Use of pressuremeter in weak rocks of the Lower Nanaimo Series

John Hughes, Ph.D., P.Eng.
President, Hughes Insitu Engineering Ltd., Vancouver, BC.

Abstract: The pressuremeter is ideally suited to testing fractured and weathered rocks in which core recovery is low. It is possible to obtain a direct measurement of the mass rock stiffness and the maximum stress that can be applied to the rock.

Introduction

Determining the mechanical properties of rocks is generally done by examining the core obtained from drilling. From a visual examination of the core, indications can be made of the direction and spacing of any fractures, the relative hardness of the rock, and the relative strength of the material between the fractures. This forms the basis for a detailed descriptive log.

If sections of the core are long enough they can be taken back to the laboratory to be cut into cylinders and tested under compression. Alternatively, simple point load tests can be conducted under field conditions. This approach is particularly useful in competent rocks, in which a full core run is obtained from which samples can be obtained for testing.

Unfortunately, many sites are on rocks that are heavily weathered and or fractured. In these materials obtaining a representative core is difficult. Even with large core barrels, good continuous unbroken core cannot be guaranteed. Often in poor core it is only the best rock that is retained, from which the engineering properties of the poor rock have to be estimated.

The approach outlined in this note is to consider the possibility of loading the walls of the borehole, rather than the core itself. In many cases, in poor weathered fractured material, the walls of the hole are relatively smooth and can be tested even though little core is recovered. This paper outlines typical data that can be obtained in the weathered sedimentary rocks of the Cretaceous Lower Nanaimo Series that underlie most the major structures in the city of Vancouver.

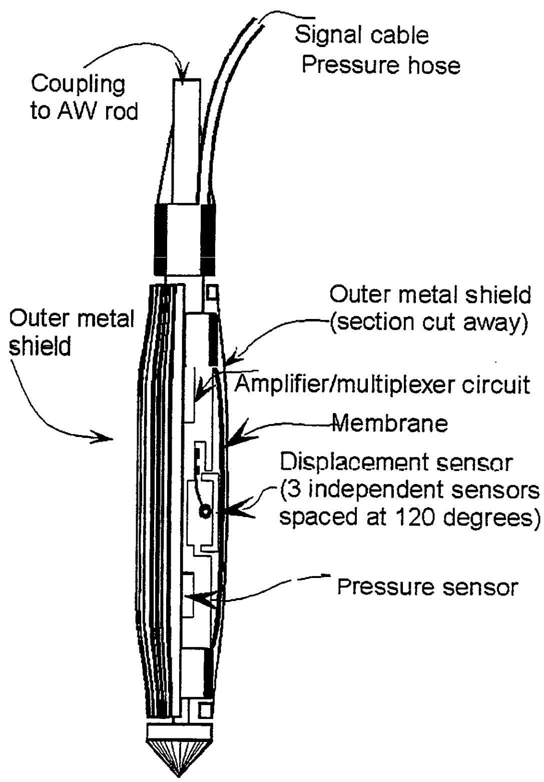
Geological conditions

The Lower Nanaimo series (formerly the Burrard Formation) is a Cretaceous sedimentary rock of varying degrees of fineness, from claystone and siltstone to sandstone. In some of the layers are thin layers of coal (Roddick 2001). The upper material is significantly weathered; it is possible to drive a full SPT with blow counts in the range of 50 - 100. With depth, the blow count rapidly increases to refusal at 50 blows/300 mm with 20 mm or less in penetration. In some locations the material is fractured, and a full core run is not readily obtained.

Pressuremeter testing of the borehole wall

The instrument lowered into the hole is a pressuremeter, on the outside of which is a flexible membrane. Once in place this membrane is forced under pressure against the borehole wall. The instrument records the displacement of the borehole wall as a function of pressure. A sketch of the pressuremeter used in this study is shown in Fig. 1.

Fig. 1. Schematic drawing of pressuremeter.



