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Field Measurements of a Diaphragm Wall Foundation

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SYNOPSIS Field measurements of a small-sectioned diaphragm wall foundation for a highway bridge have been performed to understand the stability of the trench wall during construction. In this paper, a case history on the field measurements of the diaphragm wall foundation during deep trench excavation is presented.

INTRODUCTION

In the construction of a small-sectioned diaphragm wall foundation, a serious problem is trench wall failure which is caused by excess pore water pressure during deep excavation using bucket-type excavator. Although it has been estimated through the experience of actual construction that the excess pore water pressure remarkably generates not only in the Recent Deposits but also in the Pleistocene Deposits, the mechanism of the generation of excess pore water pressure has not been elucidated yet. Field measurements of a small-sectioned diaphragm wall foundation have been performed to understand the behavior of the excess pore water pressure and also the stability of trench wall during construction.

In this paper, a case history on the field measurements of a diaphragm wall foundation is presented, together with discussing the mechanism of excess pore water pressure development and the relationship between the excess pore water pressure and the stability of foundation ground.

FIELD MEASUREMENTS

The small-sectioned diaphragm wall foundation was designed and constructed as a foundation of the elevated highway bridge of Hanshin Expressway Public Corporation, which is located at the nothern part of Osaka Bay area as shown in Fig. 1. The details of the construction site and the location of the measured diaphragm wall foundation are shown in Fig. 2.

The soil profile at the construction site is shown in Fig. 3. A reclaimed layer of about 20 meters is located at the top of the ground, being underlain by an alluvial clay layer of several meters and alternately deposited sandy and clayey layers in the Pleistocene Deposits. Soil improvement for preventing trench wall failure has been applied to the reclaimed layer and the alluvial clay layer.

The general descriptions of field measurements are shown in Table 1. The pore water pressure and the lateral earth pressure are measured in sandy layers both inside and outside the diaphragm wall foundation. The vibration acceleration, the deformation and the water level are measured in the ground inside the diaphragm wall foundation, together with sampling and some laboratory tests. The bucket movement and the excavation depth are also measured at the diaphragm wall foundation during construction. The detailed location of measuring instrumentation is shown in Figs. 3 and 4. The field measurements are focused on the Peistocene Deposits, the sandy layers of which are in danger of the trench wall failure. The field measurements are carried out, when the final element is excavated as shown in Fig. 4. That is, as the ground inside the diaphragm wall foundation is surrounded by wall concrete and trench slurry in three directions, the construction of the final element makes the inside ground fully enclosed. This may be a main reason to generate a higher excess pore water pressure in the inside ground.

A measursing system, which is composed of a personal computer and electro-magnetic oscillograph, is used at the construction site, to monitor the ground stability in real time during the construction work. At the center of

