



Test Data for Model ECI

Embedded Corrosion Instrument

Virginia Technologies, Inc.
2015 Ivy Road, Suite 423
Charlottesville, VA 22903
(804) 970-2200 Voice/Fax
www.vatechnologies.com

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The test set-up shown in Figure 1 was developed to test the performance of the Virginia Technologies, Inc. (VTI) Embedded Corrosion Instrument's (ECI) drive and sense electronics versus the EG&G VersaStat™, a commercial laboratory grade instrument. The sensor electrode array embedded in the concrete block was used to make in situ measurements of chloride ion concentration (Cl^-) and the resistivity (ρ) of the concrete as well as the polarization resistance (R_{pol}) of an electrode made from reinforcement steel. The sensor electrode array embedded in the test block has the same geometric configuration and material composition as the electrodes to be used in the ECI commercial product.

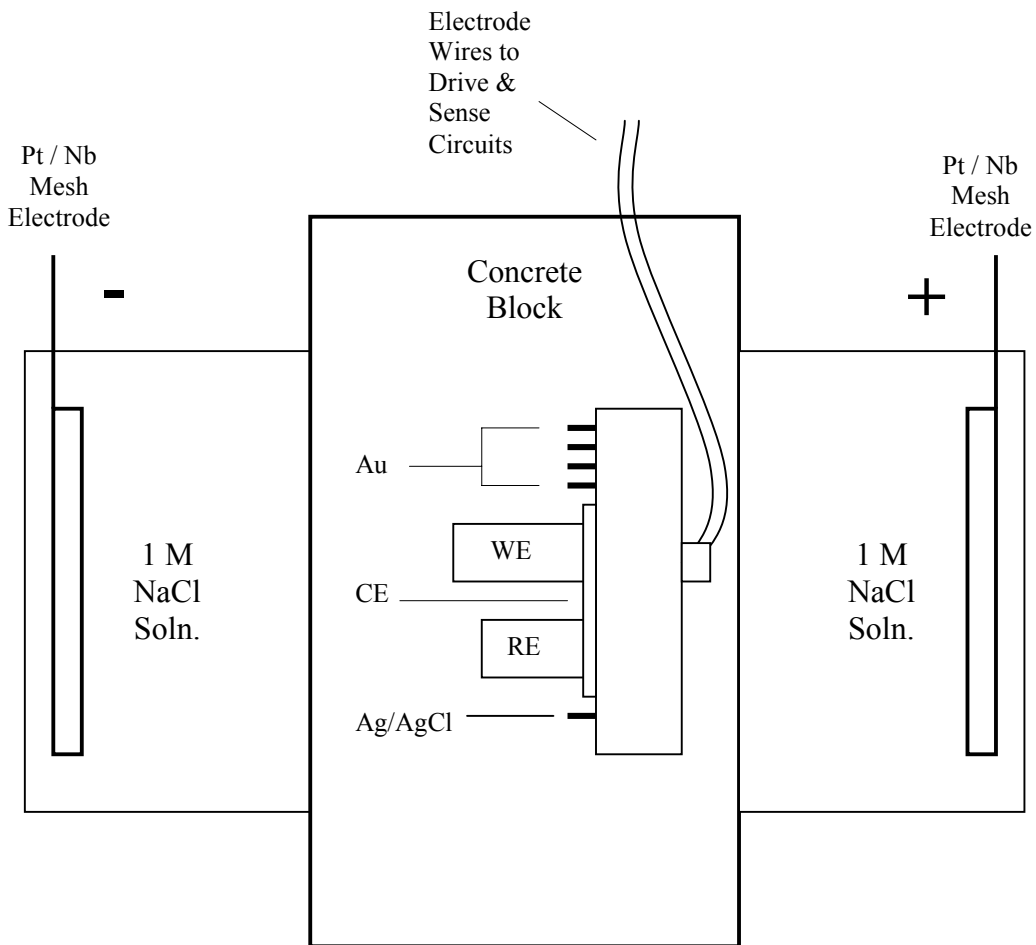


Figure 1. Embedded Corrosion Instrument Test Setup

The chloride ion concentration was measured by recording the potential of a calibrated Ag/AgCl electrode versus a MnO_2 Reference Electrode (RE). The resistivity of the concrete was measured with a four pin Au probe. The Working Electrode (WE) of the potentiostat was a piece of reinforcement steel, the Counter Electrode (CE) was made

of Pt / Nb mesh. The RE is shared with the chloride ion sensor. The electrodes were mounted on an acrylic plate. Insulated conductors from the sensor electrode array were run out of the concrete block to be connected to the ECI and VersaSTAT for comparative measurements.

