MEASUREMENT OF DISPLACEMENT AND STRESS IN GRAVEL SOIL

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Reprinted from
Proceedings of 5th International Symposium on
Field Measurements in Geomechanics
December 1~3, 1999, Singapore, pp.261-266

Measurement of Displacement and Stress in Gravel Soil

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ABSTRACT: When an inclinometer is installed within gravel soil, the measured deformation may not be representative of the global deformational behavior, as it is frequently controlled by the presence of local gravel. Meanwhile, a reliable earth pressure measurement depends on the installation skill, essentially when the cell is installed in gravel soil. To evaluate the influence of local deformation, inclinometers have been installed in gravel soil and in concrete column, respectively. The deformation measured from these inclinometers were then compared, to determine which measurement is acceptable. The results of comparison indicate that the measurement, obtained from the inclinometers installed in gravel soil, is often interfered by the local gravel and hence is not acceptable. For the inclinometers installed inside concrete column, the measurement appears to be consistent and reasonable and, is thus recommended. For the pressure cell, a method is presented based on several unsuccessful trials in installation. The variation of lateral earth pressure during the excavation process is then obtained. The results indicate that the lateral earth pressure is very little when the excavation process is completed. The interlock of the gravel skeleton may account for this phenomenon.

1 INSTRUCTION

In Taiwan, gravel soil sparsely distributes over a wide range of areas, mainly in western coastal plan and in central Taiwan. One major area covered with gravel soil is Taichung Basin and its vicinity, where the gravel soil distributes along an area of 40 km by 9.5 km, often with a depth 100's m (Teng 1996). In the areas covered with gravel soil, concrete columns is frequently adopted as retaining means for deep excavation instead of diaphragm wall, as conventional slot-digger for diaphragm wall is incapable of excavating gravel soil (Lin 1995). Concrete columns, linked by a concrete beam on their top, are placed along the peripheral of site to serve as retaining walls as shown in Figure 1. To install a concrete column, a hole was first manually excavated to the full-depth of the column. Steel reinforcement was then place inside the hole, followed by casting of concrete. A typical dimension of concrete column is 150 cm width, 80 cm in thickness and 10 m ~ 30 m in length (Chang et al. 1996). Usually, the columns are placed with a center-to-center spacing of 2.5 m.

In Taichung Basin, the gravel soil, Toukoshan Formation, is characterized with the following features (Teng 1996):

1. This gravel soil has a grain-contacted texture, which is a consequence of the tectonic activity of plate convergence;
2. The matrix material has a little cohesive strength, essentially when it is dry.
3. Thin layers of sandstone, shale and sand lens sparsely distribute inside the gravel soil body.

Figure 1. Outlook of retaining columns lined with a concrete beam on top. Also in the picture, a test pit was excavated to conduct *in-situ* tests on gravel soil.

In practice, it is difficult to produce a borehole in gravel soil using conventional drilling machine. Therefore, percussion-typed device is adopted to produce a borehole. Percussion drilling inevitably breaks the gravel and induces significant disturbance. If the borehole is used for water level monitoring, the disturbance causes less trouble. However, if an inclinometer is installed in the borehole, the effect of disturbance may have substantial impact to the displacement measurement. Furthermore, the measured deformation in fact only represents the local deformation of the gravel, instead of the global deformation behavior of gravel soil (Chu et al. 1996). Therefore, the measurements obtained from inclinometer installed in gravel soil and concrete column are compared to evaluate which measurement is reliable and acceptable.

To obtain a reliable earth pressure measurement in gravel soil is also difficult, owing to the following situations:

1. The pressure cell may pick up local contact stress of the cobbles instead of the global, mean stress around the place where the cell is installed.
2. As gravel soil has a much greater stiffness than those of sandy or clayey soils, a disturbance (e.g. loosening of particles) induced during installation process may prevent obtaining actual initial stress.
3. As the excavated surface of gravel soil is frequently uneven, it is difficult to have a full contact of the pressure cell with gravel soil. Consequently, this will also influence the earth pressure measured.

After several unsuccessful trials, a barely tolerable earth pressure measurement was obtained. The corresponding installation method is also presented in this paper.

2 SITE CHARACTERISTICS

The earth pressure and inclinometer measurements were obtained from two sites, Site A and Site B, respectively. The characteristics of the two sites are as follows:

2.1 *Site A*

Site A has a dimension of 42 m x 43 m with an excavation depth of 19.5 m with retaining columns, 21m in length (i.e. 1.5 m embedded length), as shown in Figure 2. The excavation is composed of 5 stages (Chu 1994a): (The ground elevation is referred as 0 m herein.)

