

The Perfect Ménard Pressuremeter Curve

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Abstract

As it is commonly known, to obtain a good quality Ménard Pressuremeter Test a perfectly drilled borehole (pocket) is required. It should be of proper size, only slightly greater than the diameter of the pressuremeter probe, and its walls should remain undisturbed. Unsatisfactory shapes of pressuremeter curves result usually from a poor quality drilling. Typical examples of such curves are given in all handbooks dealing with pressuremeters. They correspond to situations when the tested cavity is too large, too small or its walls are collapsed. There is, however, plenty of room between the pressure and volume axes. An infinite number of various curves can run through this field and only one of them is really the proper one.

An interpreter should be able to evaluate the quality of any curve obtained, estimate the source, the direction and the approximate scale of error and finally to draw conclusions on how to improve the drilling technique to avoid or minimize any future errors. To be able to do that, one needs to understand how the perfect curve should look. The present paper is a study on shapes of pressuremeter curves based on the author's 25 years' experience.

Key words: Ménard Pressuremeter, test curve, pressuremeter modulus

List of Symbols

- a_0 – radius of the probe at a pressure equal to total *in-situ* horizontal stress,
- E_M – pressuremeter (Ménard) modulus,
- m_E – minimum, positive value of the gradient m_i ,
- m_i – gradient of a segment of the corrected pressuremeter curve;
 $\Delta V/\Delta p$,
- p – total pressure applied to the ground, after correction,
- p_f – pressuremeter creep pressure (at volume V_f),
- p_l – pressuremeter (Ménard) limit pressure of the ground,
- p_1 – applied pressure at the origin of pressuremeter modulus range;
formerly marked p_0 ,

- V – (current) volume,
- V_l – doubled (limit) volume of cavity at p_l ; $V_l = 2V_1 + V_s$,
- V_s – initial volume of the central cell of the probe (at zero reading of the volumeter's view-finder),
- V_1 – (corrected) volume injected to the central cell of the probe at the origin of pressuremeter modulus range; formerly marked V_0 and understood either as the present V_1 or as $V_1 + V_s$ (see Figs. 2–3),
- α – reological coefficient,
- Δp – pressure increment,
- ΔV – change in volume of the test section,
- σ_h – total *in-situ* horizontal stress.

1. Introduction

The shape of a curve being the result of Ménard Pressuremeter Test (MPM) is characteristic. Unlike the curves of Self-Bored (SBP) or Pushed-In (PIP) Pressuremeters it possesses three phases (Fig. 1). Phase I occurs when the probe adapts to the size of the borehole (pocket) and pushes its walls back to their natural position. Phase II, being almost a straight line, corresponds to microplastic (or pseudo-elastic) strains. Phase III reflects large, plastic deformations of soil. It serves for limit pressure p_l determination.

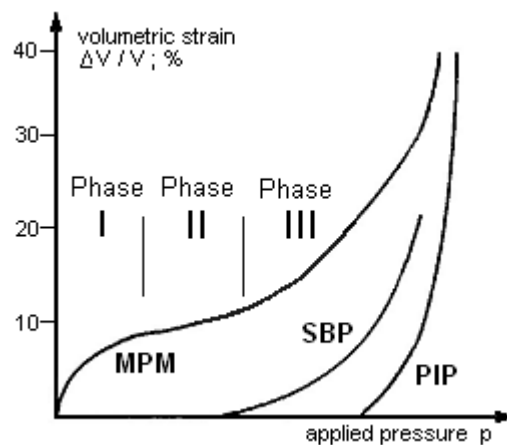


Fig. 1. Typical pressuremeter curves and three phases of the Ménard curve (after Clarke 1995, supplemented, the axes system changed)

Because of unavoidable (no matter how small) disturbance of the pocket walls, the true elastic strains, which occur at the preliminary stage of soil loading, cannot be measured during the test. Pseudo-elastic strains are noticed instead, along

Phase II of the curve. They serve for calculation of sc. pressuremeter (“Ménard”) modulus E_M . Taking advantage of this one should be aware that the stylish slope of Phase II is just a resultant of the connection of two curves of opposite curvature (Gambin 1995).

The shape of pressuremeter curve deviating from the ideal may indicate that:

- the borehole is oversized (it is too loose),
- the borehole is of too small diameter (it is too tight),
- the borehole seems to be well-calibrated but its walls are disturbed,
- the disturbance factor is more complicated.

The influence of borehole quality on test result is described in any handbook or state-of-the-art report regarding pressuremeter tests (Amar et al 1991, Clarke 1995, Clarke & Gambin 1998). Extreme examples are usually shown there. It means that the correct shape of the curve is confronted with curves obtained in boreholes of too big and too small diameter (Fig. 2). The former irregularity cannot be overcome, because of the limited volume of the system. Then the test may not pass the whole modulus zone (curve 2 in Fig. 2). The curve obtained during the test in a too tight a hole, is incomplete starting “somewhere” within the modulus zone or even beyond (curve 3).