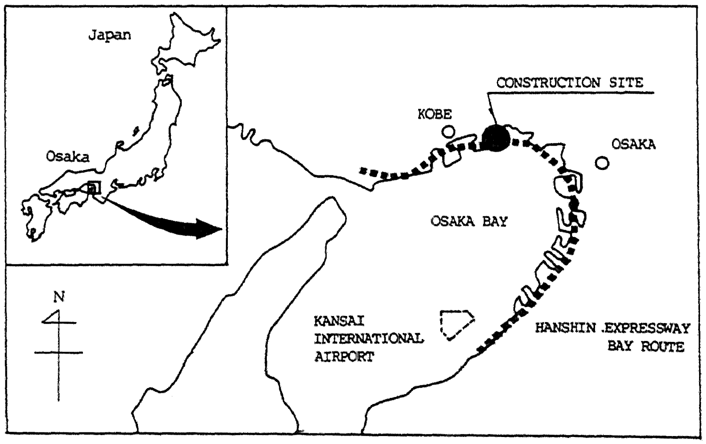

Fig. 1. Location of Construction Site

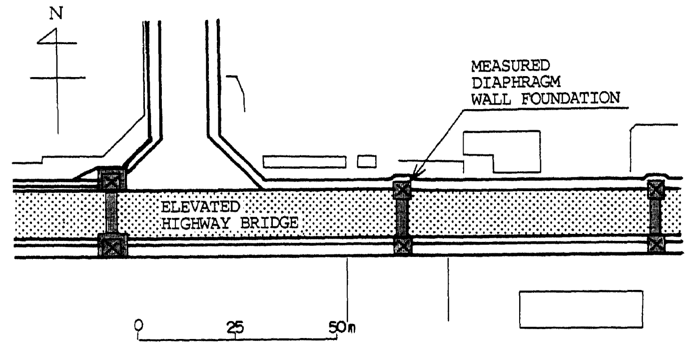

Fig. 2. Location Of Measured Diaphragm Wall Foundation

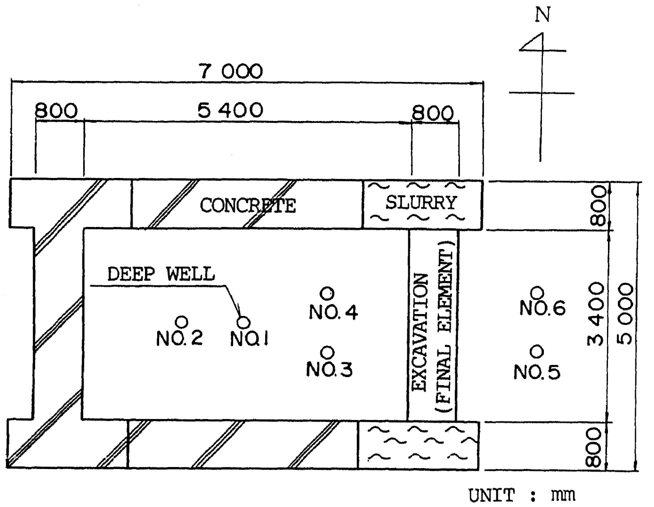

Fig. 4. Sectional Plan of Small-Sectioned Diaphragm Wall Foundation

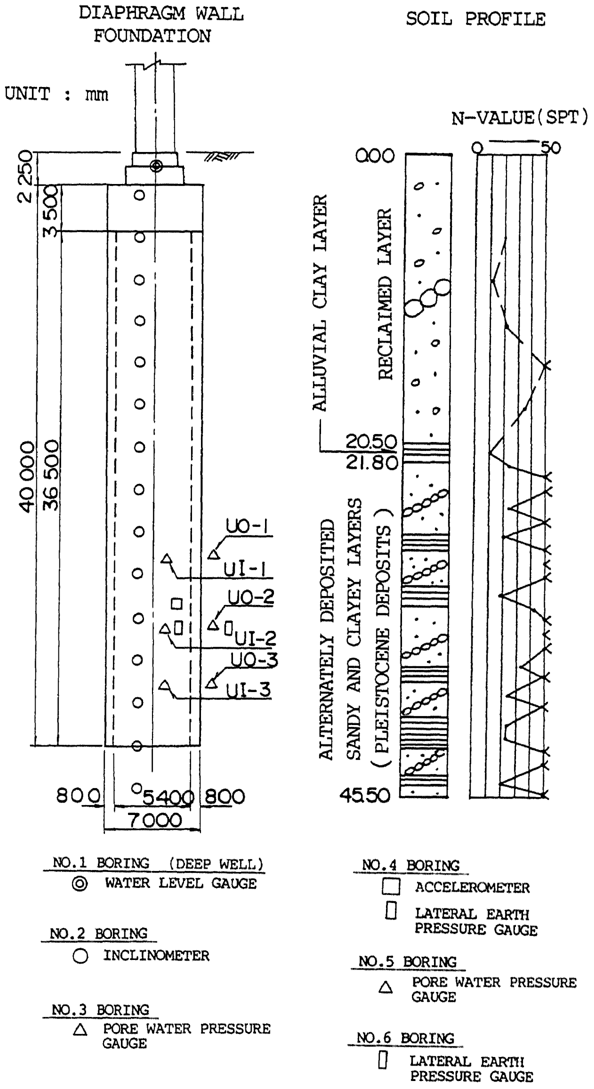

Fig. 3. Soil Profile and Location of Measuring Instrumentation

TABLE 1 General Descriptions of Field Measurements

Locations	Items	Contents	Gauges or Apparatus
Ground Inside Diaphragm Wall Foundation	• Pore Water Pressure	• Mesurement of Pore Water Pressure in Sandy Layers	• Pore Water Pressure Gauge
	• Earth Pressure	• Measurement of Lateral Earth Pressure in Sandy Layers	• Earth Pressure Gauge
	• Vibration Acceleration	• Measurement of Vibration Acceleration by Bucket Movement and Slurry Flow	• Accelerometer
	• Groundwater Level	• Measurement of Groundwater Level in Deep Well	• Water Level Gauge
	• Lateral Displacement	• Measurement of Ground Deformation and Monitoring Safety	• Inclinometer
	• Soil Properties	• Sampling and Some Laboratory Tests	• Laboratory Testing Apparutus
Diaghragm Wall Foundation	• Bucket Movement • Excavation Depth	• Recording Bucket Movement • Recording Excavation Depth	• Video Camera • Measuring Tape
Ground Outside Diaphragm Wall Foundation	• Pore Water Pressure	• Measurement of Pore Water Pressure in Sandy Layers	• Pore Water Pressure Gauge
	• Earth Pressure	• Measurement of Lateral Earth Pressure in Sandy Layers	• Earth Pressure Gauge

the inside ground, a deep well (ϕ 100mm) is set up as shown in Fig. 4 to dissipate the generated excess pore water pressure. The function of the deep well is to control water flow through the well by operating a device of water-cut-off-packer to open or shut. Using this devise, it may be possible to confirm the effectiveness of the deep well as a countermeasure against the trench wall failure.

RESULTS OF FIELD MEASUREMENTS

Pore Water Pressure

The pore water pressure prior to the excavation is nearly equal to the static water pressure, and it is confirmed that the pore water pressure gauges are duly installed and works well. Fig. 5 schematically illustrates the relationship between the bucket movement and the pore water pressure in the inside ground, together with the vibration acceleration. It is seen in this figure that the excess pore water pressure is highly sensitive to the bucket movement. That is, it is significantly increased by the quick falling of bucket excavator, and then sharply decreased as the bucket reaches the trench bottom. The amplitude of change of the excess pore water pressure during one cycle of the bucket movement reaches the maximum value of about 3.0 tf/m², when the deep well is functioned. Consequently, the great generation of excess pore water pressure may cause the trench wall failure during the construction of the diaphragm wall foundation.

In Fig. 6, the behavior of residual excess pore water pressure is illustrated both in the outside and inside grounds. Dissipation of the excess pore water pressure of the inside ground is much more delayed than that of the outside ground, because of the enclosing effect of the small-sectioned diaphragm wall foundation. This residual excess pore water pressure may contribute the trench wall failure through the repeated bucket movements.

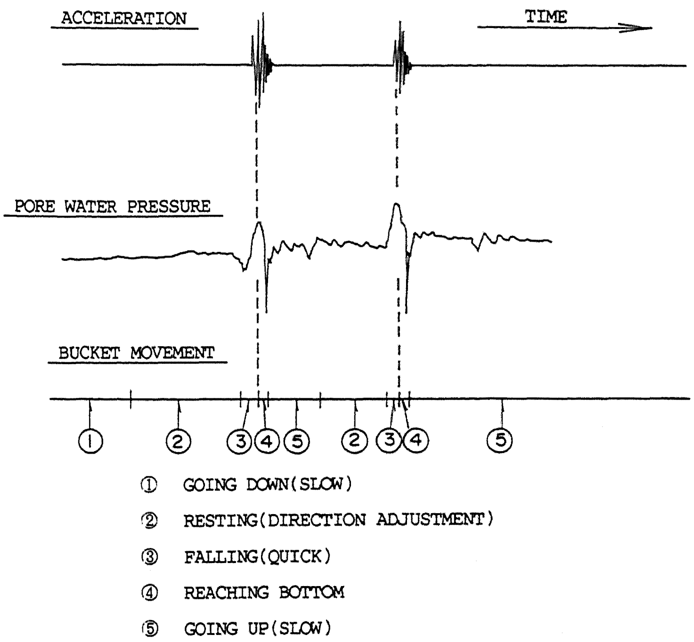

Fig. 5. Relationship between the Bucket Movement and the Pore Water Pressure

It is clarified that there is a close relation between the process of construction and the behavior of the pore water pressure. Fig. 7 illustrates the relationship between the excavation depth and the change of excess pore water pressure in the inside ground when the final element is excavated. The pore water

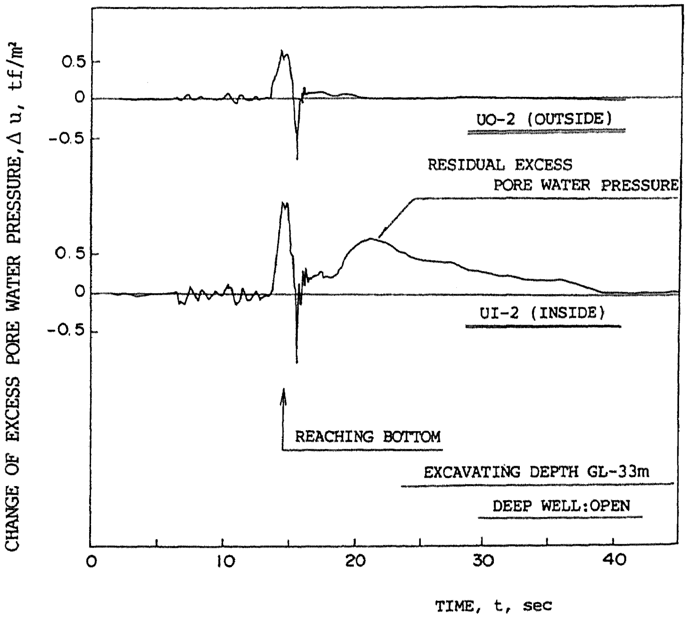

Fig. 6. Behavior of the Residual Excess Pore Water Pressure

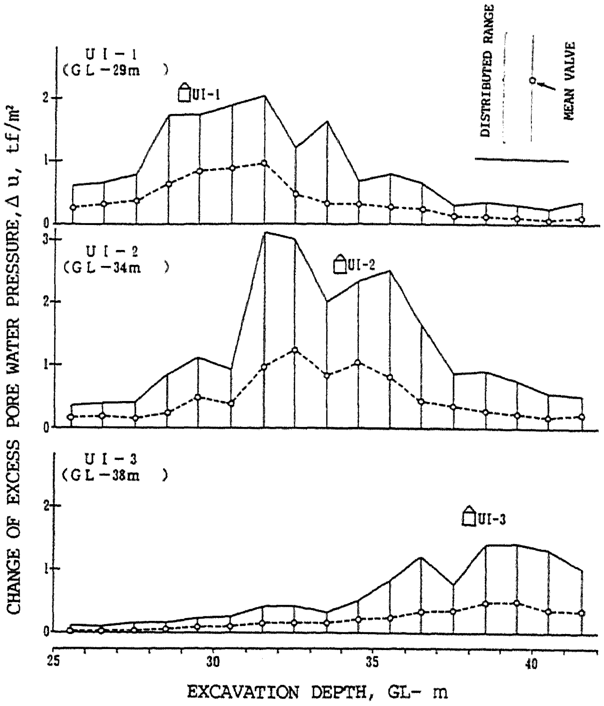

Fig. 7. Relationship between the Excavation Depth and the Pore Water Pressure

pressure gauges are installed in the sandy layers at GL-29 m, -34 m and -38 m which are lain between clayey layers, respectively. The change of the excess pore water pressure Δu in Fig. 7 shows the distributed range with its mean value. All of the three pore water pressure gagues show a greater change of the excess pore water pressure, when the excavation depth passes through the location of pore water pressure gauges. The maximum changes of the excess pore water pressure in each gauge is different, that is, UI-2 (GL-34 m) gives the highest value and UI-3 (GL-38 m) the lowest. Such difference may be due to the difference of the dilatancy characteristics of sandy soils, which are separated by the clayey layers. The maximum observed change is around 3.0 tf/ m^2, which is recorded by UI-2.

Vibration Acceleration

As shown in Fig. 5, the impact of the bucket movement gives fairly intensive vibration acceleration to the inside ground. The vibration acceleration is measured along such three directions as vertical, north to south and east to west, among which the highest vibration acceleration is observed in east to west. Fig. 8 summarizes the relationship between the excavation depth and the vibration acceleration (east-west direction) in the inside ground. In this figure, the distributed range with the mean value is plotted. The depth at which the accelerometer is installed is GL-32.5 m. When the excavation depth almost reaches around the depth of GL-31 m to GL-32 m, the vibration acceleration becomes its peak, and the maximum value and the average value are around 300 gal and 100 gal, respectively. The greater the distance from the accelerometer to the point of impact by the bucket becomes, the smaller the measured acceleration.

