THE DEFLECTION OF EARTH RETAINING DIAPHRAGM WALL DURING DEEP EXCAVATION

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ABSTRACT The technique of constructing reinforced concrete diaphragm wall together with internal bracing or tie-back system in deep excavation has been practiced for many years. It has become one of the most popular earth retaining schemes for deep excavation nowadays, yet the analytical methods on the lateral displacement and deflection of the diaphragm wall are still in vague and a sort of art.

This report describes a simple spring model method to predict the lateral displacement and deflection of the diaphragm wall in according to sequence of excavation. A scheme of selecting proper soil strength parameters and earth pressure diagram as well as determination on the soil spring constants is introduced.

Direct measurements on the lateral movement of the diaphragm wall has been carried out in site during deep excavation. The results demonstrated that the prediction for lateral movement of the diaphragm wall by the spring model method has a reasonablly fair accuracy.

Introduction

Various types of sheeting and lateral support system have been used to retain earth to prevent lateral movement of ground during excavation. The most common types of sheeting nowadays used in Southeast Asia are steel sheet piling, soldier pile and lagging. Where a higher rigidity of retaining structure is desired, a concrete panel wall formed by cast-in-situ contiguous bored piles or slurry diaphragm wall may be used. The form of support could be that of a simple cantilever or may require the incorporation of earth berm. When the excavation space is limited and extended to substantial depth, one or more layers of bracings or ties become necessary.

The conventional approach in design of such retaining system, an empirical trapezoidal pressure distribution is often assumed in determining the axial force on strut and the bending movement on sheeting element. Under such aspects of analyses, the influences of wall movement and stiffness of wall on the redistribution of lateral earth pressure are tended to be ignored. This report presents a simple method by using finite element approach to include the soil-structure interaction effect in design of rigid diaphragm wall. Each stage of excavation is analyzed by assuming elastic supports at bracing locations and a series of springs for soil below the level of excavation.

The available computer program using finite element model permits a theoretical study of soil and wall interaction.

Theoretical Analyses

The beams on an elastic support problem has been drawing the attention of geotechnical engineers for many years. The basic solution for such structure member can be described as follows:

$$P = EI \frac{d^4y}{dx^4} \qquad (1)$$

When this equation is applied to diaphragm wall design, y designates the deflection of diaphragm wall at section x. The net force P applied on wall consists of lateral earth pressure, pore pressure and reaction from struts. It varies with depth and degree of wall deflection. E and I are elastic modulus and moment of inertia per unit width of the diaphragm wall, respectively. The above mentioned equation can be solved by applying proper boundary conditions. The stiffness method of finite element approach could be the simplest way available in solving this equation.

Using finite element approach, the will is considered as a series of elements connected by nodes. The lateral pressure is converted into concentrated loads acting horizontally at the nodal points as shown in Fig. 1. If an elastic state of stress within the soil mass is assumed, the equation (1) can be written as

$$\{P\} = (K)\{y\} \qquad (2)$$

Where (K) is a stiffness matrix built with spring constant of the strut and the subgrade reaction coefficient of soil at every nodal point. Basic operations of the displacement method analyses consist of:

(a) Evaluation of the stiffness properties of the individual diaphragm wall elements.

(b) constructing stiffness matrix in the global coordinate system of the entire structure.

(c) Superposition of the individual element stiffness to each nodal point to construct the complete assemblage nodal stiffness matrix (K).

(d) Formulation and solution of the equilibrium equations expressing the relationship between the applied loads (P) and the nodal displacement (y).

(e) Evaluation of the element deformations from the computed nodal displacements and determination of element forces and moments from the element deformations.

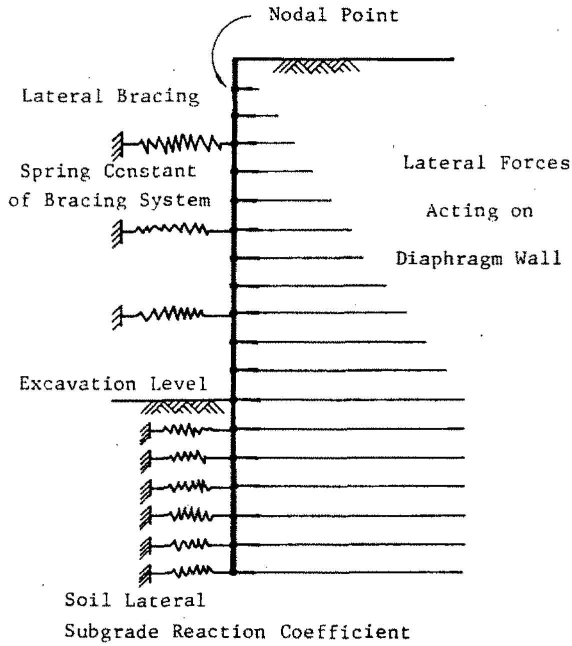


Fig. 1 Mechanism of Soil-Structure Interaction and Its Design Model

These operations are available in numerous computer programs for structural analyses. For design of diaphragm wall, a two dimensional element for analyzing the stiffness character is sufficient. Procedures prior to application of the finite element analyses are noted as follows:

(1) Assume bracing locations. Locations of bracing should be in the places where interferance caused from construction of floor slab can be reduced to minimum.

(2) Determine lateral pressure distribution and apply to the nodal points. Distance between nodes can be equally or randomly spaced. However, it is preferable to have the nodes coincided with bracing locations.

(3) Bracings are represented by a series of springs with its spring constant reflecting the section properties of bracing.

(4) Being simulated by springs, soil stiffness below the excavation level is also characterized by its horizontal subgrade reaction coefficient K_s.

Lateral Pressure Diagram

Lateral pressure acting behind the sheeting wall is contributed majorly by soil mass and groundwater pressure. Their distribution had been recommended by many investigators and verified by field studies, but actual pattern somewhat varies widely with the retaining system adopted and deflection of sheeting occurred. A triangular distribution pattern of pressure suggested by Peck (1969) might be correct if the deflection decreases from top to bottom. However, for a very rigid wall with a condition that only a little deflection is allowed to occur, the K_o condition may be the most critical state. Probably, the utmost commonly used design loading pattern for braced wall proposed by Terzaghi and Peck (1967), is a trapezoidal pressure distribution with a value close to K_o state at upper portion and approximately to 80% of K_a condition at lower portion. However, in many practical cases, when the first level of strut is installed at certain distance below the top of wall, a considerable deflection of wall could possibly occurred, thus the active state of pressure K_a appears more likely to take place.

Instrumentation And Results

The case presented herein is that of a diaphragm wall installed in perimeter of the excavation site, with a shape as a rectangular (90m × 60m) of TPC Building in Taipei. The diaphragm wall has 70cm in thickness and 22m in depth for 14.7m deep of excavation. Conventional internal bracing system by steel struting is adopted to support the surrounding ground. Instruments including sliding type inclinometers, oil filled pressure cells and reinforcing bar strain gauges are mounted into five selected concrete panels during the construction of the diaphragm wall so that the behavior of the wall can be detected.

Both pneumatic and open type of piezometers, numbers of settlement points and heave markers have been placed in the surrounding ground as well

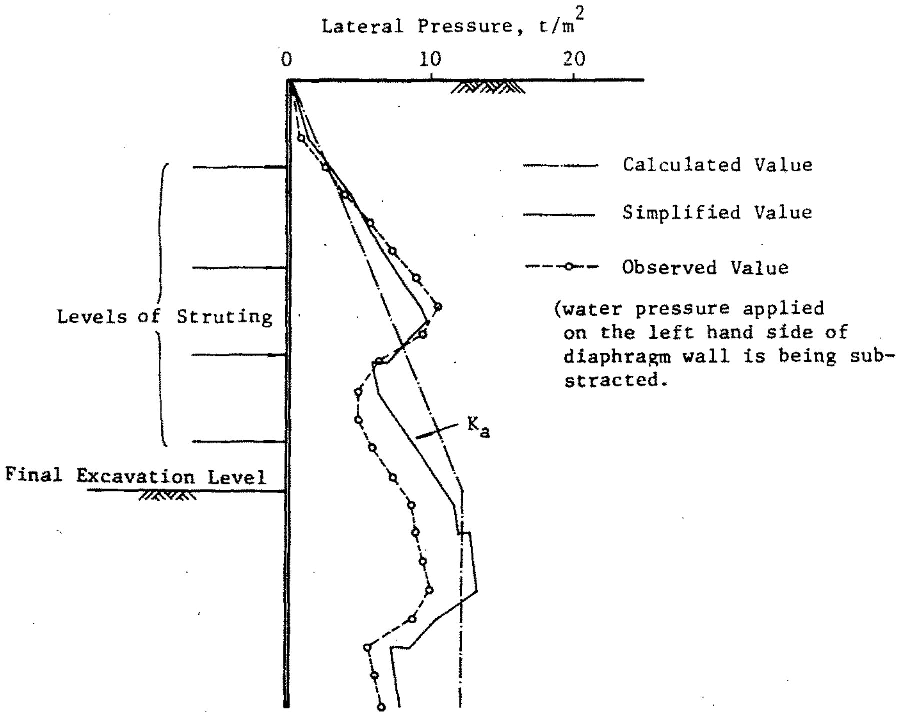
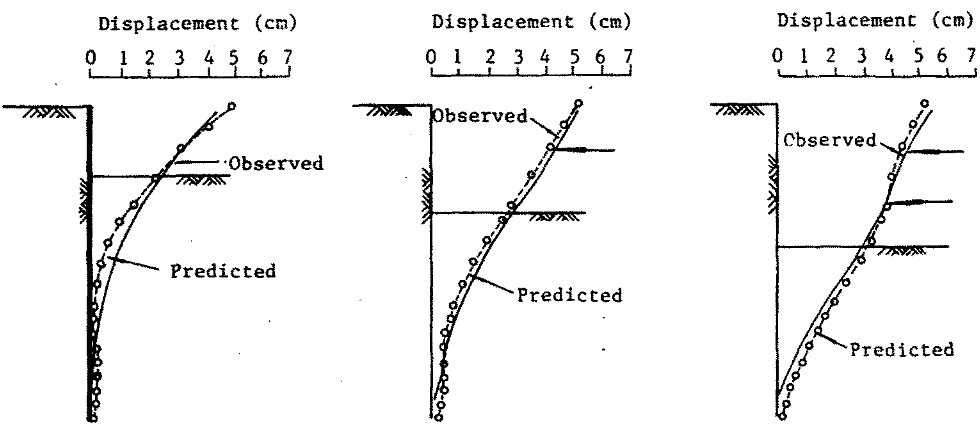


