LINEAR POLARISATION RESISTANCE (LPR) EQUIPMENT

“MONITORING YOUR STEEL REINFORCEMENT”
Introduction

BAC Corrosion Control Ltd (BAC) has introduced a range of specialist products for monitoring and determining the presence and rate of corrosion to steel reinforcement in concrete structures and buildings.

These products can be used to establish whether Cathodic Protection (CP) is needed on a structure by installing them at the build stage or retro fitting them to existing structures and then analysing the information obtained.

Corrosion monitoring

In steel reinforced concrete structures, corrosion monitoring of the rebar has become increasingly important. The steel reinforcement in concrete structures is susceptible to corrosion when chloride ions enter into the concrete from de-icing salts, or from seawater in marine environments or other chloride rich sources.

The passive film on the reinforcing steel can be broken down by carbonation and the presence of chlorides from de-icing or marine salts resulting in corrosion. Other factors affecting the corrosion rate include Oxygen content, moisture presence and temperature. Corrosion of the steel reinforcement can weaken the structural strength, create cracking, delamination and spalling of the concrete.

Structures of importance

- Road decking, bridges & car parks
- Tunnel walls (monitor seepage from bedrock)
- Water intake structures
- Marine located piers, jetties, docks & caissons
- Nuclear installations & storage facilities
- Buildings in corrosive environments

Linear Polarisation Resistance

The Linear Polarisation Resistance technique measures corrosion rate continuously in real-time. This electrochemical measurement is based on applying a small potential shift to a corroding metal electrode, the resultant current being proportional to the corrosion rate. LPR instrumentation converts the current measured to corrosion rate readings in $\mu$m/yr/100cm$^2$.

Theory

Corrosion potential readings using Silver/Silver Chloride (Ag/AgCl) reference electrodes provide limited information easily influenced by differing salt content, moisture content and temperature within the concrete. Corrosion standards and potential results are often assessed against comparative tables provided in a number of technical publications, including those in ASTM C876 which suggest that steel potentials more negative than -0.300V against Ag/AgCl indicate corrosion activity. It is, however, now well understood that wet or even moist concrete can limit oxygen availability to the steel, which can lower steel corrosion potentials, sometimes to -0.700V or more negative against Ag/AgCl, even though corrosion activity is not increased significantly.

Carrying out LPR corrosion rate surveys provides an estimate of both the corrosion potential and corrosion rate at the time of testing. These two parameters can be analysed or mapped onto contour maps. Correlation between the corrosion potentials and the corrosion rates generally increases confidence levels in condition assessment.
ASTM C876 Interpretation of corrosion potentials

<table>
<thead>
<tr>
<th>Corrosion Potential (Ag/AgCl)</th>
<th>Probability of Corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less negative than -0.150 V</td>
<td>90% probability of no corrosion</td>
</tr>
<tr>
<td>Between -0.150 V and -0.300 V</td>
<td>an increasing probability of corrosion</td>
</tr>
<tr>
<td>More negative than -0.300 V</td>
<td>90% probability of corrosion</td>
</tr>
</tbody>
</table>

Interpretation of corrosion rates

<table>
<thead>
<tr>
<th>Corrosion Rates (µm/yr)</th>
<th>Probability of Corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1</td>
<td>negligible corrosion rate</td>
</tr>
<tr>
<td>Between 1 – 10</td>
<td>low corrosion rate</td>
</tr>
<tr>
<td>Between 10 - 100</td>
<td>moderate corrosion rate</td>
</tr>
<tr>
<td>Greater than 100</td>
<td>high corrosion rate</td>
</tr>
</tbody>
</table>

Steel in concrete corrosion trend

Corrosion of steel in concrete should normally be looked at as a medium to long term trend and not be interpreted from instant one off readings, although corrosion mapping using the portable LPR probe set can give a general picture when used to map a concrete surface with both potential and corrosion rate.

When concrete is new it will contain significant water volume and the potential (mV) of the steel will be correspondingly negative (not to be confused with corroding potential levels).

Similarly the corrosion rate will appear high.