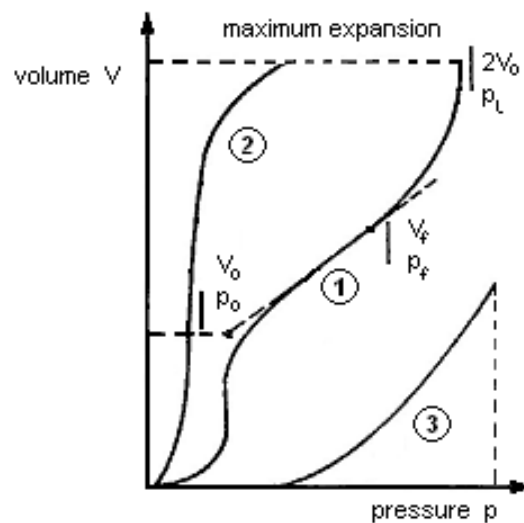


Fig. 2. Shapes of pressuremeter curves depending on the quality of drilling; 1 – correct curve; 2 – hole too large 3 – hole too tight (Amar et al 1991)

The problem of incorrect shapes of pressuremeter curves is discussed in the well-known handbook written by F. Baguelin, J. F. Jézéquel and D. H. Shields

(Baguelin et al 1978). Apart from the cases of too loose and too tight holes the description is focused there on curves of unusual, “double” shapes (Fig. 3).

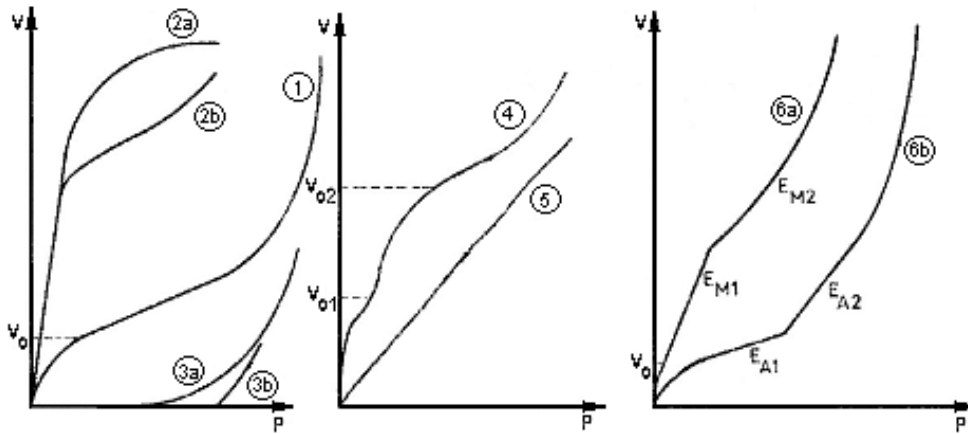


Fig. 3. Different shapes of pressuremeter curves (Baguelin et al 1978)

- oversized borehole (2) of undisturbed (a) or disturbed (b) walls,
- too tight hole (3); curve of growing curvature (a) or breaking “suddenly” away, from the pressure axis due to previously blocked water outflow to the probe (b),
- loose borehole filled with borings, which are “tested” first; the test of real soil begins after they are squeezed out (4),
- borehole walls completely disturbed, non-interpretable result (5),
- curves with two slopes of modulus zone (6) which create while testing interbedded soils, soils with hard grains in a soft background, on the border of two layers etc.; the weaker (a) or the stronger (b) element is tested first

2. Low Quality Test Results

It is obviously worth knowing how to recognize shapes of curves being the results of completely unsuccessful tests or those carried out in specific conditions. However, observing slight deviations from the standard and realizing the direction of the connected error may be even more important (Tarnawski 1983, 1985, 1998, 2003).

Shapes of curves connected with too loose holes are shown in Fig. 4¹. The initial part of the curve (Phase I; see: Fig. 1) goes up for quite a while. The *a* curve contains the whole Phase II (the range of pressuremeter modulus) and the beginning of Phase III. One can calculate the modulus value then and – if there are at least three points from Phase III – estimate the limit pressure p_l

¹ Figures 4–6 contain as comparative material, the “ideal” curve and the curve of standard calibration for pressure losses (dashed lines). The volume $V = 700 \text{ cm}^3$ means technical limitation of the equipment.

as well. The b curve ends somewhere in the range of Phase II, which allows basically fixing E_M , however, most probably underestimated, because the middle volume of the modulus zone is uncertain. The c curve contains Phase I only and it is obviously non-interpretable. One can see an important attribute of Phase I of these three curves: they all run close to the calibration curve. This means a lack of soil resistance in the borehole before Phase II begins. One can then expect the walls of the borehole (although it is too big) to be in good condition. Such situations occur in stiff, to hard cohesive soils, as the result of too fast drilling progress. It is usually enough to change the style (technique) of drilling to avoid it.

