Lateral Stress in Glacial Materials

Contraintes latérales dans un matériau glaciaire

John Hughes, *Hughes Insitu Engineering Ltd., CDN*
Oliver Hoopes, *Shannon and Wilson Inc., USA*
Richard Smith, *Jacobs Associates, USA*
Robert Whittle, *Cambridge Insitu, UK*
Keith Brown, *In Situ Engineering, USA*

ABSTRACT : Estimation of the in situ lateral stresses along the tunnel alignment of the 17.7 m diameter SR 99 tunnel through Seattle, Washington, USA and the 78 m deep, 15 m diameter shaft in the Fraser River Valley near Vancouver, B.C., CDN was a primary focus of these two exploration programs. Due to the hard consistency of these glacial clay materials and the potential for cobbles, neither self-boring pressuremeter nor dilatometer testing was feasible and therefore pre-bored pressuremeter testing was used. The pressuremeter used was an electronic type in which the displacements could be measured accurately at several locations. Instruments of this type are manufactured by Cambridge Insitu.

RÉSUMÉ : Le focus de notre programme d'exploration consistait à estimer les contraintes latérales, en place; premièrement, pour un tunnel et en second lieu, un puits d'accès vertical:
1-Tunnel, Seattle, Etat deWashington, E-U. Ce tunnel,identifié comme SR 99, remplacera une autoroute traversant la ville du Nord au Sud, reliant le Canada au Mexique le long de la côte du Pacifique. Il s'agissait de faire l'analyse des contraintes latérales, en place, pour un tunnel de 17.7 mètres de diamètre.
2-Puits daccès, banlieue de Vancouver, Colombie Britannique, Canada. Identification des contraintes latérales en place pour un puits vertical d'une profondeur de 78 mètres et ayant un diamètre de 15 mètres à bord du fleuve Fraser.
Dans les deux cas précités, les essais pressiometriques étaient dans une formation de sable, graviers et galets très compacts ce qui empêchait l'utilisation d'un pressiomètre auto foreur ou dilatomètre. La solution demandait donc un pré-forage.Le pressiometre utilisé était du type électronique fourni par Cambridge Insitu, permettant une série de résultats précis sur tout le linéaire.).

KEYWORDS: Lateral Stress

MOT-CLES: Etreinte latérale

1 METHOD OF INTERPRETATION OF THE LATERAL STRESS

The lateral stress was determined by two methods. First a modeling approach was used which models the complete pressure expansion curve. The total lateral stress is one of the parameters of the model. In the second method the "balance pressure approach" the soil was allowed to creep for a fixed time interval at specific pressures during the final unload loop.

2 MODEL ANALYSIS METHOD.

The analysis of a well defined pressuremeter curve can be made by matching the field data with an ideal pressuremeter curve derived from fundamental material properties. In ideal tests from self-boring pressuremeter tests, Jefferies (1988), has demonstrated that a simple model based on the Gibson and Anderson (1961) model can be used to model the complete loading and the unloading stages of the pressuremeter tests. With the pre-bored pressuremeter there is usually some disturbance at the initiation of the test as the result of the drilling of the test pocket which has to be accounted for. In the Jefferies model the shear modulus is taken as a linear function of the slope of the unload reload loop. However it is often noted that the unload loops, in cohesive materials, are not always linear and display some hysteresis as shown in Figure 1. The shape of these unload-reload curves can be interpreted to give the elastic stress-strain behavior of the material being tested (Bolton and Whittle (1999). With this added component, Test 136 at 44 m. in the vicinity of the SR 99 Tunnel, has been analyzed with this model developed by Whittle (1999). This particular pre-bored pressuremeter test had the form of a typical ideal tests in which all the displacement sensors followed the same trend. The hole in which the pressuremeter was placed was slightly undersize and required a small amount of pushing to get the pressuremeter into position. This disturbance effect is corrected for by shifting the strain origin of the field data to align it with ideal model curve. The result of this analysis suggested that the total lateral stress is 903 kPa. Hence the total lateral stress, for the model parameters chosen, is in the range of 900 kPa. The process of developing the ideal pressuremeter curve takes some judgment in the selection of the model parameters and possible strain shift to allow for disturbance. Further, the choice of the particular model will have an influence of the resulting parameters.

