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FIELD TEST PERFORMANCE OF HYDRAULIC SHORING WITH PLYWOOD SHEETING IN A SOFT AND SENSITIVE CLAY

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ABSTRACT

This paper presents the results of a field experimental case study carried out to investigate the performance of vertical aluminum hydraulic shoring with plywood sheeting in a soft and sensitive clay trench. Installation, instrumentation, and field test procedures are presented for this type of vertical aluminum hydraulic shoring with plywood sheeting (speed shoring) in conformity with United States OSHA guidelines and placed inside the trench to cover the total 2.4 m (8 ft) depth of excavation. The field test results are presented in terms of soil pressure distribution along the depth of excavation with and without a 30-kPa surface surcharge load next to the edge of one side of the trench. The results reveal the potential use of this type of shoring in an excavation or trench in this type of soil.

KEYWORDS: Speed shore; Earth pressure; Flexible temporary shoring; Data recording unit; Test data in real time; Total pressure cells**.**

INTRODUCTION

During earth excavation work, cave-ins are very frequent and present a very serious risk. This phenomenon is often underestimated by the construction industry [1]. Occupational accident statistics regarding soil cave-ins in trenches or excavations highlight the vulnerability of workers inside a trench or excavation within the construction industry. The main causes of accidents were the lack of proper shoring and safe working practices. This emphasizes the importance for any governmental or local authority to ensure that occupational health and safety regulations are implemented at the work site to protect workers [2].

Vertical aluminum hydraulic shoring with plywood sheeting (speed shoring) is very popular in practice as a shallow trench protection system. A prefabricated strut and/or wale system manufactured of aluminum or steel gives construction the industry more shoring alternatives. Hydraulic shoring provides a critical safety advantage over timber shoring because workers do not have to enter the trench to install or remove hydraulic shoring. The units are light enough to be installed by one or two workers, are gauge-regulated to ensure even pressure distribution along the trench line, have their trench faces "preloaded" to use the soil's natural cohesion to prevent movement, and can be adapted easily to various trench depths and widths [3]. They are designed to shore vertical trenches and offer optimum adaptability when restrictions are imposed by parallel or crossing utilities [4].

Generally, no satisfactory consensual theoretical solutions are available to estimate soil pressure for this type of supporting structure with partitions facing land pressures in sensitive clay [5]. Many researchers have suggested solutions to estimate earth pressure on a flexible temporary support based on empirical data. Consequently, for an excavation shield, the Canadian Foundation Engineering Manual (CFEM) recommends the use of pressure envelopes from empirical data. Terzaghi and Peck (1967) methods (TPM) for estimating apparent earth pressure are very popular among practitioners because they are clearly understood and easy to implement. Equation 1 proposed by Terzaghi and Peck (1967) calculates the apparent earth pressure on a flexible retaining structure in soft to medium clay:

$$p_A = 1.0\, K_A \gamma H\,, \tag{1}$$

where the earth pressure coefficient, $K_A = 1 - \frac{m4s_u}{\gamma H}$, γ = unit weight of soil, H = depth of excavation, S_u = average undrained shear strength value over the height of the wall, H, and m is an empirical factor accounting for potential base instability effects in deep excavations in soft clays. When the excavation is underlain by deep soft clay and the dimensionless number ($N = \gamma H/S_u$) exceeds 4, then m is set to 0.4; otherwise, m is set to 1.0 [6]. These formulas are clearly understood and easy to estimate; however, the method does not account for the development of soil failure below the bottom of the excavation. The total active thrust over the excavation depth on a smooth wall, as suggested by Rankine (1856), is given by:

$$P_{Rankine} = 0.5(\gamma H^2 - 4s_u H), \tag{2}$$

where γ, H, and S_u are as defined above.
On the other hand, to determine the apparent earth pressure for soft to medium clay, Henkel (1971) considered the basal stability phenomena as follows:

$$p_A = \left(1 - \frac{4s_u}{\gamma H} + \Delta K\right)\gamma H, \tag{3}$$

where the factor ΔK is related to bottom heave stability as follows:

$$\Delta K = \frac{2B}{H\left(1 - \frac{5.14 s_{ub}}{\gamma H}\right)}. \tag{4}$$

Note that in the above equations, B is the width of the excavation and S_{ub} is the average undrained shear strength below the excavation depth H. The distributed horizontal earth pressure (lb/ft^2) according to Yokel et al. (1980) can be computed using the following equation:

$$p = We\,(H + 2), \tag{5}$$

where We = lateral weight effect (lb/ft^3) and H = height of the supported bank (ft.) (2 ft. are added to allow for overloading) (Note: 1 lb/ft^2 = 48 Pa). The above discussion reveals that calculating earth pressure on a flexible retaining structure is not straightforward and that various soil parameters must be evaluated and considered when designing or validating a shoring system in a soft clay excavation or trench [7].

This study presents a full-scale field test investigation at a test site made up of soft and sensitive clay soil at Louiseville, Quebec, Canada, to evaluate the earth pressure on a trench excavation protected with temporary flexible hydraulic shoring with plywood sheeting. The trench was 2.4 m deep, and the shoring consisted of a plywood shield. Field test results are presented in terms of soil pressure with depth of soil. This paper provides a detailed explanation of the installation phase, including instrumentation, and the test phase. The experimental results are presented and compared with available Rankine (1857), Terzaghi and Peck (1967), and Yokel (1980) apparent earth pressure values.

FULL-SCALE FIELD EXPERIMENTAL PROGRAM

To satisfy the objectives related to evaluation of earth pressure and performance validation of a temporary shoring system, an experimental trench was excavated, and an excavation protection system (hydraulic shoring with plywood sheeting) was set up at a site located at Louisville, Quebec, Canada.

Soil Characteristics of the Field Experimental Site

The field experimental site is located about 100 km northeast of Montreal, on the north shore of the St. Lawrence River. It is beside Highway 138, 8 km west of Louiseville village. The elevation of the site is 9.5 m above sea level. The site is known for its so-called sensitive clay soil, and therefore it was selected for the present study. The soil is made up of a 60 m thick, Champlain Sea high-plasticity clay deposit [8]. According to Leroueil et al. (2003), this clay is very homogeneous, with 80% clay fraction, 45% average plasticity index, and an average sensitivity (St) of 22 (as determined with the Swedish fall cone). Experimental shear tests were performed at a Laval University (Quebec City) laboratory using a scissometer (Roctest model M-1000). **Table 1** shows the shear strength data for undrained soil at the Louiseville experimental site and the soil layers. The shear strength profile with depth is very similar to the shear strength profile obtained by Leroueil et al. (2003) for Louiseville sensitive clay. Triaxial and DSS testing were conducted on soil samples corresponding to 3.05 to 3.65 m depth. Soil samples were obtained with the large-diameter Laval tube sampler (200 mm diameter), which has been specifically developed for sensitive clays [9]. The details and results of these three tests are summarized in **Table 2.** Two of them were undertaken in the over consolidated domain and one in the normally consolidated domain. In the over consolidated domain, DSSstat-01 showed a contraction behavior, whereas DSSstat-02 showed a slight dilation behavior. In the normally consolidated domain, DSSstat-03 showed a contraction behavior. Effective stress parameters obtained from DSS tests are presented in **Table 3**. These parameters can be useful to model the long-term behavior of the trench. They are comparable to data published by Lefebvre (1981) for Champlain Sea clays, which are a common type of sensitive clay in the Province of Quebec. Extensive characterization and testing of the Louiseville clay (at the same test site) are presented in Leroueil et al. (2003).

Excavation and Shoring Geometry

The excavated area between the outside of the trench box and the face of the trench should be as small as possible (OSHA, 2015). Considering this recommendation, the contour of the excavation considered in this experiment was 3.8 m (12.5 ft) long and 1 m (3.28 ft) wide, accommodating the hydraulic shoring with plywood protection that was 3.6 m (11.8 ft) long, 1 m (3.28 ft) wide, and 2.4 m (7.87 ft) deep (see **Figure 4(a)**). The hydraulic shoring system shown in **Figure 1** must be implemented using plywood. This system needs manual hydraulic pressure, more labor, and more attention to prevent workers from slipping into the excavation, especially when the soil is soft and sensitive. This system can be used with or without different retaining materials such as spot bracing, stacked bracing, a wale system (typical), or plywood [3]. In this experimental study, plywood was chosen as a retaining flexible protection shield with hydraulic props. Two hydraulic props 850 mm (34 in.) to 1375 mm (55 in.) in length and 1.2 m (4 ft) apart in a frame with 19-mm (¾ in.) thick plywood sheets (speed shoring) were used for the trench. Detailed geometric properties are shown in **Table 4.**

Instrumentation

Table 5 shows the identification and capacities of the pressure cells installed on the plywood side of the hydraulic shoring. Four vibrating-wire pressure cells (model TPC) were used to capture the soil pressure at 0.9 m (3 ft) and 1.8 m (6 ft) soil depths from the top of the plywood shield. At depths of 0.9 m and 1.8 m, each pair of cells was used to observe to what extent the pressure varied in the center and beyond the centerline of the hydraulic props. The locations of the pressure cells attached to the plywood sheet for the purpose of the test are shown in **Figures 3** and **4(b)**, and the locations of the hydraulic props are shown in **Figure 4(b)**. A hydraulic shoring system has four sides, of which only two experience soil pressure in the trench. In this experiment, pressure cells were attached to one side only, as shown in **Figure 4(a)**. The other two sides were open to the soil along the trench, as shown in **Figure 4(b)**. Note that the vertical and horizontal distances between props were 1.2 m (4 ft) and 0.9 m (3 ft) respectively.