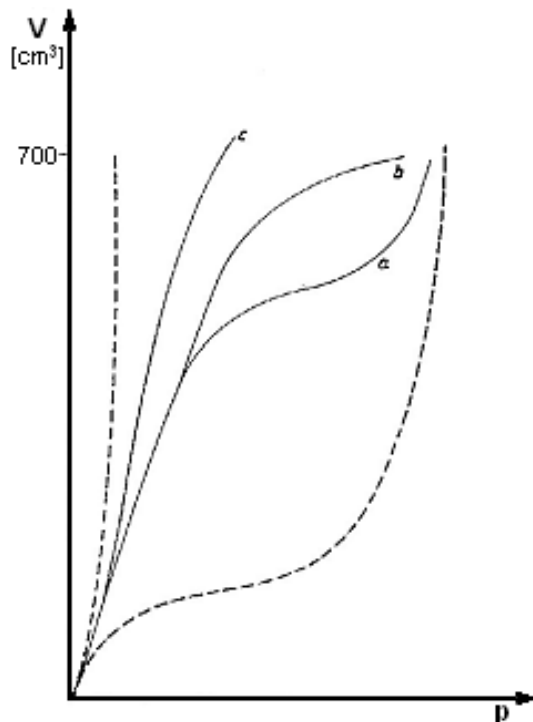


Fig. 4. Pressuremeter curves obtained from tests in the borehole of too big a diameter.
Explanations in the text

Can we be sure, however, that the shape of the a curve in Fig. 4 results from too big diameter of the borehole only and not from disturbance of walls as took place during the test which resulted in the $2b$ curve in Fig. 3? Trying to answer that, let us have a look at the bundle of pressuremeter curves shown in Fig. 5. Let us consider their run against the bisector of the axes right angle. All these curves are in their Phase I less steep than those in Fig. 4. This means some soil resistance is met soon after commencement of the test. It does not mean, however, that the

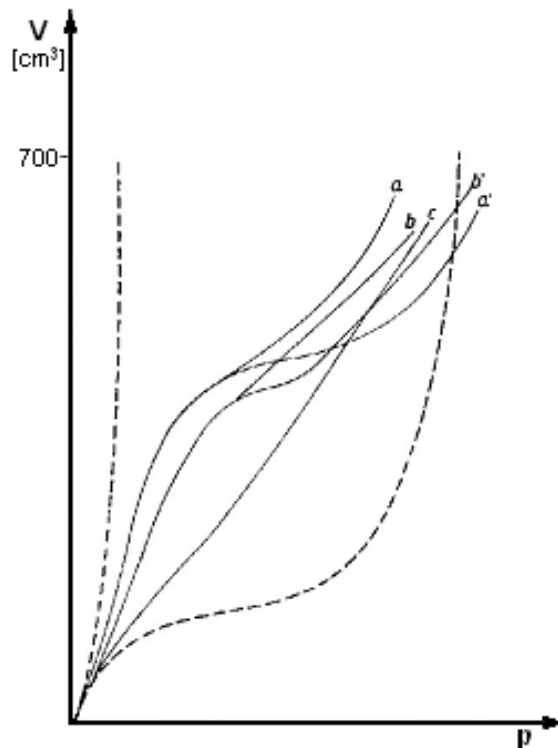


Fig. 5. Pressuremeter curves obtained from tests in the borehole of disturbed walls. Explanations in the text

quality and the diameter of the borehole are suitable now. Although Phase I runs lower than in the cases of curves shown in Fig. 4, it is still much too long (the borehole diameter is too big) and in addition, it is filled with loosened soil coming most probably from the walls surrounding the probe. Can test results be reliable under such conditions? Let us notice that the worst impression among the curves shown in Fig. 5 makes the *c* curve, the twin of curve No. 5 in Fig. 3. It does not have any marked phases (I–III) being almost a straight line. In this case the expanding probe penetrates a loosened zone most probably to the very end of the test. It usually happens in sands, if the drilling method is unsuitable or if the slurry is too thin.

As we have recognized the result obtained along the bisector² of the axes right angle unsatisfactory, we should treat in the same way the curves that run entirely above (the *a* and *b* curves). The presence of more or less distinct Phases II and III may be misleading, but it is just the measurement in a less (comparing Phase I) disturbed soil. Such cases take place in soft or firm cohesive soils, especially in silts,

² It is a line close to the real bisector if the scales of the graph are selected in such a manner that both V_l and p_l values are at similar distance (in cm) from the beginning of the graph; see also the curve No. 5 in Fig. 3.

as well as in peats or organic muds. Therefore one should reject the $a - c$ results as unsuccessful. Otherwise the parameters, especially the pressuremeter modulus, will be greatly underestimated. The variants of the curves marked a' and b' may be recognized as satisfactory although E_M will most probably be underestimated. The same with the pressure limit, which will have to be approximated because of a very high V_1 value. The presented way of curve quality control: “the bisector method” is to be supported by analysis of obtained values of E_M/p_l ratio. It depends on soil consolidation or disturbance degree as presented in Table 1.

