

Beneficial Experience from Teaching and Education to Research and Development

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Teaching and Education (T&E) constitute the most important activity in knowledge transfer from generation to generation. This can explain why government organizations consider the training of highly qualified personnel as one of the most important criteria in the selection of research and development (R&D) grant applications. A university professor should thus not only play the role of researcher, but also that of teacher. T&E and R&D combine to form an inseparable relationship for university professors. By shooting for excellence in T&E, we could get a new perception of a familiar field or initiate a brand new field altogether, which would in turn enhance our research. The quest for excellence in R&D leads to deeper and better understanding of materials taught, and progress in R&D enriches our T&E endeavors. Here, the author shares a beneficial experience from T&E to R&D.

Keywords: Teaching and Education (T&E); Research and Development (R&D); Soil Mechanics; Laboratory Tests; Excess Pore Water Pressure; Self-weight Consolidation

Introduction

As a parent and a teacher, the author considers education to be extremely important. Obviously, when we talk about “education”, we usually mean the “teaching”. Considerable importance should definitely be attributed to teaching and education (T&E) as they provide the only means of transferring social and scientific knowledge from generation to generation, and to ensure continuity in human culture and civilization. This can explain why the NSERC (Natural Sciences and Engineering Research Council of Canada) considers the training of highly qualified personnel (HQP) as one of the three most important criteria for research and development (R&D) funding allocation under the Individual Discovery Grant Program [1].

On the other hand, a university professor also plays the role of researcher who has the mission to perform research to advance human knowledge.

Thus, a university professor has an obligation to strive for excellence both in T&E and R&D. In fact, the relationship between T&E and R&D is inseparable for a university professor. There is a Chinese expression that states that “Revision of old knowledge might lead to new perception” [2]. By striving for excellence in T&E, we might initiate a brand new, as yet unfamiliar R&D field, or obtain some new ideas in a familiar field, which will enhance our R&D. T&E may thus be considered as a resource feeding our R&D.

On the other hand, striving for excellence in R&D could provide a better and deeper understanding of our materials taught. This may increase our confidence level in our teaching and facilitate the assimilation of new knowledge by students. Furthermore, R&D often enriches our T&E material.

Here, the author shares a beneficial experience from T&E to R&D.

T&E of Soil Mechanics

As a professor in geotechnics, the author teaches the “Soil Mechanics” course. In most geotechnical works, it is well established that this is a difficult course, which however includes some basic components, constituting the most important ones for further geotechnical applications. The most difficult parts of the course include the calculation of total and effective stresses and a distinction between long-term and short-term shear strengths, among other things. The latter is closely related to the generation and dissipation of excess pore water pressure in fine grained soils.

In the textbook used for the author’s “Soil Mechanics” course, a newly deposited backfill is taken as an example of under-consolidated soil with an over-consolidation ratio (OCR) smaller than unity [3]. In the author’s opinion, the newly deposited backfill is not an under-consolidated soil. Instead, it is a good example of the confusion that exists between total stress and effective stress. To illustrate this, one considers a newly deposited backfill in liquid (mud) form shown in **Figure 1**.

The relationship between the vertical total (σ_v) and effective (σ'_v) stresses is expressed as follows:

$$\sigma_v = \sigma'_v + u_w \quad (1)$$

where u_w is the pore water pressure. The vertical total stress at a depth, h , can be calculated by the following equation:

$$\sigma_v = \gamma_{tot} h \quad (2)$$

where γ_{tot} is the total unit weight of the saturated deposition. At time 0 (starting) since the deposition, the backfill is in liquid state, and no particulate-to-particulate contact exists as yet. Thus, the effective stress is zero, i.e.,

$$\sigma'_v = 0 \quad (3)$$

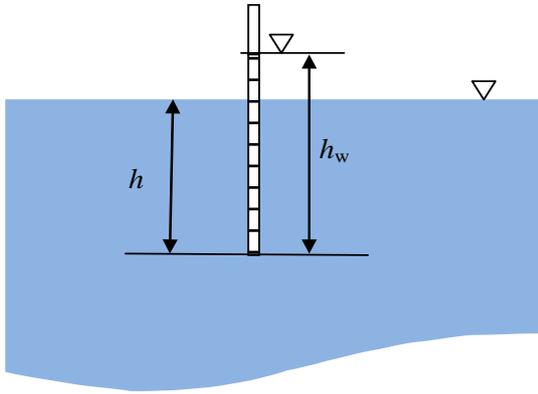


Figure 1.
A newly deposited backfill.