The pressures and displacements, measured electronically inside the instrument, are recorded and displayed during the test on a computer screen. In contrast to the standard Ménard pressuremeter, in which only a limited number of data points are recorded by hand, tests with this equipment usually contain over a hundred data points. With this definition of the data, a clear indication of the material behaviour can be obtained. Pressures of up to 20 MPa can be imposed on the rock, and accurate modulus measurements of over 1 GPa can be made.

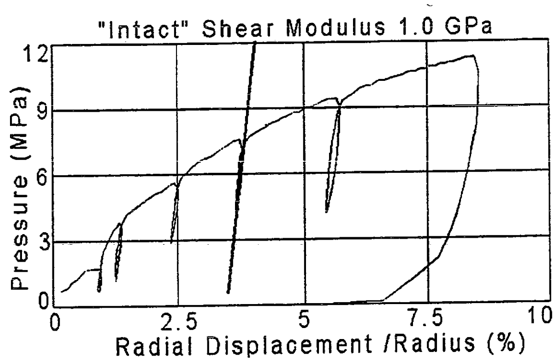
A typical test from this instrument in weathered sedimentary materials is shown in Fig. 2. This particular test is taken in the weathered and fractured sedimentary rocks of the San Francisco series in California. There are two distinct features in this typical test, which are common to all tests.

1. The pressure tends to a limit. In this rock, if the pressure is above 12 MPa, significant expansion will occur.
2. The unload-reload loops tend to be parallel.

Hence, by a visual inspection alone, the test gives a clear indication of the maximum horizontal load that can be applied to the ground without substantial deformation. Further, as the unload-reload loops are essentially parallel, this part of the test is repeatable. Therefore, the test can be used to give a reliable measure of the stiffness of the soil.

It must be stressed that the above data was obtained in material which was very difficult to core, and no sections of the core were suitable to test.

Fig. 2. Test in weathered and fractured siltstone.



Volume of material tested by the pressuremeter

During the test, the volume of rock subjected to the radial pressure on the wall is large. If, for instance, the rock can be considered to behave as an elastic material, and 10 MPa is applied to the wall, the radial stress in the rock one diameter away from the centre will still be 2.5 MPa. If the rock shears before this pressure is reached, then an even greater volume of rock will be stressed.

Hence, the movement of the borehole wall is a reflection of the movement contained in a zone at least one diameter away from the borehole. With an instrument 75 mm in diameter, this zone can be over 50 times as large as a standard core sample obtained from a core barrel 75 mm in diameter. Therefore, the pressuremeter test is a reflection of the behaviour of a large block of material — far larger than a sample on which a compression test is conducted.

Typical behaviour of tests in the sedimentary rocks of the Nanaimo Formation

Although the general shape exhibited by the test shown in Fig. 2 is common to most tests, the specific details of tests in fractured and weathered rocks indicate a very complex behaviour, which no doubt reflects the strength and fracture pattern in the rock.

This behaviour is illustrated in the following study from a site in Vancouver. This extensive study of a limited area included over 40 pressuremeter tests. As this study was for a building foundation the maximum pressure that was used in the pressuremeter test was limited to 7 MPa (1000 psi). This pressure was estimated to be at least three times the likely design stress.

Prior to this pressuremeter study, coring had been done on several holes to establish the general geological conditions. The pressuremeter testing was then undertaken at selected locations as indicated by these previous core holes.

In one location only, pressuremeter tests were undertaken in a cored hole, from which direct comparison between the test and the cores could be made.

In the other locations, in order to increase the rate of testing, the pilot holes for the pressuremeter tests were cut with a tricone bit. Hence samples were not directly available for comparative purposes. The core description was obtained from the return cutting, the relative rate of penetration and the core obtained from the nearby core holes.

