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The cases of measurement of the pressure of the open cut with earth retaining wall

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ABSTRACT: Today, buildings and highways are densely concentrated in great cities in Japan. Therefore, the only way is to use coastal zones or underground areas to make new town spaces. Although the construction is being done within confined spaces and at great depth, operations which as yet have not often been used, are utilized to cope somehow. However, there have occurred problems which are impossible to solve with the technique stored up to the present. The information obtained in the construction field is fed into actual construction sites. However, the information-oriented operation is not yet systematically established. In this document are reported the cases of measurement at the spots where the open-cut method is adopted among the tunnel constructions in soft ground around the seafront of Tokyo and Kanagawa.

1 INTRODUCTION

When construction work is large scale and complex, the proportion of time and cost occupied by temporary works becomes considerable. Construction site difficulties, such as weak ground or environmental difficulties such as working in the close proximity of existing structures often lead to unexpected accidents that are a financial and social problem.

There is also a limit to which conventional earth retaining works can be used, the excavation depth for the base of such works being several tens of metres. For cases where large scale earth retaining walls or foundations are used to depths in excess of 35m, column wall or slurry wall methods may be employed; however, the purpose of this study was to produce a design, monitoring and control system for temporary structures having an excavated depth ranging from more than 10m to approximately 30m and to review the design standards used for conventional methods. For the monitoring and control system, the system shown in Figure 1 is proposed, a part of which is the development in recent years of the penetration type earth pressure cell(Ishida, T. *et al.*, 1994) . This earth pressure cell has reached a practical level of utility, and this report describes the results of field measurement trials.

2 MONITORING AND CONTROL SYSTEM

This method of in-situ measurement is used in a borehole. The hydraulic penetration device is lowered to a prescribed depth into the prepared borehole and then the earth pressure cell (part A in Figure 1) penetrates in a direction parallel to the ground

