Virginia Transportation Research Council

research report

Implementation
of an Automated Test Setup
for Measuring Electrical Conductance
of Concrete

EDWARD J. HOPPE, Ph.D., P.E.
Senior Research Scientist

LARRY J. LUNDY, P.E.
Concrete Engineering Program Manager

THOMAS J. SCHINKEL, E.I.T.
Materials Engineer

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Virginia Transportation
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16. Abstract

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        An automated laboratory setup for conducting RCPTs was developed and implemented at VDOT. The microprocessor-controlled device is capable of unattended measurement and monitoring of up to 32 concrete specimens at a time in accordance with AASHTO and ASTM test methods. The device is based on the Campbell Scientific CR10X Datalogger interfaced with the Campbell Scientific AM16/32 Multiplexer. Date- and time-stamped test records are stored electronically in ASCII format.

        As there are no commercially available devices with a comparable function, it is difficult to assess the initial cost of development and setup. There are, however, substantial cost savings associated with the operation of this device. It is estimated that the resultant savings are equivalent to the costs of one full-time technician position in VDOT's materials laboratory. These costs are approximately $46,000 per year, accounting for salary and benefits.

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FINAL REPORT

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Edward J. Hoppe, Ph.D., P.E.
Senior Research Scientist

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ABSTRACT

This project was designed to provide the Virginia Department of Transportation (VDOT) with an automated laboratory setup for performing the rapid chloride permeability test (RCPT) to measure the electrical conductance of concrete in accordance with applicable standards. As an increasing number of construction projects is becoming subject to concrete permeability acceptance testing, there is a growing need for conducting laboratory RCPT in a timely and expedient manner. Typically, concrete cylinders arrive at VDOT's materials laboratory in large batches, sometimes more than 100 units at a time. This often results in backlogs in processing and leads to considerable delays. The lack of commercially available test equipment created a need to develop an automated device that could expedite large scale production testing. The Virginia Transportation Research Council was contacted to provide technical assistance. This report describes the practical implementation of a workable RCPT device.

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INTRODUCTION

Concrete exposed to a salt environment is subject to chloride penetration, resulting in extensive deterioration and premature failure. An effective preventive measure is to use high performance concrete with very low permeability, thus minimizing the intrusion of aggressive solutions. The concept of a low-permeability concrete created a need for a rapid and reliable material test method for quality assurance and quality control purposes.

The rapid chloride permeability test (RCPT) was originally developed for the Federal Highway Administration (FHWA) by the Portland Cement Association.[1] The results were found to correlate well with those of the commonly accepted ponding test (AASHTO T 259), which takes approximately 90 days to complete. RCPT integrates current passing through a disk of saturated concrete over a 6-hour period, resulting in an electrical charge measurement expressed numerically in coulombs. The test has been adopted as a specification tool by many agencies concerned with preventing chloride-induced damage to reinforced concrete. The Virginia Department of Transportation (VDOT) employs Virginia Test Method (VTM) 112, based on AASHTO T 277 and ASTM C 1202. Minor variations in VTM-112 include a modified curing method.

VDOT uses the RCPT results for acceptance testing. Material specifications include penalties for excessive conductance. Payments for concrete are reduced for each coulomb above the established threshold value. Concrete with a conductance of more than 1000 coulombs above the maximum permissible value can be rejected.

The determination of electrical conductance of concrete provides an indirect means of measuring the permeability of concrete. Despite its inherent limitations, the test is gaining increased acceptance in the transportation industry. RCPT is fairly easy to perform, although it can be labor intensive. The labor effort is two-fold, involving sample preparation followed by test measurements. Although the former component requires lengthy manual processing, the latter can be drastically reduced through automation. RCPT relies on a series of electric current

measurements taken at 30-minute intervals, for a total test period of 6 hours. These repetitive measurements lend themselves to an automated data acquisition and processing setup.

Currently, only one company (Forney, Inc.) supplies a commercial testing device designed to perform RCPT. This device can process four or eight samples at a time. The measurements are displayed during a test and can be printed out.

