

DECISION PAPER

THE APPLICABILITY OF ELECTROOSMOTIC
TECHNIQUES FOR PREVENTING WATER
SEEPAGE THROUGH POROUS BUILDING
MATERIALS

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DECISION PAPER: THE APPLICABILITY OF ELECTROSMOTIC TECHNIQUES FOR PREVENTING WATER SEEPAGE THROUGH POROUS BUILDING MATERIALS

0. EXECUTIVE SUMMARY

This paper presents reviews and data to support the conclusion that electroosmotic techniques, in particular electroosmotic pulse (EOP), are feasible to prevent water seepage through porous building materials. Further research in this area should be conducted to quantify the relevant design parameters and their range of values.

Based on literature review, preliminary modeling, and field tests it has been determined that electroosmosis will work in any material that fits the fundamental criteria of a capillary porous system. The following criteria determine if EOP is suitable for a particular material:

- a) pore size
- b) electrolyte conductivity (free ions).
- c) character of material (capillary surface charge)

Standard building materials, such as concrete, concrete masonry units (CMU) and brick, meet these criteria in certain instances. For example, concrete can be made with a pore size that is either too small or too large for electroosmosis to occur, however, electroosmosis will work in conventional mixes.

Based on field tests, the following EOP application criteria have been identified:

- a) material saturation (conductivity)
- b) material/structure integrity (cracks and voids less than 1/16")
- c) current density limits
 - avoid acid generation (minimize current)
 - prevent water seepage (maximize current).

EOP is applicable to building materials other than concrete such as CMU and brick.

Further work should be done to quantify voltage and current density required to oppose hydrostatic pressure while avoiding acid attack in material, to quantify how EOP pulse characteristics influence operation for various materials and soil conditions (e.g. pulse length, amplitude, and polarity).

1. BACKGROUND

Groundwater intrusion through a building's foundation can cause serious damage. In addition to increased structural deterioration and accelerated rebar corrosion, basement dampness can ruin expensive electrical and mechanical equipment; can increase maintenance requirements through frequent repainting or cleaning to combat mold growth; and can make affected areas uninhabitable or even unusable due to poor air quality.

In selective problem areas, the usual approach to the treatment of water intrusion problems is to 'trench and drain', in other words, to excavate and expose the wall area and the base of the foundation, to replace waterproofing on the wall surface, and to install a drain tile system around the building or affected area. Areas with no access to the soil side, such as floors, are untreatable using conventional methods.

Electroosmotic pulse (EOP) technology offers an alternative that can mitigate some water-related problems from the interior of affected areas without the cost of excavation. Further, by lessening water seepage through below-grade walls and floors, indoor humidity is reduced, thereby alleviating corrosion damage to mechanical equipment, lessening mold problems, and enhancing indoor air quality.

In 1809, F.F. Reuss originally described electroosmosis in an experiment that showed that water could be forced to flow through a clay-water system when an external electric field was applied to the soil. Research since then has shown that flow is initiated by the movement of cations (positively charged ions) present in the pore fluid of clay, or similar porous medium such as concrete; and the water surrounding the cations moves with them. The basic physics and chemistry of electroosmosis can be found in several textbooks and treatises (e.g. Glasstone, 1946 and Tikhomolova, 1993).

Electroosmotic systems for waterproofing masonry walls were introduced in the 1960's by the Europeans (Smith, 1984). The first applications were to prevent *rising damp*, the wicking up of soil moisture by masonry due to capillary action. To prevent the upward movement of water, these systems established an electric field at the point at which a damp course is installed. Both "active" systems that supplied a direct current, and "passive" systems that used the natural electrical potential between the saline saturated wall and the earth were installed. The natural electrical potential difference was claimed to halt the migration of moisture above a copper strand installed in the mortar joint between two courses of brick. In practice, however, there was little proof that the passive system worked. Active systems did work, but were subject to rapid corrosion of system parts.

The electroosmotic technique was further refined by incorporating a pulsating electric current. A system was developed to apply electroosmosis commercially to concrete structures by applying a pulsating electric field. It is called electroosmotic pulse (EOP) and is based on a Polish patent.

