# LATERAL LOADING USING PRESSUREMETER DATA

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## ABSTRACT

The pressuremeter can provide reliable data for design of piles subject to lateral load. This is because of the remarkable similarity between the "ideal" undisturbed pressuremeter curve and the P/Y curve. This instrument can provide a direct measurement of the P/Y curves in almost any material. It is ideally suited to obtaining data in materials that are difficult to sample, such as sands, tills, or fractured rock.

Although there have been many field trials in which the general technique has been confirmed, the model pile loading tests conducted under controlled conditions at the University of British Columbia form a unique set of data for evaluating this procedure.

Cyclic pressuremeter tests can be used to give a clear indication of the behaviour of the material under slow large cyclic loading, as might be expected to occur under earthquake loading. These cyclic tests will also give some measure of the damping which will occur under large cyclic loading.

Over the last three years the techniques described in this paper have been used on six projects, involving piles between 1.5 and 2 m in diameter. In many of these sites the materials in which the pressuremeter tests have been performed have all been tills, fractured or weathered rocks, which are extremely difficult to sample.

## INTRODUCTION

The problem of determining the lateral deflection of a single pile subjected to a lateral load may seem trivial, in view of all of the other complex problems that geotechnical engineers are called upon to solve. However, it is far from a simple problem.

The movements of the sand surrounding a pile when deflected laterally are extraordinarily complex. This can be seen, at least in a qualitative manner, by examining the movements which occur in sand surrounding a model pile. The results shown in Figure 1 are the displacements along a plane of the centre line of a model pile in a dense, normally-consolidated sand.

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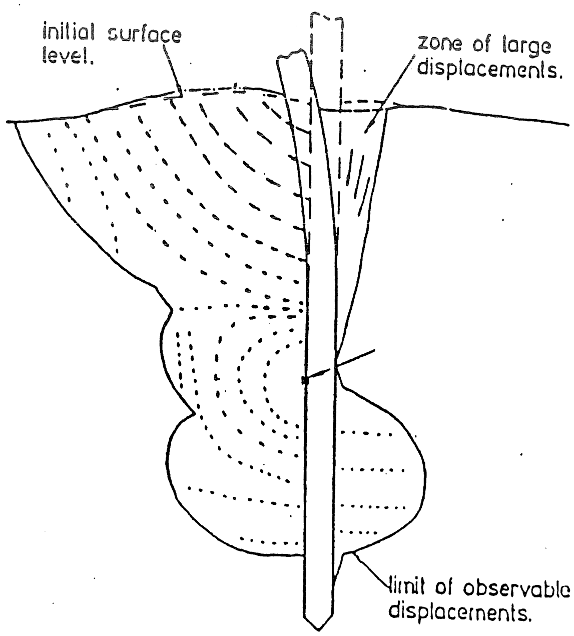


**Figure 1. Lateral displacements around a model pile in sand (Hughes and Goldsmith 1977)**

To make the problem manageable, the most common assumption made is that the soil, in resisting the pile, can be considered to act as a series of discrete springs. These springs are considered to be independent of each other; i.e. if one is moved, the adjacent spring will not be affected. To give a more realistic representative behaviour to the soil, the stiffness of the springs is often considered to be non-linear.

With these assumptions, the numerical solution of the lateral loading problem is readily available. The question then resolves down to the determination of the stiffness characteristics of the individual springs.

## THE PRESSUREMETER APPROACH

French engineers, who use the pressuremeter on a routine basis for general site investigation, have long recognized that there is considerable similarity between the pressuremeter curve and the back-calculated P/Y curve. Hence they use this data directly to determine the appropriate P/Y curves, thus taking into account any heterogeneous nature of the soil. The procedure developed in France is empirical, based on the measurement of the three fundamental measurements taken with the conventional pressuremeter: namely, the limit pressure ($P_L$), modulus (E) and the creep pressure ($P_c$ ). (Briaud 1986)

The technique advocated in this paper is to make use of the observation that the P/Y curves and the pressuremeter curve have a remarkable similarity. However rather than using the field data directly, the "ideal" pressuremeter curve, which is not influenced by disturbance, is developed from the field data. It is this "ideal" data that is used to develop the P/Y curve.