Table 1. Relationships between the kind and state of soil versus E_M/p_l ratio and coefficient α (Ménard 1975). Author’s supplements written in italics

Kind of soil	Peat		Clay		Silt		Sand		Sand & gravel	
	E_M/p_l	α	E_M/p_l	α	E_M/p_l	α	E_M/p_l	α	E_M/p_l	α
Over-consolidated			> 16	1	> 14	$\frac{2}{3}$	> 12	$\frac{1}{2}$	> 10	$\frac{1}{3}$
Normally consolidated	<i>6-11</i>	1	9-16	$\frac{2}{3}$	8-14	$\frac{1}{2}$	7-12	13	6-10	$\frac{1}{4}$
Weathered or altered			7-9	$\frac{1}{2}$	6-8	$\frac{1}{2}$	5-7	$\frac{1}{3}$	4-6	$\frac{1}{4}$

Another group of not greatly successful tests is connected with too small diameter of the borehole (Fig. 6). Irregularities occur here in Phases I and II, whereas all curves tend to more or less the same p_l value. The a curve possesses regularly shaped Phases I, II and III and can be described as an ideal curve moved down along the volume axis. It occurs in this fortunate case when the pressure of soil in a tight hole causes – undisturbed by any side effect – squeezing out of the water from the probe to the volumeter, so that the test begins from a positive pressure p value and negative volume V^3 value. Some believe it to be the result of excess pore pressure in cohesive soil (M. Gambin, verbal inf.). This problem arose especially during experiments with a self-boring pressuremeter and later became better known. This knowledge afforded recommendations regarding a waiting period from the moment of SBP probe installation to the beginning of the test. A period of half an hour has been adopted as a reasonable compromise between the time necessary for dissipation of excess pore pressure and the need to maintain an appropriate tempo of field works (Amar et al 1991, Clarke 1995). A good reason for waiting with the beginning of the test until one can be sure that the water level movement observed at the volumeter’s view-finder is over was obviously understood earlier (Tarnawski 1983). It usually goes up first, often rapidly, above zero value and again down afterwards, which confirms the argument as to pore pressure induction and dissipation. But even then it is hard to obtain a proper shape

³ We can see the pressure $p = 0$ on the gauges then, but hydrostatic pressure which depends on the testing depth is to be added. A negative volume value noted in the graph of pressuremeter curve is often affixed “+” by operators as the water level is found then above the zero position of the volumeter’s view-finder.

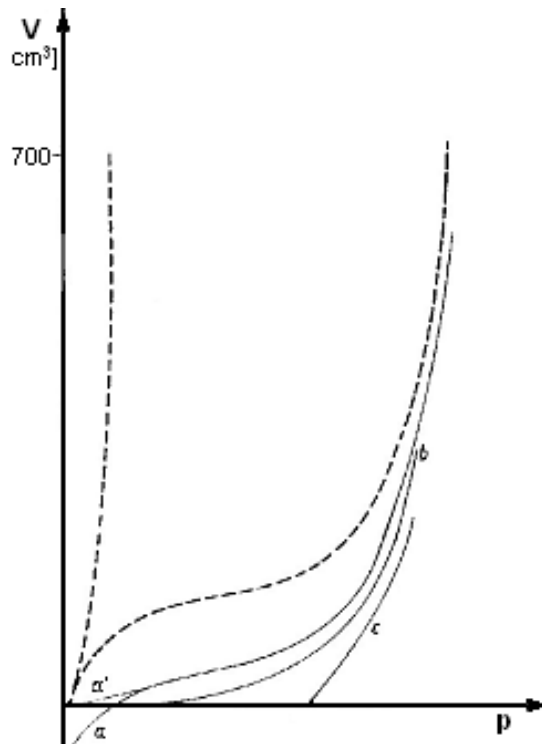


Fig. 6. Pressuremeter curves obtained from tests in too tight a borehole. Explanations in the text