The pulse sequence consists of a pulse of positive voltage (as seen from the dry side of the concrete), a pulse of negative voltage, and a period of rest when no voltage is applied. The positive voltage pulse has the longest interval and the negative pulse has the shortest interval. As a result of this, the pore fluid moves (on the average) in one direction. The amplitude of the signal is typically between 20 and 40 Volts DC (VDC). The positive electrical pulse causes cations (e.g., Ca^{++}) and associated water molecules to move from the dry side towards the wet side, against the direction of flow induced by the hydraulic gradient, thus preventing water penetration through the below-grade concrete structure. One of the most critical aspects of this technology is the negative voltage pulse. This allows control of the amount of moisture within the concrete which prevents over-drying of the concrete matrix and subsequent degradation.

An EOP system is realized by inserting anodes (positive electrodes) into the concrete wall or floor on the inside of the structure and by placing cathodes (negative electrodes) in the soil directly outside the structure. The density of the anode and cathode placement is determined from an initial resistivity test of the concrete and soil. The objective is to achieve a certain current density and thus create an electric field strength in the concrete sufficient to overcome the force exerted on the water molecules by the hydraulic gradient. Figure 1 illustrates the EOP process.

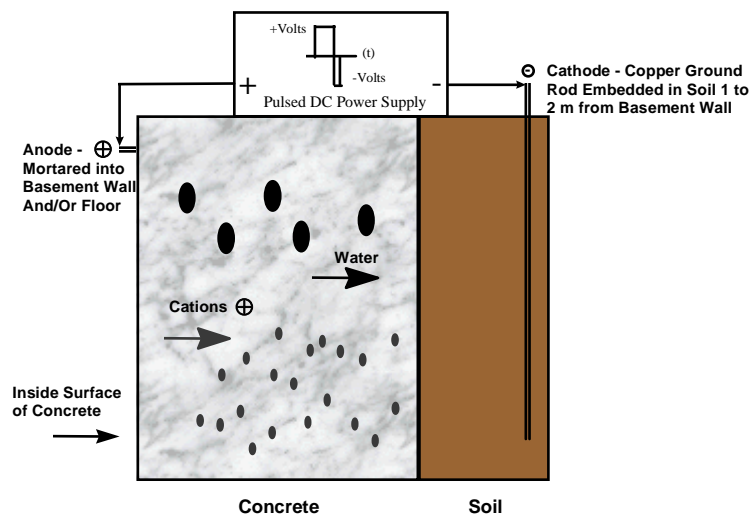


Figure 1. Cross section of concrete and soil showing the EOP process.

2. OBJECTIVE

This research effort will quantify many of these engineering parameters, increasing the effectiveness of EOP technology and leading to an extension of the technology to new materials, such as masonry block, brick and new construction.

The objective of this decision paper is to present background material and data that relate to the feasibility of electroosmotic techniques in preventing water seepage through porous building materials. The technique has been shown to work for concrete. This paper will examine the applicability to other building materials, such as concrete masonry units (CMU), brick, limestone and sandstone.

3. APPROACH

The approach of this research effort will be to examine the following EOP issues: (1) electroosmotic pressure required to balance hydrostatic pressure; (2) how material characteristics influence operation (e.g. thickness and chemical composition, and the presence of rebar); (3) how soil conditions influence operation (e.g. soil conductivity, moisture content, and pH); (4) how EOP pulse characteristics influence operation (e.g. pulse length, amplitude, and polarity); (5) how cracks and voids in the material influence operation; and (6) overall effectiveness of EOP technology in control of water seepage. Research will be a joint effort between CERL, WES, CRREL. CERL has set up a CRADA with two established manufacturing and installation companies to assist in developing new cost-effective EOP applications.

The approach of this decision paper is to review lessons learned from FEAP, reimbursable applications, and CRADA partner installations; to fabricate two test basements, one of poured concrete and one of CMU; to develop a simple hydraulic gradient model; and to begin development of an EOP application matrix.

4. RESULTS

LITERATURE REVIEW

There have been over 100 articles and reports on electroosmosis published in the last 60 years. Electroosmosis is a widely used technology in reducing moisture levels and moving water in soils, waste sludges, and processed materials (such as food products). The technique was first applied successfully on building sites in 1939 (Casagrande, 1947). The use of electroosmosis in remediating moisture problems in buildings was patented in 1981 (Sweden), 1982 (Poland), and the United States (1986).

The application of electroosmosis to dewatering is pictured in figure 2. In this application a constant dc voltage is applied between the anode and cathode. The electroosmotic effect takes place within the membrane.