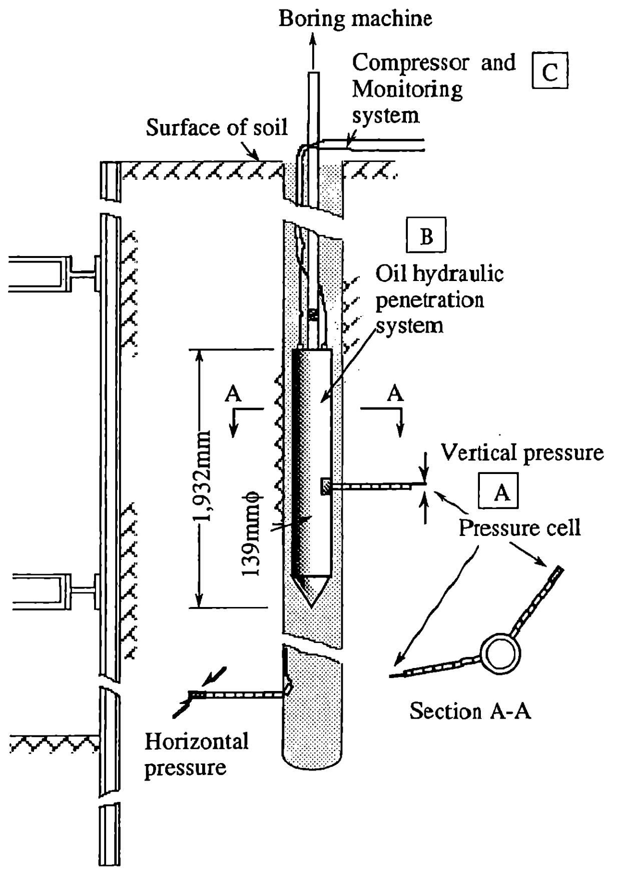

Fig. 1 Schematic of automatic observation system

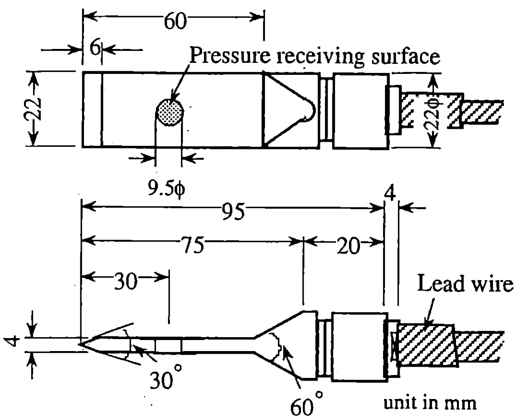

Fig. 2 Earth pressure cell

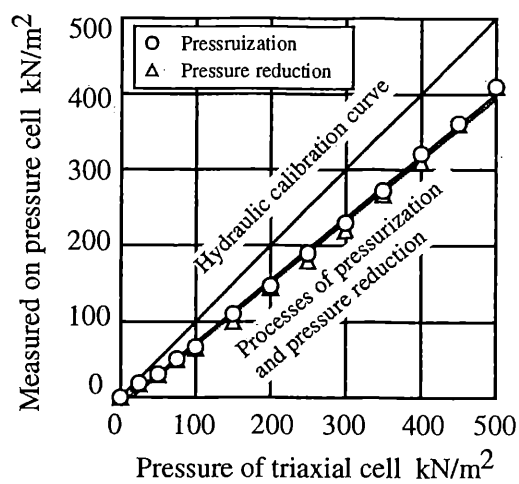

Fig. 3 Results of calibration

surface (horizontally). The vertical and horizontal components of the internal ground stresses can be measured from the inclination of the pressure bearing face. Although only one earth pressure cell is used in the penetration, by moving it a little up and down, a three dimensional evaluation of the earth pressure can be achieved. In ground where the geology is complex, instruments can be set at the various required depths. Part B in Figure 1 is the hydraulic penetration device. Part C is under investigation in combination with a ground model, ground physical properties and method of analysis in order to provide safe design and organization of the construction. It is planned to report on all of these various parts at the soonest available opportunity.

3 PENETRATION EARTH PRESSURE CELL

The newly developed earth pressure cell is shown in Figure 2. The end of the device is a knife-edge of 4mm thickness to enable it to be pressed into the ground. The centre of the stainless steel pressure bearing face is located 30mm from the end and has an effective diameter of 9.5mm. The overall length is 100mm and the maximum diameter is 22mm at the point where it is connected to the lead line. The stress sensing is performed by an electronic sealed unit comprising the pressure bearing face elastic displacements of which are picked up by strain gauges. Naturally the penetration of the device into the ground and its very existence disturb the static earth pressure conditions to some extent; however, the measuring system takes into account changes occurring with time from the start of penetration.

4 EARTH PRESSURE CELL CALIBRATION

In order to determine the strain sensitivity of the pressure bearing face in the ground, a large scale triaxial compression test device (test specimen dimensions: 39cm in diameter × H=60cm) was used to perform the calibration under isotropic loading conditions. The results of this calibration are shown in Figure 3. The soil used for the calibration was Kanto loam, having the same geological conditions as the ground of the on site measuring trials. The values indicated in the figure are converted values based on the calibration results from water pressure loadings that were additionally recorded. The calibration curves obtained during pressurizing and pressure reduction were virtually superimposed and were linear. In general, the pressurizing curve is linear but there is a tendency for the curve obtained during the pressure reduction to be curved outward. Ideally, an earth pressure cell should have a calibration curve such that this looping is negligible, and have a pressure bearing surface of high sensitivity. The device developed can therefore be considered to operate well in these respects.

5 DEVELOPMENT OF THE PENETRATING DEVICE

For the on-site measuring trials, the penetration was performed vertically from the bottom of the borehole using a rod. However, for the development of this new method of measuring internal ground stresses, in order to make effective use of the borehole, and to acquire the greatest amount of information, a penetration device was developed that would enable multi-point measuring. The penetration device so developed, utilizes an earth pressure cell that penetrates into the borehole wall by projecting horizontally, and by setting the direction of the pressure bearing face, three dimensional earth pressure measurement is made possible. Photo 1 and Photo 2 show the penetration device part of the earth pressure cell.