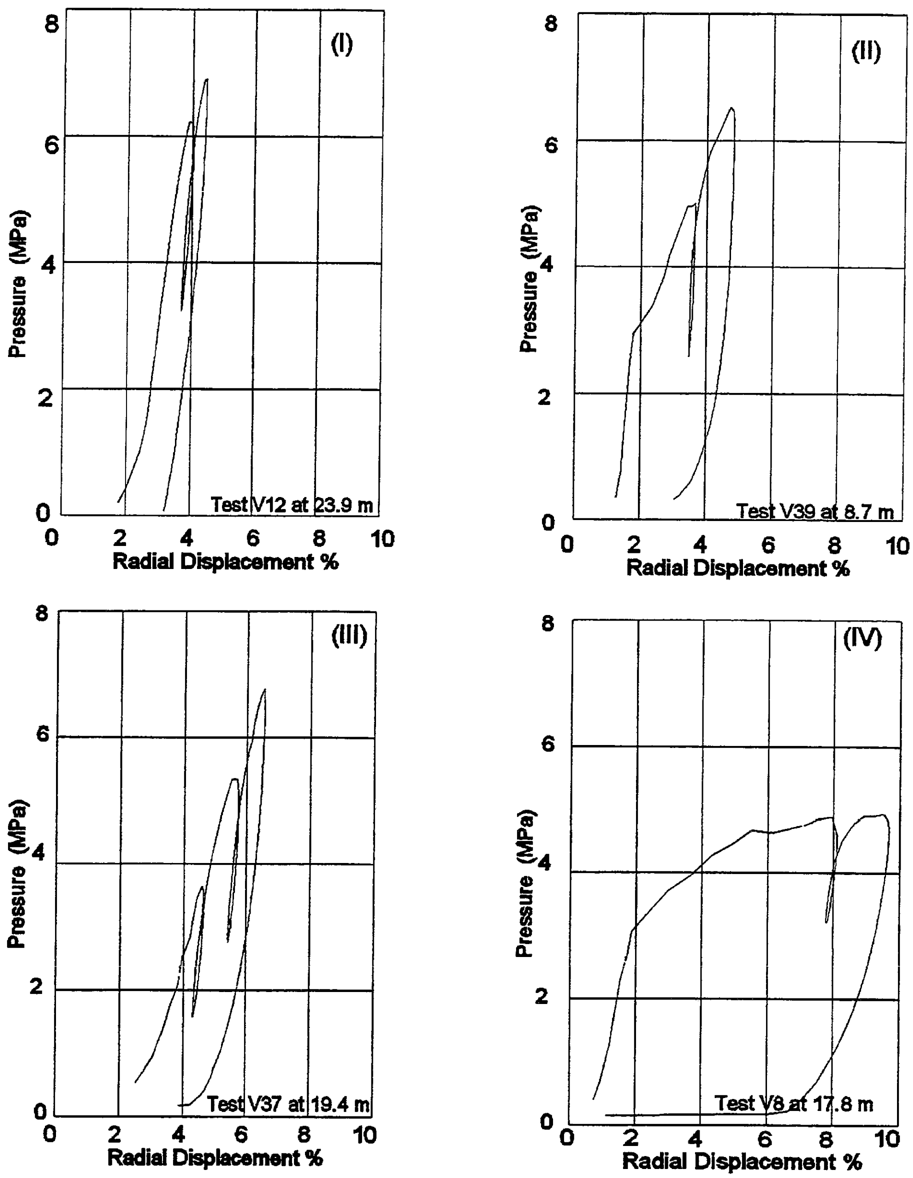
Each test falls into one of four groups. Representative tests of each group are shown in Fig. 3, the major features of which are shown diagrammatically in Fig. 4. The same lettering is used for sections of the test that behave in a common manner. The following is a detailed description of each test type and a possible general explanation of the behaviour of the rock.

Test 4-I

In Fig. 4-I the displacement increases linearly from A to B at 5.5 MPa. After 5.5 MPa, displacements increase at an ever-increasing rate to point C. However, there is no clear failure pressure, at least up to 7 MPa. The initial unloading is very steep from C to D. From there on, the unloading line D to E is parallel to the initial loading line AB. The unload-reload loop FG is parallel to the initial final unloading C to D.