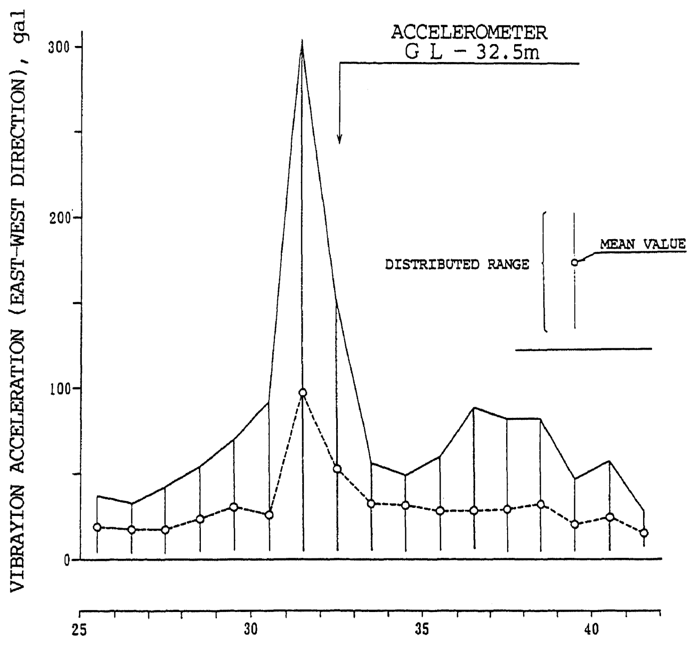

Fig. 8. Relationship between the Excavation Depth and the Vibration Acceleration

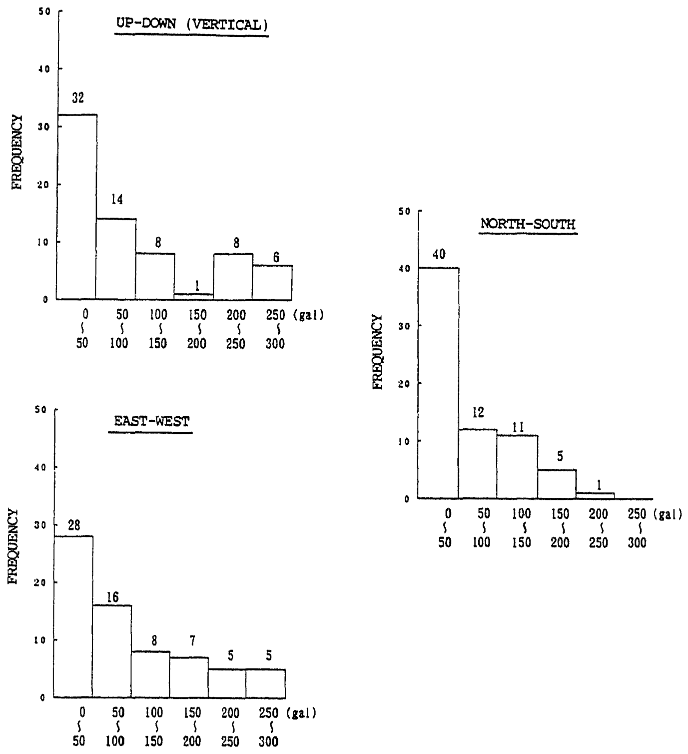

Fig. 9. Distribution of Vibration Acceleration for Three Directions

Fig. 9 shows the distribution of the vibration acceleration for three directions, when the excavation depth is in the zone of GL-31 m to GL-32 m where the greatest acceleration is observed. Greater acceleration generates along the vertical and east-west directions as compared with the north to south direction. This may be because a wall concrete is placed along the north to south direction, as shown in Fig. 4.

Groundwater Level

A groundwater level gauge is installed in the deep well in the inside ground and three gauges in the outside ground far from the diaphragm wall foundation. Fig. 10 shows that the change of the groundwater level with the elapsed time in the inside ground, when the final element is excavated. In this figure, the excavation depth is also indicated. The groundwater is always discharged from the deep well and the water-cut-off-packer in the deep well is open, to establish the safety of construction work. As previously mentioned, the significant excess pore water pressure generates by the quick bucket falling. And simultaneously the groundwater level fluctuates remarkably as shown in Fig. 10. The amount of change of the groundwater level for one cycle of the bucket movement is about 50 cm to 60 cm. It is seen in this figure that the groundwater level begins to fall at around 12 o'clock on December 21st and shows a sharp drop of about 1 m. It can be confirmed from the behavior of groundwater level measured at the other points (far from the diaphragm wall foundation) that this drop of the ground water level is not due to the