A trial penetration test was performed using the penetration device in the development stage, at a shallow depth in ground consisting of loam. After

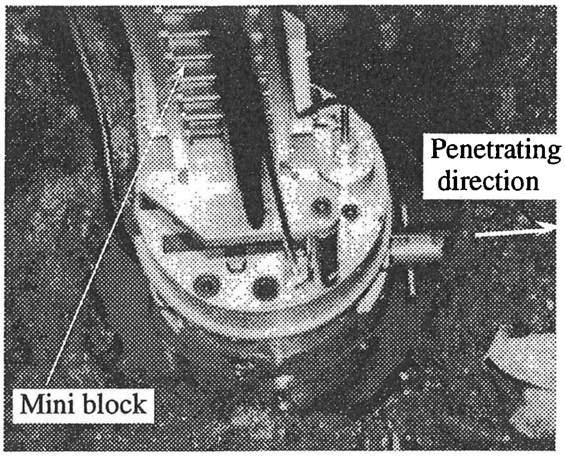

Photo 1 Oil hydraulic penetration device part of penetrating system (see upper part)

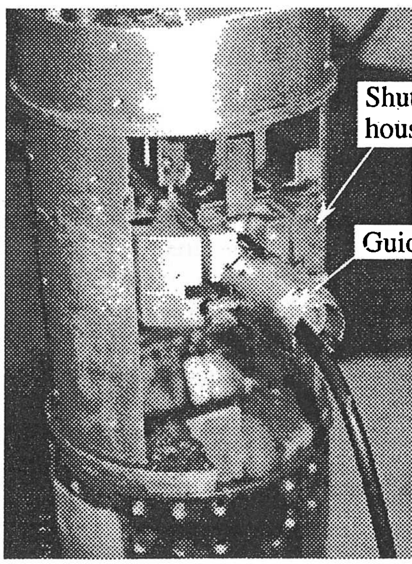

Photo 2 Oil hydraulic penetration device part of penetrating system (see side part)

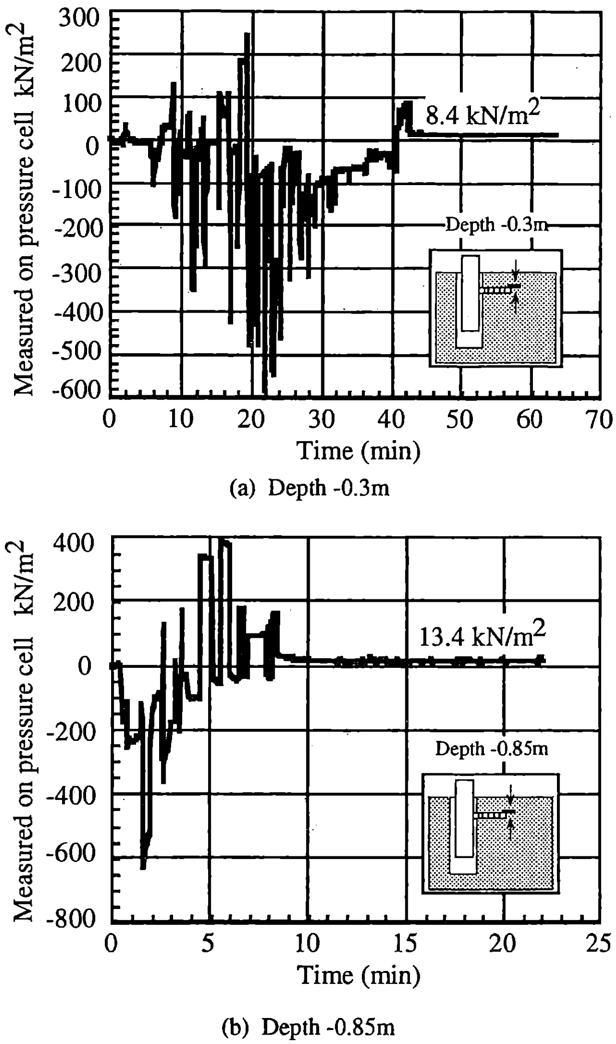

Fig. 4 Results of verification of Penetrating device

drilling an approximately 150mm diameter borehole using an auger, the penetration device was lowered into the borehole and the earth pressure cell was used to penetrate the borehole wall horizontally. The pressure bearing face was set in a direction to measure the earth pressure in a vertical direction. The measured values of earth pressure are shown in Figure 4. Considerable variation was observed in the measured values during insertion; however, this is believed to be the influence of bending forces on the earth pressure cell due to the pushing aside of lumps of earth. After withdrawing the penetration device, the effects of the bending had eased and the final values indicated were $8.4kN/m^2$ and $13.4kN/m^2$. The value had stabilized at a vertical earth pressure equivalent to the ground overburden pressure calculated from the mass density of loam.

6 ON-SITE MEASUREMENT TRIALS

6.1 *Verification Trial ; Case 1*

On-site measurement trials were carried out during slurry wall and steel strut earth retaining works for the excavation of the vertical departure shaft of a shield tunnel. The area of the works was 9.4m × 7.4m and the depth of the excavation was 36.6m. The slurry wall was 1.2m thick and constructed to a depth of 48m and 14 stages of struts were positioned. The location of the measurement was 1m from the rear face of the slurry wall guide wall. Boreholes were drilled in two locations to a depth of 4.3m and 8.8m respectively using a Swedish sounding test machine. The earth pressure cell was attached to the end of a rod and a penetration of 20cm from the bottom of the borehole was achieved using weights. Therefore, the resulting locations of the earth pressure cell were 4.5m and 9.0m (see Figure 5). In Figure 6 is shown the behavior of the measured value

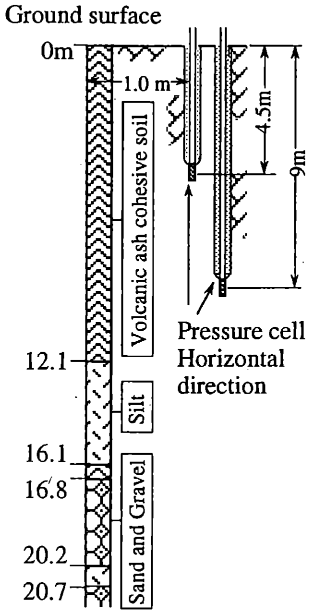

Fig. 5 Soil profile and penetration equipments

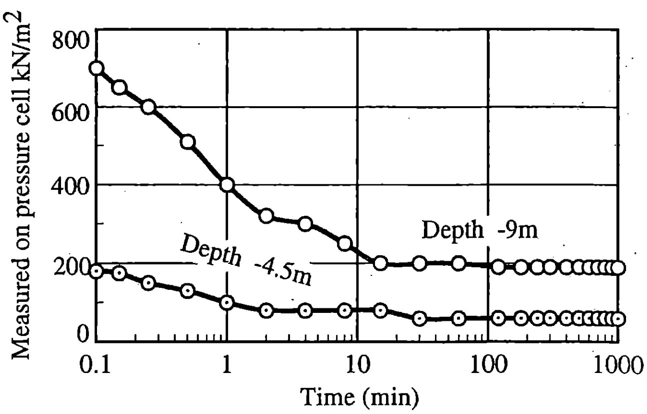

Fig. 6 Variations of the pressure in the early stage in Kanagawa

immediately after penetration during measurements made on site. For the reasons just mentioned, initially the pressure bearing surface is subject to localized stresses, but with time the excess pore water pressure disperses, the stresses arising from the existence of the device itself in the ground ease, and the measurement settles to a constant value. The variations in earth pressure on the rear face are shown in Figure 7. Despite the fact that the slurry wall was made of reinforced concrete, a certain degree of deformation took place during excavation. Although there remain problems with the accuracy, the measurement of displacement from an insertion type inclinometer shown in Figure 7 shows a displacement of about 4mm after an elapsed time of 7~10 days. This indicates the redistribution of earth pressure due to the configuration and method of the support works. It can therefore be said that the redistribution of earth pressure that took place even in the case of the earth retaining wall that has high bending rigidity was measured with good precision. It is also natural to assume that the behavior of the measurements was also influenced to some extent by loads due to the movement of heavy plant and equipment. Although the detailed records of the construction work have not yet been obtained, it is intended to clarify the situation regarding the local variations that took place for example 30 days, 52 days, and 67 days after penetration.

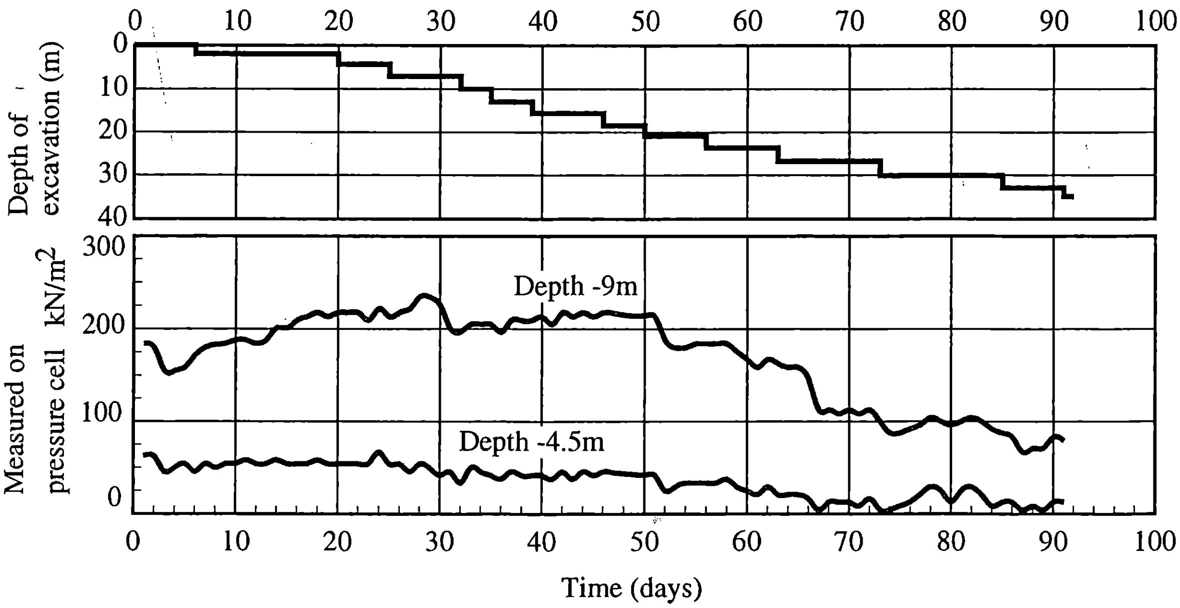

Fig. 7 Behavior of the measured values during the construction works in Kanagawa

6.2 Verification Trial ; Case 2

A verification trial was performed to evaluate the applicability and ease of use of the penetration type earth pressure cell. The site of the trial was a low land site in Tokyo facing the sea. The ground was soft alluvium and earth retaining works were constructed for a planned excavation to a depth about 12m. The trial involved positioning the penetration type earth pressure cell 0.5m behind an earth retaining wall (steel sheet piling) that had been placed to a depth of 23m and measuring the variations in earth pressure behind the wall (horizontal earth pressure) until completion of construction. Three boreholes were prepared by boring machine to depths of 4.3m, 8.15m, and 11.5m. Then, using a penetration rod, a penetration of about 20cm was achieved from the bottom of the various boreholes.

Figure 8 shows the behaviour of the measured values immediately after penetration, (as it was not possible to record the initially measured data at 4.5m, the results for only two positions are shown, namely 8.35m and 11.7m). It can be seen that there was a large value of earth pressure immediately after penetration. This was caused by the influence of disturbing the natural earth pressure conditions of the ground on the excess pore water pressure, and by bending forces acting on the cell when it penetrated the ground. With time these effects can be seen to have eased off. The variations in earth pressure on the rear face are shown in Figure 9.

Figure 10 shows the measured values of earth pressure during the various construction stages and the design lateral pressure line. The design pressure lines were decided with reference to the "Design Guidelines for Utility Conduit" (Japan Road Association, 1986). An elasto-plastic analysis was performed using these lateral pressures in the design of the earth retaining wall. The measured values shown in the figure are the results obtained from measurements made during the 3rd, 4th and final stages of excavation, and can be seen to close to the lateral pressures used during the design. However, a very large values are indicated at the depth of 4.5m from initial penetration until the 3rd stage excavation. This was assumed to be due to the influences on the gauge during initial penetration remaining.

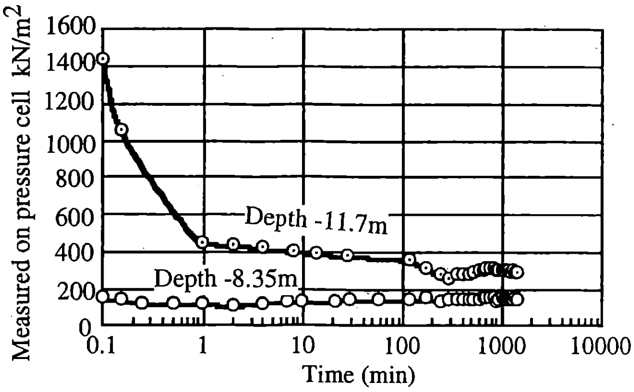

Fig. 8 Variations of the pressure in the early stage in Tokyo

7 CONCLUDING REMARKS

Having used the penetration type earth pressure cell for on-site measurements for over a year, the device has approached a practical level of durability