Entering Eqs. (2) and (3) into Eq. (1), we obtain the pore water pressure at a depth, h , as follows:

$$u_w = \gamma_{\text{tot}} h \quad (4)$$

As γ_{tot} is usually higher than the unit weight of water, γ_w , Eq. (4) indicates that the pore water pressure at a depth, h , is higher than the hydrostatic pressure of water ($= \gamma_w h$). Theoretically, if a piezometer is installed at the depth, h , a water height, h_w , would be expected in the piezometer as follows:

$$h_w = \frac{\gamma_{\text{tot}}}{\gamma_w} h \quad (5)$$

This equation indicates that the water column in the piezometer, h_w , should be higher than the water table, h as γ_{tot} is usually higher than γ_w . The water column above the water table is called the “excess pore water pressure height”, which can readily be detected by an electronic piezometer.

However, if a conventional tube piezometer was installed, nothing would probably be found in the piezometer. The reason for that will be given below. This may however lead to a false conclusion that the pore water pressure is nil and that the vertical total stress, σ_v , is the same as the vertical effective stress, σ'_v .

After a period of drainage and consolidation, the true vertical effective stress is increased to σ'_{v0} , which is the maximum vertical effective stress to which the newly deposited backfill has been submitted during its past history. Thus, its pre-consolidation pressure, σ'_p , would be:

$$\sigma'_p = \sigma'_{v0} \quad (6)$$

Obviously, the over-consolidation ratio of the newly deposited backfill is:

$$OCR = \frac{\sigma'_p}{\sigma'_{v0}} = 1 \quad (7)$$

This means that the newly deposited backfill is always a normally consolidated soil.

However, if we were to take the vertical total stress σ_{v0} , which can be directly calculated from Eq. (2), as the vertical effective stress, σ'_{v0} , we would obtain an OCR smaller than one¹, as follows:

¹Same false conclusion can also be deduced if the hydrostatic pressure is taken as the pore water pressure as the former is smaller than the latter.

$$OCR = \frac{\sigma'_p}{\sigma'_{v0}} = \frac{\sigma'_p}{\sigma_{v0}} \leq \frac{\sigma'_p}{\sigma'_{v0}} = 1 \quad (8)$$

False calculation True state

because,

$$\sigma_{v0} = \gamma_{\text{tot}} h = \sigma'_{v0} + u_w \geq \sigma'_{v0} \quad (9)$$

To confirm these hypotheses, and especially, to obtain a visualization of the excess pore water pressure, a laboratory instrumentation was built. This was part of the tasks realized by the author during the 2011-2012 school year to improve his T&E quality. The materials presented here has been used in the author’s teaching to facilitate comprehension of the very abstract “excess pore water pressure” concept by students.

Laboratory Tests for T&E

Newly Deposited Backfill Material

The material of a newly deposited backfill was made from waste clayey samples, which had been used and stored in a bucket over several terms of the “Soil Mechanics” course in the École de technologie supérieure (ÉTS) Department of Construction Engineering. All these dry clayey samples were first well mixed, ground, and brewed with sufficient water to obtain an over saturated clayey liquid-like sample (**Figure 2**).

Instrumentation and Tests

Figure 3 shows the instrumentation used to investigate the self-weight consolidation behaviour of a newly deposited backfill. Sand is put in the bottom of a rigid wall cylinder, and covered with geotextile and filter paper. A piezometer is introduced into the sand layer.

Figure 4 shows the situation in the beginning (**Figure 4(a)**) and the near end (**Figure 4(b)**) of the backfill deposition.

Visualization of Excess Pore Water Pressure

The term “excess pore water pressure” has been defined previously, and is closely related to the long-term and short-term stability of earth workings. Because the textbook [3] does not provide for its visualization, it is too abstract to understand for many students.



Figure 2.
Material of a newly deposited backfill sample.