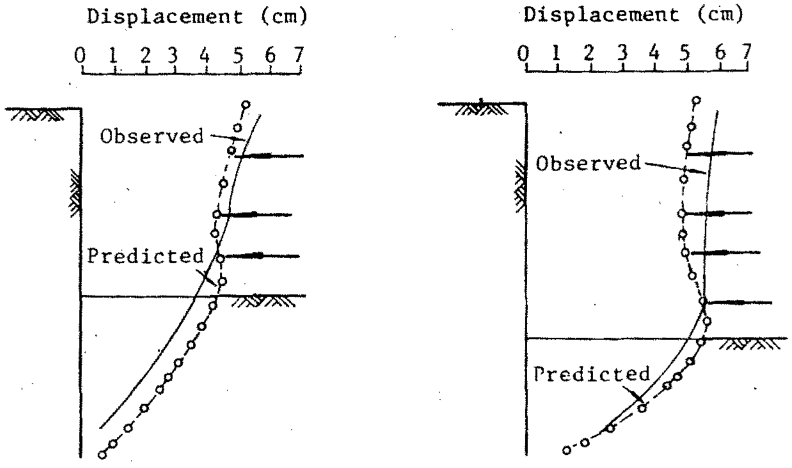
Fig. 4 Simplified Net Lateral Pressure Diagram



(a) at 1st stage of excavation

(b) at 2nd stage of excavation

(c) at 3rd stage of excavation



(d) at 4th stage of excavation

(e) at final stage of excavation

Fig. 5. Predicted and Observed Values of Displacement of Diaphragm Wall during Different Stages of Excavation

as within the excavation area to measure the change of pore pressure and movement of earth mass in each stage of excavation. A series of vibrating wire strain gauges manufactured by Genor has also been welded onto steel struts for the purpose of monitoring axial forces on struting members.