Laboratory Verification and Field Installation of Test Equipment

The pressure cells were first individually attached to plywood frames 19 mm (3/4 in.) thick with epoxy at the ETS laboratory, as illustrated in **Figure 2(a)**. Two main reasons justify this initiative: (i) to be sure that that the surface receiving the cells is plane, and (ii) to optimize the time required to attach the pressure cells to the box shield protection system at the experimental site (an open field). After all the pressure cells were bonded to the plywood surface, they were carefully tested in the laboratory to check their functionality under pressure before they were transported to the experimental site (**Figure 2(b)**). To do this, the pressure cells were connected individually to the 'Roctest SENSLOG 1000X' datalogger (a turnkey system used for remote monitoring of virtually any type of instrument), and loads were applied gradually in the structural test laboratory at ETS (**Figure 2(c)**). Note that the pressure cells were calibrated by the equipment provider and that a calibration document was supplied with the equipment. For pressure cells C-P1 (at 1.8 m) and C-P3 (at 1.8 m), the 0–200 kPa pressure range was used for calibration. For C-P2 (at 0.9 m) and C-P4 (at 0.9 m), the 0–70 kPa range was used. Because the deeper part of the trench experienced more pressure than the upper part, two 200-kPa capacity cells were used in the deeper part and two 70-kPa capacity cells in the upper portion. **Figure 4** and **Table 5** show details of the pressure cells. Once all the pressure cells had been verified as functional in the laboratory, they were transported to the experimental site. Vibrating wire pressure cells (model TPC) are reliable, faster than all other types, and almost immune to external noise because they rely on the frequency output [10]. A previous experimental study by Lan et al. (1999) successfully used this type of pressure cell to measure apparent earth pressure. To install the pressure cells on the plywood wall of the hydraulic shoring (speed shoring), the plywood wall surface was identified and prepared, and then the pressure cells for speed shoring were simply screwed between the plywood holding the pressure cells and the plywood used for the retaining wall in the speed shoring system, as shown in **Figure 3**.

Excavation and installation of protection systems

Field tests were performed in 2018 from May 15 to August 8 without overloading and from August 8 to August 10 with a 30-kPa overload consisting of concrete blocks. After all the pressure cells had been bonded to the plywood wall of the hydraulic shoring system, 1 m (3.28 ft) of 19 mm (¾ in.) thick and 2.4 m (8 in.) high soil excavation plywood sheets were installed as quickly as possible as a protection shield with the hydraulic props. Hydraulic liquid was pumped through pipes to the props. Excavation was continued until 2 m depth, and pumping was carried out until the required pressure to hold the plywood sheet in a balanced position against the soil pressure on the plywood was reached. Incremental soil pressures on the pressure cells as well as the plywood were recorded over time (from May 15 to August 10) by the data recorder. Detailed excavation/construction steps for hydraulic shoring are shown in **Figures 5** and **6**.

A space between the plywood shield exterior wall and the surrounding soil was created due to the installation process. The space ranged from 50 mm to 200 mm. OSHA (2015) states that the space between the plywood shield and the excavation side must be backfilled to prevent lateral movement of the shoring system. Therefore, after the hydraulic shoring with plywood had been successfully installed, the empty space between the retaining (shoring) exterior wall and the surrounding soil was backfilled with sand, as shown in **Figure 6(c)**. In addition, the height between the plywood top and the soil surface was kept at 300–350 mm on both sides (**Figure 6**), in compliance with the SCCI (2020) recommendation that "the shoring shall extend 300 mm above the excavation". Finally, the two other open ends of the trench were closed by inserting 10-mm thick sheet piles, thereby preventing loose soil from falling inside the excavation.

Concrete Block (surcharge load) Installation

A surcharge load of 30 kPa was applied on one side of the trench using 2.44 m × 0.6 m × 0.6 m concrete blocks from August 8 to 10, 2018, as illustrated in **Figure 7**. The aim of this loading on the surface of the protection system was to examine the movement of the soil as well as the pressure increase due to the surcharge load. The SCCI standard specifies 1.2 m (4 ft.) distance from the excavation (SCCI, 2020). However, OSHA (2015) states that temporary spoil must be placed no closer than 0.61 m (2 ft.) from the surface edge of the excavation and that permanent spoil should be placed at some distance from the excavation. Considering all these statements, the surcharge load was placed close to the wall to simulate the most unfavorable case.

Data Preparation

Data were collected using Wi-Fi technology installed at the field site by the equipment rental company. ETS has access through the file transfer protocol (FTP) to the Web site at any time (24/7) to check and collect data. To reduce their volume, data were recorded at intervals of 30 minutes 24/7. These data were in the form of raw data such as linear units and Hertz, not directly in kilopascals (kPa) for the pressure cells. Therefore, it was necessary to transform the raw data into an appropriate engineering format using the linear equation recommended by the Roctest (2005) instruction manual related to vibrating-wire total pressure cells. This equation was used as follows for each of the pressure cells separately:

$$P = C_f\,(L - L_0)\,, \tag{6}$$

where P = pressure in kilopascals (kPa); C_f = calibration factor (provided on calibration sheets for each pressure cell separately); L = current reading in linear units (LU); and L_0 = initial reading in linear units (LU). Roctest (2005) also provides a more complex polynomial method. However, the linear method is simpler and easier to use, and the maximum error rate was only 0.23% in the present case.

Next, a correction was applied to take temperature changes into account using the following equation recommended by Roctest (2005):

$$Pc = P - C_T(T - T_0) - (S - S_0), \tag{7}$$

where P_C = corrected pressure in kPa; P = pressure previously calculated in kPa; C_T = calibration factor for temperature (given in the calibration sheet), in kPa/°C; T = current temperature reading in degrees Celsius; T_0 = initial temperature reading in degrees Celsius; S = current barometric pressure reading in kPa; and S_0 = initial barometric pressure reading in kPa. The correction factor for barometric reading expressed in the above equation by the term $(S–S_0)$ was neglected given its very small value compared with the pressure measured at depth. All the above equations were used to calculate the earth pressure in the trench using Excel worksheets.

FIELD TEST RESULTS AND DISCUSSION

Hydraulic shoring with plywood installation was somewhat complex due to the nature of the soil and of the system installation process. This system required more manpower and more attention during installation than conventional systems. Sand was used to fill the gap between the plywood exterior wall and the surrounding soil. According to the recorded data, a few days after installation, this hydraulic shoring with plywood system was not working properly. Probable reasons may be that gaps were created between the plywood retaining wall and the surrounding soil, that the plywood could not hold the soil pressure, or that the rigidity (stiffness) of the plywood was not sufficient.

Temperature effect

Figure 9 shows, for the first week, the daily temperature at different trench depths as captured by the pressure cells. The figure reveals that the day-versus-night fluctuations of soil temperature were more significant in the upper pressure cells (C-P2 and C-P4) than in the deeper pressure cells (C-P1 and C-P3) in the trench. The uppermost cells experienced minimum and maximum temperatures of 9°C and 15°C in the first week of the experiment, but the deeper pressure cells (C-P4, C-P3) experienced minimum and maximum temperatures of 6°C and 9°C. **Figure 10** shows hourly temperatures (May 15–August 10) at different depths of trench. It shows that the uppermost cells (C-P2, C-P4) experienced minimum and maximum temperatures of 9°C and 30°C in the total period of the experiment, but that the deeper pressure cells (C-P1, C-P3) experienced minimum and maximum temperatures of 6°C and 21°C.

