Galvanostatic Pulse Measurement (GPM)

Target of Investigation

GPM is used to estimate the corrosion rate of steel in steel-reinforced concrete structures. The corrosion rate is very important for determining how fast a concrete member is deteriorating; this determination is not possible with either the ER or HCP technologies. GPM is also advantageous in corrosion risk assessment over HCP measurement in situations when concrete is wet, dense, or polymer-modified, and thus the access to oxygen is limited.[(1)]

Description

GPM is an electrochemical NDE technology used for rapid assessment of rebar corrosion, primarily to estimate the corrosion rate for steel rebars. GPM is based on the polarization of rebar using a small current pulse and measurement in the potential change.[(2)] GPM uses an electrode device positioned on a concrete surface and a reference electrode attached directly to the steel reinforcement to determine the half-cell potential, corrosion rate, and resistance between the reinforcement and device (figure 1).

Figure 1. Photo. Galvanostatic Pulse Measurement with Close Up of Control Unit.

This photo is of a technician demonstrating the proper operation of the galvanostatic pulse method. The technician is kneeling on a concrete deck, focused on the display screen in his left hand while pressing the probe to the concrete with his right hand. One inset shows a closeup view of the control unit, which has a small display screen and keyboard. Another inset shows the probe. The upper part of the probe is a handheld rounded tube. Wiring from the control unit enters the upper end of the tube. The bottom of the tube is attached to a large round *sponge that, when dampened, allows a pulse from the electrode to enter the concrete.*

Physical Principle

The GPM corrosion assessment is based on the measurement of the current required to change the potential difference between the reinforcement and a standard reference electrode. The current is a result flow of electrons from the anodic and cathodic sides in concrete. The anodic side is a corroding rebar where there is surplus of electrons on the base metal as a result of releasing metal ions into an electrolytically conducting liquid. Those excess electrons flow to a cathodic side, concrete with oxidizing agents in the liquid, inducing a corrosion current between the two sides. Knowing the current and voltage allows an inspector to determine the polarization resistance, which is related to the rate of corrosion. The GPM test is conducted by first applying to counter electrode a number of anodic DC pulses (5-400µA). The first, stronger pulse is between 3 to 60 seconds, and its intensity will primarily depend on the properties of the object under investigation. Several smaller consecutive pulses of gradually increased intensity may follow the first pulse. The objective of applying DC pulses is to obtain a sufficiently high polarization, at which point potential variations are recorded by means of a reference electrode (figure 2). Noncorroding or passive reinforcement possesses no current and thus will have a high resistance to current flow which is reflected in a potential shift of around 100 mV.[3] Active corrosion is likely when the potential shift gets smaller. This can be also explained as an actively corroding system can quickly compensate for a removal of electrons due to the corrosion reaction or polarization achieved by the current pulse remains low in an actively corroding area.

