*Geotechnical Aspects of Underground Construction in Soft Ground – Yoo, Park, Kim & Ban (Eds)*


# Enhancement of filterability of fiber drainage using vibrational energy from polyvinylidence fluoride (PVDF) film

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ABSTRACT: Several techniques are available to maintain environmental drainage performance. Among these, backwash and scraping are very effective. In this study, we used an innovative technique involving ultrasound to enhance the performance of cylindrical drains. The principal purpose of the method is to decrease drain clogging by small particles in order to enhance the filterability of the drain and decrease the required maintenance. We used polyvinylidene fluoride (PVDF) films to generate wave energies with various frequencies in the drain material. We found that the effect of ultrasonic energy on drainage was significant. The degree of effectiveness, however, varied with test conditions.

*Keywords*: drainage, filterability, pdvf, ultrasound, vibration

## 1 INTRODUCTION

Study of flow in saturated porous media is important in a wide range of applications. Equations to determine the rate of fluid flow through porous media were first established by Darcy (Darcy, 1856). In most countries, environmental remediation is necessary for sustainable development and requires as its foundation an investigation of saturated water flow (Bear, 1972, 1979; Kim et al., 2006). In this study, we evaluated a technique to enhance water flow through a sandy filter using vibrational energy of polyvinylidene fluoride (PVDF) films. The principal goal of this method is to accelerate the movement and permeation of water through water pores. Vibrations were generated in PVDF film at various frequencies and amplitudes. We conducted both theoretical and experimental investigations to examine how flow was affected by these vibrations.

## 2 BACKGROUND THEORY

Darcy's law is a generalized explanation of flow in porous media. It provides the volumetric flow rate as a function of flow area, elevation, fluid pressure, and a proportionality constant. It can be stated in several different forms depending on flow conditions. A linear fluid pressure function of the system and the Darcy velocity equation are needed to describe flow with vibration. The first step of the theory is based on the original one-dimensional Darcy equation for vertical flow, assuming a small pressure difference along the system and a low-frequency vibration.

### 2.1 *Modified Darcy equation for saturated porous media*

We modified Darcy original equation (Darcy's law) by introducing a pressure-dependent fluid density term (Buermann and Kinzel, 1997). Pressure-dependent fluid density is determined using the corresponding gas law for gas contained in a fluid. The permeability constant of sandy soils is found using the Hazen equation (Carrier, 2003; Darcy et al., 1983).

With respect to the gas content of a fluid, fluid density depends on fluid pressure. In the case of low-frequency mechanical vibrations (i.e., slowly varying fluid pressure), as is considered here, the isothermal ideal gas law $\rho_G/\rho_{G0} = p/p_0$ applies to the density of gas contained in the fluid. Here, $\rho_G$ [kg/m$^3$] is the gas density, and p [bara] is the absolute fluid pressure with respect to an arbitrary reference state ($p_0$, $\rho_{G0}$) indicated by the subscript 0. The saturation ratio is given by $S_F = V_W/V_F$ (Bear, 1972) for fluid containing water, i.e., the water volume $V_W$ [m$^3$] per fluid volume $V_F$ [m$^3$]. This equation describes the dimensionless fluid density as the absolute fluid pressure varies slowly

$$\rho / \rho_0 = 1/(S_{F0} + (p_0 / p)(1 - S_{F0})) \qquad (1)$$

Inserting the fluid density equation (Eq. (1)) into the original Darcy equation with the soil permeability

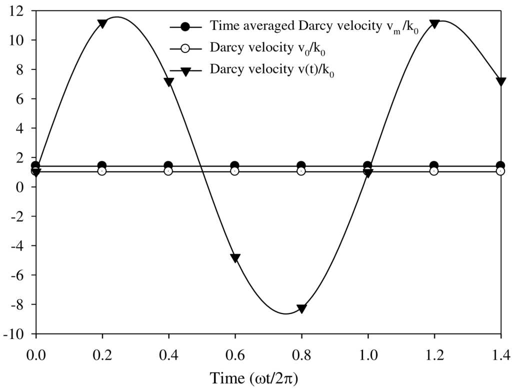


Figure 1. One-dimensional flow by vibration in the sandy soil.

constant at $k = k$ and using the continuity equation $\rho.v.A/\rho_0 v_0 A_0$ gives:

$$\frac{\partial p}{\partial s} + \rho_0 . g . \left[ \frac{v_0}{k_0} \left( S_{F0} + \frac{p_0}{p}(1 - S_{F0}) \right) + \frac{1}{S_{F0} + \frac{p_0}{p}(1 - S_{F0})} \right] = 0 \quad (2)$$

The modified Darcy equation is valid for two-phase flow ($0 < S_{F0} < 1$) of water and air in saturated soil ($S_0 = 1$). For low-frequency flow caused by vibration, which may be considered creeping flow, we introduce boundary conditions of an oscillating fluid pressure, $p(s = 0, t) = p_1(t) = p_1 + \Delta p \sin(\omega t)$, and a constant fluid pressure, $p(s = L, t) = p$, resulting in the typical time-dependent Darcy velocity for low-frequency vibrations:

$$\frac{v_0(t)}{k_0} = \frac{p_0}{\rho_0 g H} \left[ \frac{p_1 - p_0 + \Delta p \sin(\omega t)}{p_0} + \frac{1}{2}(1 - S_{F0})(\frac{p_1 - p_0 + \Delta p \sin(\omega t)}{p_0})^2 \right] - 1 \quad (3)$$