Soil pressure during the experiment (May 15–August 10, 2018)

From Figures 11 and 12, the following observations can be made:

- **Figure 11** presents the recorded hourly pressure after temperature corrections for the first week of readings. It shows how the pressure varied at different depths of trench during this period. The deeper pressure cells gave lower kPa values than the upper pressure cells. It is evident that pressure cell C-P4 (at 0.9 m depth) gave higher kPa values than the 1.8 m-depth pressure cells (C-P1 and C-P3), which is not logical for this type of speed shoring protection system. One probable cause might have been that at 1.8 m depth of trench, the hydraulic props could not create pressure over the plywood sheeting due to holes, loose soil, or dried-up soil behind the plywood sheets.
- **Figure 12** was prepared according to the available soil pressure data on the speed shoring wall from May 15 to August 10, 2018. It shows that some pressure cells (C-P1, C-P2, C-P3, C-P4) were not responding properly. Probable causes over the long term include: (i) the hydraulic props could not create pressure over the plywood sheeting due to holes, loose soil, or dried-up soil behind the plywood sheet; (ii) less stress in the hydraulic fluid or leaking hoses and/or cylinders; (iii) heavy rainfall (**Figure 15**) washing away the surrounding soil behind the plywood sheets; (iv) spot cave-ins of soil in the bottom part of the trench created gaps between the plywood retaining wall and the surrounding soil, as shown in **Figures 16(c)** and **16(d)**; and (v) the plywood sheeting could not hold the soil pressure, or the stiffness of the plywood was not sufficient for this type of soil. Only pressure cell C-P4 at 0.9 m depth responded better than the others for a few days. The maximum pressure recorded on the hydraulic shoring with plywood system was 27 kPa in the first week.

Surcharge load effect on soil pressure

From Figure 13, the following observations can be made:

- **Figure 13** shows a blowup of the last week of soil pressure to observe the effects of surcharge loading (concrete blocks) at the trench. Before the overloading, a higher hydraulic pressure was applied to the shoring system to check its functionality. Then a 30-kPa surcharge load (concrete blocks) was applied. The curve shows that from August 6 to August 10, 2018, soil pressures on the speed shoring were higher than those before the surcharge load was applied, especially near the surface.
- **Figure 13** presents a blown-up view of the last week of soil pressure versus depth to evaluate the effects of the surcharge load (concrete blocks) applied near the trench. As expected, soil pressure at 0.9 m depth (C-P4) increased rapidly. This contrasts with the minor overload effect observed at 1.8 m depth (C-P3, C-P1). Note that the pressure cells at 1.8 m (C-P3, C-P1) and 0.9 m (C-P2) depths recorded an almost constant pressure throughout the last week, except for a small increase due to additional applied hydraulic pressure before surcharge loading. This can be attributed to the fact that the surrounding soil was washed away due to heavy rainfall (**Figure 16(c)**). As expected, the effect of surcharge load was more noticeable on the upper part of the protection shield than on the deeper part of the trench.

Total pressure curve

Figure 14 presents the absolute maximum soil pressure versus soil depth at the trench excavation without overloading. Experimental values were developed based on experimental field test results (from May 15 to May 22, 2018). The soil pressure at 0.9 m depth of trench (C-P4) was observed to increase rapidly. Up to 0.9 m depth, the curve resembles the TPM (1967) apparent pressure curve. However, the lower part does not represent correct readings due to soil irregularities such as holes, loose soil, or dried-up soil behind pressure cells C-P1, C-P2, and C-P3 or the probable causes mentioned above.

According to TPM Equation (1) and **Figure 14**, the apparent earth pressure for soft clay in the Louiseville soil case is $p_A = 15.55$ kPa, with $K_A = 1-m(4S_u/\gamma H) = 0.5$. Active earth pressure formulae developed by Rankine (1857) and Yokel et al. (1980) were also used to calculate theoretical soil pressure; the results are summarized in **Table 6**. Calculated theoretical soil pressures for soft clay soil are compared at different depths of trench in **Figure 14**. It is apparent that the experimental test results are inconclusive and that therefore no conclusions can be drawn.

CONCLUSIONS

The main objective of the field experimental work was to evaluate the soil pressure on a hydraulic shoring system with plywood shield protection at shallow depth in a sensitive clay trench. The study covered the total depth of the 2.4 m (8 ft) trench in sensitive clay soil. Concrete blocks (representing a 30-kPa surcharge load) were installed very close to the trench to produce an extreme load case on the flexible wall of the shield. Soil pressures were captured by total pressure cells (TPC) using vibrating-wire transducer technology. Based on the results of this study, the following observations can be made:

- Soil temperature variations were more pronounced in the upper part of the trench than in the deeper part.
- The deeper pressure cells in the trench should experience higher pressures (kPa) than the upper pressure cells. However, in the present case, some pressure cells were not responding properly. Probable reasons include: (i) gaps were created between the plywood retaining wall and the surrounding soil; (ii) heavy rainfall; (iii) spot cave-ins of soil in the bottom part of the trench; and (iv) the plywood could not hold the soil pressure, or the rigidity of the plywood was not sufficient. Only pressure cell C-P4 at 0.9 m depth responded better than the others for the first few days. The maximum pressure recorded was 27 kPa in the first week at 0.9 m depth of trench.
- The effect of an overload applied close to the trench was more pronounced on the upper part of the protection shield than on the deeper part. It follows that the pressure cells at 0.9 m depth were more influenced by the 30-kPa surcharge load in a short period of time. This underlines the need to maintain the minimum distance of 1.2 m (4 ft) from the excavation when stacking up any materials, in compliance with OSHA and SCCI guidelines.

Compared with other trench shoring systems such as timber and pneumatic systems, vertical aluminum hydraulic shoring with plywood sheeting has some limitations for this kind of soft and sensitive soil. In this experimental study, 19-mm thick plywood as a retaining flexible shield (sheeting) with hydraulic shoring was chosen to observe its overall performance and effectiveness in a soft and sensitive clay. The stiffness of the plywood may require more attention, and investigations should be carried out into implementing other materials as a protection shield for this kind of soft and sensitive soil. Compared to other systems in use, this system needs manual hydraulic pressure, more labor, and more attention to prevent workers from slipping into the excavation when the soil is soft and sensitive. This system can be used with different retaining materials such as aluminum or steel plate with experimental test results in this type of soft and sensitive clay.

DATA AVAILABILITY

Data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

[1] A. Lan and R. Daigle, "Review of Regulations and Guides for Excavation and Trenches—Comparison with the Québec Safety Code for the Construction Industry," *Practice Periodical on Structural Design and Construction, Vol. 14, No. 4,,* pp. 201-209, 1 November 2009.

[2] M. Alam, O. Chaallal and B. Galy, ""Protection practices for trench and excavation in Quebec sensitive clay soils: Review of codes, guidelines, and research needs"," *Safety Science,* pp. 1-8, November 2020.

[3] OSHA, "“OSHA Technical Manual (OTM)”, Directive Number: TED-01-00-015, Section V, Chapter 2: Excavations: Hazard Recognition in Trenching and Shoring.," U.S. Department of Labor, Washington, DC, 2015.

[4] A. Macnab, Earth Retention Systems Handbook, United States of America: McGraw-Hill, 2002.

[5] NBCC, *“National Building Code of Canada”, Commentary K.,* Ottawa, Ontario: National Research Council Canada., 2015.

[6] K. S. Flaate, ""Stresses and movements in connection with braced cuts in sand and clay" Thesis report for Doctor of Philosophy in Civil Engineering," Graduate College, University of Illinois, Urbana, 1966.

[7] F. Y. Yokel, . L. R. Tucker and L. C. Reese, "Soil classification for construction practice in shallow trenching", Washington, DC: National Bureau of Standards, 1980, pp. 1-96.

[8] P. Leblond, *Mesure et caracteristiques de la permeabilite de argiles Champlain.,* Quebec: Universite Laval, 1981.

[9] P. L. Rochelle, J. Sarrailh, F. Tavenas, M. Roy and S. Leroueil, "“Causes of sampling disturbance and design of a new sampler for sensitive soils.”," *Can. Geotech. J.,* vol. 18, no. 1, pp. 52-66, 1981.

[10] L. ROCTEST, *Instruction manual, vibrating wire pressure cells, Model TPC & EPC, P:19-21,* 2005.

[11] K. Terzaghi and R. B. Peck, Soil mechanics in engineering practice, 2nd ed., New York: Wiley, 1967.

[12] W. Rankine, ""On The Mathematical Theory of The Stability of Earth-work and Masonry"," London, 1857.

[13] SCCI, " Safety Code for the construction industry," Government of Quebec, Quebec, 2020.

[14] S. Dourlet, "Étude expérimentale de deux excavations à Louiseville. M.Sc. thesis,," Unversite Laval, Québec, Canada, 2020.

[15] D. J. Henkel, ""The Calculation of Earth Pressures in Open Cuts in Soft Clays”," *The Arup Journal,* vol. 6, no. 4, p. 14–15, 1971.

[16] A. Lan, J. Arteau, D. LeBoeuf, O. Chaallal and J.-M. Dugré, ""Conception d'un étançonnement adapté aux excavations en milieu urbain" Phase 2," Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST)., Montreal, 1999.

[17] CFEM, “Canadian Foundation Engineering Manual”, 4th ed., Vancouver: Canadian Geotechnical Society, 2006.

[18] S. Leroueil, K. Hamouche, F. Tavenas, M. Boudali, J. Locat, D. Virely, M. Roy, P. La Rochelle and P. Leblond, "Geotechnical characterization and properties of a sensitive clay from Quebec," in *Characterization and engineering properties of natural soils*, vol. 1, T. Tan, K. Phoon, D. Hight and S. Leroueil, Eds., London, CRC Press,Taylor & Francis, 2003, pp. 363-394.