of the curve in a tight hole. First of all, Phase I dwindles and finally disappears. The field between the a and a' curves (Fig. 6) is the area of growing stresses, unloaded before the beginning of the test. The slope of the initial section of the a' line remains constant until Phase III begins, which means there is no Phase I at all. This is the last case that allows calculating safe E_M and p_l values. The b and c curves commence tangent to the pressure axis. The difference between them is that the b curve separates from p axis earlier and somehow smoothly creating further an arc-shaped curve and the c curve suddenly breaks out from the axis and goes steeply up. The c curve is simpler to describe: it has Phase III only. It may serve for limit pressure calculation though legitimacy for adopting then $V_1 = 0$, that is $V_i = V_S$ (Baguelin et al 1978) does not seem to be obvious. Analysing the b curve we cannot substantiate the choice of modulus zone: the $\Delta p/\Delta V$ ratio decreases continuously together with the growth of pressure. We could choose the first or 2–3 first m_i increments following the French Standard rules. The volume increment is very small then and when $\Delta V \rightarrow 0$, $E_M \rightarrow \infty$. This means the b curve may be recognized as the most dangerous case among the analysed variety of poorly succeeded tests, as it leads to overestimation of E_M value and underestimation of calculated settlement. It is worth emphasizing

that the use of a particular drilling technique in a specific soil environment may give repetitive results, burden by a similar error being the result of too tight hole conditions. An inexperienced interpreter may then recognize high E_M values as typical for a given formation. For fear of this kind of misunderstandings it is better to give up assessing pressuremeter modulus from the type b curve (Fig. 6).

Intermediate cases between a' and b seem to occur more often than the b example. The modulus zone turns up then, but we cannot be sure whether the straight run of the curve really corresponds with pseudo-elastic soil reaction or is a resultant of actions of various stresses inside and around the probe. We can then often see two straight sections: the arrangement similar to $6b$ curve in Fig. 3, but the run of these sections (especially of the first one) is appreciably less steep. Correct modulus value may be obtained when not the absolutely smallest $\Delta V/\Delta p$ gradient is taken to be m_E^4 , but the smallest from that second steeper section (Fig. 7).

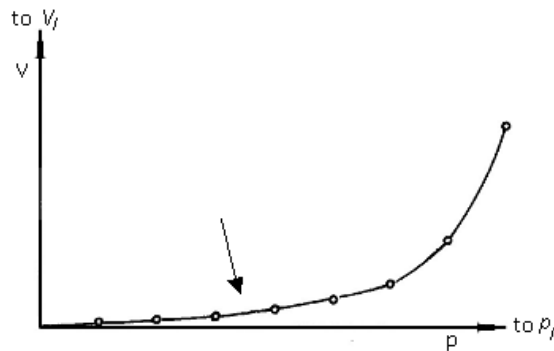


Fig. 7. A typical run of initial sections of pressuremeter curve in too tight a hole. The section of the curve recommended to choose for m_E gradient calculation (rejecting the foregoing ones) is indicated with the arrow

Too tight holes happen in cohesive soils only: the soft ones or the swelling ones (some clays), and often when the slotted tube is used. When the phenomenon of borehole walls compression is affirmed one should follow the rule “1 drilling section – 1 test” without exception. Sometimes less careful (quicker) drilling is useful, although it cannot be advised “officially”. Too big a hole will not tighten itself so as to cause results shown in Fig. 6, though one should be aware of the risk of excessive disturbance of its walls. However, generally, a borehole of too big a diameter is safer than a tight one. Difficulties during manipulations of the probe in the borehole indicate it is too tight. Minimal (or no) water movement down the viewfinder after the first pressure step is given is another sign. It is good then – keeping this pressure – to move the probe up and down a few centimetres. The

⁴ See the point D.2.1 of NF P 94-110-1N French Standard (Annex D).

borehole diameter increases slightly then and the movement of the membranes may restore the blocked water circuit. This somewhat brutal operation will disturb borehole walls a little, but it will offer the chance to obtain more acceptable test results.

Sometimes the shapes of curves are amazing (Fig. 8), but some of them interpretable. The double, interfering curves *a* and *b* relate to situations similar to those shown in Fig. 3 (the 4, 6a, 6b curves). Two soils or components of soil are tested one by one. The probe usually penetrates the weaker component first, but opposite situations (Fig. 3, the 6b curve) also occur. Let us consider the position of the border between the weaker and the stronger component in relation to the sheath of the probe. It may happen that:

- the border is parallel to the probe axis,
- the border is normal to the probe axis,
- components (and consistently their borders) are placed irregularly.

