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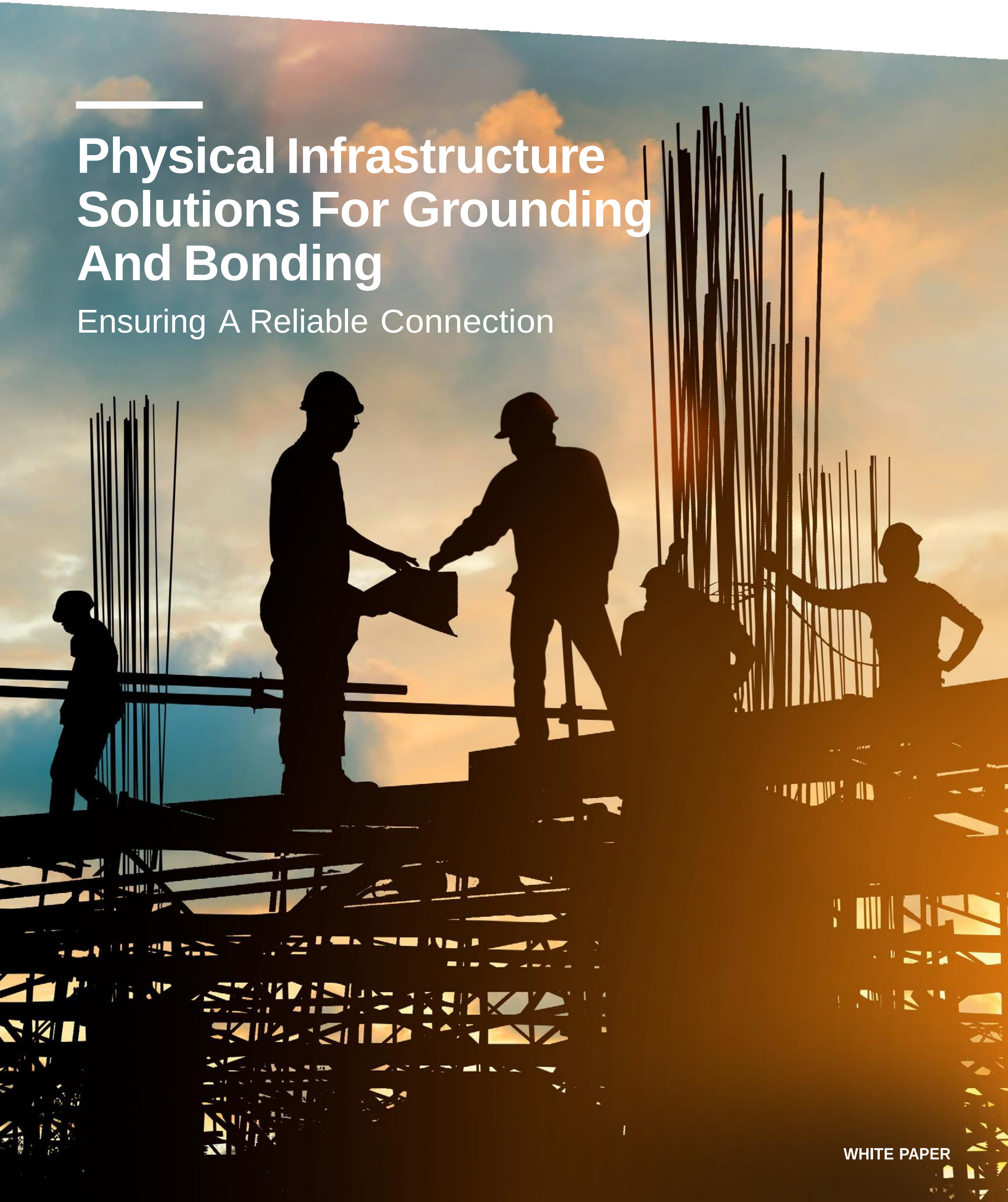
Physical Infrastructure Solutions For Grounding And Bonding

Ensuring A Reliable Connection



WHITE PAPER

Grounding compression systems have historically been questioned when it comes to harsh environments such as corrosive soils or freeze-thaw cycles of seasonal climates. Compression grounding connector systems offer numerous benefits over traditional exothermic welding systems; however, these harsh conditions and environments have been thought to compromise connections over extended periods of time. Due to connection reliability being the critical piece of long-term integrity of a grounding and bonding system, compression connectors are forced to debunk the myths regarding their reliability.

Introduction

The Institute of Electrical and Electronics Engineers (IEEE) resolved the dilemma of connection reliability by releasing the IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding (IEEE Std. 837-1989), which laid out the guidelines for testing the quality of connections in subgrade grounding electrode systems. A revision followed in 2002 (IEEE Std. 837-2002) which made testing conditions more severe, and another in 2014 (IEEE Std. 837-2014) has further altered requirements. These testing requirements apply to any permanent connection, not just compression, and can be addressed in three parts.

The first of these qualifications involves a mechanical pull-force test to ensure that a stable connection cannot be interrupted during installation or by any incidental mechanical forces. The second is an Electromagnetic Force (electrical current) test to ensure the grounding electrode system can withstand high electrical stress. The last of the testing requirements is a sequenced environmental simulation that aims to emulate a demanding life cycle for the connectors. Successful testing in these three areas imply compliance to the IEEE Std. 837.