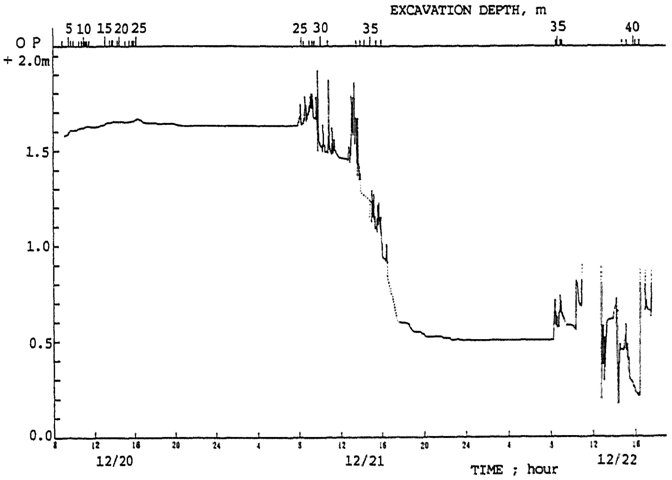

Fig. 10. Change of the Ground Water Level with Elapsed Time

fluctuation of tide, but due to the reduction of the confined groundwater pressure caused by the excavation.

CONSIDERATION

From the result of the field measurements on the small-sectioned diaphragm wall, the behavior of the inside ground during construction was caught in success. Its new knowledge on the pore water pressure, the vibration acceleration and the groundwater level as well as on the horizontal earth pressure and the horizontal displacement is summarized in Table 2.

After all, it has been confirmed that, during the final element excavation of the small-sectioned diaphragm wall foundation, the inside ground of the wall foundation vibrates sharply, followed by the significantly qreat vibration acceleration, and that a great excess pore water pressure generates in the inside ground, followed by a residual excess pore water pressure, and that the groundwater level in the deep well fluctuates significantly. Being based on these facts, it is strongly suggested that the trench wall failure might be sometimes caused by the development of a great excess pore water pressure, which generates by the ground vibration due to the bucket movement, being amplified by the enclosing effect of the small-sectioned diaphragm wall foundation. As for the generation mechanism of the excess pore water pressure, the bucket movement during construction generates the shear wave in the ground, by which the sandy soil between clayey layers in Pleistocene Deposits is cyclically sheared, followed by the generation of the excess pore water pressure due to the effect of dilatancy of soils.

CONCLUSION

A case history on the field measurements of a small-sectioned diaphragm wall foundation during deep trench excavation has been presented. Main purpose of the field measurements is to investigate the trench wall stability during construction, together with understanding the behavior of excess pore water pressure development.

Main conclusions are summarized as follows:
(1) During the final element excavation, the inside ground of the diaphragm wall foundation vibrates sharply by the impacts of bucket movement, followed by the significantly great vibration acceleration.
(2) A great excess pore water pressure in sand layers generates in the inside ground, followed by a residual excess pore water pressure during deep trench excavation of final element.
(3) The trench wall failure may be sometimes caused by the development of a great excess pore water pressure, which is due to the effect of dilatancy of soils under the shear wave during construction work.
(4) The deep well is effective as a countermeasure against the trench wall failure during deep trench excavation.

TABLE 2 Behavior of Ground during Construction

Measured Items	Behavior of Ground through Measurement
Pore Water Pressure	• During the final element excavation, a great excess pore water pressure generates (3.0 tf/m^2). • Greater excess pore water pressure generates in the inside ground than in the outside. • Due to the enclosing effect of the diaphragm wall foundation, a residual excess pore water pressure generates in the inside ground.
Horizontal Earth Pressure	• The change of horizontal earth pressure is small.
Vibration Acceleration	• During the final element excavation, the inside ground vibrates sharply and the vibration acceleration generates greatly at the location close to the excavation depth. • The maximum value of the vibration acceleration is about 300 gal. • During the final element excavation, vibrations along the vertical direction and the east-west direction are prevailing. • The vibration acceleration and the change of excess pore water pressure have a strong positive correlation.
Groundwater Level	• During the final element excavation, the groundwater level in the deep well fluctuates significantly over the range of 50 to 60 cm. • If the deep well is not functioned, the fluctuation of the groundwater level may be converted to the excess pore water pressure.
Horizontal Displacement	• The inside ground deforms horizontally toward the direction of trench excavation. • The maximum value of the horizontal displacement is 15 mm.