As the concrete cures and dries it would be usual to see a positive increase in the steel potential and a reduction in the corrosion rate. Over time it should become stable.

After a period of stability and assuming that the steel starts to corrode, then the trend will tend to be reversed. Assuming that the concrete has not become waterlogged corrosion potentials and rates should then be relatively easily identified.

Figure 1 – Graph showing typical long term trends of steel in concrete corrosion

The above is a very simplified explanation of what generally happens and whilst use of the LPR equipment is relatively straightforward, the interpretation of the readings is not always so simple and this work should be carried out by a qualified person certified to at least level 2 (R Category) of the EN15257 standard or equivalent.
CL Ladder Probes

Corrosion monitoring CL Ladder probes are advanced embeddable corrosion rate probes for use on NEW build structures. The unique design has four independent LPR electrodes at varying levels of concrete cover which allows the determination of a variety of parameters relating to the condition of the structure.

Functions

- Corrosion rate & potential measurements at each of the four electrodes plus main steel reinforcement
- Electrical Resistance (between three pairs of electrodes)
- Temperature of probe
- Estimation of rate of ingress of corrosive substances

Operation

The probe is usually installed at an angle to the surface of the concrete as in the diagram. Each of the elements (numbered 1-4) is at increasing distances from the surface; hence any corrosive substances penetrating the concrete arrive at the electrodes sequentially. A sequential increase in corrosion rate over the probe elements 1 to 4 indicates the progressive ingress of corrosive substances.

Concrete electrical resistance can be measured between pairs of adjacent elements. This augments the corrosion rate data to provide an indication of the rate of corrosive substance ingress i.e. chloride ion ingress from seawater exposure.

A temperature measuring device is included to allow for temperature related variations in corrosion rate or electrical resistance to be factored out.

Figure 2 - Typical installation of a CL Ladder probe
Electrical connections to the rebar allow LPR corrosion rate and corrosion potential to be measured. Initially, after casting, it can be assumed that the corrosion rates of the rebar and the fourth element will be similar.

After casting, initial corrosion rate data can be used to calibrate the probe to account for the differing measured corroding surface area of the rebar and the elements, and as the element area is known accurately, henceforth a more accurate corrosion rate of the rebar can be calculated.

Features

- 25mm diameter Ag/AgCl reference electrode
- Stainless steel auxiliary electrode & pseudo-reference electrode
- Approx 180x130x75mm in size (excluding cable)
- Compatible with BAC Corrosion Control Ltd and BGB Projects Ltd's testing instrumentation
- Available with 21-core cable in four different lengths.
- Used for estimating corrosion potential, corrosion rate of steel reinforcement and carbon steel element.
- Robust construction designed for casting into concrete.

Retrofit Probes

The retrofit LPR probes are designed to be installed into existing steel reinforced concrete structures providing the basis for a corrosion monitoring system.

Common features across the range of probes:

- 15mm diameter Ag/AgCl reference electrode
- MMO-coated Ti auxiliary electrode
- MMO-coated Ti pseudo-reference electrode
- ~30 mm diameter, ~80 mm long

Additional feature for the stand alone probes:

- Unique 64-bit ID Chip
- IP68 connector

Installation

The probe body should be installed in a hole in the concrete approximately 35mm diameter and 85mm deep, with the probe being properly embedded and fully grouted into the concrete. For the Stand Alone probes (both types) the surface plate should be flush with the concrete surface.
For the remote monitoring compatible probes and the stand alone probe with flying lead, connection to the reinforcement bar at an appropriate location is by means of attaching the flying lead, terminated in a crimp ring connector, by either using a 5mm Taptite™ screw or direct BAC pin braze.

**Negative connection point**

For the stand alone probe, connection to the steel is via a negative connection point which will allow connections to be made to multiple probes around the structure for testing with a portable instrument. The negative connection (see below for differing types) point should be fully grouted into the concrete with the surface plate being flush with the concrete surface.