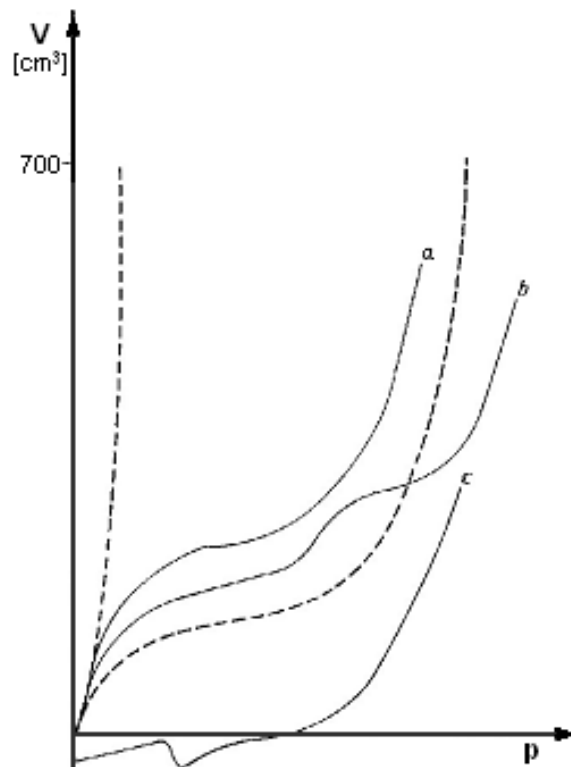


Fig. 8. Pressuremeter curves of irregular shapes. Explanations in the text

The first case, though it may seem to be extraordinary, is the most common, being the result of abnormal drilling without paying attention to accurate removal

of borings. Left in the borehole they get between the probe and the borehole wall. Compressed there they offer some resistance, but being a disturbed soil they give way after a few pressure steps. The first of the interfering curves ends and the proper test begins. A more complicated process may take place if the natural soil is weak (organic soils for example) and borings come from a cohesive soil of low moisture. It may occur, in such a situation that the borings will not be removed from the tested zone until the final phase of the test, or it will even start “to impregnate” and therefore reinforce the tested soil. To prevent such paradoxes one must not start drilling underlying stronger soil before all tests of the upper, weaker layer are carried out.

The border (or borders in a thin interbedded soil) normal to the probe axis is the case when one does not have a precise borehole profile and put the measuring cell of the probe at the border of two soils of differentiated properties. The probe penetrates the weaker soil first, then the stronger one.

The third group of cases refers to soils of very differentiated granulation, for example soft or very soft clays with gravels or boulders (residua, some tills) or fills of brick or concrete pieces mixed with clay. Depending on proportions of these components the weaker, fine-grained background may be penetrated first (for example the *a* curve in Fig. 8, the 6a curve in Fig. 3) and the bigger resistance of gravel grains is mobilized afterwards. The effect: settlement of the structure in such a soil will most probably arise from an intermediate modulus value. The situation when the less compressible stuff gives way slowly first and the soil as a whole afterwards, is more rare (the 6b curve in Fig. 3). Exerting small loadings one may expect a minimal settlement in this case as suggested by the initial section of the curve. However, if the bearing capacity of soil is to be maximally used the lower modulus value should be taken into account.

Irrespective of the reason for obtaining an atypical shape of the curve, the interference will either take place in Phase II (more often case; the *a* curve in Fig. 8 or the curves 6 in Fig. 3). Sometimes after the beginning of Phase III of the weaker material the test returns to Phase II, but of the stronger soil (Fig. 8, the *b* curve). It does not seem to be well-founded to limit this case shown also as the curve 4 in Fig. 3, called “the curve with two V_1 (V_0 in original) values”, to situations when borings are met (and “tested”) in the hole (Baguelin et al 1978). Such a picture may also be obtained in a non-homogenous soil.

Probe damage (membrane burst) is a usual result of testing two elements of greatly differentiated compressibility. It happens especially while testing the border zone of two different soils, so fortunate cases, when we can make two interpretations using the results of one test, are rare. Besides, one should be aware of the possible mutual influence of two kinds of soil on test results.

The last case to be described here – the *c* curve from Fig. 8 – is really unusual, as there is a section there showing the change of volume opposite to that expected after pressure rise: return of water to the measuring unit. This rare case

concerns Svetogorsk clay (Russia) and belongs to examples connected with too tight a hole. It is placed in Fig. 8 instead of 6 because of the unusual shape of the curve. It may probably be explained as follows. Soil pressure deformed the probe sheath breaking water film and isolating part of it in the measuring cell. A considerable overpressure arose there, while the rest state was noted at the volumeter's viewfinder slightly above (in the graph – below) zero. When the first pressure step was given the water level dropped imperceptibly. It reached a part of the measuring cell only, near the outlet. Another step and continuity of the circuit was restored. But the pressure in the soil surrounding the probe was still higher than the pressure given, so water was pushed out from the probe and its level in the volumeter rose. The next pressure step barely balanced soil pressure and the real test began being analogous in its further run to the one shown as *b* curve in Fig. 6.

Deliberating low quality pressuremeter tests one should remember that apart from the quality of the borehole other factors influence the test result. They are:

- “irremovable reasons” which means precision of measuring devices and magnitude of own rigidity of the system,
- proper preparation of the equipment⁵ and the manner of carrying out calibrations,
- the number of pressure steps and maintaining of proper differential pressure during the test.