PURPOSE AND SCOPE

This project was designed to provide VDOT with an automated laboratory setup for performing the RCPT to measure the electrical conductance of concrete in accordance with applicable standards. As an increasing number of construction projects is becoming subject to concrete permeability acceptance testing, there is a growing need for conducting laboratory RCPT in a timely and expedient manner. Typically, concrete cylinders arrive at VDOT's materials laboratory in large batches, sometimes more than 100 units at a time. This often results in backlogs in processing and leads to considerable delays. The lack of commercially available test equipment created a need to develop an automated device that could expedite large scale production testing. The Virginia Transportation Research Council was contacted to provide technical assistance. This report describes the practical implementation of a workable RCPT device.

METHODOLOGY

The principle behind the RCPT is a measurement of the current flowing through a concrete specimen. Electrical current is imposed on a sample through a regulated power supply, producing a constant 60 VDC output. A direct way to measure the resulting current would be to insert an ammeter in series with the test cell. From a practical standpoint, this would be a rather expensive and cumbersome solution. The alternative approach, as presented in AASHTO and ASTM standards, is to measure the voltage drop across a precision shunt resistor connected in series with the test cell. The current is subsequently computed as a quotient of voltage over resistance, in accordance with Ohm's law. Figure 1 illustrates the measurement concept.

A rudimentary test setup for RCPT requires measurements at predetermined time intervals by taking consecutive manual voltage readings. This approach is simply impractical (very time-consuming) to carry out on a production basis if more than a few samples need to be tested at one time. The solution is to automate the measurement process.

Conducting RCPT involves the elements of process control and data acquisition. The core of the test setup developed for this project is the Campbell Scientific CR10X Datalogger (datalogger). The CR10X is a 13-bit datalogger with 6 differential or 12 single-ended input channels, 2 pulse counters, 8 digital I/O ports, and 3 switched analog outputs. It can be used for data acquisition and control of peripherals.
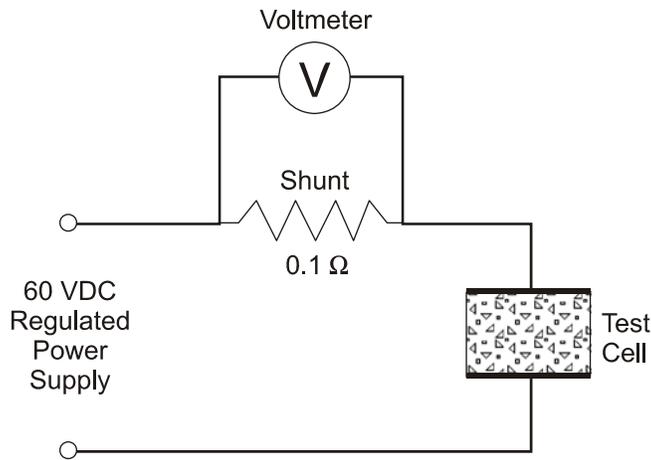
Figure 1. Basic RCPT Electric Circuit

The test setup developed for this project is shown schematically in Figure 2. The datalogger is the main data acquisition and control unit. It is interfaced with a Campbell Scientific AM16/32 Multiplexer (multiplexer) in order to perform 32 single-ended voltage measurements at a time. The multiplexer is required because there are not enough input channels available on the datalogger. A customized control program was developed, allowing the multiplexer to scan 32 separate measuring circuits sequentially. The resulting data are acquired, processed, and stored in the datalogger.