## DEVELOPMENT OF THE "IDEAL" PRESSUREMETER TEST

In all pressuremeter tests, particularly those that are conducted in pre-bored holes, there can be considerable effects of disturbance. This is often noticeable in the beginning of the test. Towards the end of the test, as the strains increase, the field curve approaches the "ideal" curve. Hence, the problem is to determine the "ideal" undisturbed tests. The technique for developing the "ideal" curve is to assume that the material being tested behaves in a particular manner, such that it can be described by a simple mathematical model as proposed, for example, by Carter et al. (1986). If the material being tested is a sand, then a simple model, based on essentially three parameters -- friction angle, modulus and lateral stress -- can be used to represent the pressuremeter test.

An example of a high-quality pressuremeter test, conducted by Fahey (1986) in a test chamber, is given in Figure 2. Overlying this data is the predicted pressuremeter curve developed from a simple model and the fundamental parameters presented in his paper. The match between these curves is particularly striking.

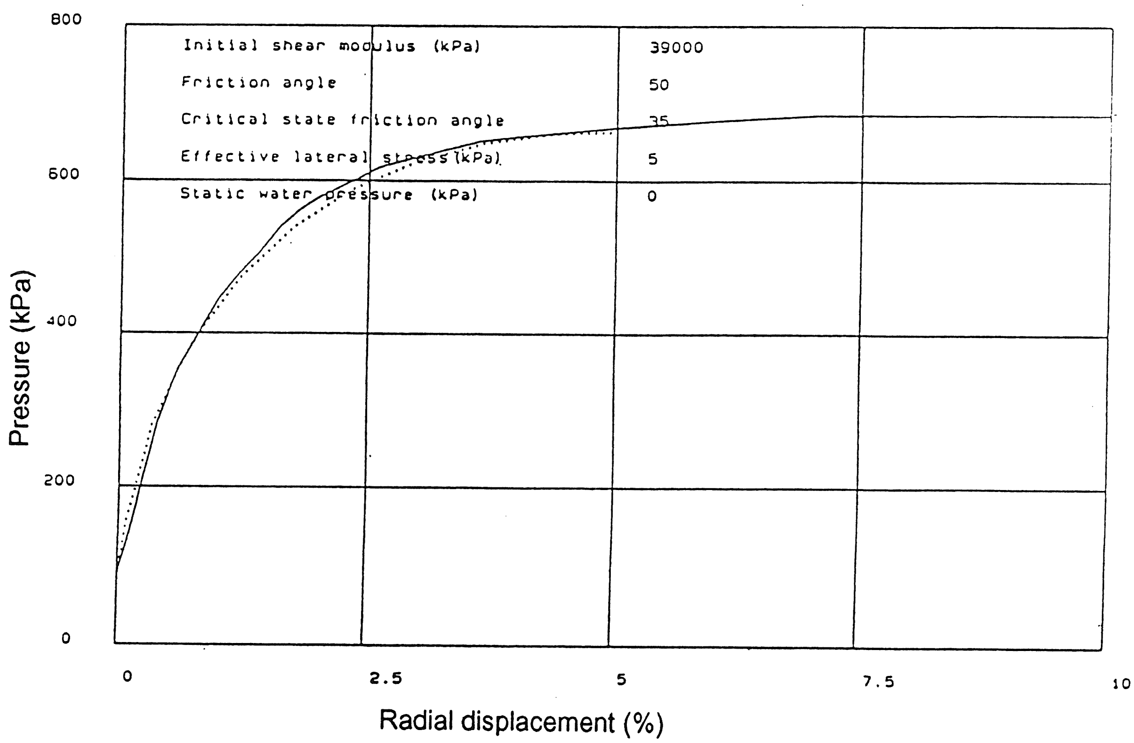


**Figure 2. Prediction of Pressuremeter Chamber Test ( Test SC7, Fahey 1986)**

With field data in which there is little disturbance, an analytical curve can be matched to the entire field data, as shown in Figure 3. The parameters in the model are then assumed to apply to the field data. However with field data, the match between a model curve will often not follow the complete field data. In general, the match will be better toward the end of the pressuremeter curve, which is less influenced by any disturbance.