These problems however lie beyond the mainstream of the present paper.

3. The Perfect Curve

Although only Phases II and III of the Ménard pressuremeter curve are used for interpretation of test results, the shape of Phase I is a good indicator of the quality of the test, as has been discussed above. This is the phase of fitting the probe to borehole walls and it ends with a distinct increase of $\Delta p/\Delta V$ gradient⁶. The p_1, V_1 point is usually found near the border between Phases I and II, but – as we learned recently – it is not precise to identify either this border or p_1, V_1 point with repeating the natural stress state equal to *in situ* total horizontal stress σ_h . Comparative analyses of PBP and SBP results indicate that σ_h value is usually not masked by damage or relaxation of the soil surrounding the probe in Phase I of the curve, but it is rather hidden “somewhere” on its straight line section, as shown in Fig. 9.

This means that at least the beginning of Phase II is a resultant of three interfering processes:

⁵ For example, the role of several preliminary inflations of new membranes is crucial while testing weak soils (Tarnawski 2003).

⁶ It should not be mixed with the opposite ($\Delta V/\Delta p$) gradient which defines m_i and m_E values.

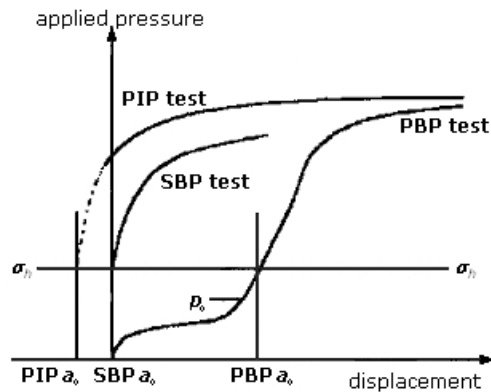


Fig. 9. The position of the total horizontal stress σ_h and the reference datum a_o on PBP, SPB and PIP test curves (Clarke 1995). The point marked p_o means the beginning of the modulus range (the p_1, V_1 point in NF P 94-110-1N Standard nomenclature)

- counteraction against relaxation acting to the middle of the hole and resulting from the difference between the value of primary horizontal stress and hydrostatic (or zero in a dry hole) pressure, up to σ_h value is reached,
- deformations of the disturbed soil zone decreasing with the growth of pressure of the curvature, calling to mind the oedometer curve, as the ring of undisturbed soil outside this zone will remain immovable nearly to the end of this phenomenon,
- gradually growing primary deformations of undisturbed soil after σ_h value is reached (Fig. 10).

If we treated (as described in Fig. 10) components 2 and 4 as volume losses and eliminated them in a similar manner as using the factor „ a ” for the equipment volume losses (see the French Standard) we could correct the shape of the curve moving it down to the intersection with the p axis in the σ_h point (which means elimination of Phase I) and decreasing the slope of the curve. We would obtain the picture of classical stress – strain curve (5) which is similar to that obtained from the self-boring pressuremeter test. However, such a movement is impossible. In so far as we may try to establish σ_h we have no chance of estimating precisely the degree of disturbance of borehole walls represented by the curve (4) in Fig. 10. Its horizontal section (marked 4a) means lack of influence of this phenomenon on the shape of the final phase of the curve. If it started before the cross with the σ_h line, we would obtain the perfect Ménard pressuremeter curve (2–3) which obviously differs from the ideal stress-strain curve (5) due to the presence of Phase I. In this ideal case the inflexion point between the decreasing and growing section of the curve should represent the *in situ* total horizontal stress σ_h value, not burden with the influence of the disturbance (damage) of borehole walls. If the volume losses

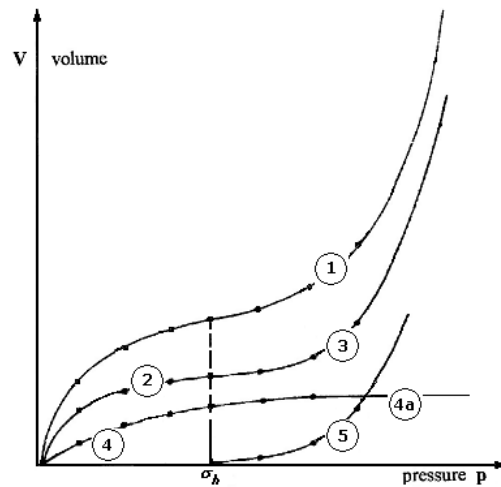


Fig. 10. Factors influencing the shape of a good quality pressuremeter curve (1): volume losses used for counteraction against relaxation (2) and being the result of squeezing the ring of disturbed soil (4). The perfect curve (3) obtained in the borehole of absolutely undisturbed walls is simply the curve (2) to the point where it meets σ_h line and then starts to follow the theoretical curvature of stress – strain curve (5)

connected with the disturbance of borehole walls are not used up to the σ_h point they will considerably influence the run of the Phase II although such a curve is still recognized as a good quality one (1; Fig. 10). The increasingly less distinct inflexion point moves to the right and as a result, the modulus value is lower. How much lower? Not much, but low enough to include the soil (because of E_M/p_l ratio) into the medium group of “normally consolidated” soils (Tabl. 1). A still lower E_M/p_l ratio value expresses the influence of a remarkable wall disturbance on the value of pressuremeter modulus.

