely *ABEF*, A*BC*, and *CDA*.

The trapezoid inscribed by *ABEF* represents the positive work generated during the active loading stage.

Area A*BC* represents negative work dissipated during the hold-load stage from zero- to 15-sec readings.

And area *CDA* represents negative work dissipated during the hold-load stage from 15- to 30-sec readings.

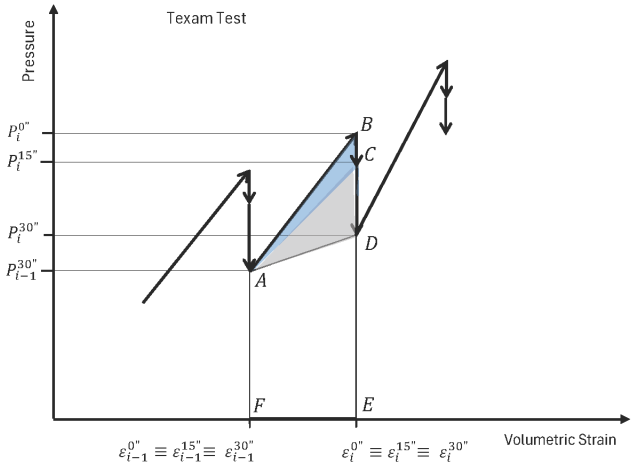

Figure 5: External work generated by the Texam unit.

Incremental work for these three stages is also correspondingly calculated as:

$$\Delta W_T^A = \frac{1}{2}(P_i^{0"} + P_{i-1}^{30"})(\varepsilon_i - \varepsilon_{i-1}) \quad (7)$$

for the active loading stage, and

$$\Delta W_T^{15"} = \frac{1}{2}(P_i^{0"} - P_i^{15"})(\varepsilon_i - \varepsilon_{i-1}) \quad (8)$$

$$\Delta W_T^{30"} = \frac{1}{2}(P_i^{15"} - P_i^{30"})(\varepsilon_i - \varepsilon_{i-1}) \quad (9)$$

For the total hold-load stage then:

$$\Delta W_T^{HL"} = \frac{1}{2}(P_i^{30"} - P_i^{0"})(\varepsilon_i - \varepsilon_{i-1}) \quad (10)$$

With subscript T refers to Texam Test. And the cumulative work for either the active loading or the hold-load stages are calculated as:

$$W_T^y = \sum_{i=0}^n \Delta W_{Ti}^y \quad (11)$$

Unlike the Menard test, Texam hold-load stages result in the accumulation of negative work due to the pressure drops or relaxation.

Based in the work criterion suggested here, it is evident that Menard and Texam units impart different loading conditions during *hold-load* stages.

4.4. Work estimates from available PMT data

Comparisons of work rates between Menard and Texam are hereby attempted in terms of:

a) Incremental work for active stages,
b) Incremental work for hold-load stages, and
c) Total or cumulative work for both active and hold-load stages.

Expressions (2), (5), (6) for Menard, and (7), (10), (11) for Texam are sufficient to complete such numerical comparisons of work generated during Menard and Texam tests.

Since the PMT data sets from this test series do not include zero-sec readings, it is necessary to adopt certain working assumptions. Next subsections present the basis for these zero-sec reading assumptions.

4.4.1. Menard Test: assumed zero-sec reading

At hold-load stages, it is known that the rate of volume increase for Menard tests is faster from zero-sec to 30-sec delay than from 30-sec to 60-sec delay. We hereby assume that this rate is 30% faster during the former than the later, or

$$\left(\varepsilon_i^{0"} - \varepsilon_i^{30"}\right) = 1.3\ \left(\varepsilon_i^{30"} - \varepsilon_i^{60"}\right) \qquad (12)$$

An exponential decay approximation might be more representative to describe the rate of volume decrease within the hold-load stage. However, the parameters necessary to define such behavior are not warranted for the given or available data, and errors related to exponential decay would likely result in larger uncertainties than those associated with our 30% larger rate assumption.