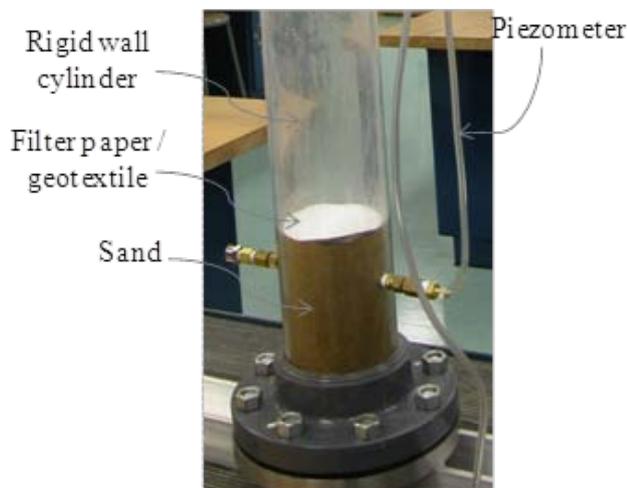


Figure 3.
Self-weight consolidation instrumentation.

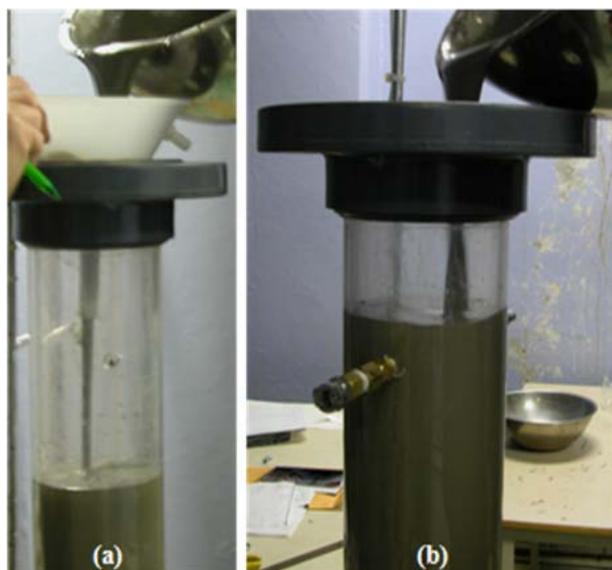


Figure 4.
Deposition of a backfill at the beginning (a) and near the end (b) into a rigid wall cylinder instrumented with piezometer.

Figure 5 shows the water column in two piezometers: one inserted into the lower sand layer, and the other directly introduced into the upper clayey backfill. A water column higher than the water table is observed immediately after the end of the backfill deposition, but no water is observed in the upper piezometer (**Figure 5(a)**).

After about two days of drainage and consolidation, the water column in the lower piezometer becomes lower while some water begins to be observed in the upper piezometer, whose head is much lower than the water table in the cylinder (**Figure 5(b)**). This is due to the fact that the clayey backfill has a very low permeability compared to sand. Thus, the lower piezometer can be fed with water immediately as long as it is requested by the pore water pressure, while little water is available from the clayey backfill to feed the upper piezometer. The latter corresponds to the case when a tube piezometer is installed in a newly deposited low permeability backfill.

Visualization of Drainage Flow

With the standard consolidation (oedometer) test [4], it is usually difficult to see water flow, given the limitations in sample size and availability of expelled water from the consolidated sample. In fact, water outflow is usually smaller than the evaporation, and as a result, water must be added to ensure the sample saturation during standard consolidation tests.

With the instrumentation presented here, one-dimensional upward drainage is allowed even though a pervious sand is placed at the base of the deposition.

Figure 6 shows a picture in which a 5.2 cm water decantation is clearly formed after about 260 hours of self-weight consolidation. Doubtless, this material can be used in teaching the “Soil Mechanics” course in order to facilitate comprehension of drainage and consolidation.