This material is probably massive with few fractures. If the load remains under 5.5 MPa it will respond in a linear elastic manner. The secant modulus of the unfractured rock

Fig. 3. Typical pressuremeter tests in the weathered sedimentary rock.



over a stress range of 2 MPa or less is probably the average slope of the unload-reload loop. There is no indication of a limiting failure pressure under 7 MPa. Hence, provided the applied stresses are under this value, there is unlikely to be any significant movement.

Test 4-II

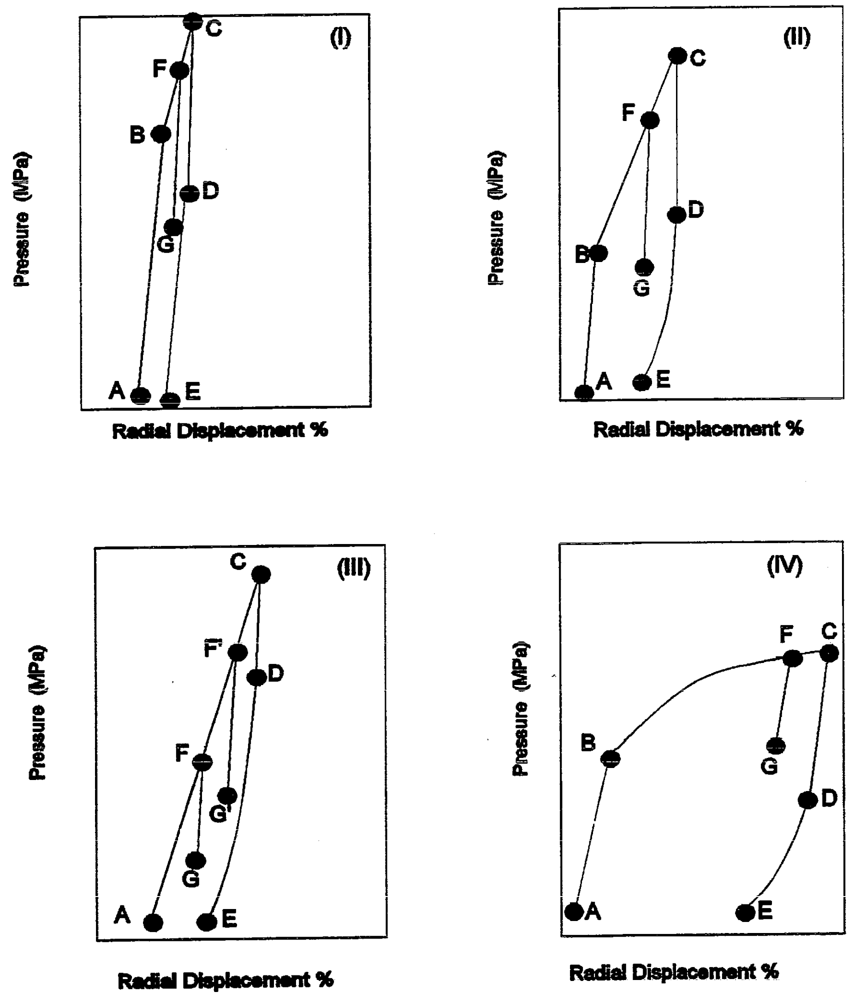
Fig. 4-II shows initially very stiff material, having a high modulus up to point B at 2.7 MPa. From then on, there is a distinct change in slope until the maximum pressure is reached at point C, the maximum pressure in this test. Again, there is no clear indication of a limiting failure pressure.

As in Fig. 4-I, the initial unloading from C to D is steep, and of similar slope to the unload-reload slope F to G. However, the final unloading from D to E is increasingly curved inwards.