Stage 1: Remove the top 1.5 m silty sand, excavate holes for retaining columns, install inclinometers (length = 20.5 m) and cast the column in place.

Stage 2: Excavation to GL. –4 m, install anchors at GL. -3 m.

Stage 3: Excavate to GL. –11.5 m with a soil embankment, 2 m in width and 4 m in height, to protect the side walls; install struts at GL. –7.5 m; and pre-stress the anchors to an axial force of 400 kN.

Stage 4: Excavate to GL. –19.5 m with a soil embankment, 3 m in width and 8 m in height; install struts at GL. –11.5m.

Stage 5: After all the struts are installed, remove the embankment and the entire excavation is completed. The outlook of the excavation is shown in Figure 3.

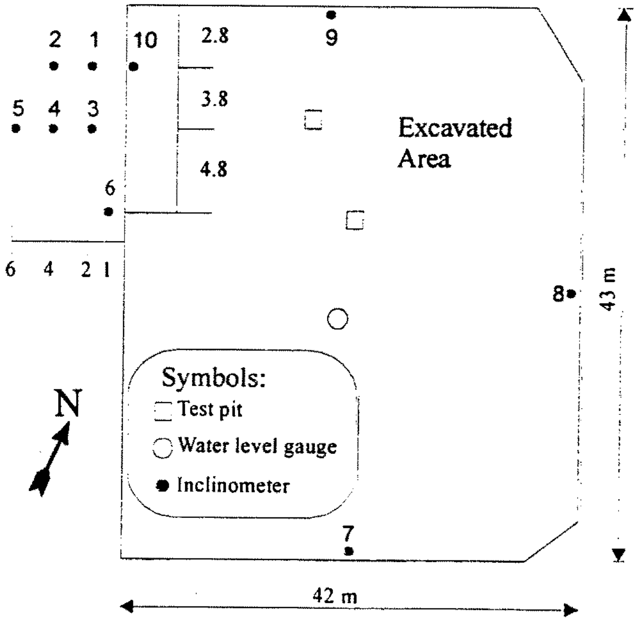


Figure 2. Layout of Site A. Inclinometers were installed both in gravel soil (number 1 ~ 6) and in concrete column (number 7 ~ 10) with a depth of 21 m. Density and grain size distribution of gravel soil were measured from two test pits as indicated in the figure.

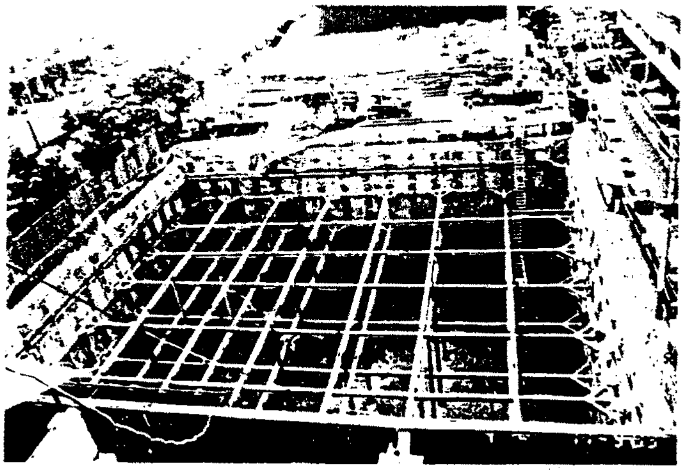


Figure 3. Outlook of the excavation of Site A.

A total of 10 inclinometers were installed, with 6 (No. 1 ~ No. 6) in gravel soil and 4 in concrete columns (No. 7 ~ No. 10).

In addition to inclinometers, a water level gauge was installed at the middle of the site. Meanwhile, the physical properties of gravel, including density and grain size distribution, were also conducted. The gravel soil samples were obtained from two test pits located in the excavated area as indicated in Figure 2.

Based on sieve analysis, the grain size distribution of gravel soil is illustrated in Figure 4. In general, this gravel soil is poor graded. As summarized in Table 1, more than 80% (in weight) of the soil are cobbles and gravel and the rest of the soil (less than 20%) are fine materials, including sand, silt and clay. As a result of grain-to-grain contact and continuously tectonic squeezing, many of the cobbles are crushed as shown in Figure 5.

Table 1. Summation of grain size characteristics of gravel soil.