4.4.2. Texam Test: assumed zero-sec reading

Likewise, for the Texam tests pressure drop is faster from the zero-sec to 15-sec delay than for 15-sec to 30-sec delay. It is assumed here that this rate is 30% faster during the former than the later, or

$$\left(P_i^{0"} - P_i^{15"}\right) = 1.3\ \left(P_i^{15"} - P_i^{30"}\right) \qquad (13)$$

4.5. Comparisons using the work criterion

While fifteen test sets were completed in two boreholes, for the purpose of evaluating approximately incremental and cumulative work values, we selected one test pair, namely Test No. 4 from the Menard borehole, and the homologous from the Texam borehole, both at a depth of z = 6.43 m. These two tests are shown in Fig. 1.

In order to eliminate work generated during the expansion of the probes inside the cavity and prior to full contact with its walls, the volumetric axis (volume change per unit volume) for both Menard and Texam are shifted to the left, as shown in Fig. 6 below.

Comparison values will be shown next in the preferred display of estimated work versus pressure, or W vs. p.

Other frames of reference might be used, such as Work vs. volumetric strains, or Work vs. time. For conceptual visualization of rate of loading effects, we use here the Work vs. pressure format.

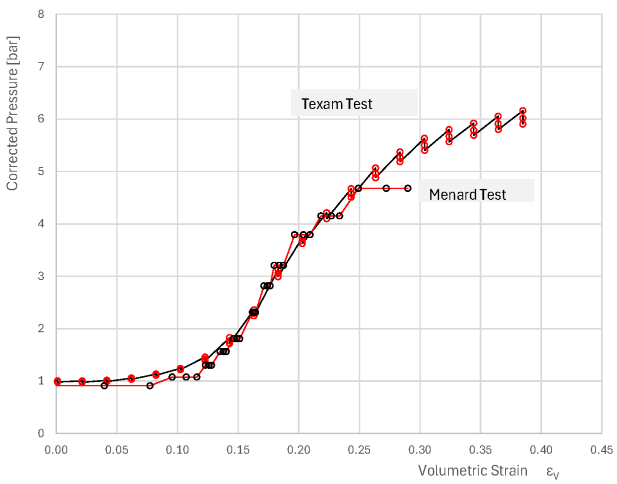

Figure 6: Test data shift for Menard and Texam units

4.5.1. Work from *active loading* stages

Incremental and cumulative of Work vs Pressure plots from the active loading stages for Menard and Texam are shown below in Fig. 7 and Fig. 8.