3 BALANCE PRESSURE METHOD.

At about 6% strain on the final unloading (Figure 1) the pressure was held constant for approximately 100 seconds at 702 kPa then the pressure raised to approximately 1,125 kPa and held for approximately 100 seconds. The strain at 702 kPa was inwards (i.e. membrane contraction) as the pressure was held constant. At 1,125 kPa the strains were outward. Hence the lateral stress should probably lie between 702 and 1125 at the point at which no movement would have occurred. Unfortunately the pressure was then raised to 1250 kPa in error before being lowered to 850 kPa and held for a further 100 seconds then the movements were observed to be inwards, that is, below the total lateral stress. Then finally raised to 930 kPa and held. In the final stage the pressure was reduced to zero to complete the unloading phase. The creep strain curves are shown in Figure 2. The final creep pressure of 930 kPa shows a slight outward movement. To obtain a more accurate determination of the equilibrium balance pressure, at which no movement would occur, a plot can be made of the strain at various time intervals such as at 25 seconds, 50 seconds, and 100 seconds with creep pressure (Figure 3). The creep pressure at which no movement occurs is in the range of 900 to 920 kPa. This pressure is in the range of that determined from the model analysis. However unlike the model analysis, which required considerable skill to implement successfully to obtain the lateral stress the "balance" pressure can be completed with less attention to detail. The above example came from the first initial trials of this technique. It was part of a series of trial tests to get some understanding of the likely total lateral stress for the proposed SR 99 tunnel.

4 RANGE OF DATA IN COMPLEX GEOLOGY.

(1982) empirical method of determining the K_0 the range of possible values based on the overconsolidation ratio (OCR) are calculated by the following formula:

$$K_0=K_{onc}(OCR)^{\alpha}\ldots\ldots\ldots\ldots(1)$$

The profiles of the K_o from the range of the upper and lower bound of the OCR from Figure 4 are shown in Figure 5. The K_o values from the Balance pressure and from the model analysis for Test 136 are shown as single points.

During this process considerable experience was gained in devising a test procedure in which this method could be accomplished more efficiently. It was then tried in a deep shaft in Vancouver. This was a large diameter shaft 15 m. in diameter going down 78 m. depth. The technique proposed is as follows as referenced to test 11 at the shaft location:

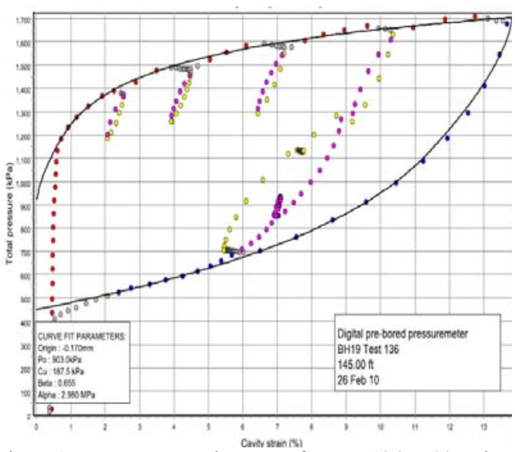

Figure 1. Pressure expansion curve for Test 136 at 44m. depth for the Seattle SR 99 Tunnel compared with the ideal pressure expansion model.

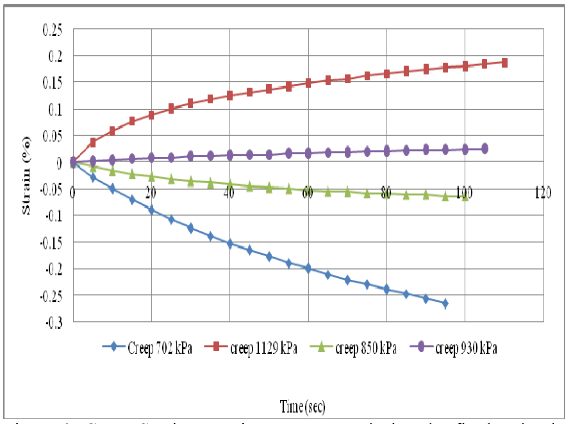

Figure 2. Creep Strain at various pressures during the final Reload-unload loop in Figure 1.

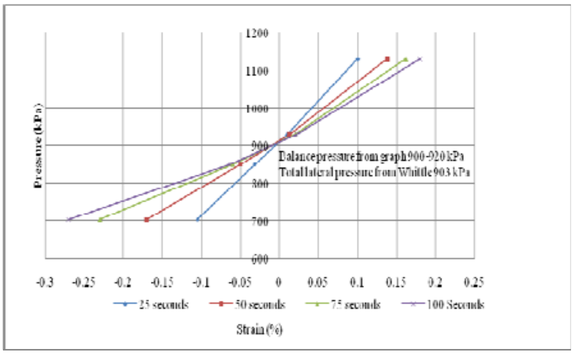

Figure 3. Creep Strain at various time intervals for constant pressure

During the final unloading, the pressure was unloaded to below the estimated total lateral stress,

(1) shown in Figure 6 (Test 11). An enlarged view of the final unload reload loop is shown in Figure 7
(2) The pressure was held constant, at that point, for three minutes.
(3) Raise the pressure a small increment to point A and held constant for three minutes. If the pressure raised is not too large the movement should be inwards as in point A in Figure 7
(4) Raise the pressure further and hold. Again , if the pressure is below the "balance" pressure the strain will be inwards.
(5) Continue to raise the pressure, in approximately equal magnitude pressure increments, until the strains start to move outwards (point C). Again holding the pressure for three minutes.
(6) Repeat the procedure until one obtains points below the creep or "balance" pressure and above.
(7) the "balance" pressure can be obtained by plotting the creep strain against pressure for various time intervals as shown in Figure 8.

The "balance" pressure can be obtained by plotting the creep strain against pressure for various time intervals as shown in Figure 8. The "balance" pressure from Figure 8 is 1,070 kPa. The above simple procedure was applied at 8 locations down the hole. The results were very consistent and showed little scatter. This is consistent with the more simple glacial geological history at this site. Hence there was some confidence that this method could give a value for the total stress.

5 CONCLUSIONS

The material tested, at both sites, were glacially overridden silts and silty clays. The material in Vancouver was much more sandy, with less clay, than in Seattle. A qualitative indication of this is given by the range of creep strains which occur. For test 136 at 702 kPa the total creep strain is 0.25% strain where as in Test 11 at 900 kPa the total creep was only 0.04% strain.

The " balance" pressure can be identified in all tests, which show a tendency to creep, in an analogous manner to the Menard Creep Pressure. However the Menard's Creep Pressure occurs at a much higher pressure than the total insitu lateral stress, as the material is commencing to fail plastically at the onset of creep.

This "Balanced" pressure method is a simple technique, in materials which exhibit creep, under constant pressure. It appears to give an indication of the total lateral stress in materials that are very difficult to sample.

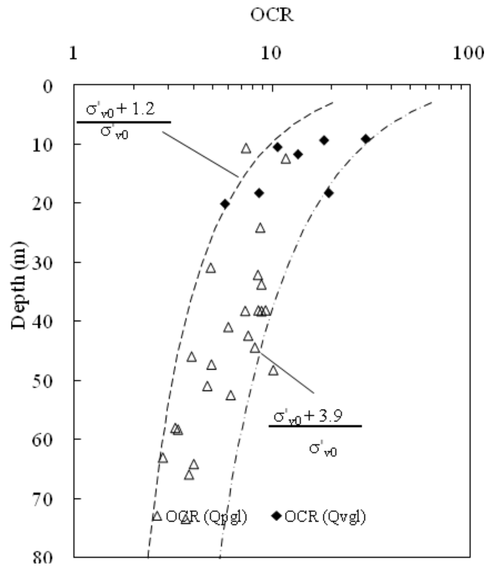

Figure 4. OCR from Laboratory test

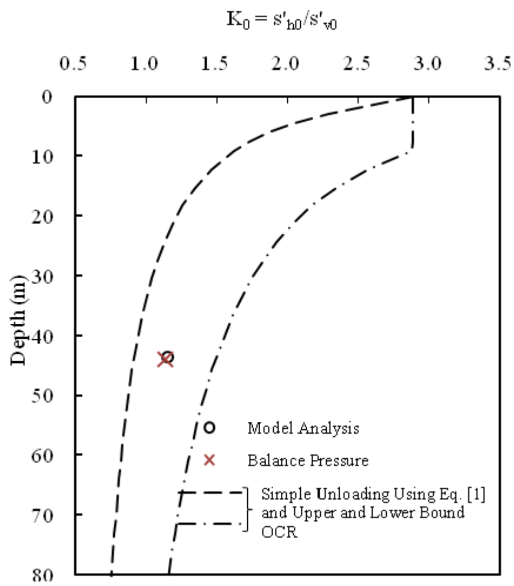

Figure 5. K_o from "Balance" pressure from Test 136

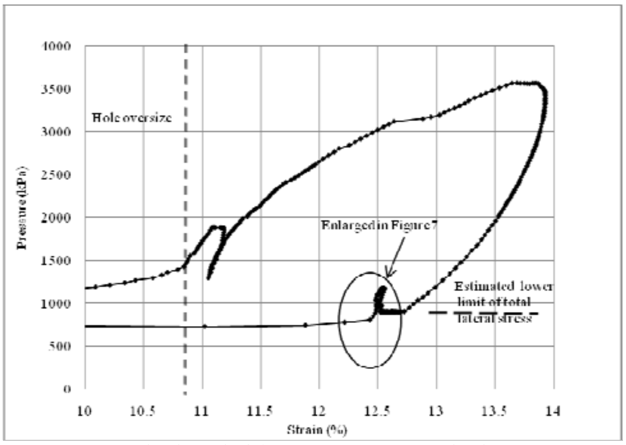

Figure 6. Test 11 at the deep shaft in Vancouver at 74 m depth.

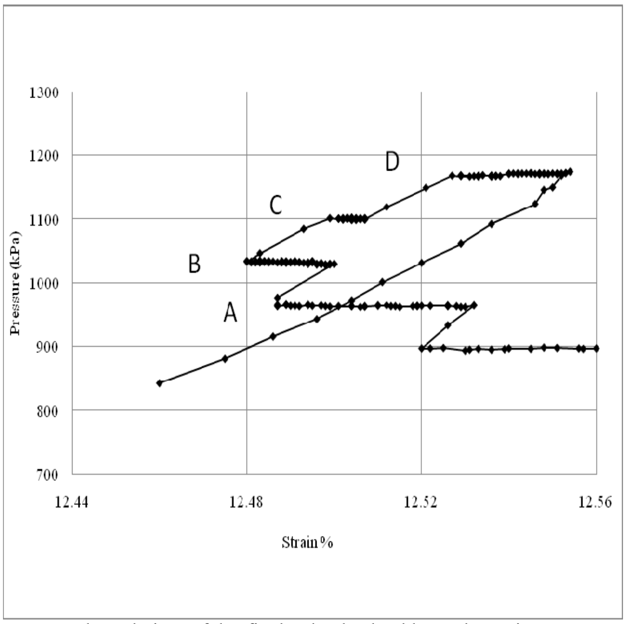

Figure 7. Enlarged view of the final unload reload loop shown in Figure 6.

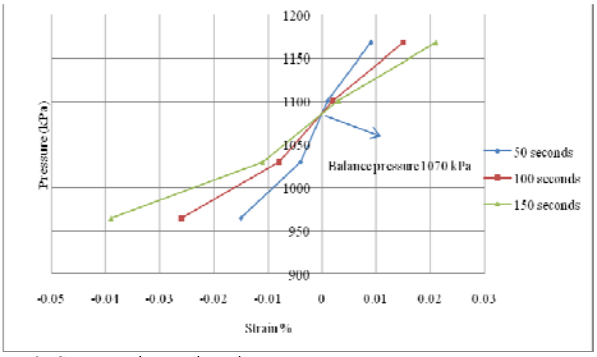

Figure 8. Creep strains against time at a constant pressure

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