Site	Cobble (%)	Gravel (%)	Sand (%)	Clay (%)	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c	Soil Type
A	53	32	10	5.20	0.36	47	108	300	56.8	GP-GM
A	43	42	13	1.65	0.49	37	80	163	34.9	GP
B	75	11	12.8	1.20	0.52	85	150	300	96.3	GP

Remarks:
1. The types of soil are defined by Unified Soil Classification System, USCS.
2. Based on USCS definition, the sizes of cobble, gravel, sand and clay are: Cobble (>75 mm); Gravel (75 mm ~ 4.75 mm); Sand (4.75 mm ~ 0.075 mm); and Silt & clay (<0.075 mm).

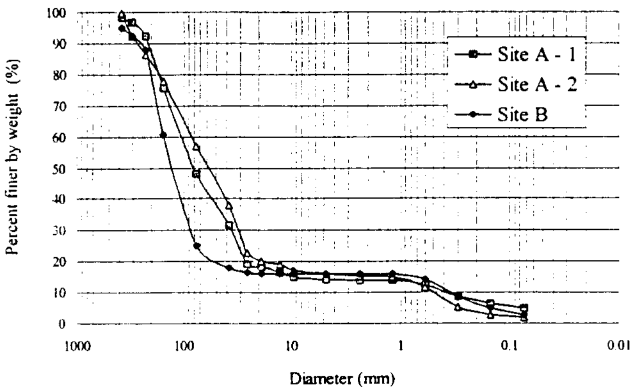


Figure 4. Grain size distribution of gravel soil obtained from the sites.

Figure 5. Appearance of the crushed cobbles and gravel.

2.2 *Site B*

Site B has a dimension of 30 m x 60 m with an excavation depth of 10 m as shown in Figure 6 (Chu 1994b). The excavation is composed of 4 stages: (The ground elevation is referred as 0 m herein.)

Stage 1: Remove the top 2 m silty sand, excavate holes for retaining columns, install inclinometers (length = 11.5 m) and earth pressure cells, followed by casting the column in place.

Stage 2: Excavate to GL. –7 m, with an embankment, 1 m in width and 2 m in height.

Stage 3: Excavate to GL. –10 m, with an embankment, 1 m in width and 3 m in height; install struts at GL. –1.2 m.

Stage 4: Remove the embankment and apply 250 kN axial load to pre-stress the struts.

The properties of gravel soil in Site B are similar to those of Site A, as summarized in Table 1 and Figure 4.

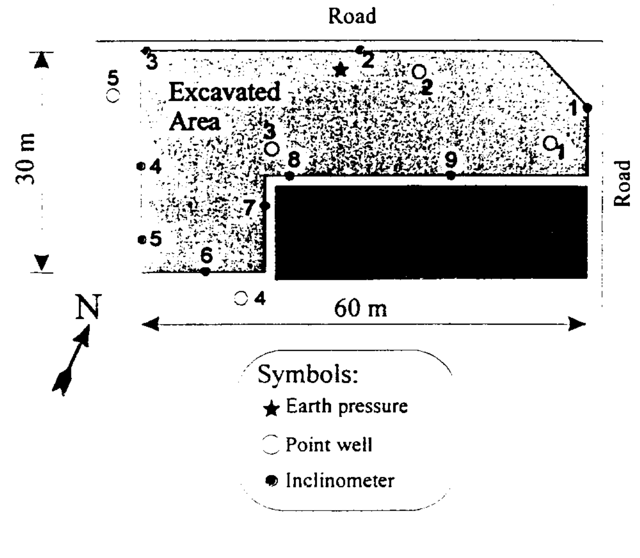


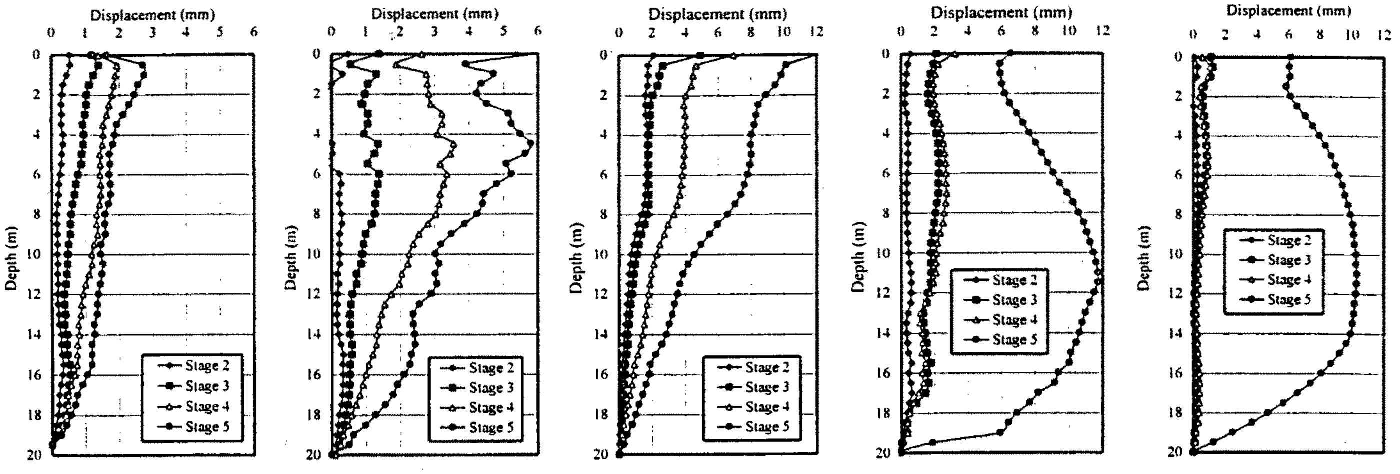
Figure 6. Layout of Site B. A total of 9 Inclinometers, 5 point wells and 3 pressure cells was installed.

3 MEASURED LATERAL DEFORMATION

At Site A, the lateral deformation of the gravel soil and the concrete columns were continuously measured during the excavation process. Figure 7 shows typical deformation measured in gravel soil (No. 1, 3 and 5) and in concrete columns (No. 7 and No. 8).

As depicted in Figure 7, the measurement, obtained form inclinometers installed in gravel soil, exhibits the following undesired characteristics: (The locations of the inclinometers are referred to Figure 2.)

1. The deformation curves are jagged. This is possibly induced by the local deformation of cobbles, which may differ from the global, mean deformational behavior.
2. Measurements of No. 1 and No. 3 are inconsistent. These two inclinometers are installed at similar locations corresponding to retaining column. However, neither the pattern of deformation curve nor the magnitude of deformation is similar.
3. Measurements of No. 3 and No. 5 are also inconsistent. Compared to No. 5, No. 3 is more close to the excavation surface and hence, more lateral deformation is expected. However, the maximum deformation measured from No. 5 is 12 mm, which is about twice of that measured in No. 3.



(a) No. 1 (b) No. 3 (c) No. 5 (d) No. 7 (e) No. 8

Figure 7. Measured lateral deformation from inclinometers at various stages of excavation. The location of each inclinometer is shown in Figure 2

4. The effect of lateral support (tieback anchors, struts and lateral beam) is not reflected in the measured deformation curves. Tiebacks had been installed in Stage 2 at GL. –3m. All the measurements obtained from inclinometers installed in concrete columns show the effect of tieback as illustrated in Figures 7a, 7b. However, when inclinometers are installed in gravel soil, only the deformation curve of No. 3 shows this effect.

When the inclinometer is installed in concrete columns instead of in the gravel soil, the measured deformation is more reasonable and consistent for the following concerns:

1. The deformation curve is smoother. The deformation curves obtained from inclinometers installed in concrete columns as shown Figures 7d, 7e are much smoother than those obtained in gravel soil (compared to Figs. 7a, 7b, 7c). This indicates that the influence of local gravel deformation can be effectively avoided.
2. The measured deformations are consistent. By comparing Figures 7d and 7e, both of the magnitude and the deformation pattern are similar. In fact, the deformation pattern of inclinometers installed in other sites is also similar.
3. The effect of lateral support can be reflected. This indicates that the measured deformation may better represent the actual deformation.

If the measured deformation obtained from concrete columns is representative of the actual deformation of gravel soil, then this measurement reveals the following information:

1. In general, the lateral deformation of gravel soil is little, only in the magnitudes of several milimeters.
2. The embedded length of the retaining columns, about 1.5 m, may not be sufficient. As shown in Figures 7d, 7e, before excavation to the full-depth, only negligible lateral deformation occurred. However, in the last stage of excavation, significant deformation occurred. This indicates that sufficient embedded length of retaining column, up to Stage 4, can efficiently prevent lateral deformation. Later on, this 1.5m embedded length becomes insufficient, which results in significant deformation at the last stage of excavation.
3. The lateral support system (tieback anchors, struts and lateral beam) installed in the upper part of the retaining columns, performs well in supporting the retaining columns, essentially at the last stage of excavation. As a result, the deformation at the upper part (6 cm) is less than that at the middle part (10 cm).
4. One potential problem associated with the installation of inclinometers in concrete column is that the column may be too rigid to deform such that only a rigid body displacement may occur. If the column mostly went through a rigid body displacement, the deformation can not be measured by the inclinometer, as it can only measure the relative displacement between the end and the top of the column. Fortunately, the magnitudes of measured lateral displacement obtained from concrete columns are similar to those obtained in gravel soil. This indicates that the displacement measured from concrete column corresponds to that of gravel soil. Therefore, the rigid body displacement of the column should be negligible.