Chloride ingress in concrete is a lengthy process in the field. To facilitate this process two containers of 1 M NaCl solution were clamped to either side of the concrete block shown in Figure 1. Rubber O-rings (not shown) were used to provide a leak tight seal between the containers and concrete block. Pt / Nb mesh electrodes were placed in both containers to apply an electrostatic field with the polarity shown in Figure 1 to drive the Cl^- from left to right, towards the sensor electrode array. The chloride driving current was maintained at approximately 10 mA. The 1 M NaCl solution was changed on a regular basis to prevent the accumulation of hydroxide ions (OH^-) during the chloride driving process. The incoming Cl^- concentration shown in Figure 2 was measured with the Ag / AgCl electrode versus the MnO_2 reference electrode.

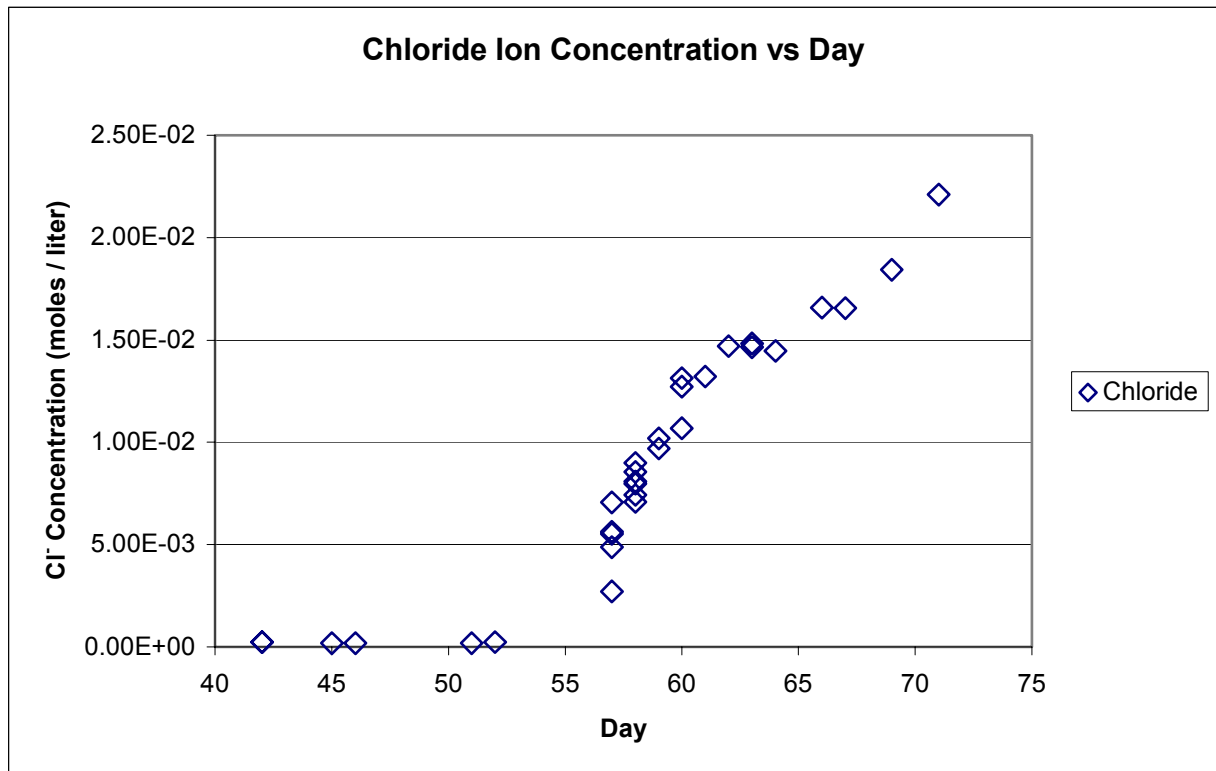


Figure 2. Chloride Concentration vs. Day

After curing for two weeks in a humidity chamber, the concrete block was connected to the NaCl containers. Even though the block had a significant portion of its surface area in contact with the NaCl solution it was observed to be slowly drying out by changes in the resistivity measured with the resistivity probe. These measurements were

made over time and the results are displayed in Figure 3. Comparing Figures 2 and 3 on day 57 of the measurements it can be seen that there is a marked increase in resistivity coinciding with the step increase in Cl^- concentration. This may be due to Cl^- displacing OH^- in the concrete. Since the mobility of Cl^- in concrete is less than that of OH^- the resistivity of the concrete was increased.