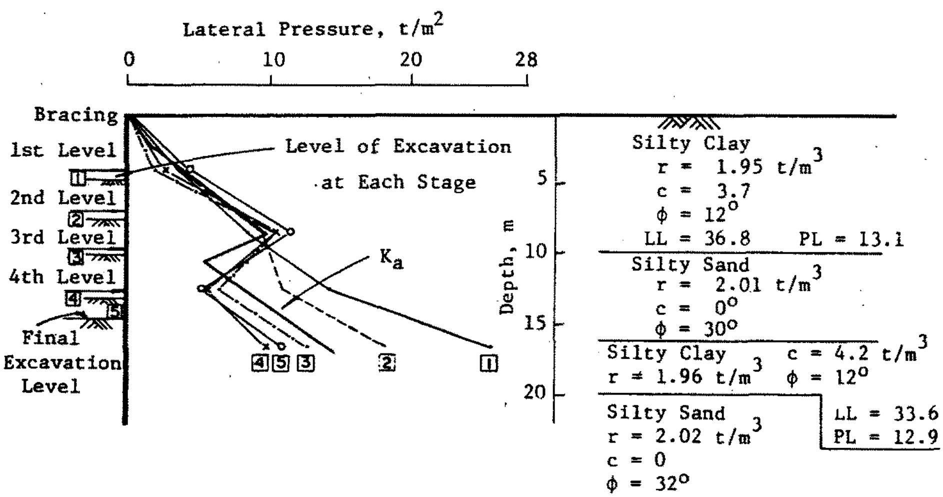
Subsoil condition in the project site is, in general, a very uniform Taipei silt (Moh and Ou, 1979). Characteristics of the subsoil layers are shown in Fig. 2(a). The observed pore water pressure in the subsoil strata among project site indicated that the groundwater is not under static condition, due to overdrawing of the groundwater reservation in the Taipei Basin (Fig. 3).

The excavation works were carried out at five stages with four layers of internal steel bracing. The struts were placed as the excavation work being proceeded to a level 50cm below the designed struting level. No dewatering was allowed outside the excavation zone thus groundwater table was assured in its original condition throughout the construction period. Due to the low permeability of subsoil stratum and cut-off effect of the diaphragm wall, it was observed that the attempt of maintaining groundwater table was successful.

Fig. 2(b) presents the record of total lateral pressure at each stage of excavation prior to the installation of respective level of strut. Results of the record indicate that the lateral pressure reduced greatly with the increase of inward movement of wall to excavation zone. While the amount of horizontal wall displacement reached 0.0035 H (H is the depth of excavation), the lateral earth pressure reduced to active K_a condition approximately. Fig. 4 shows the observed net pressure applying on wall at the final stage of excavation. Rankine state of earth pressure is also shown to illustrate the similarity of theoretical and actual value. To simplify the design, a triangular pressure diagram with a uniform distributed load on the lower portion (below excavation level) is suggested to be used in the analysis and design of the diaphragm wall.

To assemble the stiffness matrix, spring constant of the strut is determined by:

$$K = \frac{E_s A_s}{LB} \quad (3)$$



(a) Observed Total Lateral Pressure at Different Stages of Excavation

(b) Soil Properties

Fig. 2 Measurement of Total Lateral Pressure During Stages of Excavation

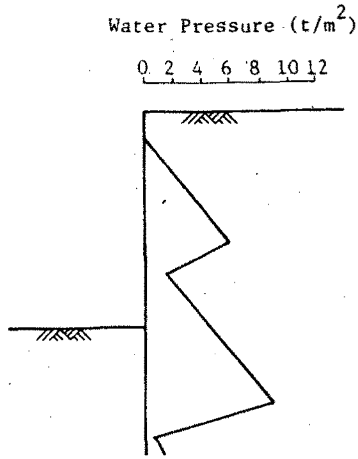


Fig. 3 Distribution of Water Pressure Behind Diaphragm Wall During Stages of Excavation

where E_s, A_s and L are elastic modulus, section area and effective length of the strut, respectively. B is the horizontal spacing between struts. Establishing K_s for subsoil strata is one of the problems coming up with the design of diaphragm wall by elastic method. Bowles (1977)'s recommendation in describing K_s is

$K_s = \alpha + \beta Z^n$

α, β = coefficient related to depth and soil strength parameters, are determinable from bearing capacity factor

Z = depth below the ground surface

n = exponent, may be greater or less than 1

On considering the disturbance at the surface of excavation level, the constants of the springs at the first and second nodal points right below the excavation level are each reduced by 50% and 25% in this analysis.

Through finite element analyses, deflection of the wall at each stage of excavation can be determined and shown in Fig. 5. Monitoring results are also shown in the same figure. It indicates that theoretical analyses are in reasonable agreement with the observed data.

Conclusion

The finite element approach incorporated with varying soil strata and random location of strut level provides engineers a useful tool in design of internal braced diaphragm wall and its general applicability has been further confirmed by the observation records.

Based on the measurement results, it appears that the trapezoidal pressure distribution could be used for design. It should be noticed, however, that magnitude of the pressure is greatly affected by the degree of wall movement and arching of soil. Below the excavation level, earth pressure on wall might be dropped to K_a condition or even somewhat lower, when the displacement of wall tip occurred. Under such circumstances, uniform distribution of net pressure under undrained condition could be assumed to simplify design with reasonable accuracy.

Acknowledgement

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