4 LATERAL STRESS MEASUREMENT

The earth pressure is placed inside gravel soil and must reasonably close to the retaining columns. One major problem arisen is that the cavern for earth pressure cell frequently has uneven surfaces. Therefore, to ensure a match contact of the earth pressure cell with the surrounding gravel soil, the following procedures should be followed:

1. The location where earth pressure cell is installed should not have coarse gravel, including boulders or cobbles. Accordingly, a sand lens is often selected for this purpose.
2. A layer of compacted, dense sand with a thickness of 2 ~ 5 cm should be applied between the earth pressure cell and the gravel soil as shown in Figure 8. This not only enables a full contact of the surfaces but also reduced the influence of local gravel deformation and associated stress induced.
3. The earth pressure cell should be properly fastened prior to applying of mortar, followed by casting of concrete. In this work, a steel bar was used to keep the earth pressure cell in place and then, motar was applied to further secure the cell.

Once mortar is applied, the initial reading of the cell is taken and is used as offset pressure. Further pressure variation can thus be measured during various stages of excavation.

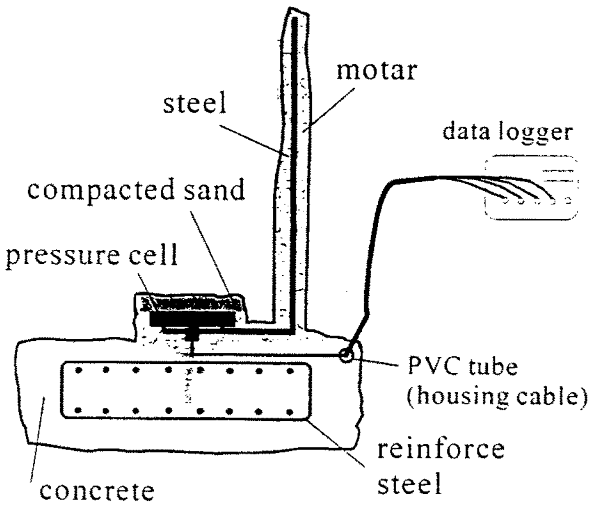


Figure 8. Schematic setup of earth pressure cell in plan view.

In this work, a total of 3 pressure cells were install in Site B at the location shown in Figure 6. To obtain the lateral earth pressure distribution along the depth, these 3 cells were install in the depths of – 5.65m, 8.5m and 10.5m, respectively. Sand lenses were found in these depths, which accounts for why they were selected. Accordingly, the earth pressure distribution during the four stages as described in *Sec. 2.2*, were obtained as shown in Figure 9.

Observing the measured pressure distribution in depth, it seems that the lowest pressure cell (at the depth of 10.5m) may not be properly installed such that the initial pressure is much lower, compared to those measured by the upper two cells. Insufficient contact of the cell with the gravel soil may account for this phenomenon. However, the lowest cell can still response to subsequent excavation process. If the initial stress of the lowest cell can be modified by assuming the initial stress distribution with a *lateral stress ratio*, k_o = 0.35, the modified stress distribution has the appearance as shown in Figure 10.

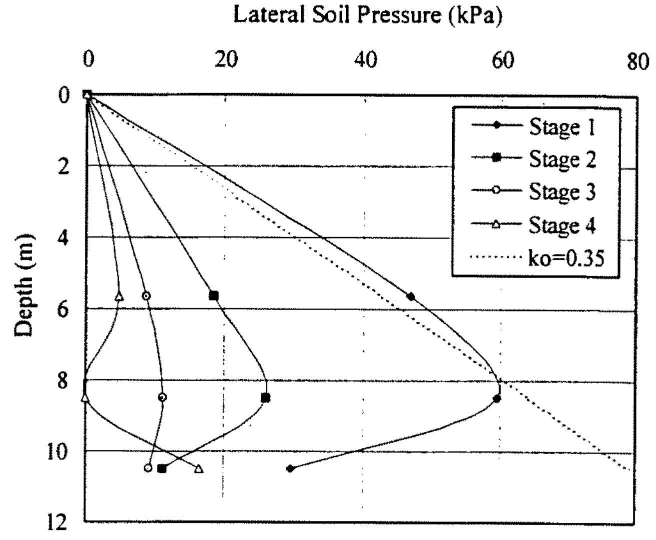


Figure 9. Measured lateral earth pressure during various stages of excavation.