Table 1. Experimental versus Leroueil et al. (2003) undrained soil shear strength values at Louiseville experimental site (Data adapted from Dourlet 2020).

Soil type and depth	Experimental Shear strength (kPa)	Shear strength from Leroueil et al. (2003) (kPa)
Fissured brown clay (0.0- 0.6m)	51	30
Plastic brown clay (0.6 m - 2.0 m)		
At 1.5 m	26	19
At 2 m	18	22
Sensitive blue clay (2.0 m +)		
At 2.5 m	23	26
At 3 m	27	30
At 3.5 m	28	32
At 4 m	27.5	30

Table 2. Undrained shear strength from the soil based on DSS testing.

Test	Consolidation		Initial rupture		Large deformations	
	σ'_{vc} (kPa)	e_c	S_u (kPa)	g_h (%)	$S_{u\text{-}gd}$ (kPa)	g_h (%)
DSS_{STAT}-01	57	2.287	28	2.3	23	15
DSS_{STAT}-02	25	2.290	20	2	22	15
DSS_{STAT}-03	143	1.804	40	5	36	15

Table 3. Effective stress parameters from DSS testing.

Domain	DSS tests
Over consolidated, domain	c’= 9 kPa f’ = 28°
Normally, consolidated domain	c’= 0 kPa f’ = 26.5°

Table 4. Geometric properties of the shield.

Properties (one-shield geometry)	Hydraulic shoring with plywood
Plywood Length, m (ft.)	0.9 (3)
Height, m (ft.)	2.4 (8)
Thickness of the Plywood, mm (in.)	19 (3/4)
Hydraulic props outer diameter, mm (in.)	50 (2)
Hydraulic props length, mm (in.)	800-1375 (32-55)

Table 5. Pressure cell identification and capacities.

Pressure cell identification	Capacity (kPa)
C-P1	200
C-P2	70
C-P3	200
C-P4	70

Table 6. Experimental vs. theoretical and field performance soil pressures at different trench depths in soft clay soil

Pressure cell identification	Depth from top of the soil (m)	Maximum experimental stress (kPa)	Calculated stress from Terzaghi and Peck (1967): $p_A=1.0\ K_A.\gamma.H$ (kPa)	Calculated stress from Yokel (1980): $p=We\ (H+2)$ (kPa)	Calculated stress from Yokel (1980): $p=We\ (H+2)$ (kPa)
	0	0	0.00	0.00	30.35
C-P4	0.9	29	15.55	26.64	30.35
C-P2	0.9	8	15.55	26.64	30.35
C-P3	1.8	-14	15.55	53.28	30.35
C-P1	1.8	10	15.55	53.28	30.35

Note: H= 1.8 m for above calculated stresses.

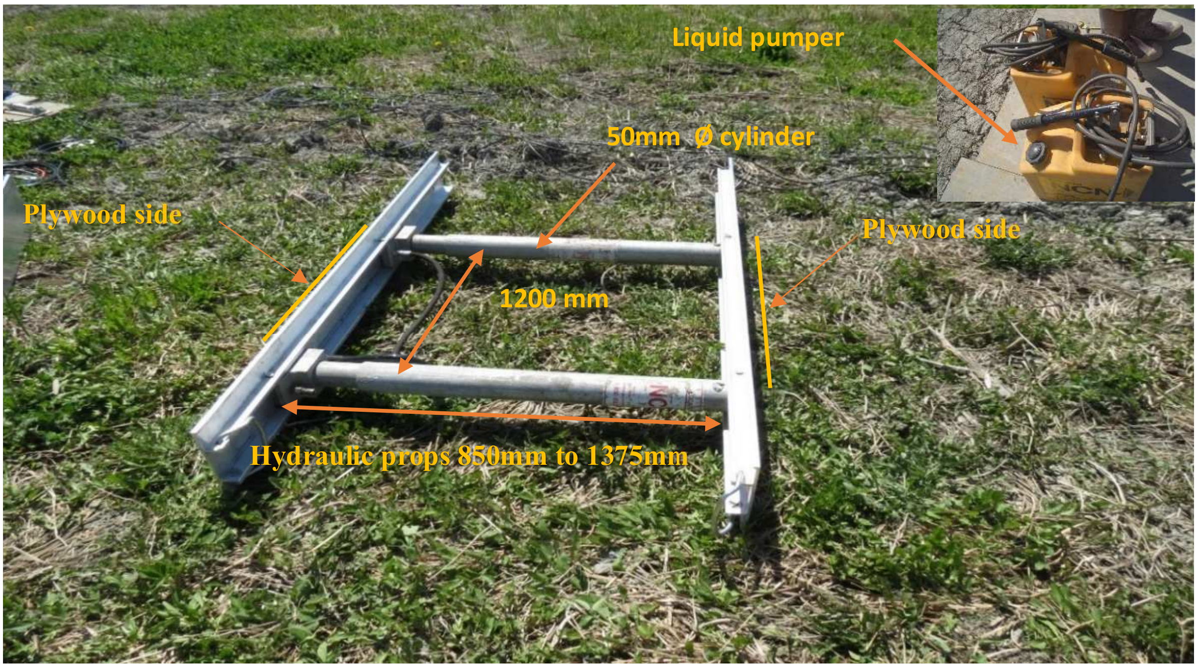
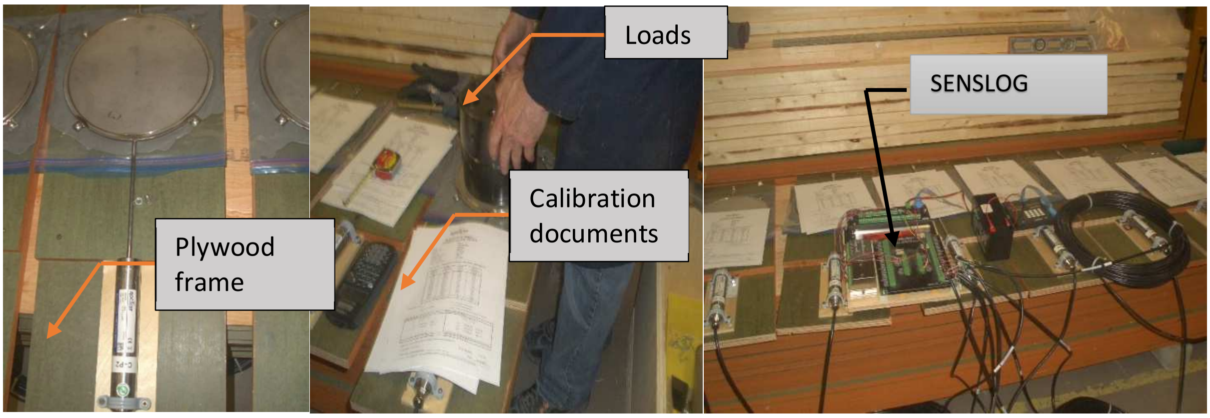


Figure 1: Hydraulic shoring protection system



(a) (b) (c)

Figure 2: (a) Pressure cells are are attached to the plywood frame; (b) Pressure are placed on the cell; (c) cells are tested by the SENSLOG in the ETS lab before site installations.