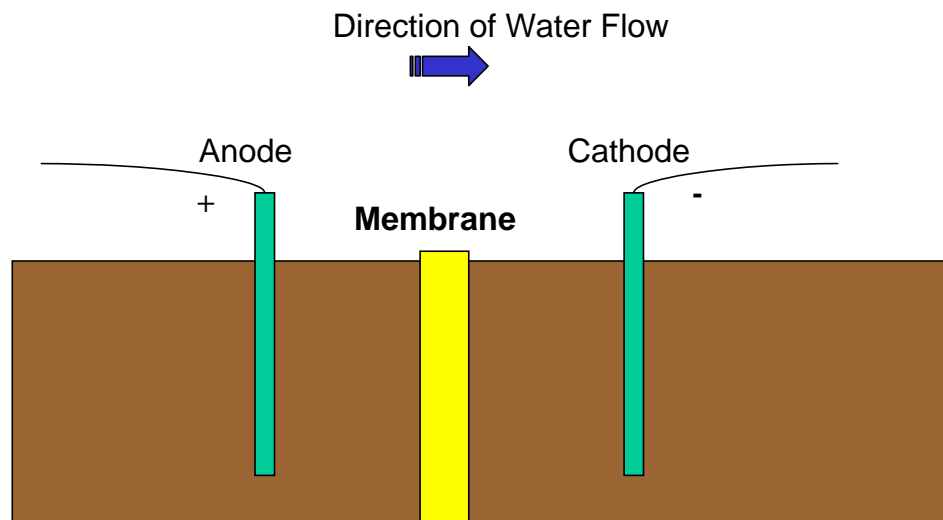


Figure 2. Schematic of electroosmotic dewatering operation

The electroosmotic process can be very efficient especially in clayey soils. Records from electroosmotic dewatering operations in the field indicate over 400 liters/hr from a 36,000 sq m site in Trondhjem, Norway, with a power efficiency of 4 gal/kWh (Casagrande, 1947). A laboratory test with clayey soil showed efficiencies up to 6 gal/kWh are possible for clayey soil (Gray and Mitchell, 1968). Laboratory tests with industrial sludge showed 2.5 gal/kWh (Greyson, 1970).

TECHNOLOGY DEMONSTRATIONS

Technology demonstrations of ElectroOsmotic Pulse (EOP) technology are described in one technical report (Hock, 1998) and two conference papers (Hock, 1998 and McInerney, 1998). Two sites were selected for EOP technology demonstrations, Building 3265, a guest barracks at Fort Jackson, South Carolina; and Building 5, the Health Clinic at McAlester AAP, Oklahoma. In both cases, the location of the groundwater intrusion was through the floor and walls of a poured concrete basement.

Ft Jackson

Building 3265 had a history of water seepage into the concrete basement mechanical room. The mechanical room had experienced water levels within the structure as high as 36 cm. On the average, there existed about 5 cm of standing water. In addition, there was seepage through cracks in the wall, efflorescence, and poor air quality as a result of the high indoor humidity. This seepage initiated corrosion of the mechanical equipment located in the basement, which then required replacement as often as every two years.

The EOP dc output current was within acceptable limits, varying from 0.75 amps for a high humidity environment to less than 0.2 amps for a low humidity environment. Direct variation of current with humidity is a result of the characteristics of the EOP system. Table 1 shows measured current and voltage outputs of the EOP power supply. The slight increase in output current is due to the higher water table during July and August 1996.

TABLE 1. Ft. Jackson EOP power supply dc output current.

Date of Reading	DC Volts	DC Amps
1995/01/10	+37	0.20
1996/08/15	+30	0.75

Concrete moisture readings were taken at different locations on the walls. Table 2 lists the moisture measurements that were taken at three different times; at the time of installation, at the 5-month performance check, and 2 years after installation. The data are presented as percent relative humidity. All measurements were made at the concrete surface, not internally. Note the direct correspondence between the power supply current (Table 1) and the concrete humidity (Table 2).

TABLE 2. Concrete moisture readings in Building 3265, Ft. Jackson.

Date of Reading	% Relative Humidity at Surface			
	A	B	C	D
1994/08/23	94	92	98	98
1995/01/10	44	43	68	64
1996/08/15	73	72	76	77

The water table level is a good indication of EOP system performance: if the water table is above the floor of the basement and the basement remains dry, then the EOP system is fulfilling its purpose. A monitoring well was installed just outside the basement wall for the purpose of tracking the level of the water table relative to the basement floor. Figure 3 shows the hydrograph for the monitoring well from September 1995 until September 1996. (Groundwater temperature just happened to be included in the standard monitoring well 'package', it was not used in this study.) Note there are several times during the recording period when the water table exceeded the basement floor level. In previous years the basement would have flooded during these periods, however now because of the EOP system the basement remains dry.

