

Primer for the Inspection, Testing and Analysis of Electrically Continuous Reinforced Concrete Structures

Samuel R. Rivera Jr.
Piping and Corrosion Specialties, Inc.
8371 Jumpers Hole Road
Millersville, MD 21108
United States of America

ABSTRACT

This paper will present field verified methods for corrosion engineers and/or technicians to accurately inspect and log structure configuration, field conditions and perform field tests to verify electrical continuity prior to concrete operations (prepour testing). Additional topics will include troubleshooting as it pertains to prepour testing and also if a structure has already been poured (postpour) whether it was previously tested or not. The concluding topic addresses the utilization of project documents such as structural and shop drawings to extract relevant reinforcing steel information used in the creation of theoretical resistance and when to use either a standard mathematical analysis or Simulation Program with Integrated Circuit Emphasis (SPICE) software to develop said theoretical resistance as a computer model.

Key words: stray current, continuity, prepour, postpour, reinforcing steel, longitudinal, collector, bond, inspection, testing, analysis

INTRODUCTION

Population growth in city centers has spurred the expansion and new construction of direct current (DC) powered transit systems throughout the world¹. Despite stringent design criteria, quality assurance and quality control (QA/QC) monitored construction practices and ongoing track maintenance, it is a fact that DC stray current will eventually occur and negatively impact buried and/or submerged metallic structures immediately adjacent and within the transit right-of-way (ROW)². In combination with other methods to reduce stray current such as high track-to-earth (TTE) resistance values and shorter distances between substations, transit agencies are specifying the welding of reinforced steel structures within their purview such as retaining walls and footings, approach slabs, aerial inverts, and bridge abutments to prevent stray current from reducing the design life of surrounding metallic structures. The information presented in this paper is intended to share safe and efficient methods developed and refined in the field at multiple transit projects. However, these methods can be applied to projects exposed to transit as well as alternate sources of DC stray current. Consider nuclear power plants with facilities adjacent to high voltage direct current (HVDC) transmission lines and reinforced concrete buildings within the influence of impressed current cathodic protection (ICCP) systems set at

© 2022 Association for Materials Protection and Performance (AMPP). All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means (electronic, mechanical, photocopying, recording, or otherwise) without the prior written permission of AMPP.

Positions and opinions advanced in this work are those of the author(s) and not necessarily those of AMPP. Responsibility for the content of the work lies solely with the author(s).

levels to protect a multitude of underground metallic piping networks. The ultimate goal is that corrosion engineers and/or technicians successfully document visual inspections, develop efficient prepour and postpour continuity test methodologies, and construct accurate computer simulation models for data analysis.

VISUAL INSPECTION

The visual inspection of welded (bonded) reinforcing steel (rebar) structures is a process requiring the verification of the integrity and placement of critical welds in accordance with notes and/or details located within the project cathodic protection (CP) design and structural drawings. Visual inspection can be carried out by field personnel of all technical levels. However, it is beneficial to be familiar with the various configurations and terminology of said structures in order to extract and document the relevant information required for subsequent testing and analysis. The most elementary bonded rebar structure is the retaining wall and its footing, shown below in Figure 1:



Figure 1: Retaining wall footing

Retaining wall construction can depend on a variety of factors beyond this scope, we will focus on the most likely design one will encounter during typical visual inspections. The components consist of a footing, with a top mat and a bottom mat of rebar, and a wall above with an inner face and an outer face of rebar. These two-dimensional mats and faces are then bonded together with additional rebar (bond bars) or steel plates at the corners to create three-dimensional electrically continuous structures.

Rebar is typically fastened with ties, either metallic or non-metallic, but for stray current mitigation it is welded together in series-parallel circuits with longitudinal bars lap spliced³ as necessary and bonded at the ends to transverse (collector) bars. Longitudinal bars route stray current flow to the transverse (collector) bars that are usually installed at either the ends of a structure or at expansion joints. Transverse (collector) bars can also be installed where longitudinal bars are not easily lap spliced or at a construction joint for testing purposes. The use of bond jumpers, copper wire cables with thermite welded plates attached for field installation, maintain electrical continuity across said joints. See Figure 2 below which details the corner of a bonded rebar footing. There is a bond bar welded between the top mat and the bottom mat and also to the outermost longitudinal bar and the transverse (collector) bar along with a combination test lead/bond strap plate. Locking pliers are installed for continuity testing:



Figure 2: Bonded rebar footing corner

The orientation of longitudinal bars versus transverse (collector) bars may not, at first glance, be readily apparent. On occasion, the structural or CP design drawings may label these components within the reinforcing steel schedule for reference. However, it is more likely the corrosion engineer and/or technician will be called upon to direct welding operations in accordance with the project specifications.