**Portable LPR Kit**

‘Bigfoot’ and ‘Littlefoot’ surface mounted probes were developed to provide assessment information on the corrosion condition of steel reinforcement by supplementing traditional surface mapping corrosion potential surveys.

**Features**

- BigFoot
- Littlefoot
- Resistivity Probe
- Extension pole
- Extension pole brackets
- Connection leads
Operation

The corrosion rate system using hand held LPR meters and ‘Bigfoot’ or ‘Littlefoot’ probes provides potential and corrosion rate simultaneously. Readings taken on a grid formation usually take some 30-90s at each reading site.

With a trailing test lead connected to the electrically continuous steel reinforcement, the probe is held against the concrete surface in a grid formation. The LPR meter carries out testing at each node point, recording the steel corrosion potential (mV or V against Ag/AgCl) and corrosion rate (µm/yr/100cm²). If the surface area of the steel beneath the probe diameter can be estimated, the factor is applied to provide an actual corrosion rate reading.

Resistivity meter

For use with the portable LPR kit, Megger DET4 Series Soil resistivity Meters are available from BAC. The DET4TD2 model is a dry-cell battery powered basic 4-terminal tester, and the DET4TR2 is a rechargeable battery powered tester.

Features

- 2, 3 and 4 point testing
- Stakeless (clamp-on) testing capability
- ART (Attached Rod Technique) capability
• Multiple, user selectable test frequencies
• Resistance measurement range to 200 kΩ
• IP54 rated
• Warning indicators prevent test failure
• Simple one button operation
• Included leads, stakes, calibration certificate and rugged carry case

LPR Meters

The LPR meters are used to carry out measurements of current parameters from the probe sets of steel reinforcement in concrete from embedded ladder probes, retrofit LPR probes and the BAC portable LPR probe set.

The portable meters are housed in rugged machined Aluminium cases and the use the LPR corrosion rate measurement technique. It is a self contained battery powered system which provides compatibility with all relevant probes.

Technical data

The corrosion rate range covered by the meters are from 0.2µm to 5mm/year for a 100 square centimetres surface area test electrode with the results being displayed on the meter screen. Both meters are able to identify Unique ID chips contained in the probes where present.

The Manual LPR meter is used to read the range of BAC retrofit probes as well as being used with the portable LPR kit. It can also be used to measure limited readings on the CL Ladder probes.

The Automatic LPR meter is used to read the BAC LPR ladder probes, and when switched to the manual mode, used to read the BAC retrofit probes and portable LPR kit.

Features

• Enclosure dimensions 160 x 75 x 220mm
• Weight 2.5kg
• Power supply battery Rechargeable batteries
• Temperature Range 0 to 50 deg C
• Corrosion potential -1024 to 1024mV
• Corrosion rate surface 0.2µm to 5mm/year
• Area (Max) 100cm²
• Resolution corrosion potential 0.5mV
• Memory 500 readings
• Clock type Real time

Supplied with

• Universal mains charger
• USB download cable
• Shoulder strap
• CD with utility software
**Manual meter leads available**

M1 - Cable lead 3 x 4mm plugs - 3 x 4mm plugs  
BAC Part No 160 004 0265

M2 - Cable lead 6 way - 3 x 4mm plugs  
BAC Part No 160 004 0233

M3 - Cable lead 3 Way - 8 Way  
BAC Part No 160 004 0268

**Automatic meter leads available**

A1 - Cable lead 26 way - 26 way  
BAC Part No 160 004 0290

A2 - Cable lead 26 way - 6 way  
BAC Part No 160 004 0288

A3 - Cable lead 6 way - 3 x 4mm plugs  
BAC Part No 160 004 0289

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**LPR Meter Protective Case**

For use with both the manual and automatic LPR meters, protective cases are available to ensure the meter is kept in pristine condition and allows the operator full use of the meter while encased.

**Utility software**

A free download utility is used to download the data from the meter and save it to a Microsoft Excel spread sheet. The imported data is automatically loaded into a table as shown below. Automatic and Manual readings are filtered and stored in two separate tabs on the form.

