Electroosmotic Pulse Technology for Groundwater Intrusion Control in Concrete Structures

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Abstract

Groundwater intrusion into a building can cause serious damage to mechanical equipment; can increase maintenance requirements, and can make affected areas uninhabitable or even unusable. Electroosmotic pulse (EOP) technology offers an alternative to conventional water control techniques. Not only can it mitigate some water-related problems from the interior of affected areas without excavation, but it can further mitigate corrosion damage to mechanical equipment along with humidity and mold problems. EOP technology is based on the concept of electroosmosis; the movement of an electrically charged liquid under the influence of an external electric field. A system has been developed to apply electroosmosis within concrete structures by applying a pulsating electric field. During fiscal years 1994 and 1996, EOP technology was demonstrated at two Army sites. In both cases, the location of the groundwater intrusion was through the floor and walls of poured concrete basements. This paper presents the results of the experimental evaluation of system performance at McAlester AAP. The most conclusive data from this field test is the output power of the EOP power supply. Power data clearly indicates the beneficial effect of the EOP system on the moisture content of the concrete.

1. INTRODUCTION

Groundwater intrusion through a building's foundation can cause serious damage. In addition to increased concrete deterioration and accelerated rebar corrosion, basement dampness can ruin expensive electrical and mechanical equipment, which is often located in basement space; 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. Other areas, 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 concrete 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).

A system has been developed to apply electroosmosis commercially to concrete structures by applying a pulsating electric field. It is called electroosmotic pulse (EOP). 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 overdrying 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.

Currently, the reasons for the increased performance of the EOP system over standard DC electroosmosis for drying concrete are not well understood. However, it is speculated that the change in polarity results in the reversal of some of the chemical reactions occurring during electrolysis. It is also believed that the rest phase (no applied voltage) allows the system to equilibrate. As a result of these effects, undesirable side effects such as acid production and increased corrosion are avoided. Also, use of a pulse sequence might prevent the concrete from becoming too dry.

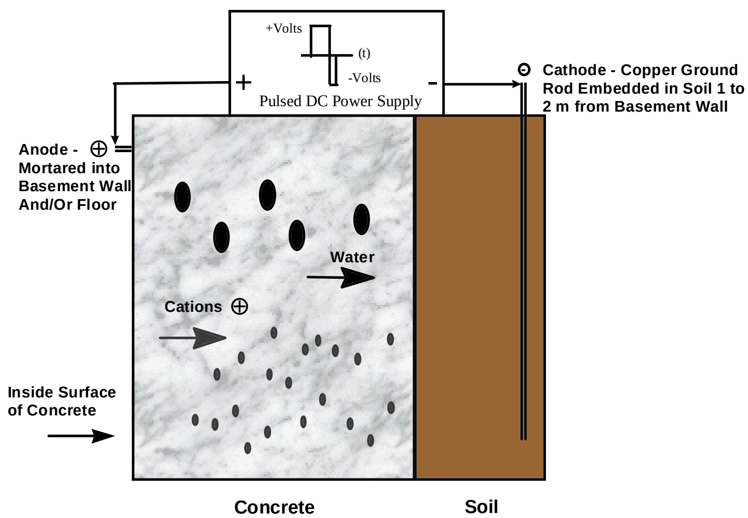

Figure 1. Cross section of concrete and soil showing the EOP process.

2. TECHNOLOGY DEMONSTRATION

During fiscal years 1994 and 1996, EOP technology was demonstrated at two Army sites; the mechanical room of a guest barracks at Fort Jackson, South Carolina and an office and storage area in the basement of the Health Clinic at McAlester AAP, Oklahoma. In both cases, the location of the groundwater intrusion was through the floor and walls of poured concrete basements. These demonstrations were performed under a technology demonstration program, and therefore a large research and development effort was not possible. Monitoring of system performance was performed in the field, as best as possible. Supporting laboratory work was not available nor was it possible. These demonstrations, and the EOP technology, are described in detail in Hock et al. (1998). This paper discusses the experimental measurements taken at McAlester AAP.

The EOP system was installed in the basement of the Health Clinic (Building 5) at McAlester AAP during July 1996. At that time the basement had standing water in several areas; water seepage from cracking in the wall; efflorescence and high indoor relative humidity. Analysis of water infiltration revealed that only about half the basement was leaking, therefore the EOP system was installed only in the areas of infiltration. Rubber-graphite anodes were installed 13 cm above the floor and 28 cm on center. The total number of anodes used was 95. Four copper-clad steel ground rods (cathodes), 2.44 m long, were driven into the soil in the crawl spaces adjacent to the concrete wall in selected areas. Large cracks were repaired by filling with epoxy or nonshrink grout. Figure 2 shows the arrangement of the EOP installation.