A typical degree of disturbance is connected with the kind and state of the soil. It is easier for one to obtain a very good quality test pocket in a highly cohesive soil (clay⁷) of low natural moisture than in a loose sandy soil. This is why the values of reological coefficient α (Ménard 1975) decrease in the same direction (from upper left to lower right angle of Tabl. 1): from $\alpha = 1$ to $\alpha = 1/4$. They simply serve for correcting the modulus value complying expected, average degree of soil disturbance in the borehole: the intervals of E_M/p_l ratios also decrease in this direction. If we reserve very high E_M/p_l values for special cases of strongly overconsolidated, dried-up or cemented soils we shall expect them to be near the border between the formal classes of overconsolidated and normally consolidated soils (Tabl. 1) when the borehole and the test are perfectly made. The class of normally consolidated soils and corresponding E_M/p_l values refer to typical tests. They are believed to be properly made although some devastation of borehole

⁷ As long as it will not tend to swell.

walls certainly takes place then. Still lower E_M/p_l values are obtained in boreholes of disturbed walls. When ratios are below the minima the modulus values should be rejected. How to explain the same α values proposed by L. Ménard for both normally consolidated and altered silts, sands and gravels? It is most probably an additional safety factor. The soil, which can easily be damaged in the borehole, may behave in the same way at the bottom of an excavation.

Even if the borehole was perfectly made and the pressuremeter curve had a perfect shape (Fig. 10, curve 2–3) one should not expect the pressuremeter modulus to be equal to modulus of elasticity or – even more so – to oedometer modulus. The pressuremeter modulus zone is intentionally wide, as it includes all sections of the test sloping to approximately 20% more than the minimal slope m_E (Clarke & Gambin 1998). Hence the pressuremeter modulus does not exemplify an inconsiderable, truly elastic reaction of soil under small loading (Fig. 10, the beginning of curve 5), but pseudo-elastic behaviour expected as long as the allowable bearing capacity is not surpassed.

4. Conclusions

Pressuremeter test results may contain errors. The same concerns other geotechnical tests. But no other method enables analysing sources and effects of errors in such detail. Owing to this, an experienced operator and interpreter will prevent the use of erroneous parameters in further geotechnical calculations.

Especially the quality of the borehole: its size, effectiveness of cleaning, and degree of wall disturbance influence test results and derived parameters fundamentally. As discussed above, the shape of the curve indicates itself whether the pocket is properly made or not. The high V_1 value ($V_1 > 200 \text{ cm}^3$) attained at the third or fourth pressure step is an additional indicator of an over-loose borehole or one with disturbed walls. Low E_M/p_l ratio (underestimated modulus) will be obtained in the latter case. Too big a diameter of the hole may have lesser influence on pressuremeter modulus value, but pressuremeter limit pressure may only be estimated approximately (or – the b curve in Fig. 4 – not qualified at all), which means its value will be underestimated as recommended extrapolation methods are intentionally conservative. The curve of the test in an over-tight hole does not have Phase I. As long as E_M/p_l ratio does not surpass to any great extent the maximum value reserved for normally consolidated soil (Tabl. 1) we may treat it as the a' (Fig. 6) type curve and recognize the test result as satisfactory. If this is not so and m_E gradient applies the first pressure step we should be afraid that the pressuremeter modulus value is overestimated.

As has been proven above, one should expect underestimated pressuremeter modulus value in the borehole of disturbed walls and this concerns the majority of tests recognized as correct ones (Fig. 10, curve 1). The reological coefficient α is to level the expected influence of wall disturbance on the modulus value. The less

cohesive soil is tested, the more difficult it is to keep the borehole walls entirely undisturbed. In sands or gravels – practically impossible. Hence the particular direction of change of the reological coefficient (Tabl. 1).

The pressuremeter modulus reflects neither true elastic strains of soil (as Young modulus do) nor the influence of progressive consolidation when lateral deformations are impossible (oedometer test). But such conditions are usually far away from the real relations between structures and subsoil. The concept of the pressuremeter modulus serves for settlement calculations in these typical engineering cases, when the bearing capacity of soils is used at most, for economic reasons. At the same time it is the only method known which has at its disposal an efficient tool for correcting its own permanent errors: the reological coefficient α . Considering the above one should recognize the Ménard Pressuremeter Test as the method worth popularizing to a greater extent.

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