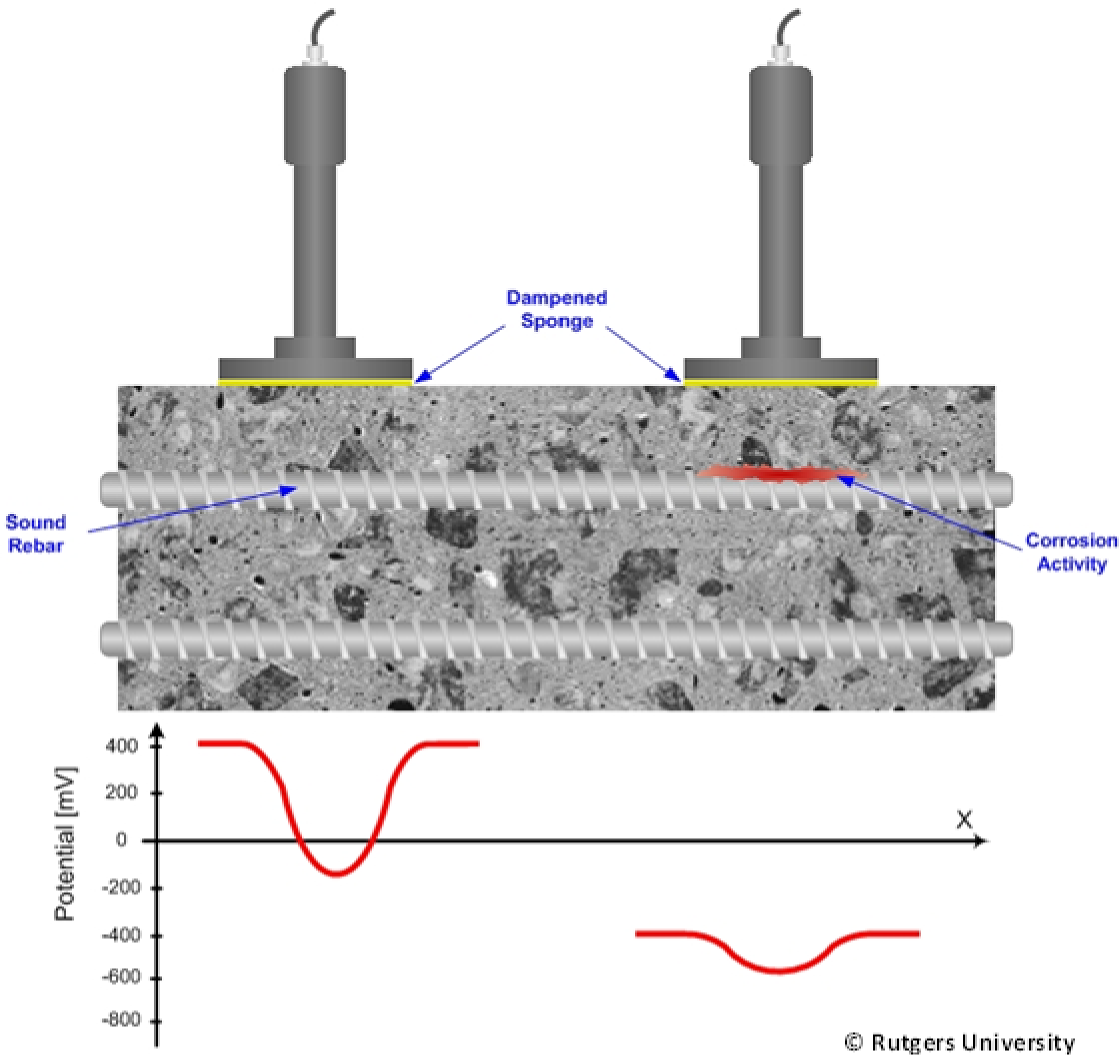

Figure 2. Composite Graph. Galvanostatic Pulse Measurement of Corrosion Activity.

This figure consists of two graphics. The graph on the top is a two-dimensional side view of a portion of a concrete slab. Two horizontal rebars, one above the other, are embedded in the slab. The left portion of the upper rebar is labeled "Sound Rebar." A portion of the right side of the upper rebar is labeled "Corrosion Activity." Two galvanostatic pulse method probes are resting on the upper surface of the slab. Each probe's dampened sponge is in contact with the slab. The probe on the left is above the sound portion of the rebar. The probe on the right is above the portion of rebar labeled "Corrosion Activity." The graph at the bottom compares the effect of corrosion on a test current from a galvanostatic pulse method probe. The y-axis of the graph is potential in millivolts. The x-axis is location. The location corresponding to the noncorroded sound rebar shows higher potential than the location corresponding to the rebar with corrosion activity.

Data Acquisition

For data collection using the galvanostatic pulse method on concrete pavement, follow the procedure described in ASTM C876-09, *Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete*. The procedure is summarized as follows:[4]

1. Identify points or lay out a grid for data collection on the pavement, ensuring that points are not so close together that measurements overlap and are not so far apart that localized corrosion is missed.
2. Electrically connect the reinforcing steel to the positive lead of the system (figure 3). The following are typical steps to accomplish this procedure:
    a. Locate the steel using a rebar locator, drill down to the reinforcement, and connect a lead wire to the steel using a self-tapping screw drilled into the rebar.
    b. Ensure all measurement locations are electrically continuous with this tap.
    c. Confirm that the entire survey area is covered; this may require multiple taps and corresponding measurement areas.

Figure 3. Photo. Electrical connection to exposed reinforcement steel.[1]

This photo shows the connection of a galvanostatic pulse method device to an exposed rebar. An alligator clamp is attached to the rebar. A small cable connects the clamp to the device, which is sitting on the concrete surface.