How will one accurately determine the best welding layout to create a continuity circuit? There are two rules of thumb to discern longitudinal bars from transverse (collector) bars. The first rule identifies the longest bars in the system as the longitudinal bars and is the more cost-effective and easier procedure. The second rule is to identify the nearest transit right-of-way and direct welding so the longitudinal bars are in parallel with the track. There are situations where the rules may not align and field personnel will need to use good engineering judgement to determine which of these rules takes precedence over the other. For example, Figure 3 below shows a transit station under construction with the grade beam bonded perpendicular to the footing running in parallel with the direction of the track. The grade beam violates the second rule but the increased material costs and additional time required to weld each grade beam stirrup in the direction of the track outweigh the benefit of rebar bonding in this orientation:



Figure 3: Grade beam to footing construction

There are times when field personnel must rely upon the second rule, such as when a slab is sequentially formed in small sections for concrete placement rather than a large monolithic pour. The longitudinal bar orientation would need to be in parallel with the track despite the possibility of shorter reinforcing steel length. Bond jumpers are key here to create electrical continuity between the isolated slab sections and are usually routed through notches cut into the concrete forms.

Assuming the welding is in accordance with project specifications, the project contact will schedule the visual inspection with the corrosion engineer and/or technician. Standard documentation of a visual inspection should include but is not limited to the following: date, company project number, project label including address, weather conditions, shift (day or night), personnel onsite, structure(s), sketch detailing most relevant information usually in plan view or elevation view, rebar size, rebar type (uncoated or epoxy), longitudinal bar length, longitudinal bar spacing, transverse (collector) bar length, number of longitudinal bars, number of transverse (collector) bars, bond bar length, number of bond bars, bond jumper type and amount, and dowel size with location for extending continuity into the retaining wall above from the footing below.

It is the responsibility of corrosion engineers and/or technicians to communicate inspection results with project personnel of all levels, including but not limited to trades, inspectors, field engineers, superintendents, and government representatives. Project personnel should be notified when deficiencies are discovered during a visual inspection. Photos accompanied by a short text of the issues are usually sufficient if the welder is not present for corrective action during the inspection. Spray paint is very useful, before and after welding operations, to mark out a continuity circuit and also to mark missing, deficient and/or broken welds. Weld location gaps can be overcome with small lengths of rebar bonded into the space. Broken welds may be symptomatic of a missing mat chair, incorrect rebar installation, or at worst poor technique and should be marked in spray paint for corrective action. Proper welds may not hold under some circumstances such as a thick slab with work crews in constant movement at transverse (collector) bars. Lap splices typically hold due to their weld length but it depends on the lap type. Welds are often designated as “tacks” on cathodic protection design drawings when bonding longitudinal bars to transverse (collector) bars, but it must be related to project personnel that this is not meant to be a tack weld for fitting bars together temporarily⁴ but rather a large weld bead that will not easily break. It may be necessary to use a flashlight to inspect welds and their quality due to the layout of reinforcing steel in a structure which can obstruct the view of field personnel. At first glance a structure may even seem to be missing welds, but in practice certain structures such as abutment wingwalls and drilled shaft rebar cages may be welded from the opposite side of field personnel points-of-view. Safely feeling for the weld with a gloved hand will suffice in this instance where the trained eye or a camera cannot provide confirmation.

Since the system is reliant on the welding of many bars, there is opportunity for lower quality welds, weld breaks, and missed welds. When compared to a bonded rebar structure an isolated length of metal contains a smaller anodic discharge surface area relative to the cathode and can be consumed very quickly⁵. The visual inspection must be thorough to identify as many deficiencies as possible and have them corrected prior to concrete placement. An effective visual inspection will usually offset the need for troubleshooting unusually high measured resistance values during the testing phase due to an unnecessarily complex continuity circuit.