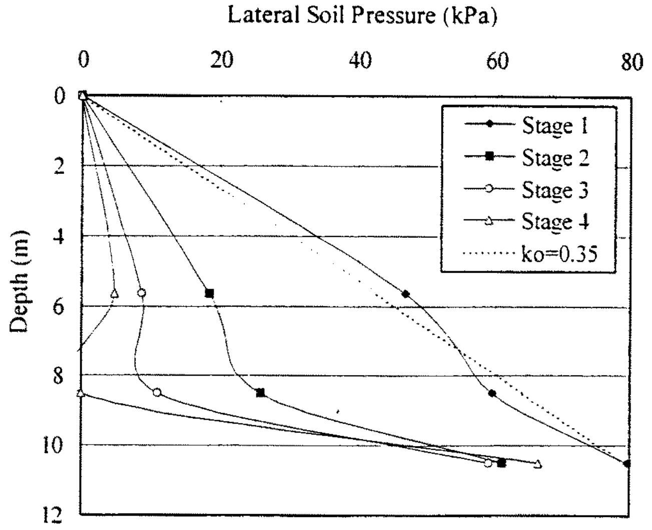


Figure 10. Lateral earth pressure distribution with the measurement of the lowest pressure cell modified.

Based on the measurements taken from the upper two cells (at depths of 5.65m and 8.5m) as shown in Figures 9 & 10, the following assertions can be made:

1. The *lateral stress ratio*, k_o, seems to be 0.35 as indicated by the dashed line shown in the Figures 9 & 10.
2. A 50% loss of lateral pressure occurs at Stage 2, after the removal of 10m gravel soil.
3. More than 90% loss of lateral pressure occurs at the end of excavation.
4. This pressure distribution corresponds to the deformation pattern shown in Figure 7: the lower part of the retaining has the most outward defor-

mation to the excavated area such that the lateral stress is significantly relaxed.

5. Even most of the lateral pressure has been released, the retaining column remain standing. This implies that the gravel soil has capacity of supporting itself, provided that there is no water. As the gravel soil exhibits grain contact characteristic, this well packing nature of the gravel may account for this good self-standing ability.

If the pressured measured by the lowest cell can still partially reflect the actual lateral stress, the variation of the lateral stress at the embedded end first has a 22% relief and then followed by increases. This indicates that the retaining column may go through a rotation near the embedded end.

5 CONCLUSIVE REMARKS AND DISCUSSION

The measurements of inclinometers installed in gravel soil and concrete retaining columns have been obtained and compared. The results indicate that the measurements obtained from gravel soil are not acceptable. On the other hand, the measurements from concrete column are reasonable, and are thus recommended. Furthermore, owing to the high stiffness nature of gravel soil, the displacement measured is in the scale of several mili-meters. Therefore, the precision of the measurement device should be sufficient to comport with this concern.

As to how an acceptable measurement of lateral earth pressure can be obtained, this paper suggests procedures to meet the minimum requirements. Based on the obtained measurements, most of the later earth pressure was relived after excavation except at locations near the embedded end. This corresponds to the deformation pattern of the retaining columns.

However, the following concerns should be investigates to ensure that the measured lateral pressure is representative of the actual earth pressure:

1. The *lateral stress ratio*, k_o, was estimated to be 0.35. This stress ratio was obtained after casting of concrete. Potentially, it may represent the lateral stress ratio of concrete, provided that k_o of concrete is less than k_o of gravel soil.
2. Gravel soil may have been severely disturbed while excavating a cavern for installing a pressure cell. The impact of this disturbance requires further evaluation.
3. The last but not the least, sand lens was chosen to install pressure cell. However, the rigidity of sand lens may lower than the gravel deposit and thus may response differently compared to the grain-to grain contacted gravel.

Indeed, the earth pressure measurement obtained in this work is merely tolerable rather than acceptable. To obtain a reliable and representative later earth pressure measurement in gravel soil requires a further development of new pressure measuring devices.

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