A computer is interfaced with the datalogger through a serial port. The function of the computer is to initialize the datalogger at the start of RCPT, monitor the test by displaying interim measurements on a screen, and collect data upon completion of the test. Since these tasks require very little processing power, the computer selected for this application is a legacy Pentium 486-based model.
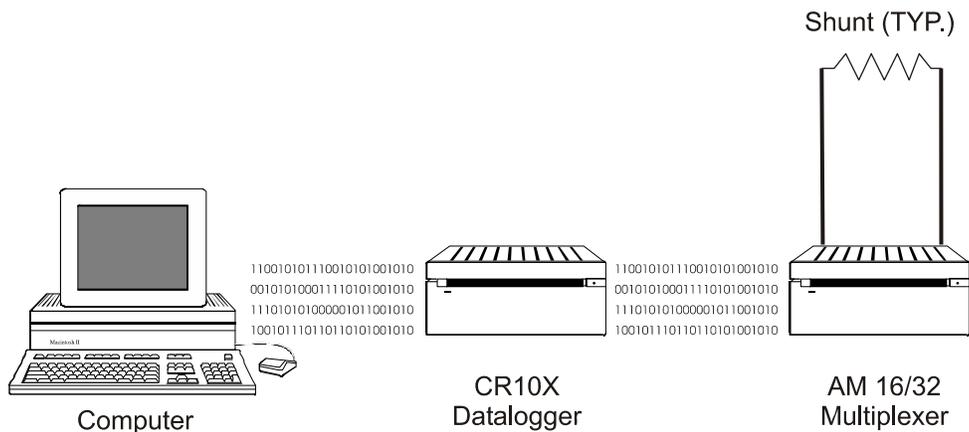

Figure 2. Schematic of Automated Test Setup

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The test sequence is as follows:

1. Start the control batch file on the computer.

2. Enter the laboratory sample numbers corresponding to the test cell numbers.

3. Initialize the datalogger and load the control program.

4. Switch on 60 VDC to all samples.

5. Acquire, process, and store voltage measurements from all test cells every 30 minutes.

6. Display interim measurements, converted to current values, every 10 seconds.

7. Compute permeability (charge expressed in coulombs) at the end of the test by integrating current over time.

8. Shut off 60 VDC to all samples.

9. Transfer test data from the datalogger to the computer.

10. Date- and time-stamp the test results.

11. Append the master records file with the latest test results.

12. Display the latest results on the computer screen.

13. Copy the latest results to an ASCII file on a diskette.

Starting with Step 3, tasks are fully computer controlled, requiring no operator intervention. The control batch file consists of a series of DOS-based commands for sequencing various tasks. The datalogger control program (DLD file) performs Steps 4 through 8. Figure 3 shows the actual automated laboratory test setup.

The test voltage (60 VDC) is generated by a regulated power supply, Model RA60-14A, manufactured by Mid-Eastern Industries. It is rated at 0.01% voltage regulation regardless of the current draw. Power is switched on and off through a relay activated by the datalogger. The automatic shutoff feature allows a new test to be initiated at the end of a regular workday and run unattended, with the results waiting the following morning. The device is also designed to allow the power to the unused test cells to be switched off to prevent short circuits (leads touching). Each of the eight front-mounted toggle switches controls a bank of four test cells. All circuits are individually protected by 1A electrical fuses should an accidental short occur. The current is calculated from a voltage drop measured across an 0.1-ohm shunt resistor with 1 percent tolerance. All resistors are encased in metal heat sinks to ensure stable readings (shunt resistance is affected by heat generated through a flowing current).