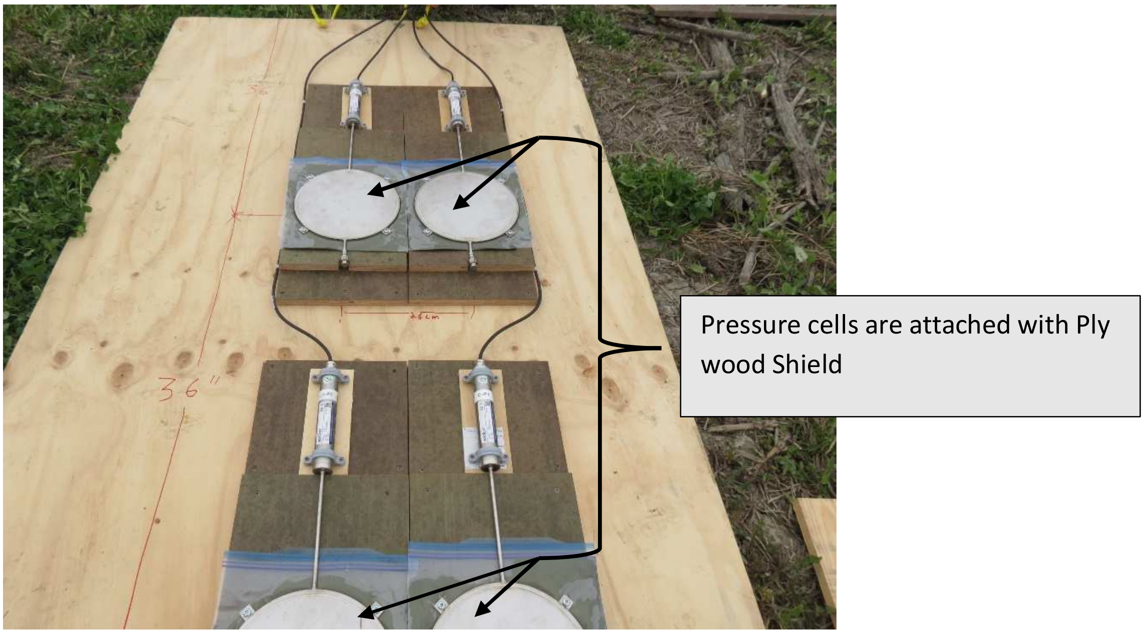
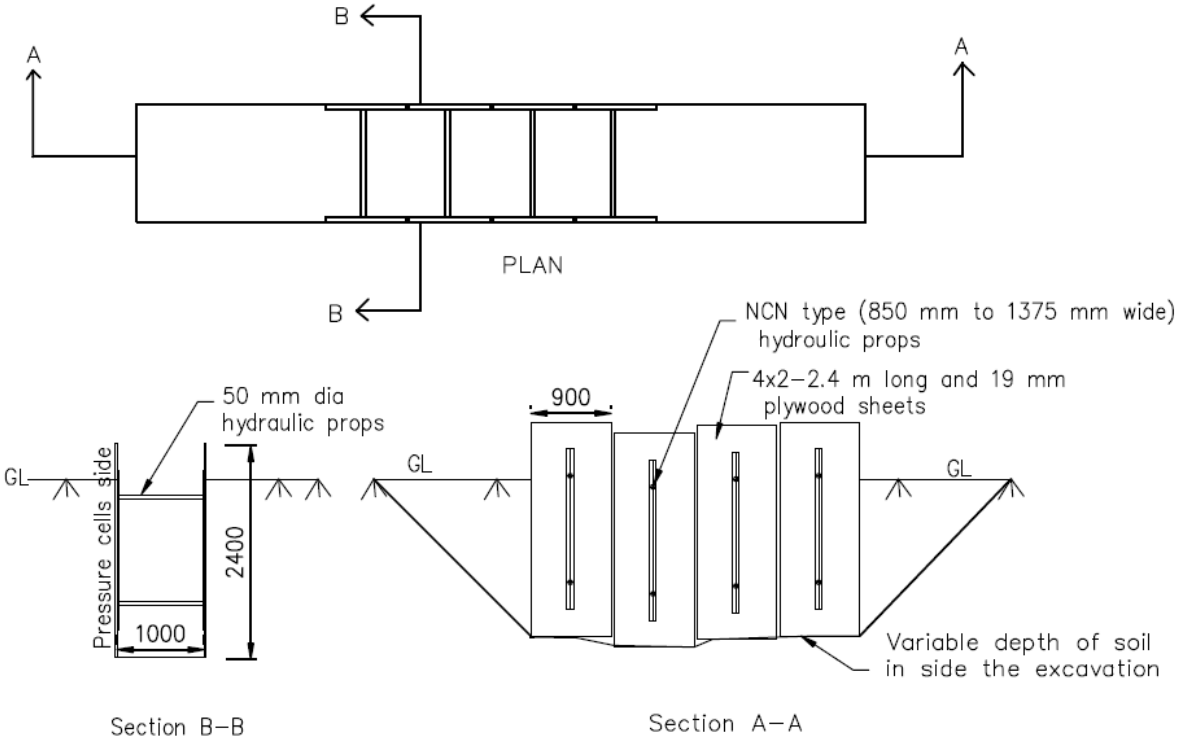
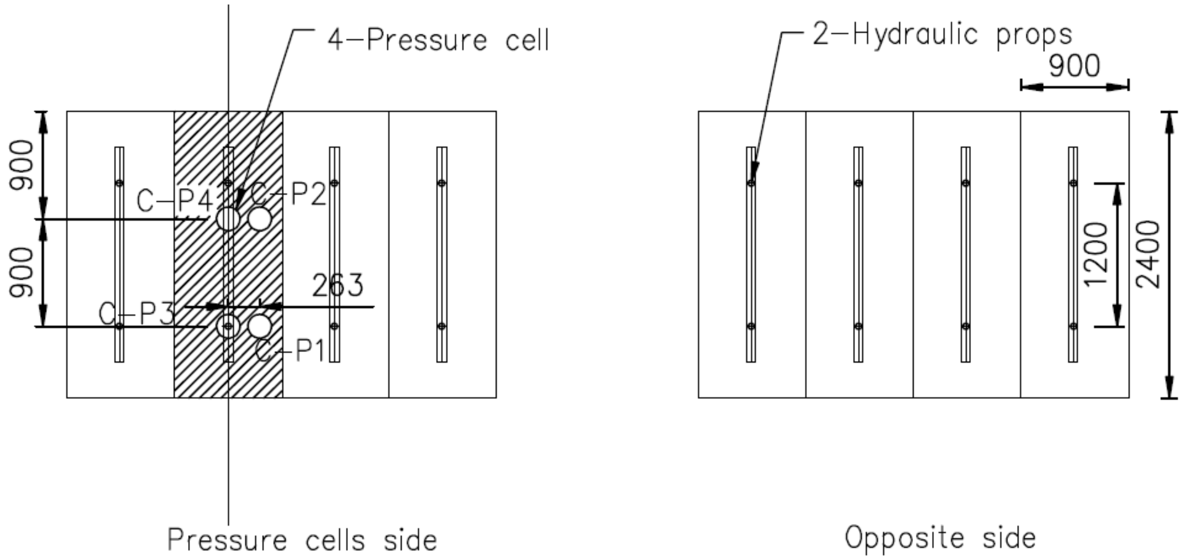


Figure 3: Pressures cells installation on the Plywood shield at the site before installations in the trench.



(a) Plan and Elevation details



(b) Hydraulic shoring side views

Figure 4: Test setup details for Hydraulic shoring (with plywood sheeting) in trench excavation.

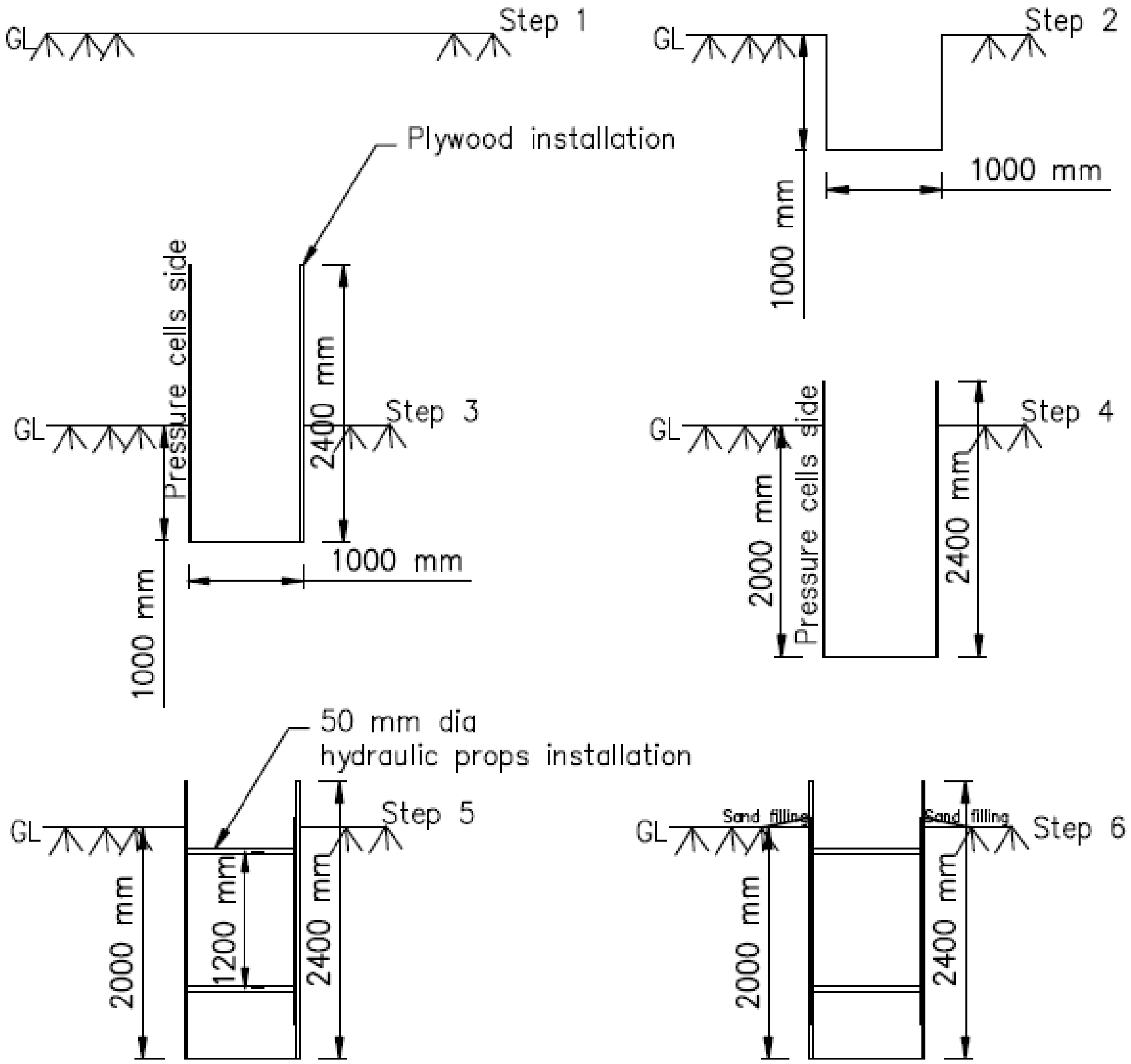


Figure 5: Excavation / Construction sequences for Hydraulic shoring with Ply wood sheeting in a trench.