Integrating Eq. (3) over one vibration period $T = 2\pi/\omega$ [s] and frequency $f = 1/T$ gives:

$$\frac{v_m}{k_0} = \frac{1}{T} \int_{t=0}^{T=\frac{2\Pi}{\omega}} v_0(t) =$$
$$= \frac{p_0}{\rho_0 g H} \left( \frac{p_1 - p_0}{p_0} + \frac{1}{2}(1 - S_{F0}) \left( \frac{p_1 - p_0}{p_0} \right)^2 + \frac{1}{4}(1 - S_{F0}) \left( \frac{\Delta p}{p_0} \right)^2 \right) - 1 \quad (4)$$

for the time average $v_m$ of the Darcy velocity at each location in the system. The time-averaged Darcy velocity does not depend on the angular velocity. Figure 1 shows the dimensionless Darcy velocity due to vibration $v(s,t)/k_0 = v(t)/k_0$, without vibration $v_0/k_0$, and the time-averaged dimensionless Darcy velocity $v_m(s)/k_0 = v_m/k_0$ over the dimensionless time $\omega t/2\pi$. It is clear that the Darcy velocity of flow in saturated porous media significantly increases with vibration, with a 1.3–1.5-fold enhancement over one vibration period T.

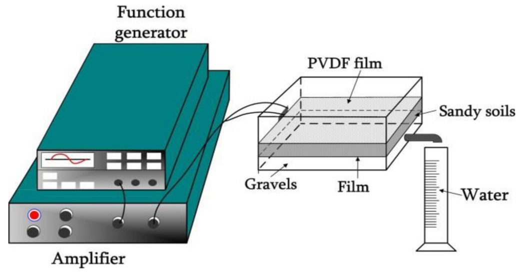


Figure 2. Test Set-up.

## 3 LABORATORY EXPERIMENTS

### 3.1 *Experimental equipment and measuring instrumentation*

Different frequency vibrations were generated in PVDF films. PVDF is the film shape piezo sensor that is flexible. Application of a small AC and large voltage (up to +/−90 V) can generate a vibration. The frequency of the vibration could be controlled in the signal generator.

A goal of this study was to investigate whether the effects of sound waves generated from a PVDF film could enhance water flow in silty sands. The main items of equipment used in this study were PVDF films, a function generator (Tabor – 8020), and an amplifier (EPA-104). The test setup comprised graduated cylinders, a soil box, a stopwatch, and gravel (Fig. 2). The test procedures were as follows.

Gravel covered a porous film placed in a soil box. Next, sandy soil was placed into the soil box. If necessary, the porous film was placed between the sandy soil and gravel to avoid mixing. Using the graduated cylinder, water was added to the soil box until soil saturation. The volume of water was noted and used to calculate the initial water content. In the last step, vibrational energy was applied to a PVDF film placed on top of the soil, and the PVDF film was connected to a function generator. The rate of flow was measured every five minutes using graduated cylinders.

### 3.2 *Results and discussion*

As shown in Fig. 3, there were significant differences in outflow with and without vibration, especially during the initial stage. When the frequency was 6 kHz at a fixed amplitude, outflow varied significantly between the case with vibration and that without vibration.

It can be postulate that the possible disruption of the inter-particle bond as well as the bonding between water molecules and soil particles and the reduction of the viscosity due to the sonication would increase the water flow. Thus, the use of vibrating PVDF film accelerated outflow and shortened the dewatering time.

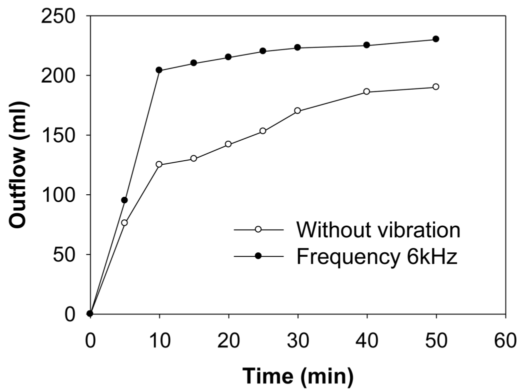


Figure 3. Outflow in different frequencies – amplitude 10 V.

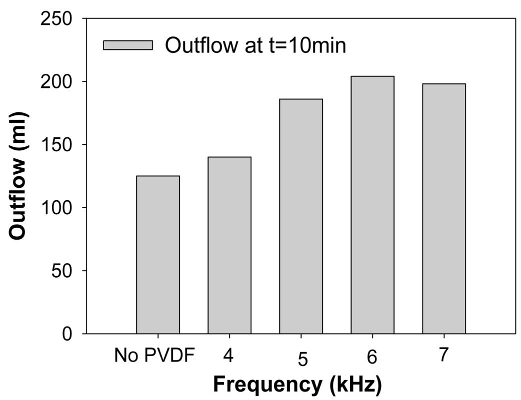


Figure 4. Compare outflow in different time with same amplitude 10 V.

Figure 4 shows that vibration accelerated drainage of water during the initial stage.

## 4 CONCLUSION

In this study, we theoretically and experimentally investigated the effect of vibrational energy on drainage of water through saturated porous media. The presented one-dimensional theory, based on the Darcy equation and the fundamental principles of flow, incorporates pressure-dependent fluid density. Extension of the theory demonstrated that Darcy velocity through saturated porous media increases with vibration. Laboratory investigations revealed that vibration significantly increased the amount of outflow. Within the range of study conditions, our test results indicate that, at high acoustic pressure, flow rate through porous media increased in the frequency range from 5 kHz to 7 kHz.

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