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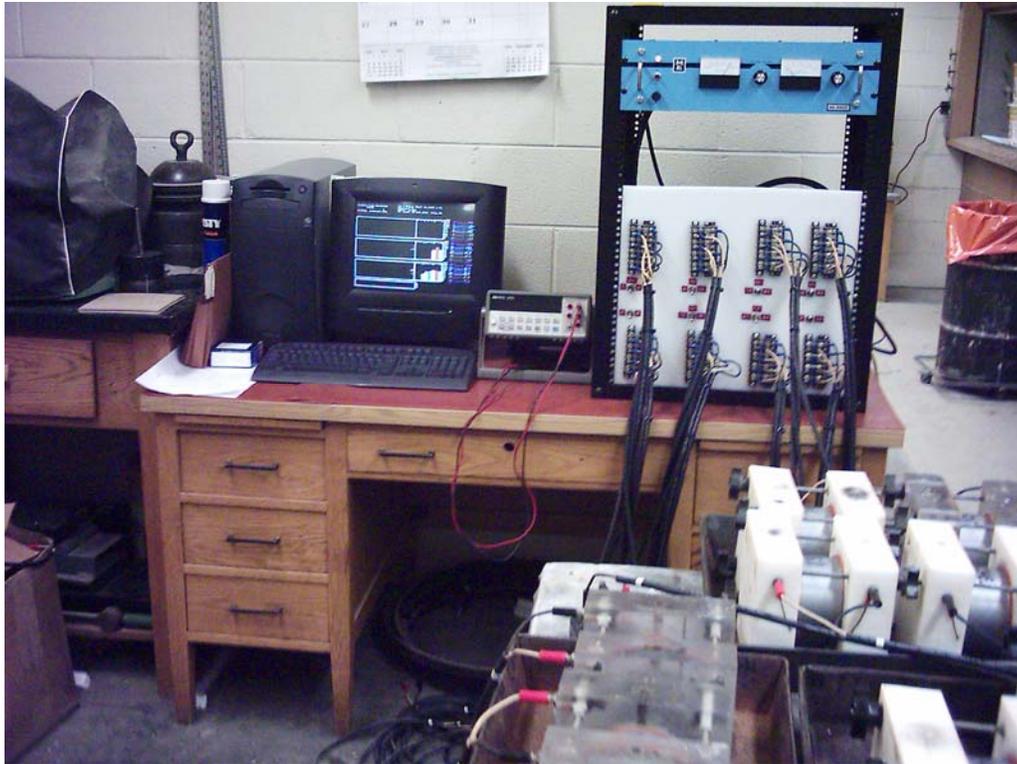
Figure 3. Automated RCPT Device

Each of the 32 measuring circuits was individually calibrated with a precision digital ammeter. Calibration factors, which are multipliers for current readings based on the nominal 0.1-ohm shunt resistance, form an integral part of the datalogger control program. Verification checks conducted using a fixed-value resistor simulating a test cell indicate accuracy within 2 percent of the "true" value.

RESULTS

Figure 4 shows an example of a typical output data file containing test results. It includes measurements taken at the beginning of the test and at 30-minute intervals thereafter. Final coulomb values are automatically computed (rounded to the nearest integer) for each sample, and the results are date and time stamped.