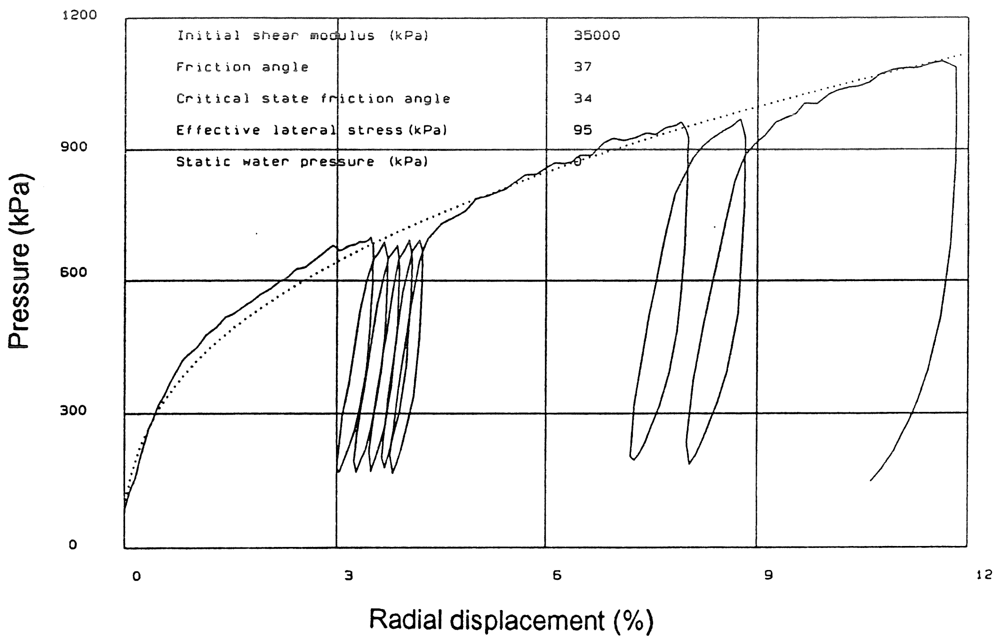


**Figure 3. "Ideal" Pressuremeter test in sands**

Therefore, the procedure for determining the ideal pressuremeter curve is to use an interactive graphics computer program, in which the pressuremeter curve, based on some model, and a set of assumed parameters can be overlaid over the field data. Adjustments are then made to the data set and a new prediction made. This process can be repeated very rapidly until a suitable match is obtained. In this manner the influence of disturbance on the test results can be reduced.

The set of parameters that is obtained is a coupled set of parameters, related to each other in the connection of a theoretical framework. For example, if the modulus, G, is raised, then some other variable must be reduced for the prediction to match the field data. In most other methods of analysis of pressuremeter data, the parameters are obtained without coupling them. This often leads to misleading results, particularly if the set of uncoupled parameters is used to predict some other loading situation.

## DEVELOPMENT OF THE P/Y CURVES FROM "IDEAL" PRESSUREMETER CURVES

The step from the ideal pressuremeter test to the P/Y curve is by simply scaling the pressuremeter curve above the lateral stress. This is graphically illustrated in Figure 4. The ideal pressuremeter curve, above the in situ lateral pressure, is scaled by a factor. This factor depends on the material type. Finite element studies conducted by Byrne and Atukorala (1983) have shown that a factor of 1.5 should be used for P/Y curves in sands.