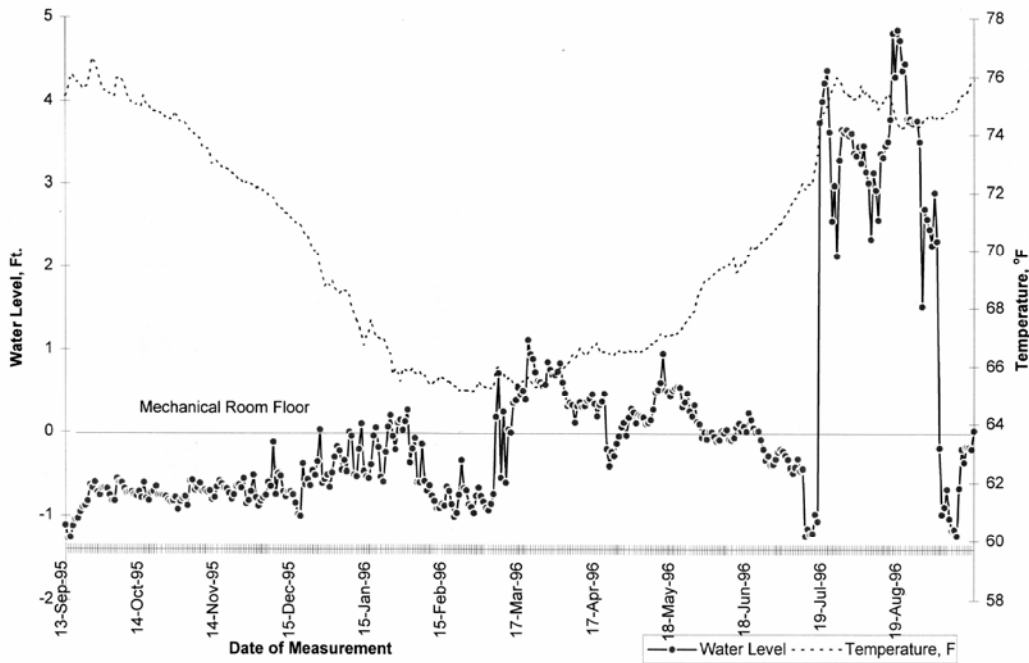


Figure 3. Hydrograph from monitoring well at Fort Jackson, South Carolina.

The basement of Building 5 had standing water in several areas. Problems similar to the basement at Fort Jackson were prevalent; water seepage through cracks in the wall, efflorescence and high indoor relative humidity (70 percent). In this case the reduction of the indoor air humidity is very important, as one of the rooms is the Industrial Hygiene Office, occupied by an individual 40 hours a week.

The most significant data from the McAlester field test is presented in figures 4 and 5. These figures show the output power of the EOP system and the daily rainfall for a one year period. In addition to calculating energy costs, output power can be used to qualitatively evaluate the moisture content of the concrete. Because the system driving voltage is constant, the power output is directly proportional to the moisture content of the concrete. (Power is directly proportional to current; current is inversely proportional to resistance; and resistance is inversely proportional to moisture content.) A drop in power therefore indicates that the concrete is drying out, i.e. the resistance is increasing. Conversely, a rise in power indicates moisture absorption by the concrete. This effect can be seen in the data for May through August 1997 (figure 6), where the power increases following large rainfalls, and then decreases as the system drives the water out.

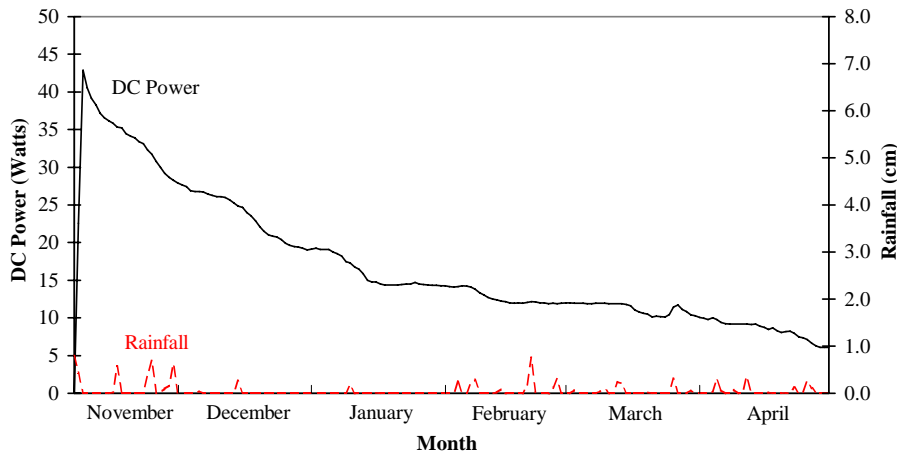


Figure 4. EOP Control Unit output power and local rainfall for November 1996 through April 1997.