To assess the effectiveness and evaluate the limitations of EOP technology several system and environmental parameters were monitored. The corrosion potential of rebar was measured using a 33-cm long piece of 1.27-cm steel rebar which was grouted into the wall along with a Ag/AgCl reference half cell. The half cell was installed so as to be behind the rebar, and separated from it by about 5 cm of concrete. (Three additional 15-cm segments of 1.27-cm diameter rebar were placed in other basement walls to provide different EOP conditions from which to measure the corrosion potential of the rebar.) The humidity inside the concrete wall was sampled using a dual humidity/temperature probe which was sealed in a small cavity in the wall. Since the cavity is sealed, the temperature and humidity of the cavity should be proportional to the temperature and moisture content of the concrete. Ambient room humidity and temperature sensors monitored the Environmental Health Office. The level of the water table directly outside the basement was also monitored. In addition to these sensors and probes, the electrical power consumption of the EOP Control Unit and power supply was tracked. The locations of these sensors are indicated in Figure 1. All these monitoring devices, except the rebar corrosion potential were fed into a datalogger that was installed on site and was remotely accessible via modem. The data was collected and stored in the datalogger until uploaded to a computer. The rebar to half-cell potential measurement could not be properly interfaced to the datalogger because of ground reference problems. The daily rainfall, average outdoor temperature, and average outdoor relative humidity at nearby McAlester airport were obtained from the Oklahoma Climatological Survey. Data was downloaded monthly from their INTERNET site.

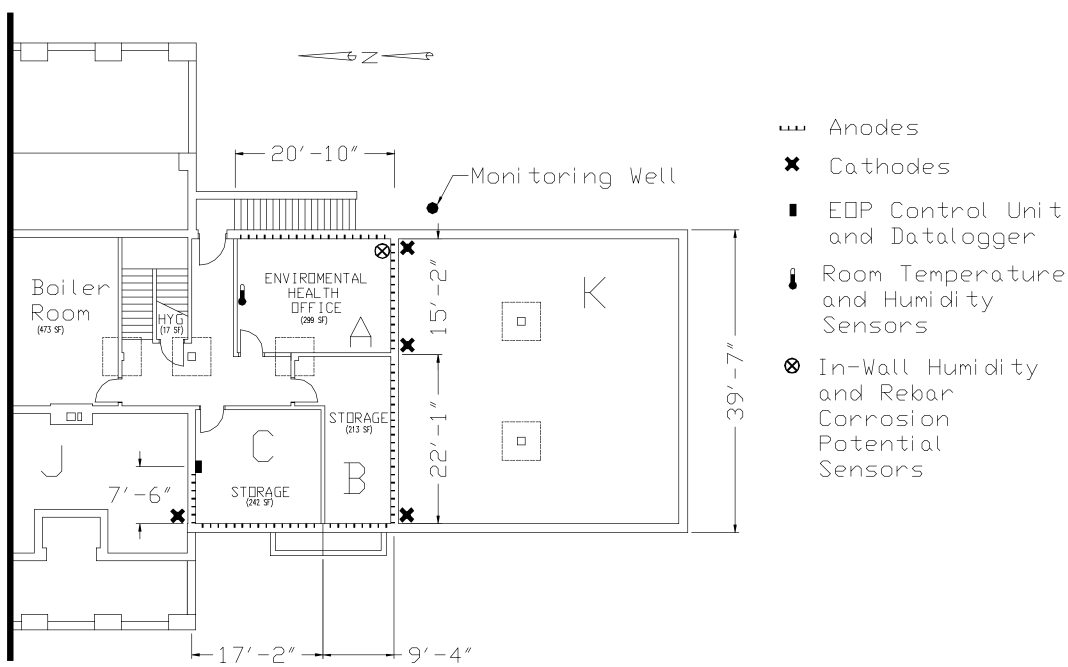

Figure 2. Location of EOP system components and environmental monitoring sensors in Health Clinic basement. (1 ft = 0.3048 m, 1 in. = 2.54 cm)

3. DATA PRESENTATION AND DISCUSSION

The most significant data from the McAlester field test is presented in figures 3 and 4. 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, where the power increases following large rainfalls, and then decreases as the system drives the water out. The most likely explanation for the few inconsistencies in power versus rainfall can be explained by the location of the rain gauge, which is located about 8 km from the base at McAlester airport. Because thunderstorms in the plains are localized events, the rainfall at McAlester AAP can differ from that at the airport.

Water table data indicated that intrusion was not caused by a high water table. (At the Fort Jackson demonstration site, basement flooding occurred yearly because of the very high water table, often rising 1.5 m above the level of the mechanical room floor.) The water table never rose nearer than 0.65 meters below the basement floor, confirming that the water intrusion problem at McAlester was due to the saturation of the surrounding soil following rainstorms, as reported by the building's occupants. Occupants also reported that the heavy rainfall at the end of May 1997 was a rainfall that normally would have "flooded" the basement, however the water was held back by the EOP system.

Results of the other experiments were inconclusive:

(1) Indoor absolute humidity was found to correspond directly with outdoor absolute humidity, as is shown in figure 5. (Relative humidity was converted to absolute humidity in order to eliminate temperature dependence.)

(2) Cavity humidity did not vary directly with power as was expected. Figures 6 and 7 show the absolute humidity (i.e., temperature dependence removed) of the wall cavity. Cavity temperature data indicates a strong correlation with room temperature and the sudden drop in absolute humidity in March corresponds to the end of the heating season.

(3) Results of the rebar corrosion potential experiments were inconclusive. There is evidence that the Ag/AgCl half cell is not compatible with the concrete and might be drifting from its reference potential. Measurements were also taken using a $Cu/CuSO_4$ reference half cell, not only at the long rebar segment but also at the other three shorter segments, two of which were placed in non-EOP system walls. Measurement results were inconsistent, due possibly to the noise of the measurement technique, +/- 200 mV.

4. CONCLUSION

The most conclusive data from the McAlester AAP field test of an EOP system is the output power of the EOP power supply. Because the moisture content of the concrete is inversely related to its resistance, a decrease in power indicates that the concrete is drying out, while an increase in power indicates moisture absorption by the concrete. This is confirmed by comparing power and rainfall data where power is seen to increase following large rainfalls, and then decrease as the system drives the water out again. This correspondence also supports the assumption that the water intrusion problem at McAlester was due entirely to periodic saturation of the nearby soil, as reported by the building's occupants who stated that, prior to installation of the EOP system, the water came in following rain storms.

This field test concludes that the application of EOP technology for control of groundwater intrusion in below-grade concrete structures is a desirable alternative to conventional trenching and tiling: the EOP system installed in the

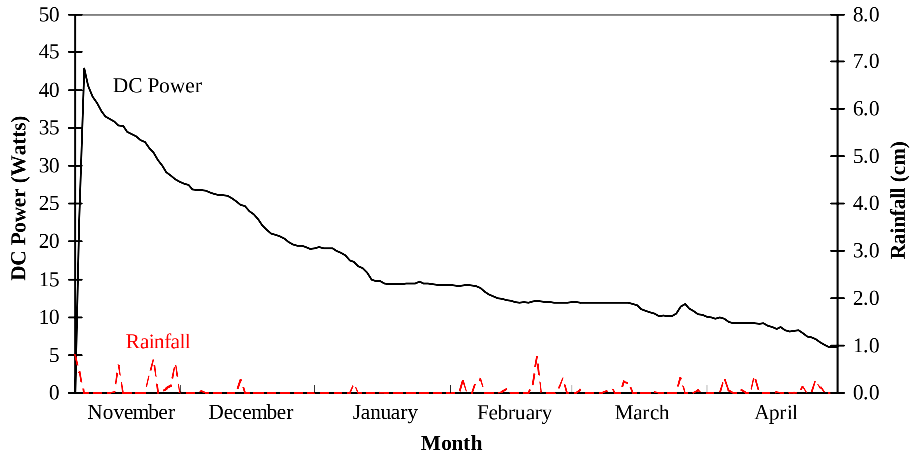

Figure 3. EOP Control Unit output power and local rainfall for November 1996 through April 1997.

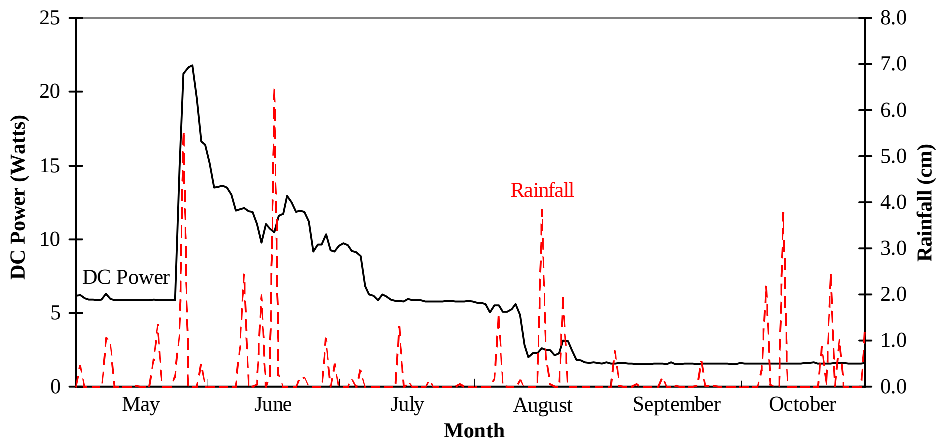

Figure 4. EOP Control Unit output power and local rainfall for May through October 1997.

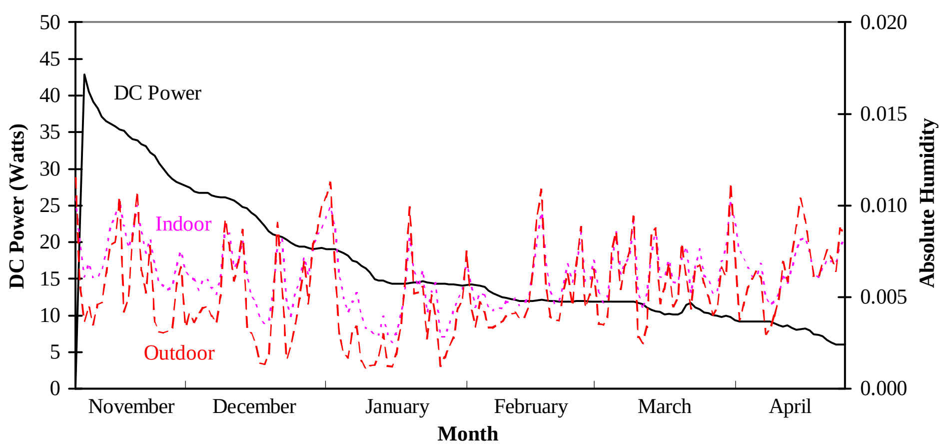

Figure 5. EOP Control Unit output power and indoor and outdoor absolute humidity for November 1996 through April 1997.

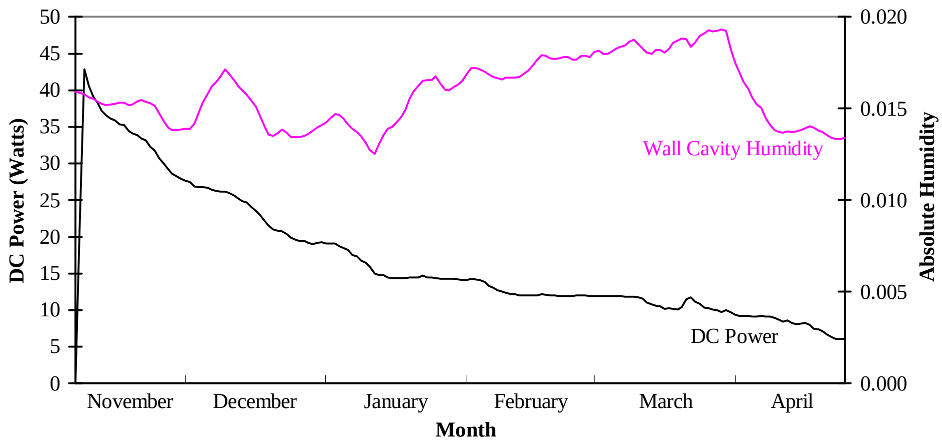

Figure 6. EOP Control Unit output power and absolute humidity of the wall cavity for November 1996 through April 1997.

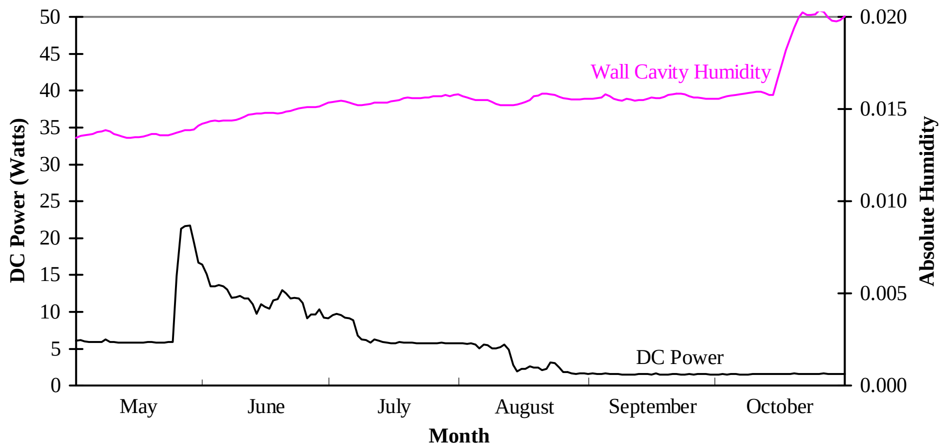

Figure 7. EOP Control Unit output power and absolute humidity of the wall cavity for May through October 1997.

basement of Building 5, McAlester AAP, Oklahoma successfully prevented water seepage; the cost of installation was 40 percent lower than the cost of the conventional trench and drain approach; the operating cost of the EOP system is negligible, less than to the expenditure of burning a 25W light bulb, and; a cost/benefit analysis using Payback-Upon-Price-Comparison and Payback-Over-Time show a very favorable payoff of the EOP technology over conventional technologies.

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