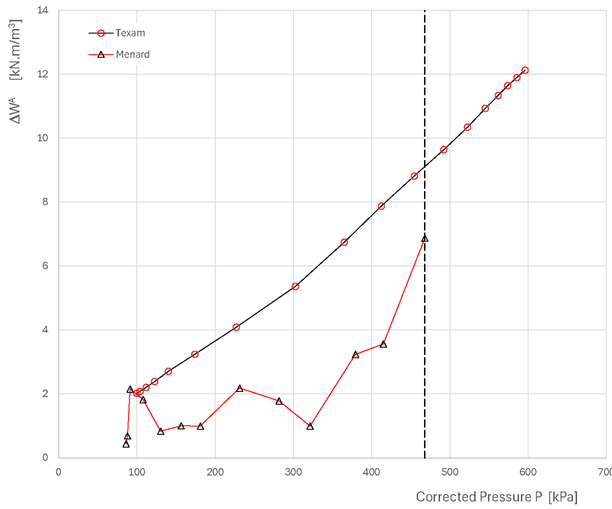

Figure 7: Incremental work from active loading stages

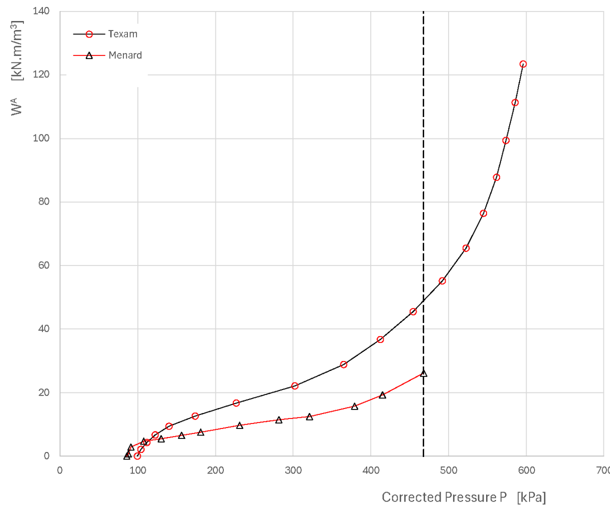

Figure 8: Cumulative work from active loading stages

While work comparisons shown in Figs. 7 and 8 are susceptible to working assumptions, as per eqns. (12) and (13), and for the given soils, i.e., silt and clay mixtures, some effects related to rates of loading might be noted:

- Work increments from the Texam test show a steady, smooth trend. While the Menard test shows a broken but ever-increasing work increments.
- Both tests appear to ramp up in incremental work at higher pressures, suggesting that plastic deformations may become more prominent during the active loading stages. Menard test also appears to ramp up faster than the Texam test.
- Fig. 8 illustrates a Texam cumulative work during active loading almost twice larger, at any pressure level, than the Menard test.

4.5.2. Work from *hold-load* stages

Similarly, for hold-load stages, the incremental and cumulative work vs pressure graphs are illustrated in Figs. 9 and 10.

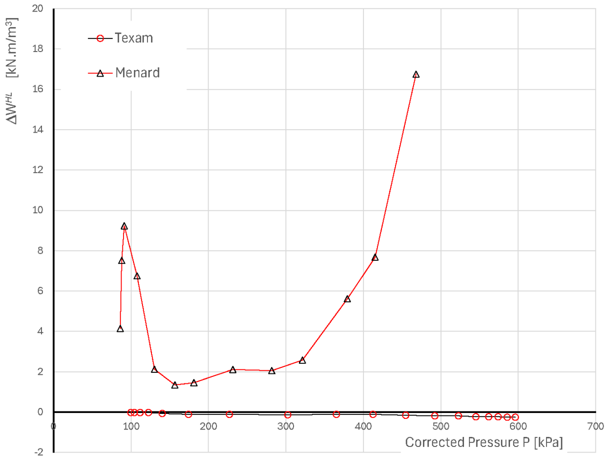

Figure 9: Incremental work from hold-load stages

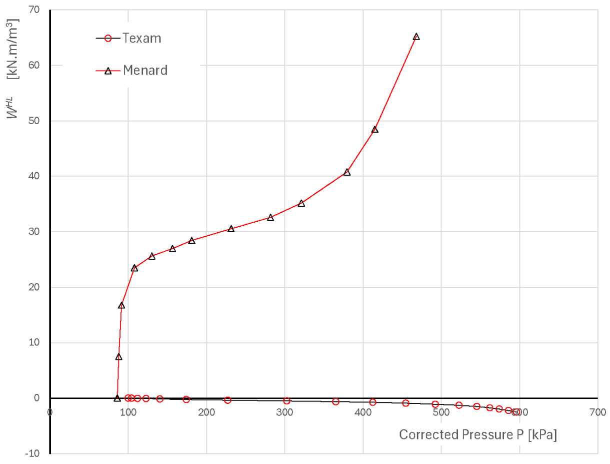

Figure 10: Cumulative work from hold-load stages

It is during hold-load stages when the work criterion presents important discrepancies between Menard and Texam loadings procedures.

Regardless of possible inaccuracies associated with assumptions in eqns. (12) and (13), and likely for any type of soil, Menard loading procedures impart significant strain energy or work, both incrementally and cumulative during the hold-load stage to the soil mass being tested. Whereas the Texam loading exhibits a pressure drop or relaxation during the hold-load stage, and a very small amount at that.