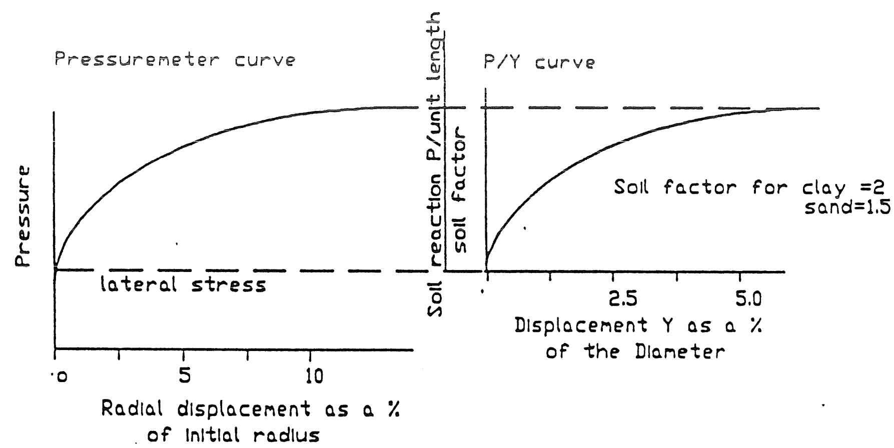


**Figure 4. Development of P/Y curves from "ideal" pressuremeter tests**

## VERIFICATION OF THE METHOD

Although P/Y curves reported from field tests (Robertson et al. 1988) have been used to confirm the general pressuremeter method, the results are always subject to the uncertainty of the soil conditions. However the carefully-controlled laboratory tests reported by Yan and Byrne (1992) form an ideal data base on which to assess the above approach. They conducted laboratory tests on model piles in saturated sands which had been carefully prepared at a uniform density. The gravity stresses, similar to those developed in the field, were developed by pumping water through the sand under a very high hydraulic gradient to increase the effective stress in the model. By measuring the stresses in the pile, they were able to back-calculate the P/Y curves at various depths. Their results (Figure 5) show that there seems to be a unique normalized P/Y curve for the sands.

They did not run any pressuremeter tests, but they did publish the material properties from which the "ideal" pressuremeter curves could be calculated and the P/Y curves developed. The P/Y curves, when normalized by the method proposed by Yan and Byrne, do form a unique curve (Figure 6). The magnitude of the normalized P/Y curve is almost identical to the experimentally-observed P/Y curves. Hence there is reason to expect that, at least in normally-consolidated uniform deposits of sands, the pressuremeter can be used to obtain the appropriate P/Y curves.