3. Electrically connect the reference electrode to the negative lead of the system.
4. Wet the contact sponge of the reference and counter electrodes to ensure good electrical contact with the concrete pavement; prewetting can also be used if conditions allow. The following steps describe the prewetting process:
    a. Wet the entire surface of the testing locations but make sure no free surface water remains between test locations before taking measurements.
    b. Place a prewetted sponge on each test location before taking measurements and leave it in place for the duration of collection at that location.
5. Place the reference electrode on the test point (figure 4).

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Figure 4. Photo. Data collection with galvanostatic pulse system.

The photo shows an operator placing a galvanostatic pulse probe on a concrete surface for data collection. The probe's wet sponge is in contact with the concrete surface.

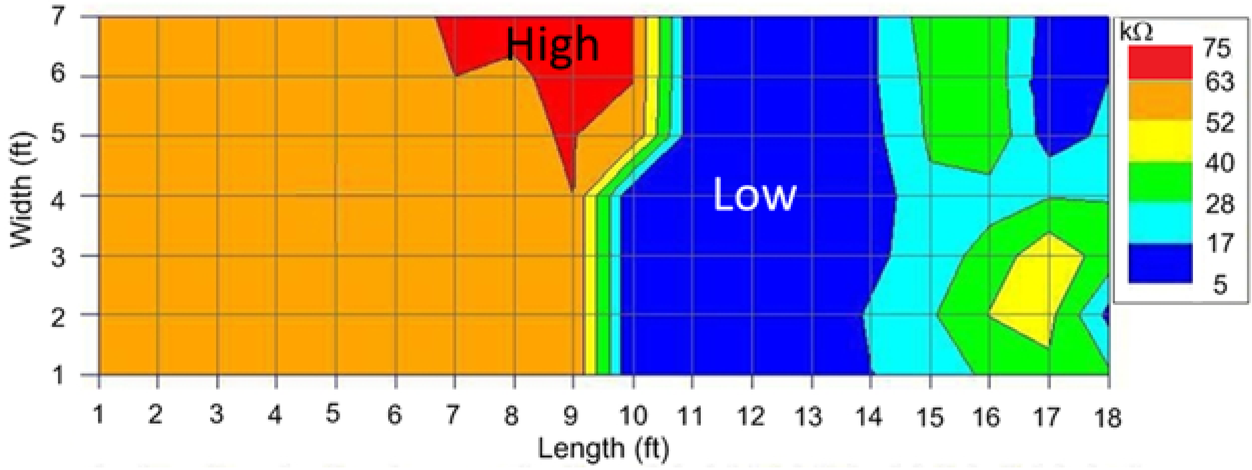
6. Adjust the current pulse amplitude with one strong and then several shorter pulses until the reinforcing steel reaches a sufficiently high polarization.
7. Record the potential variations using a handheld computer with data acquisition software.
8. Move to the next test point and repeat the collection procedure.
9. After testing is completed, patch all tap locations.

Data Processing

Typically, no processing is performed for data collected using the galvanostatic pulse method. The system usually has contour-mapping software for gridding and plotting data for visualization purposes. The slope of the potential–time curve measured during the current pulse can be used to provide information about the corrosion state of the steel reinforcement, and the potential data can be used to obtain a measure of the concrete ER for a given concrete cover depth.

Data Interpretation

Figure 5 and figure 6 are typical contour maps from a galvanostatic pulse method survey. Figure 5 is an ER map that shows values ranging from 5 to 63 kΩ. Areas with lower ER values indicate a higher probability of a corrosive environment from the intrusion of moisture, chlorides, and salts in the concrete. Areas with higher ER values indicate a noncorrosive environment.