(a) Quick placing of plywood of hydraulic shoring system after right away the excavation

(b) Props of hydraulic shoring are placing and Hydraulic liquid is pumping to pre stress in the hydraulic cylinder.

(c) Hydraulic shoring protection system retain the sensitive clay soil pressure

(d) Sand are used to fill exterior gap

Figure 6: Installation process detail of Hydraulic shoring with Plywood in a shallow trench of soft and sensitive clay.

(a) *(b)*

(c) *(d)*

Figure 7: Concrete blocks (surcharge load) placing in a trench of soft and sensitive clay.

(a) Data cables are entering inside, which are connected with test apparatus.

(b) Inside the data recorded unite

Figure 8: Data recoded unite in the experimental site.

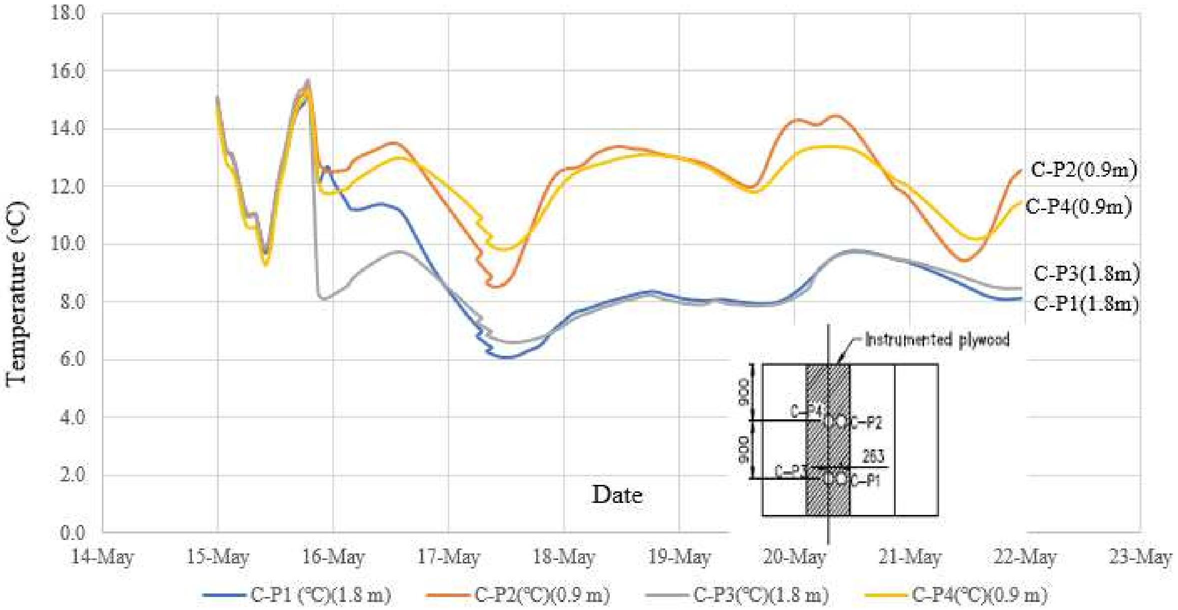


Figure 9: First week hourly temperature at different depths of tren

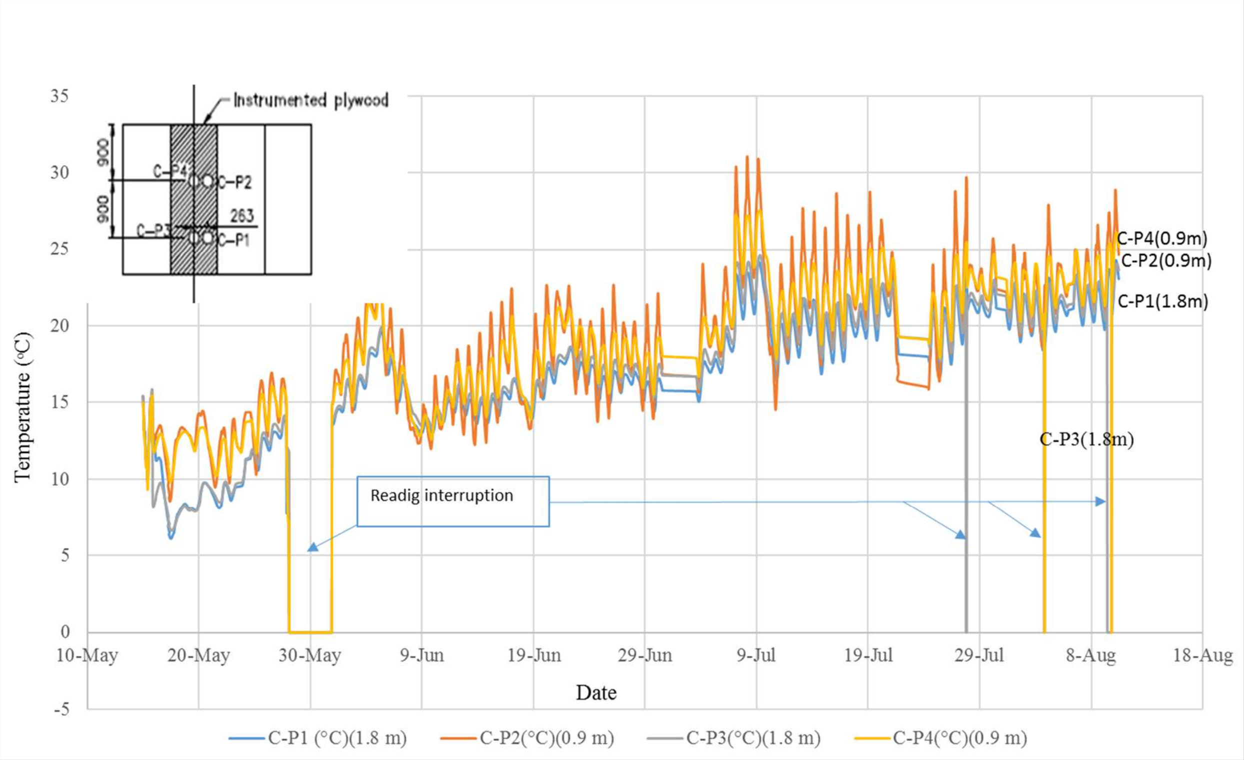
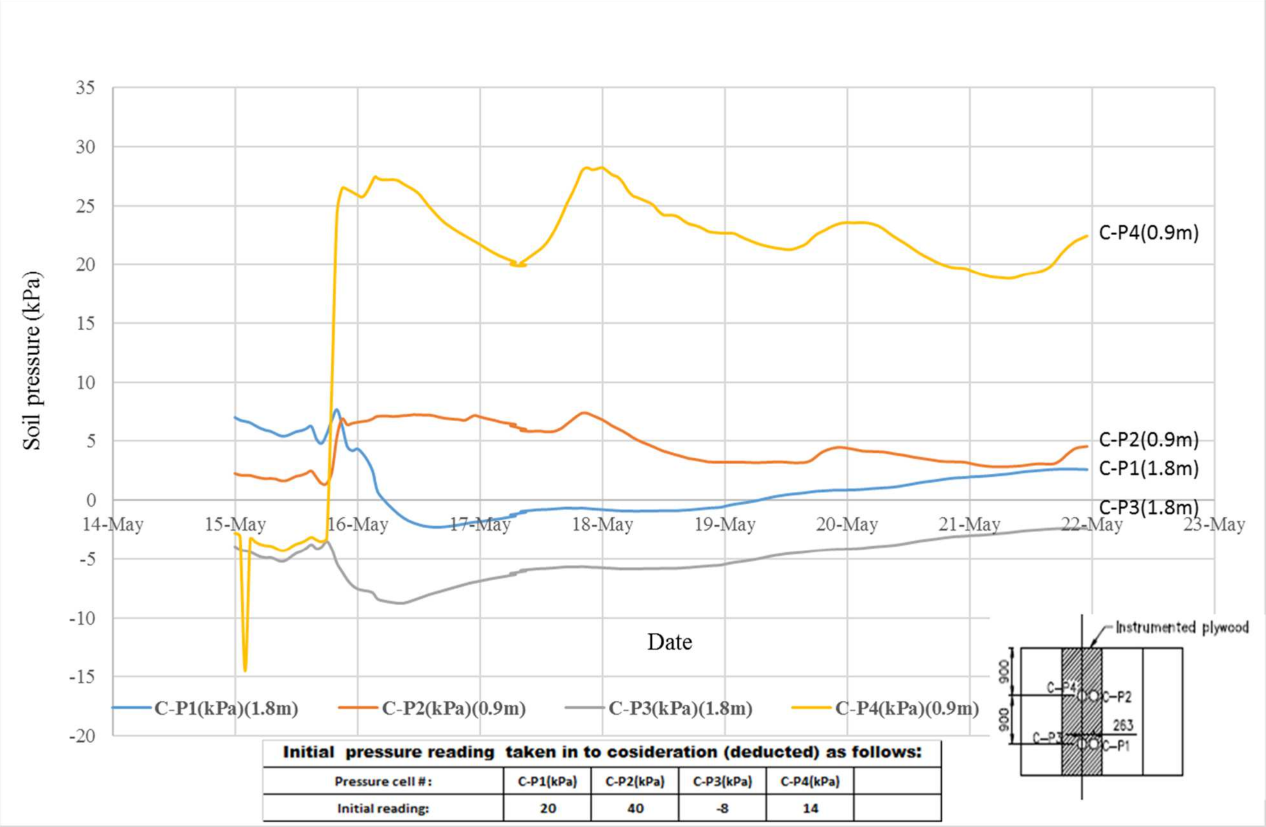


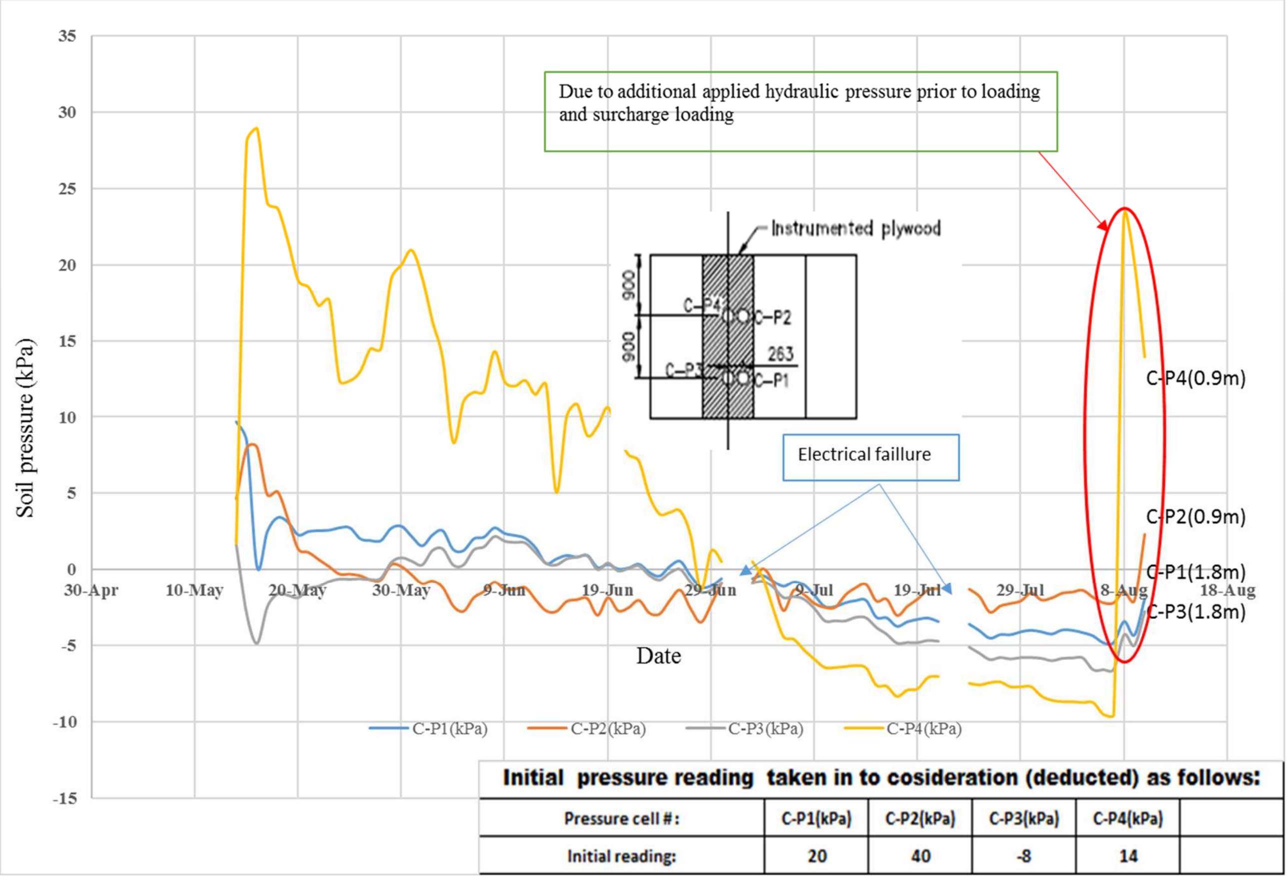
Figure 10: Hourly temperature (15th May-10th August) at different depths of trench.



Initial pressure reading taken in to cosideration (deducted) as follows:

Pressure cell #:	C-P1(kPa)	C-P2(kPa)	C-P3(kPa)	C-P4(kPa)	
Initial reading:	20	40	-8	14	

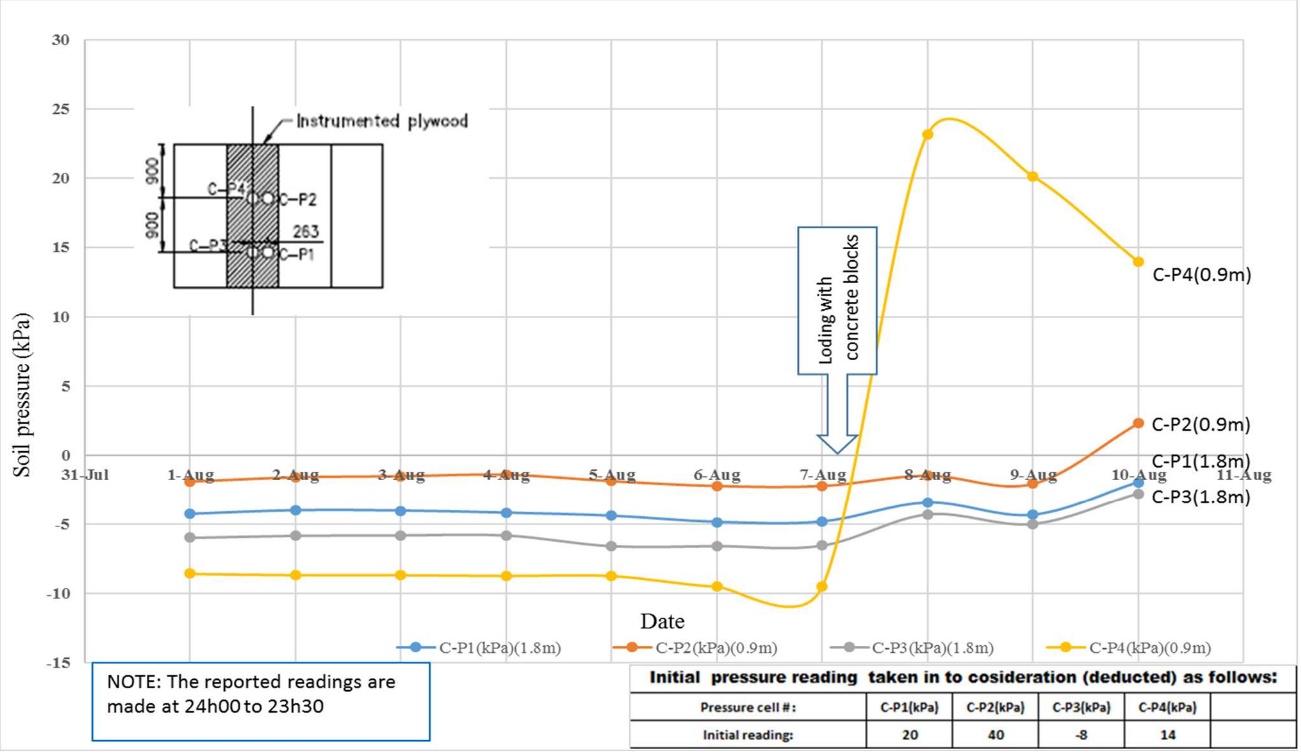
Figure 11: First week hourly pressure after temperature correction for trench.