The results shown in Figure 4 reflect a test run with 16 active cells (Samples 1 through 16). This test was started on November 21, 2006, at 14:29 and completed 6 hours later at 20:29. The first line of data starts with the identification number 310, followed by the year (2006), Julian day (325, corresponding to November 21), and the start time (14:29). Each subsequent line beginning with the identification number 314 shows time of measurement (every half hour), followed by 32 current (mA) readings. These readings terminate in the following row of data. Final coulomb values for Samples 1 through 32 are printed sequentially on the line beginning with the identification number 337, terminating on the following row (concluding with the string [COULOMB VALUES]). Corresponding laboratory sample numbers are shown

```
310,2006,325,1429
314,1429,50.401,49.948,43.909,49.971,47.245,43.315,48.308,53.25,44.773,52.011,51
.255,104.06,91.101,57.244,0,48.641,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1459,50.396,51.275,44.57,53.297,47.906,45.31,50.635,56.573,46.105,56.007,52.
581,115.38,99.735,60.566,63.962,53.3,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1529,51.388,52.603,45.897,55.292,49.233,46.639,52.631,58.566,47.439,57.337,5
4.242,123.38,106.05,63.89,67.289,55.962,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1559,52.382,53.935,46.895,57.29,50.564,47.972,54.296,60.562,48.107,58.67,55.
905,130.05,111.03,65.886,70.619,57.96,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1629,53.708,54.601,47.892,59.289,51.894,48.638,55.961,61.893,48.775,59.336,5
7.902,134.72,115.69,68.548,72.618,59.959,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1659,54.371,55.932,48.558,60.621,53.225,49.971,56.628,62.559,48.775,60.003,5
9.233,139.72,119.01,70.545,75.283,61.957,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1729,55.035,56.598,49.888,62.62,54.556,50.637,57.96,63.89,49.443,61.003,60.5
64,142.72,121.67,73.207,76.615,63.29,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1759,55.698,56.598,50.553,63.952,54.556,51.303,58.626,64.555,50.111,61.337,6
1.23,145.39,123,74.538,77.948,63.956,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1829,56.361,57.264,51.218,64.618,55.221,51.969,59.292,64.555,50.111,61.337,6
2.561,147.39,124.33,75.869,79.28,64.622,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1859,57.024,57.264,51.218,65.951,56.552,51.97,59.959,65.221,50.779,62.003,63
.226,149.39,124.99,77.2,80.613,65.288,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1929,57.024,57.597,51.218,66.617,57.217,52.636,60.625,65.886,50.779,62.003,6
3.892,150.05,125.66,78.531,81.612,65.954,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,1959,57.687,57.93,51.883,67.283,57.882,52.636,60.625,65.886,51.447,62.67,64.
557,150.72,124.99,79.197,82.611,65.955,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
314,2029,57.687,57.93,51.883,67.949,58.548,53.302,60.625,65.886,51.447,62.67,65.
223,150.72,124.99,79.862,82.945,65.955,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
337,1179,1197,1057,1324,1155,1076,1227,1349,1061,1294,1285,2981,2527,1541,1565,1
323,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0 [COULOMB VALUES]
    13791 13788 13811 13801 13792 13786 13812 13802 [SAMPLES 1-8]
    13785 13787 13733 13803 13804 13799 13810 13798 [SAMPLES 9-16]
    00000 00000 00000 00000 00000 00000 00000 00000 [SAMPLES 17-24]
    00000 00000 00000 00000 00000 00000 00000 00000 [SAMPLES 25-32]
Current date is Tue 11-21-2006
```

Figure 4. Example of Test Results

below in groups of eight. The last line is a date stamp at the test completion. The format of the test results output file lends itself to a quick post-processing with data analysis software, such as Microsoft Excel.

In addition to generating an individual output data file, the control program appends the master test file with the latest records. This is a comprehensive listing of all concrete permeability tests performed to date, designed for audit purposes.

DISCUSSION

The device developed in this study allows for continuous monitoring of ongoing tests. Interim current measurements are refreshed on the computer screen every 10 seconds. These values can also be plotted on the screen as a function of time. Continuous monitoring provides a means of a quick assessment of the final permeability value based on the initial few minutes of the test. Previous studies indicate that a fairly accurate estimate of concrete conductivity can be established from current measurements taken at between 1 and 10 minutes after the voltage is initially applied.[2]

The test setup has performed satisfactorily to date. It allows for two batch runs per workday, resulting in the ability to process 64 samples per day. If additional processing power is required in the future, the existing device can be easily upgraded. The datalogger can be

interfaced with up to four multiplexers, theoretically allowing a test setup for 128 concrete specimens at a time.

CONCLUSIONS

- *The automated laboratory test setup for measuring the electrical conductance of concrete developed and implemented at VDOT can test up to 32 concrete specimens at a time, resulting in the ability to process 64 samples per day.*

- *The datalogger can be interfaced with up to four multiplexers, theoretically allowing a test setup for 128 concrete specimens at a time.*

RECOMMENDATION

1. *VDOT should use the automated laboratory test setup for measuring the electrical conductance of concrete developed in this study and provide feedback to the Virginia Transportation Research Council regarding possible future enhancements.*

COSTS AND BENEFITS ASSESSMENT

As there are no commercially available devices with a comparable function, it is difficult to assess the initial cost of development and setup. There are, however, substantial cost savings associated with the operation of this device. It is estimated that the resultant savings are equivalent to the costs of one full-time technician position in VDOT's materials laboratory. These costs are approximately $46,000 per year, accounting for salary and benefits (D. P. Cognata, personal communication).

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