This test is indicative of a relatively stiff material behaving elastically until some form of failure occurs at 2.7 MPa. At this point, the rock surrounding the cavity deforms in a different manner, as blocks continue to fracture or slip along existing joint sets. The general slope of the curve is again linear but much softer.

The initial portion of the pressure-expansion curve — the initial unloading section and the unload-reload — are parallel. The slope of these sections probably represents the elastic behaviour of the intact rock.

Fig. 4. Diagrammatic representation of the tests shown in Fig. 3.



The final unloading portion from D to E shows an increase in the rate of inward movement as the pressure decreases, which is in contrast to the same section in Fig. 4-I. This type of behaviour is indicative of material failing inwards on the pressuremeter, as the pressure is reduced. It is rather analogous to the inwards movement of a rock moving radially inwards on a shaft.

Finally, there is no indication of a limiting failure condition under 7 MPa. Hence, provided the applied stresses are under this value, there is unlikely to be any significant movement.

Test 4-III

This test shows a linear behaviour for the whole loading stage from point A to point C at 7 MPa. Again, there is no clear indication of a limiting failure pressure. The slope of the two unload-reload curves FG and F'G', and the initial slope of the unload curve CD, are parallel. The final section of the unload curve from D to E is increasingly inwards.

The relatively flat linear response is common in frictional materials. This is probably jointed sandstone in which shearing is occurring along pre-existing frictional joint surfaces. The slope of the unload-reload lines probably represents the modulus of the intact rock. The final unloading portion from D to E shows an increase in the rate of inward movement as the pressure decreases, as in Fig. 4-II.

Again, there is no indication of a limiting failure condition under 7 MPa.

Test 4-IV

Fig. 4-IV shows the fourth distinct type of behaviour. Up to point B the curve is linear, similar to AB in Test 4-II. As the pressure increases beyond B, the displacements rapidly increase. A limiting or failure pressure is clearly established in the range of 5 MPa.

As with Fig. 4-II, the slope of the initial section of the loading curve, the unload-reload curve and the slope of the initial part of the final unloading curves are parallel.

Again, as with Fig. 4-II, the final section of the unload curve from D to E is increasingly curved inwards. This type of behaviour is indicative of an elasto-plastic material, which initially behaves in a linear manner, then fails under shear until a pressure limit is clearly established.

Summary

The above comments are based on the pressuremeter test data alone. However, the results are consistent with the rock cores, either from nearby core holes or from the one hole in which pressuremeter tests were undertaken in a cored hole.

In materials of type I and II, the rate of penetration was the slowest. These tests were in relatively massive siltstone. Fracturing was more pronounced in the Type II material. In both of these materials, the core could readily be obtained from which intact sections, of sufficient length for laboratory testing, could be cut.

In Type III tests, the material was a sandstone. In this material, the core would tend to break up. Representative samples for conventional testing were not readily obtained.

The Type IV materials had the highest rate of penetration during drilling. These materials were coal/claystone seams. Obtaining a representative core sample suitable for testing was almost impossible. The core broke up and the recovery was poor. It is in these materials, in which laboratory tests cannot be undertaken, that a direct measurement of the modulus and the strength can be made with the pressuremeter.

In confined stress situations, such as large foundations, it is the soft weak layers that dominate the movement and hence influence the foundation design, rather than the hard competent materials that can be readily tested under laboratory conditions. It is in the materials that cannot be sampled by conventional means that the pressuremeter can often obtain direct measurement of the mass stiffness and the limiting stress that the foundation can carry.

Conclusion

Just from a visual examination of these tests, a picture can be obtained about the likely behaviour of this material. Some tests clearly have a limit pressure. Others show no indication of any limiting pressure, at least up to the stress limit of the test. As can be seen from these tests the data, although well defined, is complex. However the pressure-expansion curve undoubtedly reflects the behaviour of the rock from which the engineering properties can be measured rather than estimated.

References

Roddick, J.A. 2001.Capsule geology of the Vancouver area. Geological survey of Canada, open file 4022.