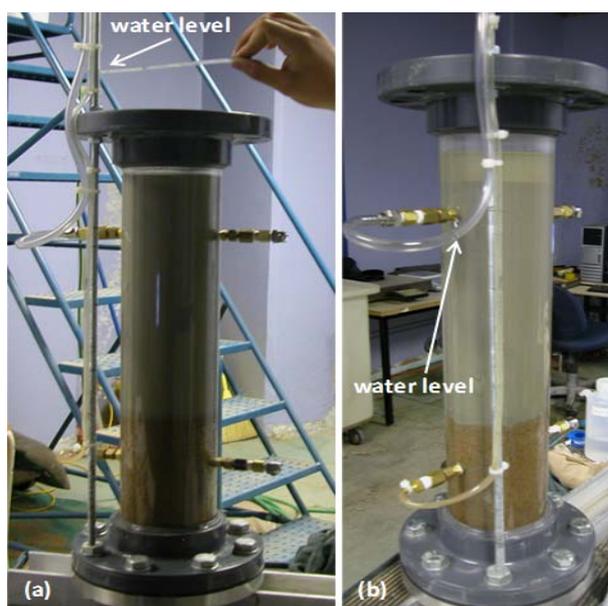


Figure 5.
Piezometer readings: (a) immediately after the backfill deposition; (b) after about two days of self-consolidation.

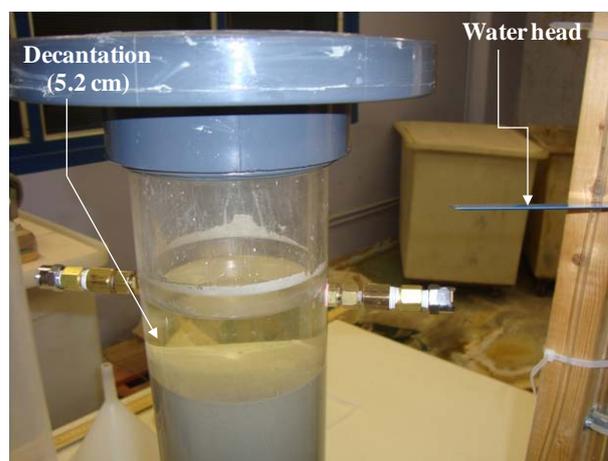


Figure 6.
Water decantation after 260 hours and 33 minutes of self-weight consolidation.

R&D Benefits from T&E

Improvement in Instrumentation

The pictures shown in **Figures 2 to 5** were taken during the primary tests. **Figure 7** shows an instrumentation after several improvements, including a better sealing system, the placement of a sand layer only slightly higher than the piezometer needle position, and the attachment of the piezometer to avoid or reduce human disturbance to the water head during testing. The picture presents the designations of several measured parameters, including the total height of the backfill deposition (H_t), the thickness of the sedimentation due to self-weight consolidation (H_c), the water height in the piezometer (H_w) corresponding to the pore water pressure at the base of the sedimentation, and the excess pore water pressure height ($H_e = H_w - H_t$).

R&D Benefits from T&E Laboratory Tests

The author has been working for mining backfill for many years, an area in which he has made several contributions (e.g., [5-9]). The consolidation of fill materials in backfilled stopes is a critical concern [10-14]. The T&E laboratory tests provided the author with an opportunity to examine the self-weight consolidation process. A further review of the literature indicates that self-weight consolidation is also a concern in coastal and canal transportation engineering due to the disposal of dredged materials [15-18]. It is also a critical concern in management of the surface disposal of mining tailings and fly ash [18-25].