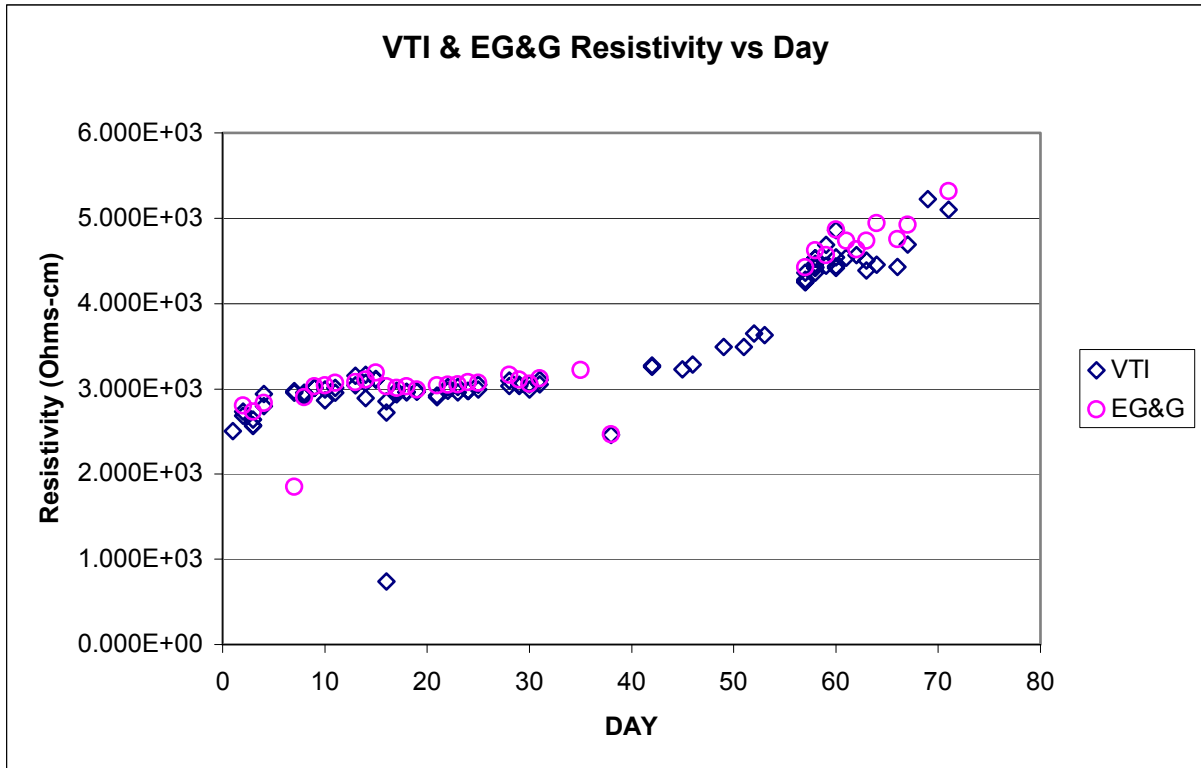


Figure 3. Resistivity vs. day

Figure 4 shows the depassivation of the reinforcement steel working electrode due to the increased concentration of chloride as evidenced by the changing R_{pol} . Data is only shown for R_{pol} from $1 \text{ M}\Omega\text{-cm}^2$ to $1 \text{ K}\Omega\text{-cm}^2$, which is the operating specification of the ECI. The Open Circuit Potential (OCP) of the steel was measured between WE and RE. The R_{pol} data were collected versus the open circuit potential measured on both the ECI and the EG&G VersaSTAT. The cell was passive ($R_{pol} > 1 \text{ M}\Omega\text{-cm}^2$) until Day 57 of chloride driving. The onset of corrosion in the WE corresponded to a sharp decrease in the Ag/AgCl - RE potential, a sharp increase in chloride ion concentration, and resulted in a rapidly changing OCP and R_{pol} . The depassivation occurred over a holiday weekend where the test cell was reading $2.4\text{-E}04 \text{ mol/liter Cl}^-$, -363 mV OCP and $1490 \text{ K}\Omega\text{-cm}^2 R_{pol}$ on a Friday, to measurements of $2.3\text{-E}03 \text{ mol/liter Cl}^-$, -636 mV OCP and $543.7 \text{ K}\Omega\text{-cm}^2 R_{pol}$ by the following Tuesday morning. This resulted in a gap in the data between $1 \text{ M}\Omega\text{-cm}^2$ and $550 \text{ K}\Omega\text{-cm}^2$. The rate of change in OCP and R_{pol} slowed but got as low as an OCP of -830.0 mV and R_{pol} of $206.9 \text{ K}\Omega\text{-cm}^2$ and eventually began

to repassivate. Chloride driving was again applied for two hours on Day 60. After only two hours of chloride driving the OCP was -1.069 V and the Rpol was 20 KΩ-cm². The cell slowly passivated again and chloride was driven again on Day 64 for an hour. This resulted in no significant change in the corrosion rate, which has reached a plateau at the time of this report.