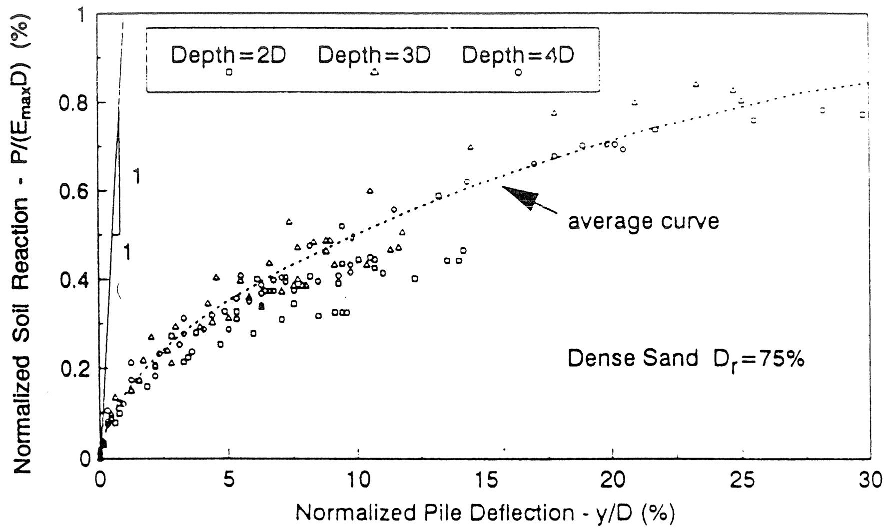


**Figure 5. Normalized P/Y curves from Yan and Byrne (1992)**

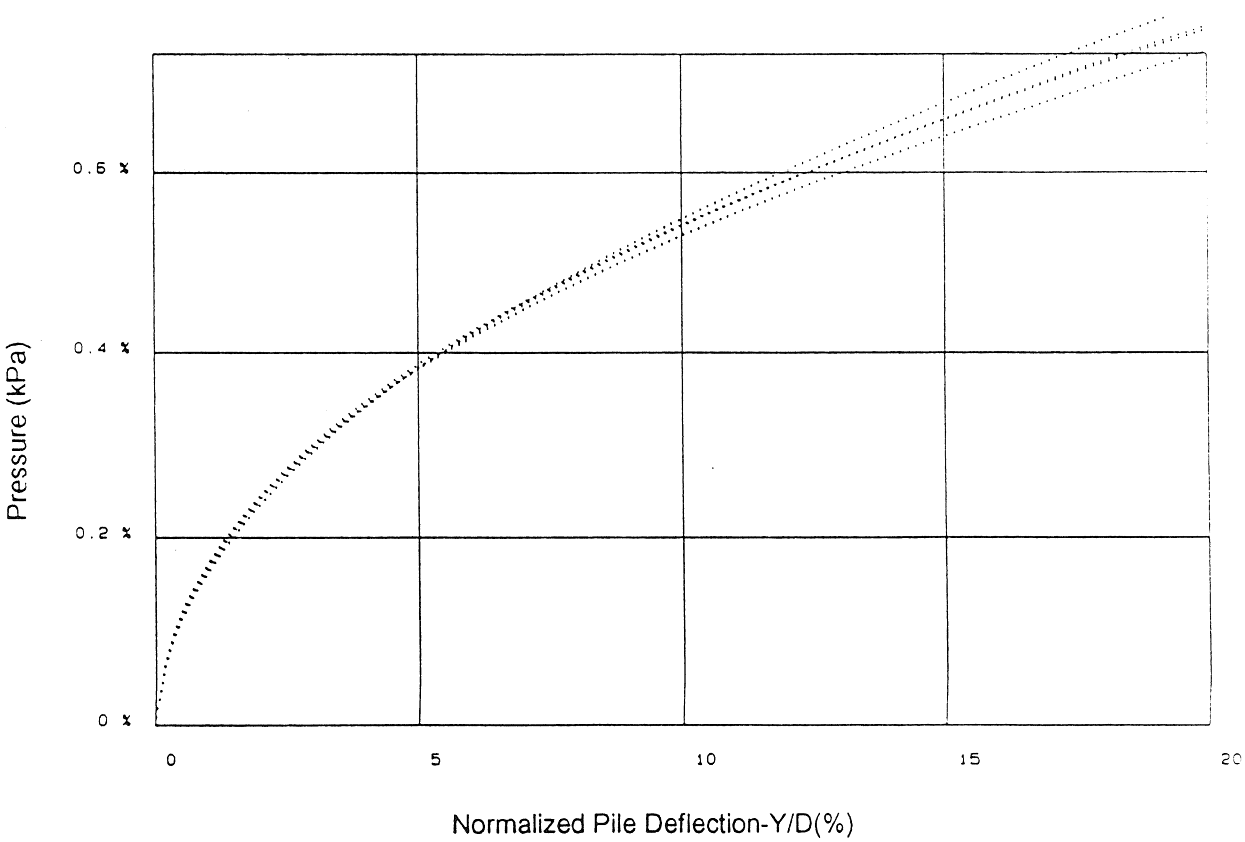


**Figure 6. Normalized P/Y curves at 2D,4D,6D,8D developed from derived pressuremeter tests**

High-frequency, small strain lateral loading of piles for machine foundations has been studied extensively. In this situation, the inertia effects of the soil and damping often play dominant roles. However, the problem of concern in this geographical region is large-strain low-frequency lateral loading, such as could occur under earthquake conditions. The conventional approach is to develop the P/Y curve by the same empirical approach as is used for monotonic loading, then reduce the allowable maximum load. Essentially the P/Y curve has the same geometric shape as the static monotonic curve. Although the pressuremeter cannot properly simulate full-reversal cyclic P/Y curves -- it can only simulate loading from the zero position outwards and back to the zero position -- nevertheless, this data can be used to give a clear insight as to how the material might behave under full reversal of load.

Consider the pressuremeter test shown in Figure 7, from the Klamath Falls Bridge investigation in Oregon (LaVielle and Hughes, 1993). In these tests, large load cycles have been conducted. The first point, that is very clear, is that the shape of the unloading curve is not the same as the loading curve, and further, a gap seems to form about the pile on successive loading.