CONTINUITY TESTING

Once the corrosion engineer and/or technician completes an initial visual inspection of a bonded rebar structure and determines the welding is in accordance with the cathodic protection design drawings, said structure is now ready for electrical continuity prepour testing. Prepour testing is defined as the continuity testing of a bonded rebar structure prior to concrete placement operations. Similarly, postpour testing is defined as the continuity testing of a bonded rebar structure after concrete placement operations are concluded and the concrete is set. The focus of continuity testing moving forward will be on prepour testing while postpour testing will be revisited later in this section.

© 2022 Association for Materials Protection and Performance (AMPP). All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means (electronic, mechanical, photocopying, recording, or otherwise) without the prior written permission of AMPP.

Positions and opinions advanced in this work are those of the author(s) and not necessarily those of AMPP. Responsibility for the content of the work lies solely with the author(s).

Several factors governing a successful outcome when testing the effectiveness of a bonded rebar structure are as follows: time of day, weather conditions, access to the structure, and test connections applied to the structure. Only one of these factors is under the control of field personnel but we will attempt to maximize success of all factors.

Continuity testing time of day can be scheduled advantageously during a site break (e.g., lunch or shift change) with project personnel and usually accompanies a successful initial visual inspection. However, if welding or structure rework occurs after the initial visual inspection a subsequent visual inspection will be required prior to electrical continuity testing. Rework includes instances such as rebar installation with insufficient concrete cover or cut rebar compromising the continuity circuit. Field personnel may also be challenged by poor lighting conditions during a night shift. Project personnel may have lighting available for other site operations, but it is the responsibility of the corrosion engineer and/or technician to possess a flashlight, hardhat headlamp and other lighting accessories to properly illuminate the bonded rebar structure and a surrounding area for equipment setup prior to testing.

It is advantageous to monitor weather conditions as they can impact the terrain for equipment setup, obscure field personnel's view of the critical welded components within the structure, and at worst skew continuity circuit test measurement values. Conditions such as extreme heat, snow, and rain should be avoided when testing a bonded rebar structure if at all possible. These conditions can adversely affect test equipment to the point of malfunction and even damage. Extreme heat will make direct contact with and/or applying test connections to the reinforcing steel challenging and in some climates unsafe. Snow, depending on the amount, obscures a complete view of the bonded rebar structure, creates an unsafe environment for field personnel and can skew test measurement values similar to rain. Rain and fresh snowfall can mislead the corrosion engineer and/or technician as wet rebar conducts test current easily through metal to metal contact. Deficient welds missed during initial visual inspection may go on uncorrected since test data may be within the suspected range of resistance values. Field personnel will also need to find cover from the rain in order to record legible continuity test data for analysis.

There are many types of reinforced concrete structures which may be welded for continuity and each has different methods for access. For example, access to a footing may be as simple as stepping over the soil cutout onto the rebar mat but field personnel will likely need to don a harness for a ladder climb to abutment wingwall scaffolding. A pile cap may require both ascending and descending ladders from a scaffold for entry. A slab may be so deep below grade that test equipment must be tied off with a rope and lowered to the area prior to descending into the work area. On rare occasions the corrosion engineer and/or technician may need to use an aerial work platform to reach bonded rebar structures. Safe access to the structure requiring continuity testing must be a consideration prior to setting up the test equipment.

With the prior factors accounted for by field personnel, it is now time to set up the testing area and connect test equipment to the bonded rebar structure. So which arrangement of test equipment and test connections sufficiently captures valid field data for various structures such as grade beam, footing, track invert or even complex configurations like stem wall to slab? We will need to briefly refer to Ohm's Law so the selection and connection of test equipment becomes clear. The definition of Ohm's Law states the strength of a direct current (I) is directly proportional to the potential difference (V) and inversely proportional to the resistance (R) of the circuit, see Equation 1 below:

$$V \text{ (potential difference)} = I \text{ (applied current)} * R \text{ (circuit resistance)}$$
$$V = IR$$

Equation 1: Ohm's Law

There is a more useful rearrangement of Ohm's Law for the purposes of bonded rebar continuity testing and analysis as shown below in Equation 2: