International Conference on Case Histories in Geotechnical Engineering

(1984) - First International Conference on Case Histories in Geotechnical Engineering

08 May 1984, 8:00 am - 10:00 am

Predicted and Observed Lateral Deformations of Anchored Retaining Walls

Tj. Kooistra
Fugro B. V., Leidschendam, The Netherlands

F. L. Beringen
Fugro B. V., Leidschendam, The Netherlands

Predicted and Observed Lateral Deformations of Anchored Retaining Walls

Tj. Kooistra and F. L. Beringen

Project Engineer and Manager of Engineering, respectively of Fugro B. V., Leidschendam, The Netherlands

SYNOPSIS Backanalysis of deflection measurements for a diaphragm and a sheet pile wall in Holland has shown that the results are mostly sensitive to the profile of coefficients of subgrade reaction. A sensitivity study performed to compare the wall deflections calculated with the Mēnard and Terzaghi theory shows that the moduli according to Mēnard produces best agreement. The analyses were carried out using a one dimensional finite element programme.

It is shown that displacement measurements obtained from easy to perform inclinometer surveys provide both control of safety during construction and a check on performed design calculations.

INTRODUCTION

The prediction of the displacements of soil retaining walls and surrounding soils has become more important last decade. The two main reasons hereto are increases in excavation depths and closer proximities of adjacent buildings.

The major difficulties in predicting the displacements of the retaining walls are:
- the estimation of the lateral soil pressures against the wall
- the determination of three dimensional effects with which to adjust the results of commonly used one dimensional calculation models
- the determination of the influence of anchors and rods, supporting the walls.

To measure the actual lateral displacements of retaining walls and surrounding soils, inclinometer surveys can be carried out. The results of the surveys can be used to control the safety of both the retaining structure and any adjacent buildings and to check the design calculations.

This paper presents two case histories and describes the procedure and the results of the back-analyses performed.

The main object of the paper is to improve understanding of the interactive behaviour of retaining structures and surrounding soils. The case histories also demonstrate the usefulness of inclinometer surveys.

CASE HISTORIES

For two underground car parks in Holland a retaining wall had to be installed. The first wall consisted of a diaphragm wall and the second of a sheet pile wall. To determine the actual lateral displacements of the structures, inclinometer surveys were performed during the various stages of excavation. A Sinco inclinometer was used, running down inside tubes attached to the wall. The inclinations were obtained with respect to two orthogonal vertical planes at closely spaced intervals to an accuracy of more than 0.1 mm/m.

Diaphragm Wall

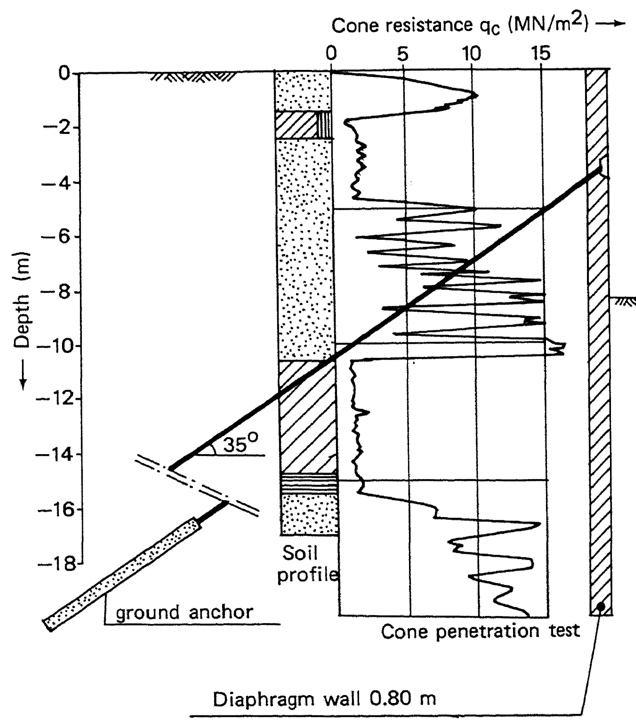


Fig. 1. Construction and Soil Profile Diaphragm Wall

The construction of the diaphragm wall is shown in Figure 1. It consists of a 18.0 m long wall with a thickness of 0.80 m. It is supported by one row of ground anchors connected to the diaphragm wall at a level of about 3.7 m below ground surface. The final depth of the excavation is about 6.8 m below ground surface.

The soil mainly comprised medium to dense sand alternated with normally consolidated clay-layers. At a level of 14.7 to 15.5 m below ground surface a peat layer was found. The ground water table measured during the soils investigation was about 1.8 m below ground surface.

To determine the wall displacements during and after excavating, an inclinometer survey has been performed at 5 locations. For this purpose 50 mm square steel pipes have been installed at the same time as the reinforcement.

Before starting the excavation, a reference survey has been performed. The surveys at the various stages of excavations have been related to this reference measurements. The calculation of the deflections and the graphical output were made with a mini-computer with attached plotter.

The deflected profile of the wall has been measured 5 times at the various stages of excavation. In Figure 2 the results of the surveys are shown for a characteristic location.

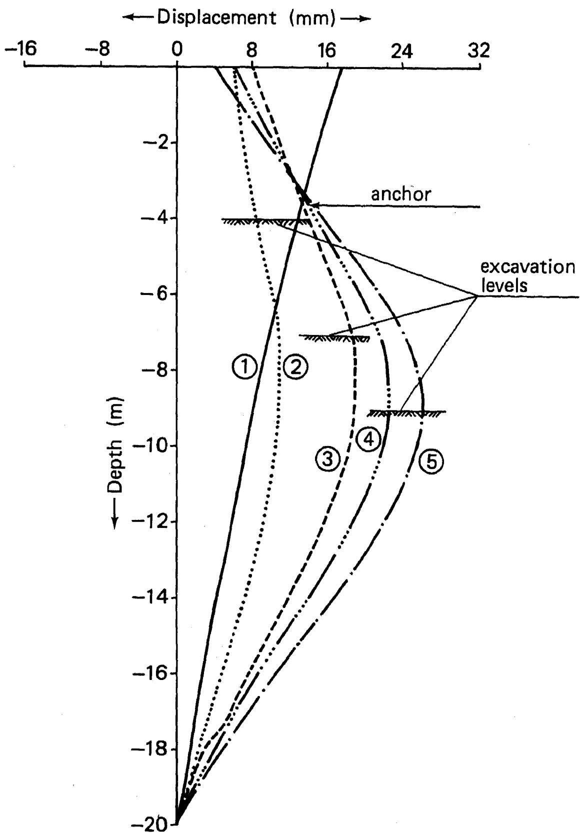


Fig. 2. Inclinometer Surveys Diaphragm Wall

It can be seen that the anchors have been installed and prestressed between the first and second measurement. The maximum displacement measured immediately after reaching final exc vation level is about 22 mm. After a period 2 months this displacement increased to 26 mm

Sheet Pile Wall

The other retaining structure, shown in Figur 3, consists of a sheet pile wall BU 20. At a level of about 4 m below ground surface the w is supported by ground anchors with a length 12 to 13 metres. The penetration level of th wall and the maximum excavation level are respectively 18.0 m and 7.0 m below ground surface.

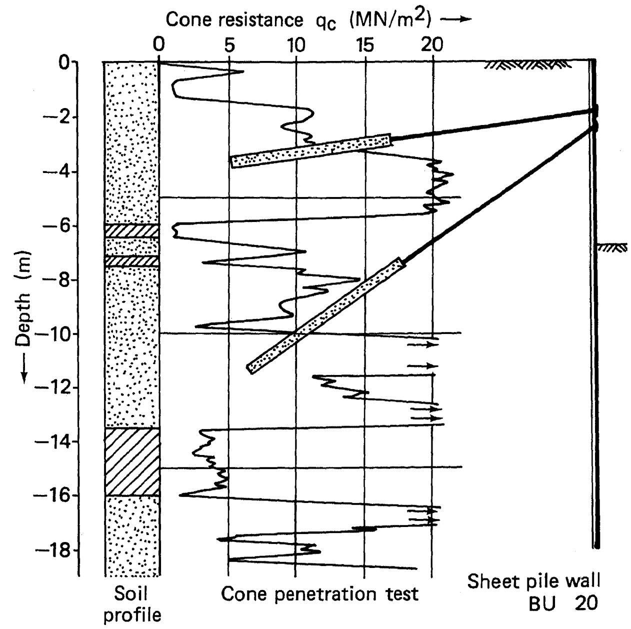
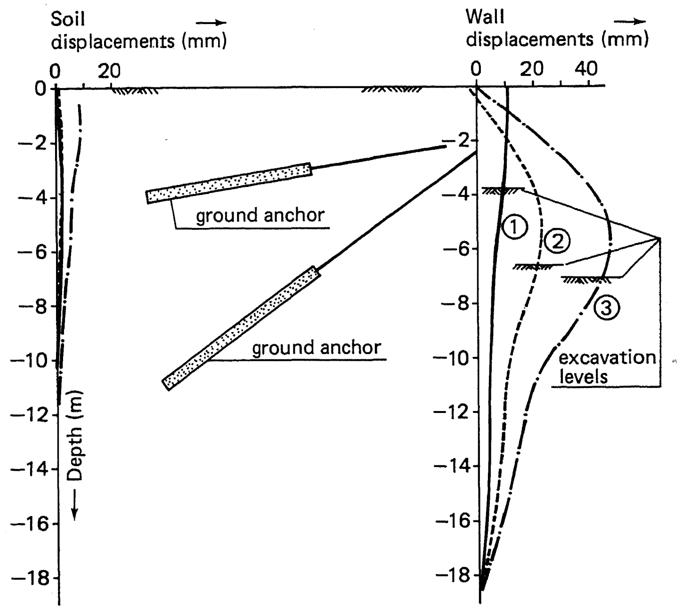


Fig. 3. Construction and Soil Profile Sheet Pile Wall

The soil profile shows medium to dense sand layers upto the penetration level. At levels of 6, 7 and 13.5 metres clayey layers have bee detected. The ground water table is located a level of about 0.4 m below ground surface.

At 5 locations, 50 mm square steel pipes have been welded on the sheet piles before driving them to final penetration. In these pipes inclinometer surveys have been performed, registrating three different excavation stages. Pr cedures were similar to those, adopted for the diaphragm wall. Behind the ground anchors an inclinometer tube has been installed in a bore hole to measure the lateral soil displacements at the same three stages of excavation.

Figure 4 shows the results of the inclinometer surveys. The maximum wall displacements in th second stage are about 23 mm, while almost no soil movement behind the anchor row has taken place. However, the last survey performed three months later shows an increase of wall displacement of maximum 25 mm, while a relativ soil displacement behind the anchors of maximu 10 mm at ground surface occurred.



-Fig. 4. Inclinometer Surveys Sheet Pile Wall

METHOD OF ANALYSIS

Shear forces, bending moments and displacements have been calculated with a one dimensional finite element program. This in-house computer program called FEWAND (Kay and Kooistra, 1981) is a beam column type of program especially developed for soil retaining walls. The input parameters consist of:

- wall parameters such as bending stiffness and length of the wall
- anchor data such as the level, the stiffness and the prestress force in the anchor
- soil parameters, such as densities, coefficients of lateral soil pressure and coefficients of lateral subgrade reaction
- water pressure distribution
- surcharges
- excavation levels.

The soil behavior is simulated by elasto-plastic springs. In Figure 5 a typical relationship between lateral soil pressure and displacement is shown. The active and passive lateral soil pressures and the soil pressures at rest σ_a, σ_p σ_o respectively, have been determined according to Coulombs theory. The soil behavior between minimum and maximum lateral soil pressures is approximated with coefficients of lateral subgrade reaction. Figure 5 demonstrates the difficulty of employing a constant modulus to simulate accurately the soil stiffness over the full range of behavior.

Approximate methods for determining the reaction modulus are described by Ménard (1968) and Terzaghi (1955). Ménard proposed a relationship between the coefficient of lateral subgrade reaction and in-situ measurements performed with the Ménard pressuremeter. This factor is independent of the soil displacements. The figure shows that a decrease in modulus will give an increase in soil displacement. On the other hand Terzaghi gives two different values of the coefficient depending upon the displacements of the soil. As Figure 5 shows, a high coefficient is obtained for small soil displacements and a much lower value for larger displacements.

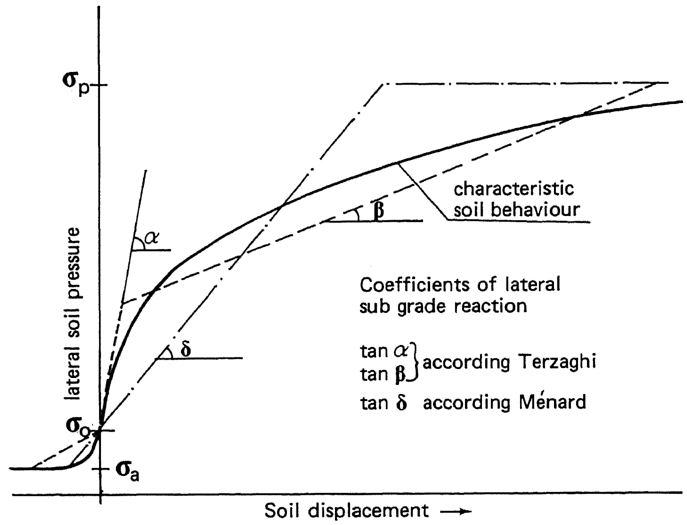


Fig. 5. Relationship between lateral soil pressure and wall displacements

Design Calculations

Design calculations are generally performed with input values that embody factors of safety. Thus predicted or design soil pressures and deflections may not correspond directly to real pressures and deflections measured under working loads.

The input values which have been employed for the design of the sheet pile wall can be summarized as follows:

- a relative high surcharge due to possible storage near the excavation
- lower bound soil parameters related to the least optimistic soil profile along the wall
- conservative coefficients of subgrade reaction according to the theory of Terzaghi, because the displacements and moments calculated with this theory were higher than those derived using Ménard's theory. It was not known which of the two methods was the more realistic.

The resulting maximum design displacement of the sheet pile wall was calculated to be 70 mm. The design calculations of the diaphragm wall were performed by another company.

Backanalysis

A backanalysis has been performed for both retaining structures using the measured deflection. The basic procedure of these analyses is given in the flowchart in Figure 6.

For the various stages of excavation three series of analysis were been performed. Firstly a match between the backfigured displacements and the actual measured lateral displacements

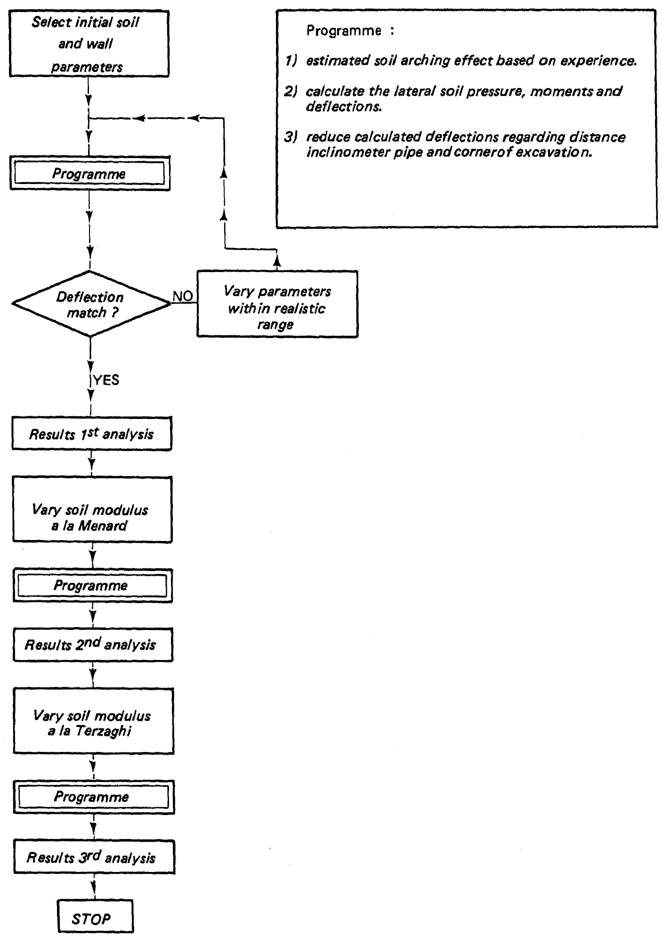


Fig. 6. Procedure of Back-analysis

was found by varying the soil and wall parameters within a realistic range. The results appeared to be sensitive to the coefficients of subgrade reaction employed.

Therefore, in the additional analyses all parameters except for the coefficients of subgrade reaction were held constant. In the second series of analyses, coefficients according to Ménard have been employed. Since no pressuremeter tests were performed the coefficients were related to the measured cone resistances.

The third series of analysis used coefficients of subgrade reaction according to Terzaghi.

In the flowchart, two influences have been mentioned, which cannot be modelled directly in the one dimensional computer program used. For the walls analysed these influences are:

- The determination of the influence of vertical soil arching behind the wall between anchor-fixity point and the excavation level. Measurements described by Milligan (1983) and Breth and Stroh (1976) show that the lateral soil pressures are lower than the vertical pressures multiplied with the Coulomb active earth pressure coefficient.
- The calculated wall deflections were reduced in order to take into consideration the distance between the inclinometer pipes and the corners of the excavation. The applied relationship as described by Ulrichs (1981) is shown in Figure 7.

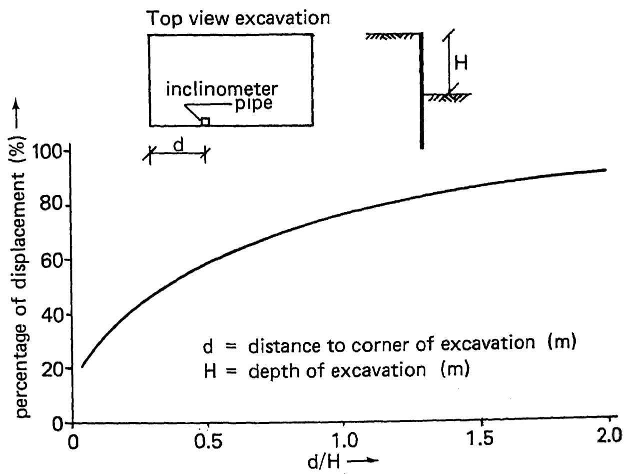


Fig. 7. Relationship between Wall Displacement and Distance to the Corner of the Excavation

Diaphragm Wall

The calculated displacements showed a minor sensitivity for all soil and wall parameters except for the coefficients of lateral subgrade reaction.

For excavation stages 1 to 4 the coefficients evaluated according to Ménard's theory produced reasonably good agreement with the measured displacements. The calculated result for the final excavation level is given in Figure 8. The coefficients according to Ménard have to be reduced by about 20 percent in order to obtain agreement with the measured values of the last performed survey.

The Terzaghi approach gives less satisfactory results. Input of the appropriate coefficients over-predicted the final wall displacements by 50 to 80 percent.

Sheet Pile Wall

The same backanalysis procedure has been performed for the sheet pile wall. Again the results are mostly sensitive to the coefficients of subgrade reaction. The Ménard approach produces the best agreement with the first and second survey results. The back-calculation results for the second survey are shown in Figure 9.

The deflections measured during the last survey have to be divided into two parts before back-analysis. The measurements in the survey tube behind the ground anchors show a soil movement of maximum 10 mm at ground surface. A theoretical analysis described by Ulrichs (1981), indicating the deflected shape of the wall has two components:

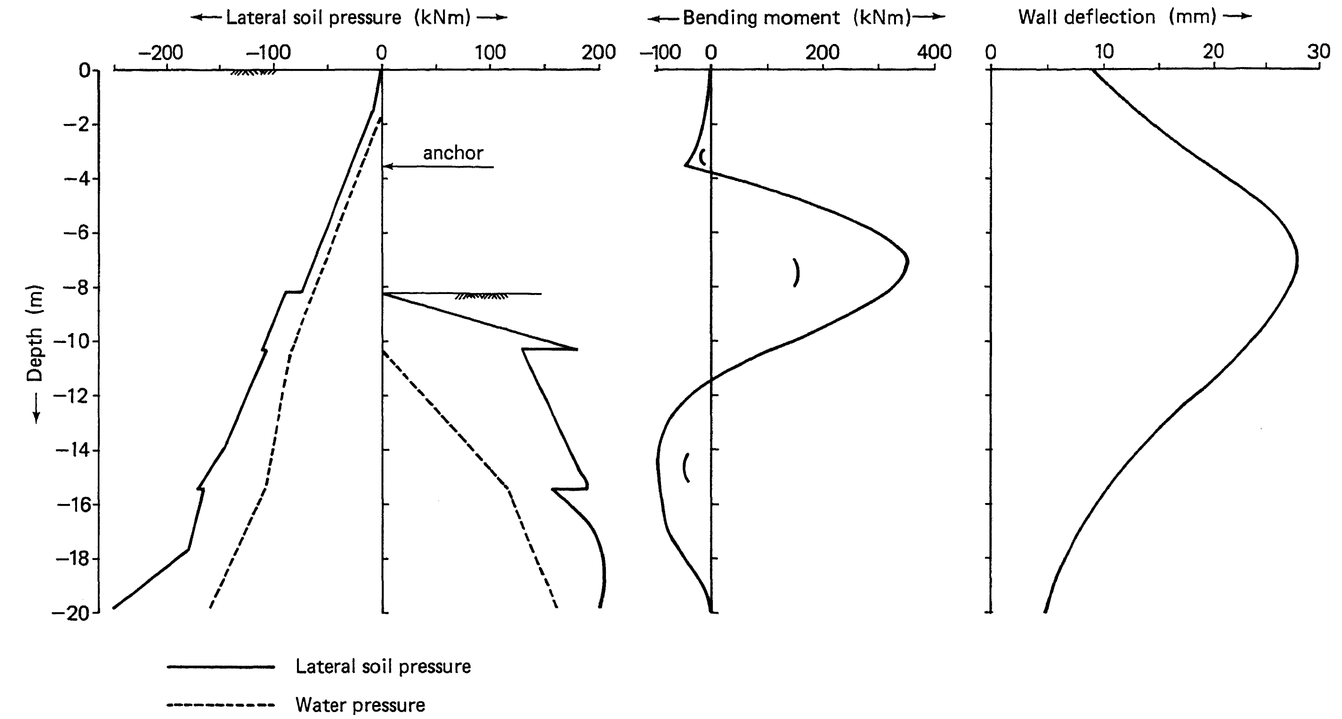


Fig. 8. Results Back-analysis Diaphragm Wall

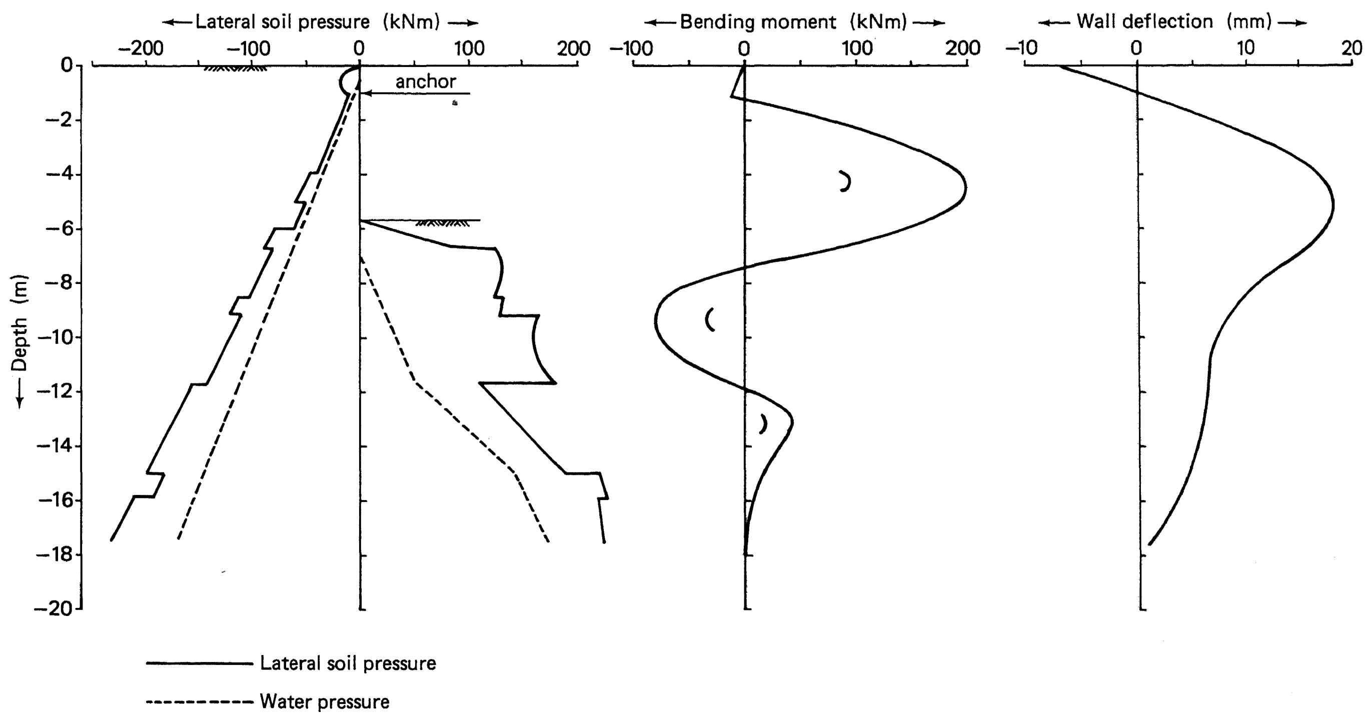


Fig. 9. Results Back-analysis Sheet Pile Wall

- deflection of the wall due to soil movement behind the wall
- deflection of the wall due to the lateral pressures against the wall.

The basic principle of this division is shown in Figure 10. The program, FEWAND, calculates the deflections due to the lateral soil pressure against the wall. Therefore the measured wall deflections have to be reduced by the measured soil movement behind the wall before back-analysing the survey results.

It was found that the Ménard coefficients of subgrade reaction have to be reduced by about 40 percent to obtain a proper match between the final deflected profile and the calculated deflections. In comparison the Terzaghi moduli should be increased to over 100 percent.

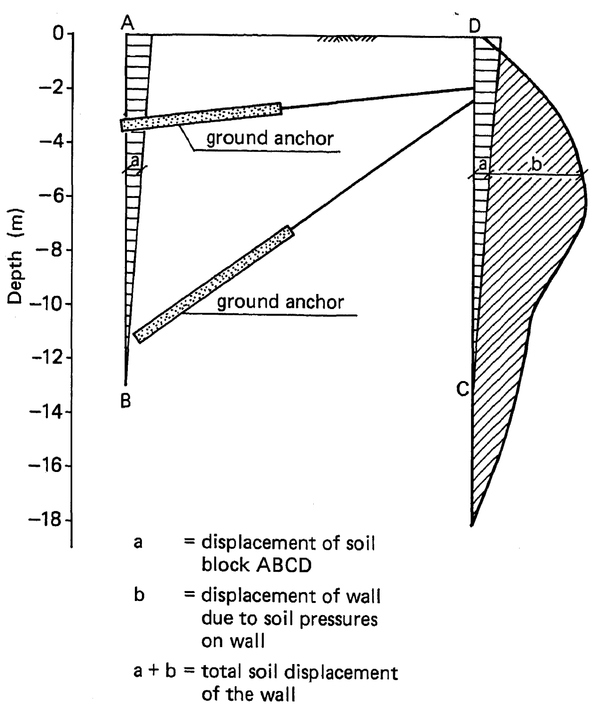


Fig. 10. Soil Movement behind the Wall

CONCLUSIONS

- The case histories demonstrate that inclinometer surveys not only provide control of displacements during construction but with appropriate back-analysis they provide valuable data for the determination of soil pressure bending moments, and the interaction between wall and ground anchor.
- The back-analysis carried out for the two case histories reported herein, show that:

  1. Calculated lateral soil pressures are very sensitive to the coefficients of lateral subgrade reaction.

  2. For the two retaining structures analysed, coefficients of subgrade reaction evaluated according to Ménard's theory give a deflected profile similar to the deflections measured during the inclinometer surveys. However to allow for time creep effects, the coefficients should be reduced with 20 to 40 percent.

  3. Input of coefficients of subgrade reaction according the Terzaghi approach give 70 to 100 percent too high displacements.

REFERENCES

Breth, H. and Stroh, D. (1976), "Ursachen der Verformung im Boden beim Aushub tiefer Baugruben und konstruktive Möglichkeiten zur Verminderung der Verformung von verankerten Baugruben", Bauingenieur 51,

Breth, H. and Wolff, R. (1976), "Versuch mit einer mehrfach verankerten Modellwand", Die Bautechnik 2,

Kay, S. and Kooistra, T. (1981), "FEWAND manual", internal manual for one-dimensional computer program FEWAND for analyses of retaining walls, Fugro B.V.

Ménard, L., Bourdon, G. and Gambin, M. (1968), "General Method to Calculate a Pile or a Diaphragm Subject to Horizontal Loading in Terms of Pressure Test Results", Sols/Soils No. 22/23.

Milligan, G.W.E. (1983), "Soil Deformations near anchored Sheet Pile Walls", Geotechnique 33.

Terzaghi, K. (1955), "Evaluation of coefficients of subgrade reaction", Geotechnique, Vol. 5.

Ulrichs, K.R. (1981), "Untersuchungen über das Trag- und Verformungsverhalten verankerter Schlitzwände in rolligen Böden", Die Bautechnik 4,