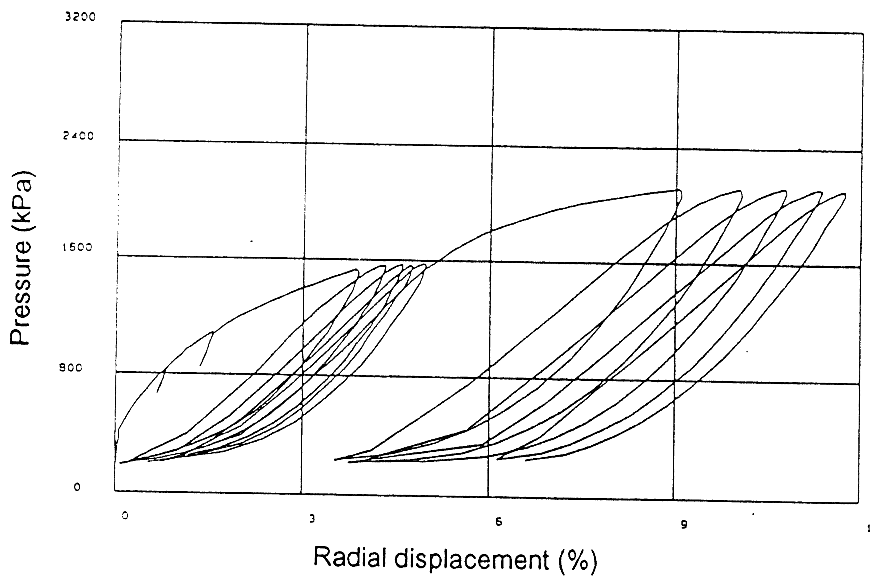


**Figure 7. Cyclic pressuremeter test in cemented silts**

If it is assumed that the full reversal of loading has the same form as the unloading curve, the cyclic loading curve would be expected to have the form shown in Figure 8. It is interesting to note that this form is remarkably similar to that observed under laboratory conditions by Huaren Dou (1991 -- Figure 9). It is not at all similar to the API recommended cyclic curve. However, despite the difference in form, Finn and Gohl (1992) suggest that the shape of the P/Y curve may have little influence on the ultimate prediction of the pile behaviour. This is presumably assuming that the ultimate lateral resistance is the same, regardless of the shape of the P/Y curve. Hence the problem perhaps resolves into determining the ultimate lateral resistance under heavy cyclic loading, and the reduction in resistance with cyclic load reversals.