Initial pressure reading taken in to cosideration (deducted) as follows:

Pressure cell #:	C-P1(kPa)	C-P2(kPa)	C-P3(kPa)	C-P4(kPa)	
Initial reading:	20	40	-8	14	

Figure 12: Maximum daily soil pressure after temperature correction for trench (15th May – 10th August, 2018).



NOTE: The reported readings are made at 24h00 to 23h30

Initial pressure reading taken in to cosideration (deducted) as follows:

Pressure cell #:	C-P1(kPa)	C-P2(kPa)	C-P3(kPa)	C-P4(kPa)	
Initial reading:	20	40	-8	14	

Figure 13: Blow up of last week soil pressure to see the effects of surcharge (concrete block) loading at trench.

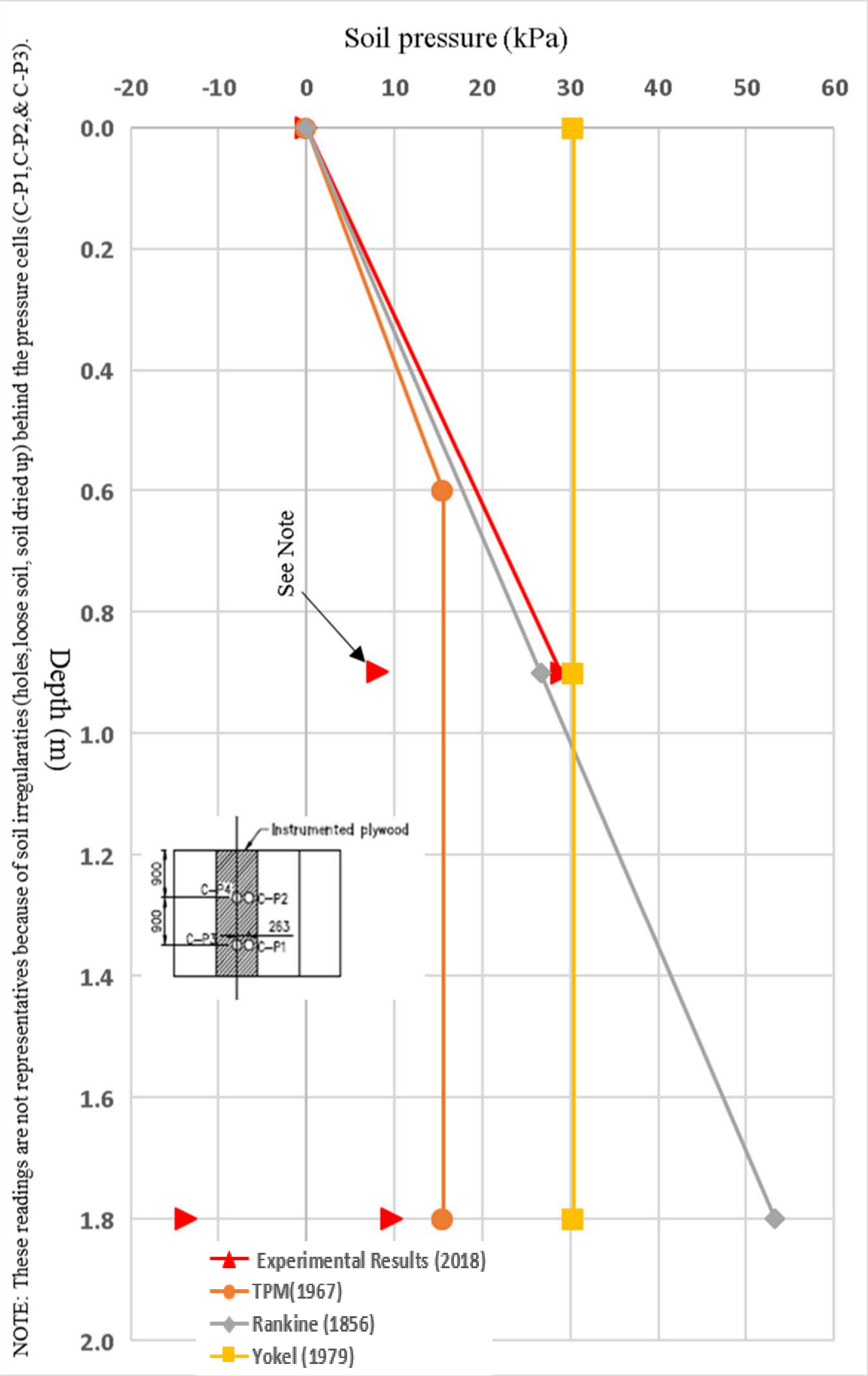


Figure 14: Experimental vs. theoretical soil pressure curves with respect to trench depth.

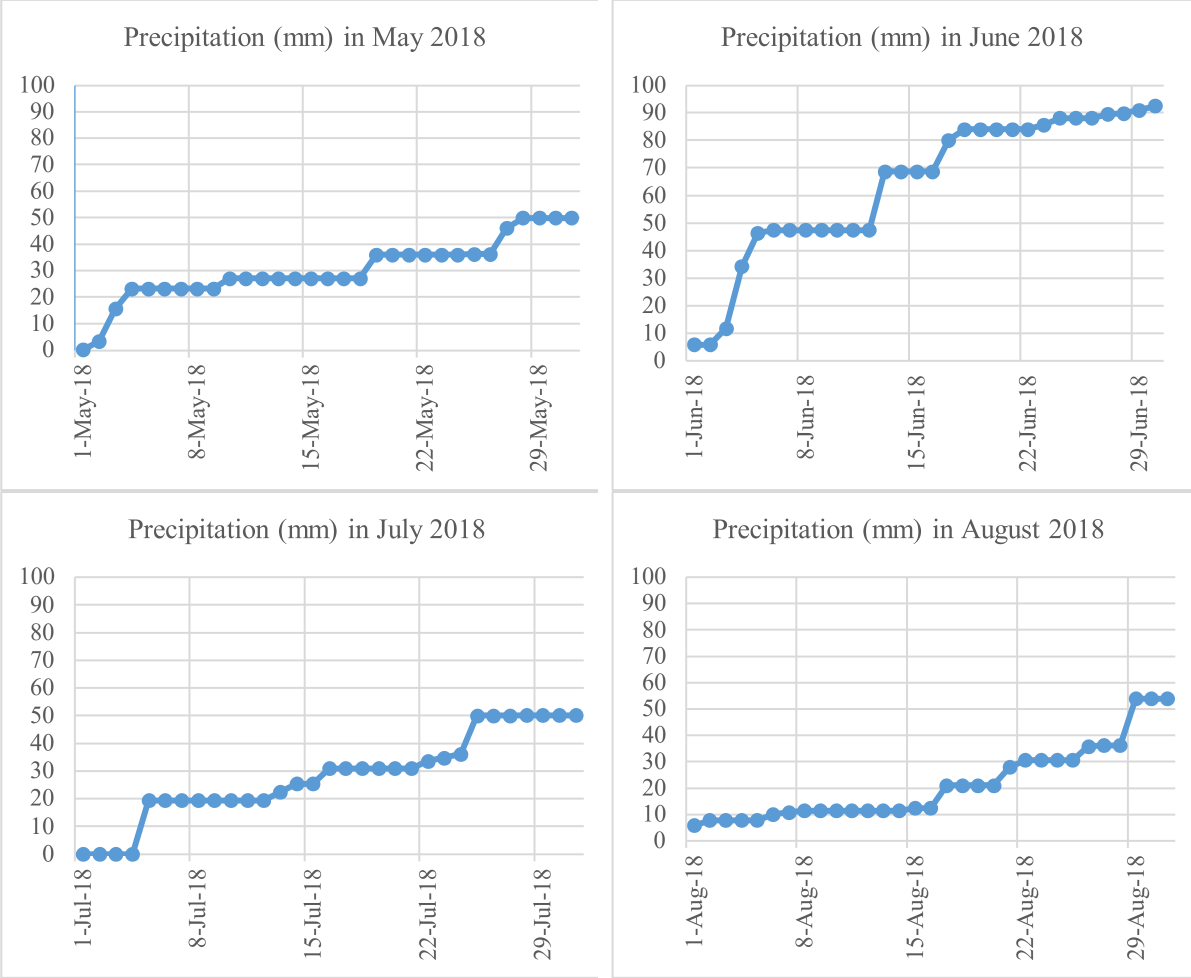


Figure 15. Recorded accumulated precipitation quantities (in mm) for each month from May to August 2018 at the Louiseville field test site.

(a) Many people are required to installed this shoring system in this soft and sensitive clay.

(b) It takes time and manpower to arrange the shoring in this type of soil.

(c) Spotted soil cave-in to the trench after the installation of shoring system

(d) Rain water washed away the soil between the plywood and shorrowing soil.

Figure 16: Some of irregularities have found during and after the installation process of Hydraulic shoring (with Plywood sheeting) in this type of soft and sensitive clay.