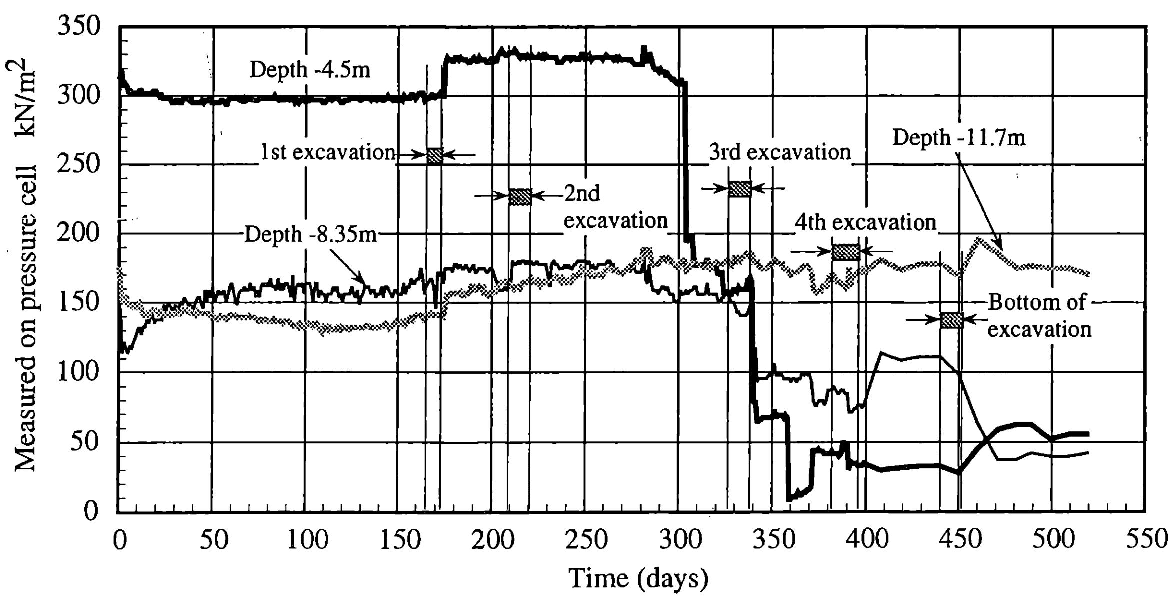

Fig. 9 Behavior of the measured values during the construction works in Tokyo

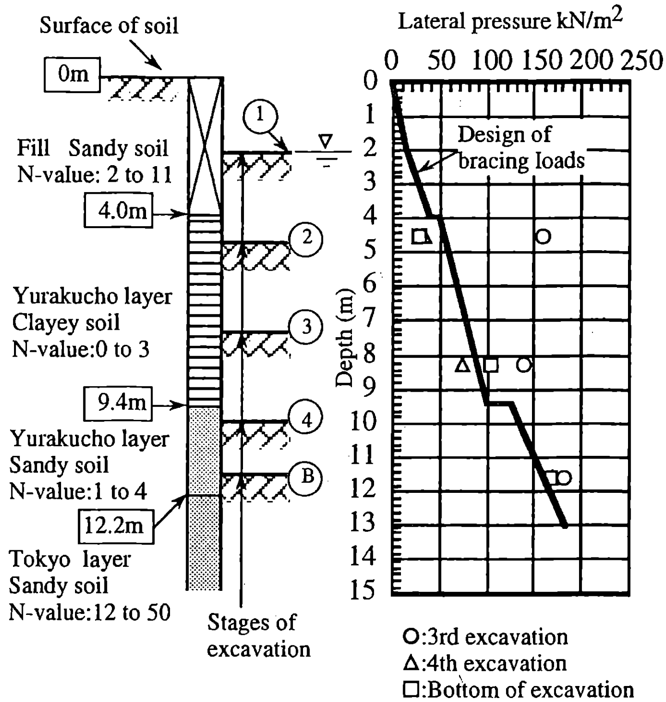

Fig. 10 Comparison between design value and measurement value

for practical use in the construction site environment. Further studies will be carried out to reduce the influences on the measured values and to achieve an improvement in the reliability. The basic mechanism of the penetration device has been verified and it now remains necessary to perform studies and continue field tests to make the device more practically adaptable to the construction site. In addition, it is planned to study ways to make effective use of this method as part of an information control system.

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