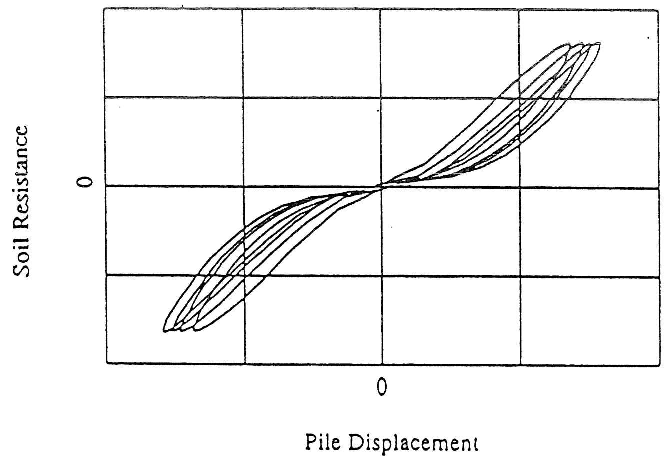


**Figure 8. Possible form of cyclic P/Y curves from pressuremeter data shown in Figure 7**

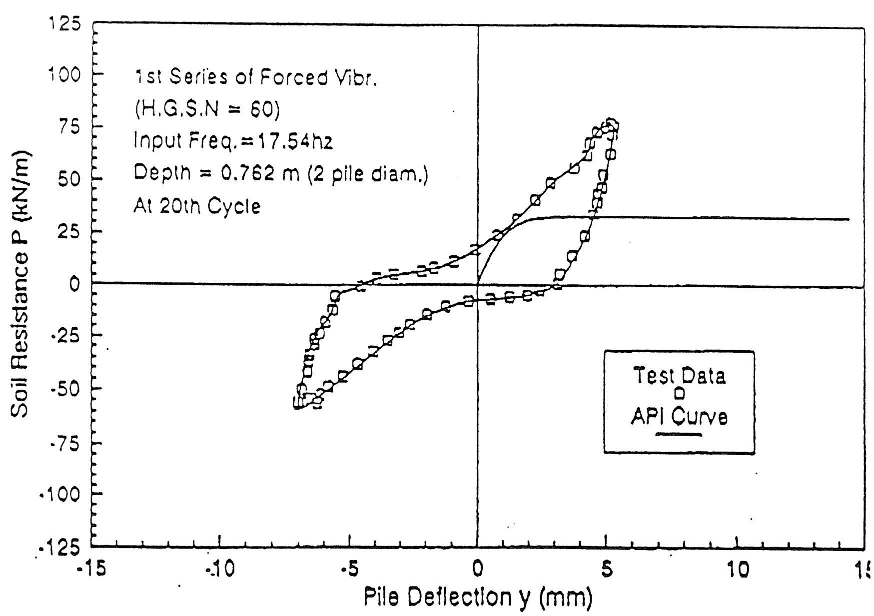


**Figure 9. Cyclic P/Y curves observed by Dou (1991)**

ENERGY DISSIPATION UNDER CYCLIC LOADING

With cyclic P/Y curves developed from the pressuremeter, some indication of the energy dissipated per cycle in the "near field" can be determined from the area contained within the P/Y loop. For most sands the dissipation decreases rapidly from the initial cycle. However silty clays do not show such a dramatic decrease in energy dissipation (as illustrated in Figure 9 ).

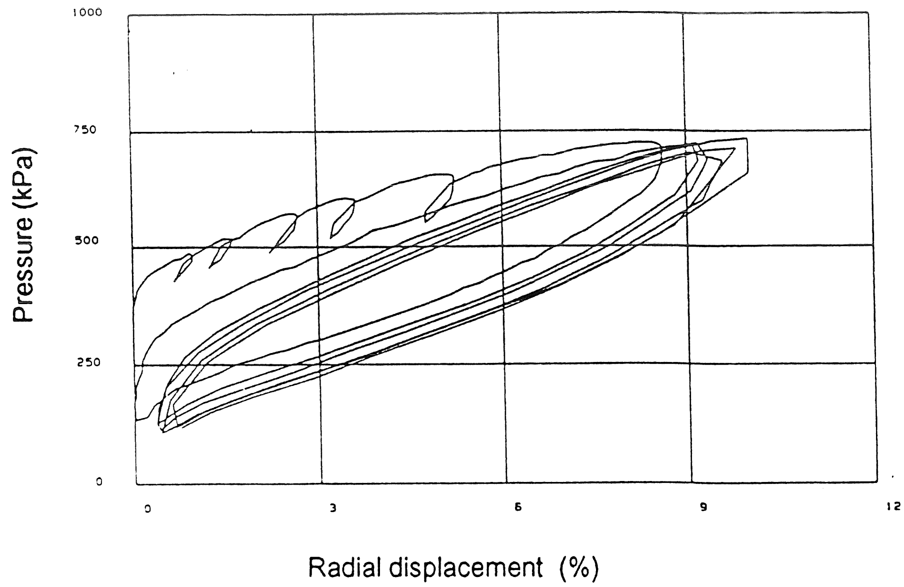


**Figure 10. Cyclic pressuremeter tests in silty clay**

## PRESSUREMETER TESTS IN HARD MATERIALS

In materials such as dense tills and fractured rock, in which samples cannot be taken or which are too hard for an SPT to penetrate, the pressuremeter is one of the only means of directly acquiring P/Y data. The example shown in Figure 12 is of a heavily-fractured siltstone at the Rocky Point bridge site in Oregon. At this location, the core was very difficult to recover. No solid core was recovered over 100 mm in length. However, by casing the hole and carefully coring a pilot hole, into which the pressuremeter was inserted, successful tests could be obtained.