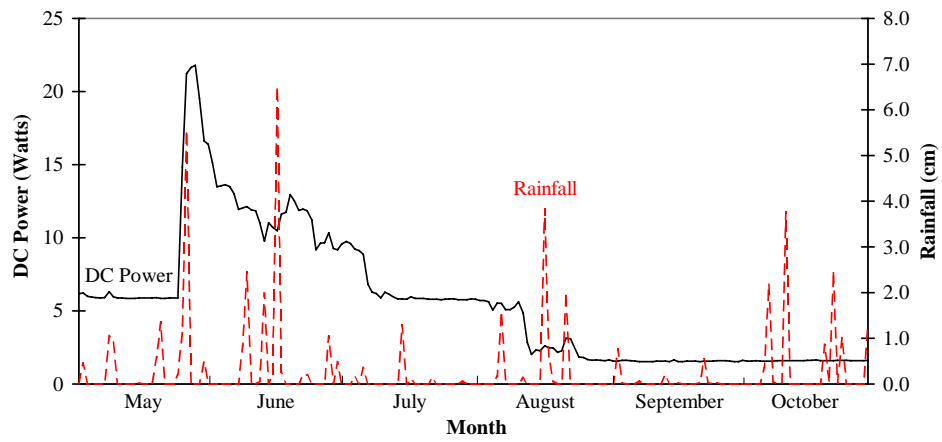


Figure 5. EOP Control Unit output power and local rainfall for May through October 1997.

MODELING

The basic equation for movement of the pore solution in a capillary porous system due to electroosmosis contains several forces:

$$\rho \frac{d\bar{v}}{dt} = \bar{g}\rho \quad 1.a$$

$$- \text{grad } p \quad 1.b$$

$$+ \eta \nabla^2 \bar{v}^0 \quad 1.c$$

$$+ \left(\frac{\rho^+ z^+ e_0}{m^+} + \frac{\rho^- z^- e_0}{m^-} \right) \bar{E} \quad 1.d$$

$$- \frac{kT}{m^+} \text{grad } \rho^+ - \frac{kT}{m^-} \text{grad } \rho^- \quad 1.e$$

where:

ρ = density of the solution

ρ^\pm = density of the medium of the positive (negative) ions

\bar{v} = velocity of the solution (center of mass)

\bar{v}^0 = velocity of the solvent

\bar{g} = acceleration of gravity

p = pressure

η = shear viscosity coefficient

z^\pm = charge of an ion

e_0 = elementary electric charge

m^\pm = mass of a positive (negative) ion

\bar{E} = strength of the electric field of the system

k = Boltzmann constant

T = temperature

Equation 1. Force equation for pore solution in a capillary porous system.

The term designated 1.a is the component of force due to gravity; the term designated 1.b is the force component due pressure, the term designated 1.c is the component due to viscosity, the term designated 1.d is the force component due to electroosmosis, and term 1.e is the component due to temperature.

The dominant force components are generally those due to pressure and electroosmosis. In applications for preventing water seepage, where the seepage is caused by hydrostatic pressure, the electroosmotic force must balance or exceed the pressure force.

For electroosmosis to be effective capillary pores must be present in the medium, the medium must have fixed surface charges (clays, concrete and related materials are

common media), the medium should be saturated, and the fluid must be a dilute electrolyte.

The velocity equation of the pore solution is:

$$V_e = \frac{\epsilon \xi E}{4\pi \nu l}$$

where:

V_e = flow velocity of solution (meter/sec)

ϵ = dielectric constant of water (Farad/meter)

ξ = zeta potential (Volt)

E = potential applied across material (Volt)

ν = viscosity of liquid (centipoise)

l = distance between electrodes (meter)

Equation 2. Velocity of pore solution.