![Figure 5 - Screen shot of the LPR utility tool](image-url)
<table>
<thead>
<tr>
<th>Part No</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 004 0182</td>
<td>Portable LPR Kit (Complete)</td>
</tr>
<tr>
<td>160 004 0302</td>
<td>LPR resistivity probe meter kit (rechargeable) DET4TR2</td>
</tr>
<tr>
<td>160 004 0303</td>
<td>LPR resistivity probe meter kit DET4TD2</td>
</tr>
<tr>
<td>160 004 0219</td>
<td>Ladder probe + 5 meters of cable</td>
</tr>
<tr>
<td>160 004 0220</td>
<td>Ladder probe + 10 meters of cable</td>
</tr>
<tr>
<td>160 004 0221</td>
<td>Ladder probe + 15 meters of cable</td>
</tr>
<tr>
<td>160 004 0222</td>
<td>Ladder probe + 20 meters of cable</td>
</tr>
<tr>
<td>160 004 0141</td>
<td>Single Probe Terminal Box</td>
</tr>
<tr>
<td>160 004 0142</td>
<td>Double probe Terminal Box</td>
</tr>
<tr>
<td>160 004 0223</td>
<td>Retrofit Probe (Standalone)</td>
</tr>
<tr>
<td>160 004 0232</td>
<td>Retrofit Probe (Standalone) + Flying Lead</td>
</tr>
<tr>
<td>160 004 0298</td>
<td>Retrofit Probe (Wired) + 5 meters cable</td>
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<td>160 004 0299</td>
<td>Retrofit Probe (Wired) + 10 meters cable</td>
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<tr>
<td>160 004 0151</td>
<td>Retrofit Probe (Wired) + 15 meters cable</td>
</tr>
<tr>
<td>160 004 0300</td>
<td>Retrofit Probe (Wired) + 20 meters cable</td>
</tr>
<tr>
<td>160 004 0204</td>
<td>Negative Connection Kit - Taptite Type</td>
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<tr>
<td>160 004 0224</td>
<td>Negative Connection Kit - Pin Braze Type</td>
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<tr>
<td>160 004 0276</td>
<td>Manual Handheld Meter Set</td>
</tr>
<tr>
<td>160 004 0265</td>
<td>M1 Cable lead - 3x 4mm plugs to 3x 4mm plugs</td>
</tr>
<tr>
<td>160 004 0233</td>
<td>M2 Cable lead - 3x 4mm plugs to 6 way IP68 plug</td>
</tr>
<tr>
<td>160 004 0268</td>
<td>M3 Cable lead - 8 way plug to 6 way IP68 plug</td>
</tr>
<tr>
<td>160 004 0274</td>
<td>Manual Meter Lead Full Set</td>
</tr>
<tr>
<td>160 004 0277</td>
<td>Automatic Handheld Meter Set</td>
</tr>
<tr>
<td>160 004 0290</td>
<td>A1 Cable lead - 26 way plug to 26 way plug</td>
</tr>
<tr>
<td>160 004 0288</td>
<td>A2 Cable lead - 26 way plug to 6 way IP68 plug</td>
</tr>
<tr>
<td>160 004 0289</td>
<td>A3 Cable lead - 6 way IP68 plug to 3x 4mm plugs*</td>
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<tr>
<td>160 004 0286</td>
<td>Automatic Meter Lead Full Set</td>
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<tr>
<td>160 004 0224</td>
<td>Attaché Case (Replacement)</td>
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<tr>
<td>160 004 0332</td>
<td>LPR Meter Protective Case</td>
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<tr>
<td>160 004 0225</td>
<td>Spare battery (Replacement)</td>
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<td>160 004 0270</td>
<td>Detachable Neck Strap (Replacement)</td>
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<tr>
<td>160 004 0271</td>
<td>230V AC Mains Charger (Replacement)</td>
</tr>
<tr>
<td>160 004 0269</td>
<td>USB Cable (Replacement)</td>
</tr>
<tr>
<td>160 004 0272</td>
<td>Software CD (Replacement)</td>
</tr>
</tbody>
</table>

*A3 leads need to be ordered with A2 leads*