- During the hold-load stages of a Texam test, the borehole cavity remains constant in diameter while the contact pressure drops. This is likely attributed to dissipation of excess-pore-pressure within the soil mass being tested.
- Menard incremental work vs pressure curve during hold-load stage is akin to the typical Menard creep pressure plots.
- Menard cumulative work during hold-load stage is comparable in values with the cumulative work imparted during the active loading stage. That is to say that similar amount of work is introduced into the soil amass from both stages at any load step. On the other hand, Texam work during the hold-load stage is negative and non-significant.

4.5.3. Total cumulative work

Finally, the total contributions from both active and hold-load stages are presented in Fig. 11.

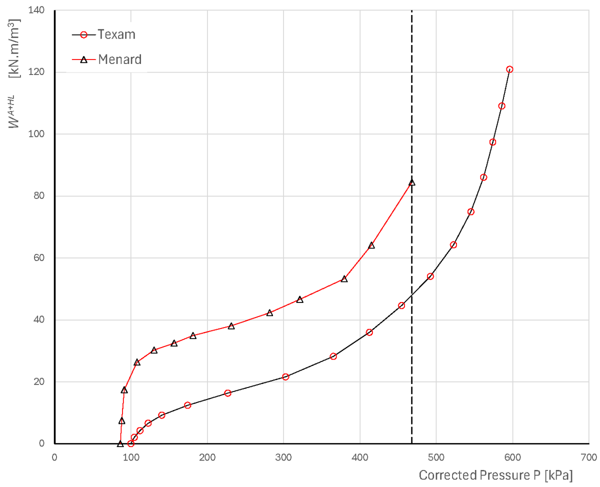

Figure 11: Cumulative work for active plus hold-load stages

As seen above, Menard loading procedure generates almost twice as much work as the Texam, at least up to the maximum pressure attained during the Menard test. Once again, the rate of work generated by Menard test is shown to be different from the Texam.

5. Conclusions

A work criterion has been implemented in this paper to analyse rate of loading effects on an existing PMT database.

Out of fifteen sets of PMT tests, one particular set of Texam and Menard tests was selected for this presentation. Analysis and comparisons however were completed for all fifteen pair of tests, and the overall observations are similar or equivalent to those characteristics shown for the selected data set, as included in this paper.

Since no zero-sec readings were included nor available in the existing PMT test database, we had to select a set of working assumptions, as outlined by eqns. (12) and (13).

The conclusions presented hereby are applicable to normally or slightly overconsolidated silt and clay mixtures, but conceptually they would apply to most soils. Based on the evaluation completed here, the following conclusions are presented:

1. Menard loading imparts almost twice the amount work, from both active and hold-load stages, into the soil when compared to that of the Texam loading.

2. During the hold-load stage, Menard loading is significant while the Texam loading produce a negligible amount of work.
3. Since the hold-load stages only produce consolidation and creep deformations, it is suggested that Menard loading results is a higher degree of partial consolidation and attendant increase of stiffness and shear strength properties than the Texam loading, which showed negative or almost zero contribution of work during the same hold-load stages.
4. Because of these consolidation and reduction of the void ratio, Menard will produce higher values of the Pressuremeter Modulus E_M and limit pressure p_L than the Texam loading procedure.
5. Current developments are intended to implement a dissipation test stage using PMT testing, like CPT and Flat Plate Dilatometer in-situ testing. It is foreseen that this development will be much more effective using the Menard Pressure-controlled loading. The work criterion introduced in this paper clearly points to the advantages of this loading inducing an aggressive rate of consolidation. The implementation of pore pressure measurements will be necessary if degree of consolidation estimates are to be determined.
6. Texam test data may not be compatible with Pressiorama charts and their correlations to infer soil material properties. However, lower-bound estimates of PMT moduli and shear strength parameters may be inferred. Texam users should develop similar correlations for Texam data.
7. Texam tests can be performed using pressure-controlled loading, with 30-sec and 60-sec time delay readings, in which case no significant differences would be expected from Menard tests. Based on comparisons using the work criterion, the active loading and hold-load stages will be comparable with Menard tests.

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