From this equation a number of observations can be made as to how to increase the effectiveness of electroosmosis for movement of water:

- 1) use porous media with high zeta potential, such as kaolinite slurry wall (maximize ξ),
- 2) establish a short distance between electrodes (minimize l),
- 3) reduce any contamination of the existing groundwater (maximize ϵ),
- 4) maintain the medium in a saturated condition,
- 5) use non-polarizing electrodes or pulsed reversing systems (EOP) to reduce resistance at the electrodes, and
- 6) reduce any hydrostatic pressure that opposes electroosmotic force.

APPLICATION FACTORS

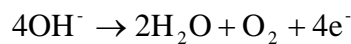
Capillary pore size and pore solution conductivity are the key factors for determining the suitability and effectiveness of electroosmosis in a material. Standard building materials such as concrete, concrete masonry units (CMU) and brick are all suitable materials for electroosmosis. A standard construction industry property that is directly related to pore size is permeability, or absorption. The permeability of concrete can vary from zero (pore size too small for electroosmosis) to a value too large for electroosmosis (Olin, 1975). This is true for CMU and brick as well. For economic and

workability reasons the greatest application of these materials is with a permeability that is in the range for electroosmosis to be effective.

Pore solution conductivity Water to be “pumped” is a dilute electrolyte (for example, 10^{-3} N NaCl solution, about the conductivity of drinking water)

A very important consideration in the application of electroosmosis is that the electric current must not alter the chemical composition or the pore solution. The pulse technique may be important in this respect. By allowing the inside surface to be dry, the outside surface to be wet, and interior to retain some moisture, it may help the material to maintain its chemical integrity.

Anode/cathode current density must be large enough to control water seepage, yet small enough to prevent gas generation. While increasing the current density reduces seepage, this must be balanced with the need to minimize acid generation at the anode so as not to lead to degeneration of the material. The process of acid attack in concrete begins with the typical anodic reaction of oxidation of hydroxyl ions producing (four each four hydroxyls) two molecules of water, one oxygen molecule and 4 electrons which are transferred via the system metallic path to the cathode.



Equation 3. Anodic reaction at anode in concrete.

In the process of using up hydroxyls in the vicinity of the anode, hydrogen ions increase in concentration and the pH drops significantly, quite often in concrete measured at values lower than 5. This will cause acid attack of the cement paste adjacent to the anode wire.

FIELD TEST DATA

Several technology demonstration sites were monitored to evaluate the application factors.

Aberdeen Proving Ground

An EOP system was installed in the concrete floor of a facility at Aberdeen Proving Ground in May 1998. Power supply waveform, voltage and current; anode and cathode voltages and currents; and concrete slab moisture content were monitored periodically. Two EOP application concerns were found at this site.

Data from this site demonstrated the dependence on moisture removal on power supply voltage. For a period of several months the system was operated at half voltage (15 Volts), during this time moisture was continuing to seep through the floor at areas of high hydrostatic pressure. When the system voltage was increased to 30 Volts, water seepage ceased.

CMU basement sites

EOP systems were installed in CMU basements in Fisher, Illinois, Dakota, Minnesota, and Minneapolis, Minnesota in 1998. In each case cavities in blocks were filled with grout. These initial applications EOP technology in CMU have performed excellently. Since installation there have been no signs of water intrusion and performance has been similar to that of the concrete basement installation.

5. CONCLUSIONS

Based on literature review, preliminary modeling, and filed tests it has been determined that electroosmosis will work in any material that fits the fundamental criteria of a capillary porous system. The following criteria determine if EOP is suitable for a particular material:

- a) pore size
- b) electrolyte conductivity (free ions).
- c) character of material (capillary surface charge)

Standard building materials, such as concrete, concrete masonry units (CMU) and brick, meet these criteria in certain instances. For example, concrete can be made with a pore size that is either too small or too large for electroosmosis to occur, however, electroosmosis will work in conventional mixes.

Based on field tests, the following EOP application criteria have been identified:

- a) material saturation (conductivity)
- b) material/structure integrity (cracks and voids less than 1/16")
- c) current density limits
 - avoid acid generation (minimize current)
 - prevent water seepage (maximize current).

6. RECOMMENDATIONS

EOP is applicable to building materials other than concrete such as CMU and brick.

7. FUTURE WORK

Quantify voltage and current density required to oppose hydrostatic pressure while avoiding acid attack in material.

Quantify how EOP pulse characteristics influence operation for various materials and soil conditions (e.g. pulse length, amplitude, and polarity).

Develop performance specifications or engineering instruction for porous building materials.

7. REFERENCES

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