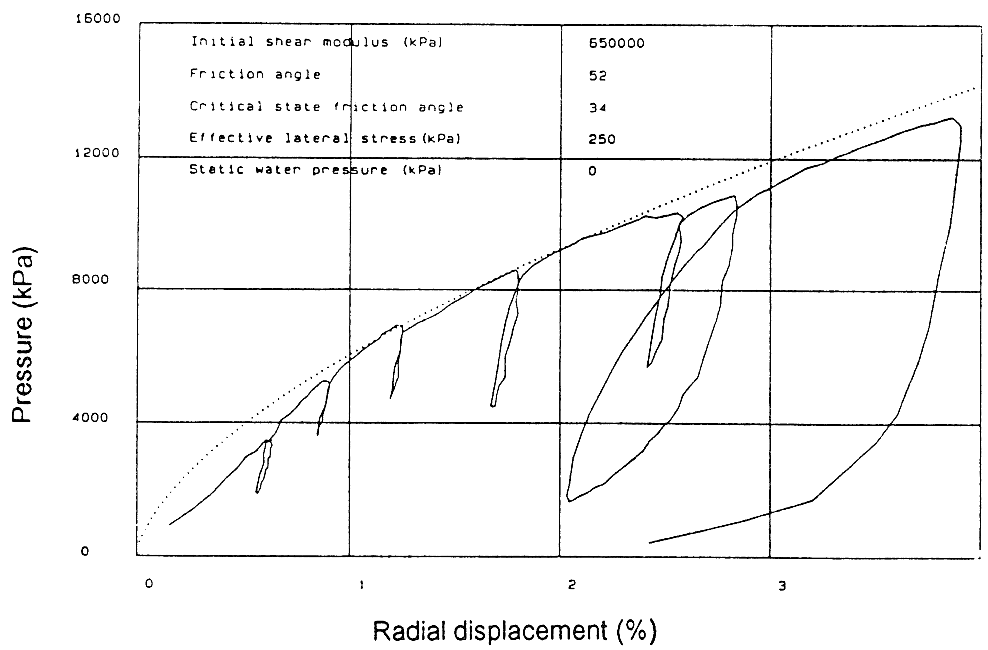


**Figure 11. Pressuremeter test in fractured rock**

## RATE OF TESTING

The rate of testing varies significantly depending on the material being tested. In sands having a blow count under 20, in which a pressuremeter can easily be "jetted" into the ground, it is possible to perform between 6 and 10 tests per day. However in sands it may well be more economical to obtain the P/Y data from empirical correlations with the cone. In materials which are difficult to sample, such as tills and fractured rocks, it is the time taken to cut a suitable pocket for the pressuremeter which determines the rate of production. As an example, the pocket for the test in fractured rock shown in Figure 11 took two attempts, with a total time of about three hours, to cut a suitable pocket and perform the test. However there are few alternatives other than empirical correlations which can be used to obtain the P/Y data in such materials.

## CONCLUSIONS

The objective of these notes is to outline the use of pressuremeter data as an alternative method of obtaining P/Y data for the design of piles.

There are two major advantages in the pressuremeter approach:-

1) The pressuremeter tests can be conducted in materials that are <u>difficult to sample, too hard to push a cone into, or drive an SPT</u>.

2) The cyclic pressuremeter test can give some insight into the behaviour under the large cyclic loading that might be expected to occur under earthquake conditions.

## ACKNOWLEDGEMENTS

The ideas developed in this paper are based on several studies for bridge piers. Almost all of the piers were above 1.5 m in diameter. The support from the following Companies in developing this approach is gratefully acknowledged:-

Converse Consultants Inc., Seattle
Golder Associates, Seattle and Portland
Oregon Department of Transportation
Puget Sound Power and Light Company
Shannon and Wilson Inc., Seattle and Boston

The author wishes to thank the Oregon Department of Transportation, for permission to publish the data obtained during the Klamath Falls Bridge and the Rocky Point Bridge investigations, and B.C. Hydro and Puget Sound Power and Light Company, for permission to publish the cyclic pressuremeter tests on silty clay and sand. The author is particularly grateful for the assistance of Mr. Eric Jorden, Geotechnology Ltd., Dartmouth, Nova Scotia.

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