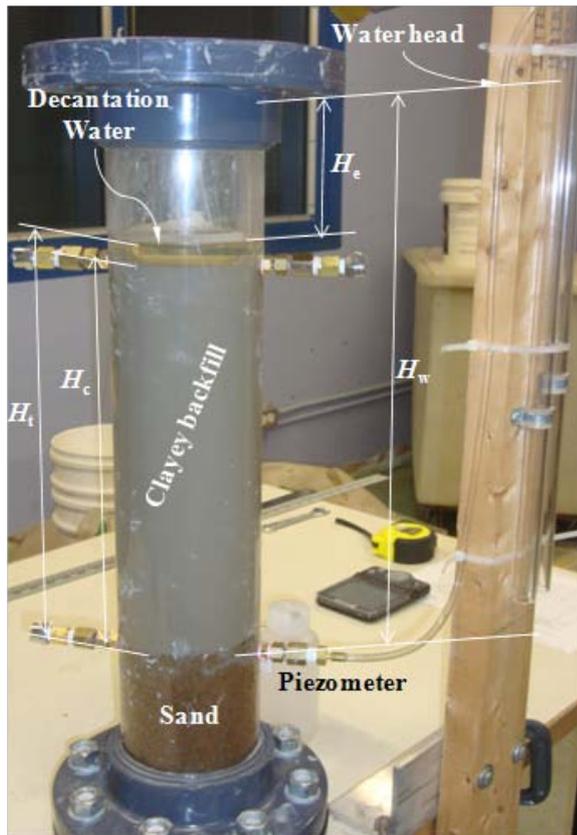


Figure 7. An improved instrumentation (picture taken after 26 hours and 45 minutes of self-weight consolidation).

A further investigation reveals that the T&E instrumentation presented here is very simple, but quite innovative in terms of measurements of the evolution of the physical and hydraulic properties of slurried deposition. This has led to the publication of a peer-reviewed paper in which test result interpretation details have been presented [26]. In the following section, some typical results will be shown to demonstrate the benefits to R&D arising from the T&E laboratory tests.

1) Evolution of Physical Properties:

When the newly deposited backfill is submitted to drainage and consolidation, its physical properties, such as the total density (ρ_t) and the void ratio (e), change with time. At the moment of deposition, its initial total density (ρ_{t0}) would be at a minimum while its initial void ratio (e_0) would be at a maximum.

The initial density of the newly deposited backfill can be estimated as follows [26]:

$$\rho_{t0} = \frac{H_{w0}}{H_{t0}} \rho_w \quad (10)$$

where ρ_w is the density of water, H_{t0} is the initial thickness of the newly deposited backfill, H_{w0} is the maximum water head in the piezometer immediately following the deposition.

Equation (10) indicates that it is possible to obtain an estimate of the initial density of the slurried sample by measuring H_{w0} and H_{t0} . This leads to $\rho_{t0} = 1.33 \text{ g/cm}^3$ with test results presented in Li et al. [26].

Once the initial total density (ρ_{t0}) is obtained, the total density, ρ_t , of the consolidated deposition can be estimated as follows [26]:

$$\rho_t = (\rho_{t0} - \rho_w) \frac{H_{t0}}{H_c} + \rho_w \quad (11)$$

The void ratio, e , of the newly deposited backfill is estimated by the following equation:

$$e = \frac{\rho_s - \rho_t}{\rho_t - \rho_w} \quad (12)$$

where ρ_s is the density of the solid particulate. For most cases, its value can be taken as 2.7 g/cm^3 .

Figure 8 shows some results of the evolution of the void ratio (e) and the total density (ρ_t) of the newly deposited backfill.

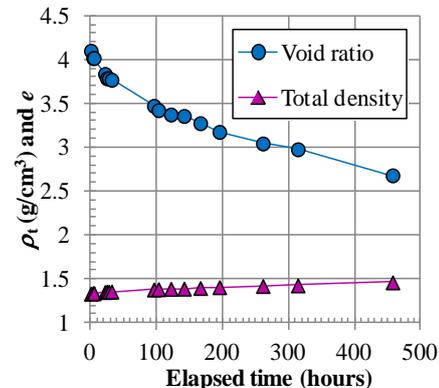


Figure 8. Evolution of physical properties due to self-weight consolidation of newly deposited backfill.

It can be seen that the void ratio decreases while the total density increases with the time of self-weight consolidation.

2) Evolution of Pore Water Pressures and Stresses

With the instrumentation presented here, the pore water pressure, u_w , and the excess pore water pressure Δu , at the base of the deposition can be readily obtained as follows:

$$u_w = \rho_w g H_w \tag{13}$$

$$\Delta u = \rho_w g H_e \tag{14}$$

where g ($= 9.81 \text{ m/s}^2$) is the gravity accelerator.

The total vertical stress, σ_v , at the base of the deposition can be estimated with the following equation [26],

$$\sigma_v = \rho_w g (H_t - H_c) + \rho_t g H_c \tag{15}$$

while the vertical effective stress, σ'_v at the base of the deposition is estimated by the following equation:

$$\sigma'_v = \sigma_v - u_w \tag{16}$$

Figure 9 illustrates the evolution of (excess) pore water pressures and (total and effective) stresses at the base of the newly deposited backfill. It can be seen that the pore water pressure and the excess pore water pressure decrease at the same pace with the time of self-weight consolidation. Regarding the vertical stresses, the total one decreases while the effective one increases with time of self-weight consolidation. Within the tested period, the difference between the total and effective stresses remains significantly high, indicating that the drainage and consolidation process are still far from complete.