Figure 4. Rpol vs. OCP

The data shown in circle A of Figure 4 were taken with the ECI with an incorrect gain resistor in the current range selector. This resulted in signals which were in the >10mV range and were lost to some extent in the noise floor of the system. The data in circle B were the result of a measurement error. These three measurements were made successively without allowing the OCP to stabilize between measurements. The data point in circle C was the result of the ECI prototype electronics measuring an incorrect value for the OCP prior to measuring Rpol. This should not present a problem in the final ECI products since a higher resolution analog to digital converter will be used.

The test cell has had Cl⁻ driven into the concrete for a total of 655.84 hours at a nominal current of 10 mA. The number of hours of chloride driving per day is shown below in Figure 5.

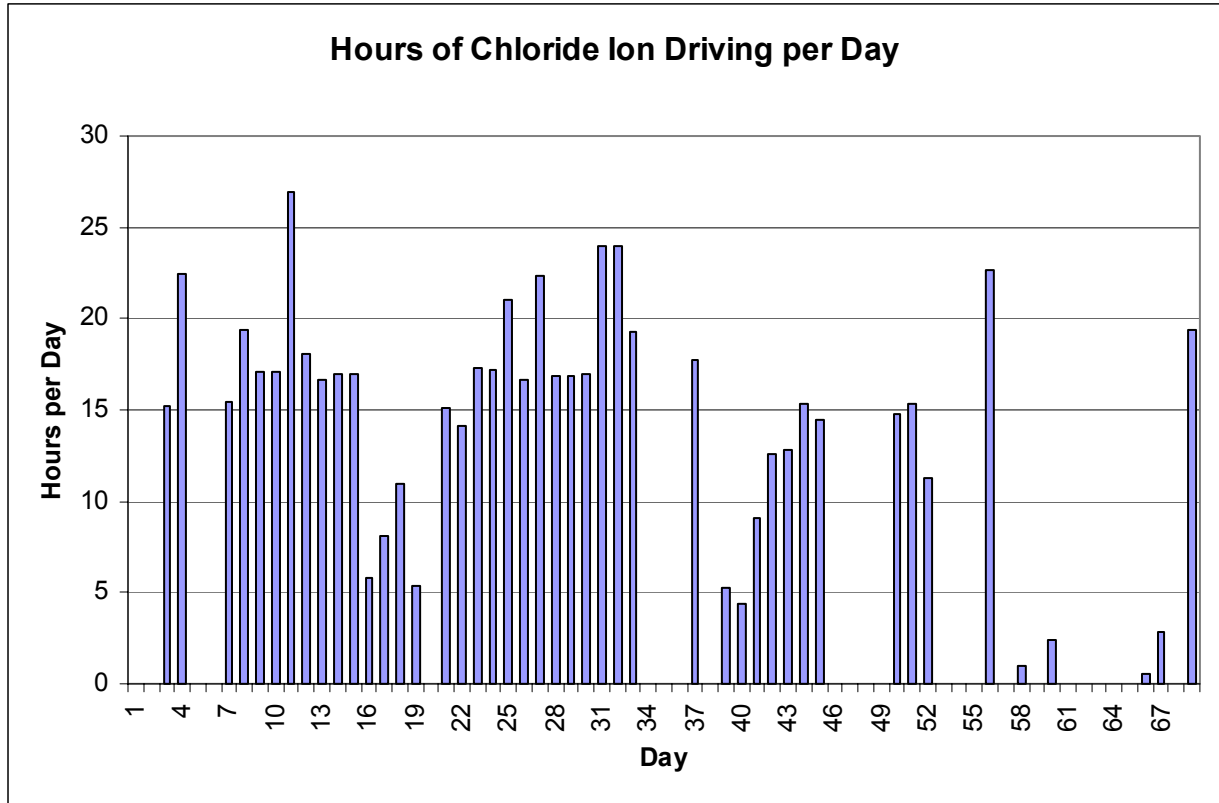


Figure 5. Hours of Chloride Ion Driving per Day

Conclusion:

The model ECI embedded corrosion instrument provided resistivity and polarization resistance measurements comparable to those of the EG&G VersaStat™. In addition it performs Cl⁻ concentration measurements. The geometric configuration and material composition of the instrument's electrodes in conjunction with its electronics allowed the ECI to produce repeatable measurements over its specified operating range.