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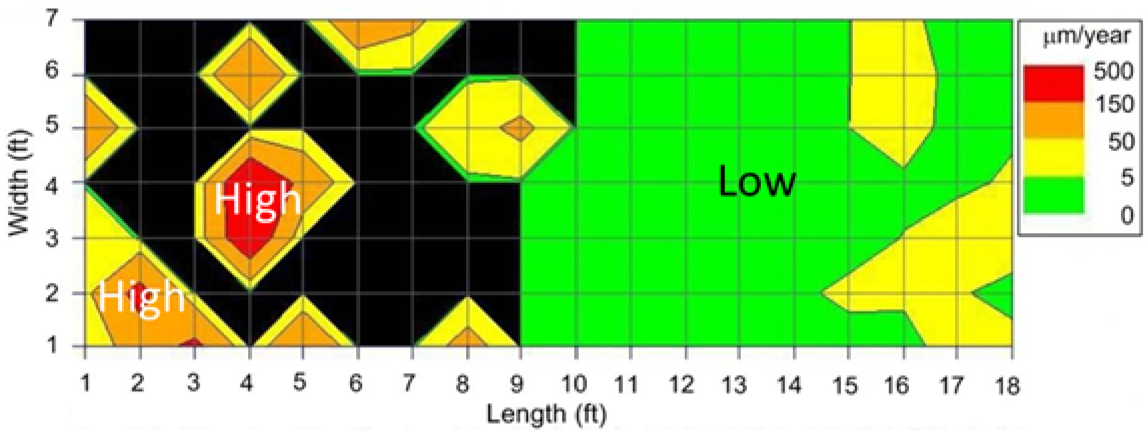
1 ft = 0.3 m.

Figure 5. Contour map. Concrete ER from a galvanostatic pulse method survey.[5]

This contour map shows the concrete electrical resistance measured by the galvanostatic pulse method. A grid overlays the map. The x-axis is length in feet, ranging from 1 to 18. The y-axis is width in feet, ranging from 1 to 7. The entire graph is color-coded to indicate electrical resistivity in kilohms. The left side has high resistivity and is labeled "High." The highest measurement, which covers much of the graph between x equals 1 and x equals 9, ranges from 52 to 63 kilohms. The right side has low resistivity and is labeled "Low." The lowest measurement, which covers much of the graph between x equals 10 and x equals 14, ranges from 5 to 17 kilohms.

From the corrosion rate, cross section loss can be estimated using Faraday's law of electrochemical equivalent. Figure 6 shows cross section loss assuming that a corrosion rate of 1 $\mu A/cm^2$ (6.45 $\mu A/inch^2$) corresponds to a cross section loss of about 11.6 µm/yr (0.457mils/yr) for carbon steel.



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1 ft = 0.3 m; 1 µm = 0.039 mils.

Note: Black indicates no data for those areas.

Figure 6. Contour map. Estimated section loss based on corrosion rates from a galvanostatic pulse method survey.[5]

This contour map shows the corrosion rate of steel reinforcement measured by the galvanostatic pulse method. A grid overlays the map. The x-axis is length in feet, ranging from 1 to 18. The y-axis is width in feet, ranging from 1 to 7. The entire graph is color-coded to indicate the corrosion rate in micrometers per year. The left side has high corrosion rate and is labeled "High." The highest measurement, which covers a small area centered on x equals 4 and y equals 4, ranges from 150 to 500 micrometers per year. The right side of the graph has low corrosion rates and is labeled "Low." The lowest measurement, which covers much of the graph between x equals 9 and x equals 18, ranges from 0 to 5 micrometers per year.

The obtained corrosion rate is an instantaneous average value. A more detailed knowledge of the daily and seasonal changes in the corrosion rate is required to obtain lifetime predictions of service life and condition. The data obtained from the galvanostatic pulse method survey should be combined with data from other nondestructive tests and other investigations to determine concrete integrity and penetration rates.[1]

Advantages

Advantages of the galvanostatic pulse method include the following:

- Calculates reinforcement steel corrosion rates.
- Obtains HCP and ER measurements.
- Requires low to medium level of expertise to operate data collection equipment.
- Does not require much data processing.

Limitations

Limitations of the galvanostatic pulse method include the following:

- Requires electrical connectivity to reinforcing steel throughout test area.
- Gives unstable measurements when ER of the concrete cover is high.[1]
- Requires a few minutes for stabilization of potential before measurements can be recorded.[1]
- Is time consuming and labor intensive for large survey areas.
- Cannot be used with epoxy-coated reinforcing steel.[4]

References

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4. ASTM C876-015 (2015). “Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete.” *Book of Standards 03.02*, ASTM International, West Conshohocken, PA. Strategic Highway Research Program. (n.d.) “SHRP2 NDToolbox.” (website) Washington, DC. Available online: https://www.fhwa.dot.gov/goshrp2/Solutions/Operations/R06/NDToolbox, last accessed