2) Evolution of Hydraulic Properties

The hydraulic conductivity (or coefficient of permeability), k , is an important parameter in drainage and seepage calculations. Considering Darcy's flow, the hydraulic conductivity can be obtained by the following equation:

$$k = \frac{v}{i} \tag{17}$$

where v is the flow velocity through the sample, and i is the hydraulic gradient. With the instrumentation presented here, they can be obtained by the following equations:

$$v = \frac{\Delta(H_t - H_c)}{\Delta t} \tag{18}$$

$$i = \frac{H_w}{H_c} - 1 \tag{19}$$

where Δt is the time interval between two time points of measurement, $\Delta(H_t - H_c)$ is the thickness variation of the decantation water during the period Δt .

Figure 10 shows the evolution of hydraulic conductivity of the newly deposited backfill estimated from experimental results. It can be seen that the hydraulic conductivity decreases quickly at the early stage of self-weight consolidation, and tends to become constant after about 200 hours of consolidation. The figure also plots a description proposed by Li et al. [26]. It can be seen that the proposed equation describes the experimental data quite well.

Discussion

The results presented above stem from a very simple instrumentation aimed at providing a visualization of excess pore water

pressure during the self-weight consolidation of a newly deposited backfill. The instrumentation was initially designed for T&E purposes. The results presented above clearly show that this target is achieved.

Furthermore, it has been shown that the laboratory test method presented here can be used to measure a variety of physical and hydraulic properties of slurried depositions under self-weight consolidation. Compared to existing test methods for measuring slurried deposition physical and hydraulic properties [4, 15-16], the method presented here has an important advantage: no external hydraulic or mechanical solicitation is applied. Consequently, the state of the deposition is not disturbed during the test. Results obtained with the proposed method should be more representative than with existing methods.

Of course, the instrumentation presented here is still far from perfect. More work is needed to improve the testing method. Nonetheless, the results shown above clearly demonstrate the R&D benefits from T&E.

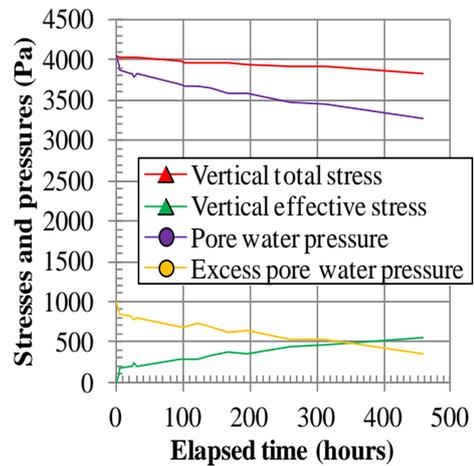


Figure 9. Evolution of (excess) pore water pressures and (total and effective) stresses at the base of the newly deposited backfill.

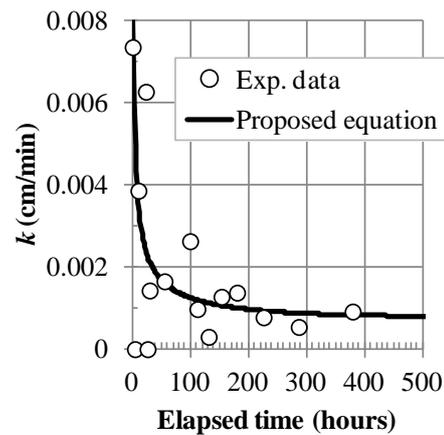


Figure 10. Evolution of hydraulic conductivity of the newly deposited backfill estimated from measurement and described with an equation proposed in Li et al. [26].

Conclusion

The benefits of T&E for R&D have been shown. Doubtless, T&E and R&D are two indivisible components for a university professor who has the obligation to transfer knowledge from generation to generation, and the mission to advance human knowledge. As an integrated professor, equilibrium should be granted to both aspects and efforts should be encouraged on both.

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