This paper explores the importance of implementing a grounding infrastructure that complies with this standard to optimize the performance of the below grade grounding electrode system. This paper also aims to identify the key differentiators that prove compression grounding to be a safe and more efficient connection method over traditional exothermic welding.

It is important to note there is no agency backing, listing, or approval required for this standard. It is recommended to validate compliance by reaching out to suppliers for testing data. To help understand these results, Panduit has outlined the essential information associated with the testing in the following sections.

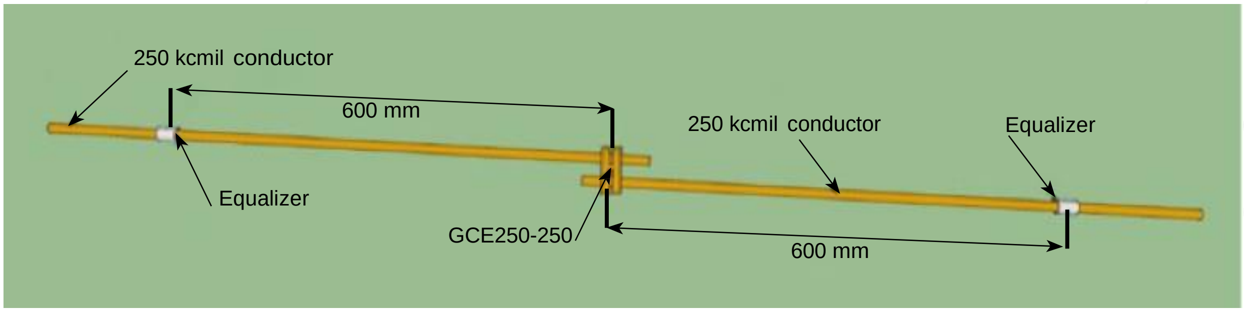
IEEE Std. 837-2014 Overview

All versions of the IEEE Std. 837 recognize that the best indication of connection degradation involves the change in resistivity, or impedance, of a connection. By measuring the resistance of a connection at the beginning and end of a test sequence, a comparison of the values is used to evaluate how much damage has occurred from the test conditions. Paired with visual inspection and other metrics, connector reliability is validated or disproven by these results.

Resistance is what it sounds like—a property of a material that resists the flow of electricity. Resistance, or lack thereof, is key to system health and reliability. The flow of electricity is dependent upon a variety of factors; but the most important of these is the surface area of the metal-to-metal contact that exists between a connector and the conductor(s). Imperfections, corrosion, or other means of separation of the contact surface each contribute to increasing the resistance. Therefore, a connection that can maintain its low resistance throughout a lifetime of exposure to variables that increase the likelihood of separation, can be considered a reliable connection.

Resistance measurements are usually taken at the beginning and end of both the Sequential and Electromagnetic Force (EMF) Tests; however, in the 2014 revision of the standard, the resistance requirement has been removed from the EMF test parameters and remains only in the Sequential test requirements. The IEEE Std. 837-1989 originally allowed for a 150% increase in resistance as a result of these tests, but the new acceptable value for the 2002 and 2014 editions has been limited to a 50% increase in resistance. See Figure 1 for more information.

IEEE Std. 837-1989	IEEE Std. 837-2002
$Resistance_{final} = Resistance_{initial} \times 2.5$	$Resistance_{final} = Resistance_{initial} \times 1.5$



Resistance measurements were made using a micro-ohmmeter from equalizer to equalizer on a test setup as illustrated above. The use of equalizers and distance between the equalizers and the connector is dictated by IEEE Std. 837. Resistances were taken at dimples in each equalizer to ensure that the measurements were always conducted in the same location.

Figure 1. Calculating the allowable resistance change.

Electromagnetic Force Test

Other revisions to the EMF test include testing only one connector at a time, the number of current cycles increasing to 15 from 12, and the most impactful change which nearly doubled the current (A) applied. See Table 1 for more information and Figure 2 for an image of a sample test setup. The higher current ratings are intended to further vet out less robust connections and ensure that even the smallest wire connections are safe from high fault energies. Due to the removal of the resistance test, failure or success of this test is defined by the movement and visual inspection of the connectors during and after the current is applied. The 2014 current values are aggressive, but the lack of resistance test may not necessarily prove a connection’s reliability. It may be beneficial to utilize 2002 results data in conjunction with 2014 data to justify the choice of connector for an installation.

Table 1. EMF Current Test Comparison Between IEEE Std. 837-2002 and -2014.

Conductor Size	2002 Test Current (kA)	2014 Test Current (kA)	Increase Multiplier
#2 AWG	6.7	15	2.24
1/0	10.7	23	2.15
2/0	13.4	29	2.16
3/0	16.9	37	2.19
4/0	21.3	47	2.21
250 kcmil	25.3	52	2.06
500 kcmil	50.4	75	1.49

Figure 2. EMF test setup involving a Panduit GCE connector.

Mechanical Pull Test

The second most impactful change from the 2002 to 2014 revisions of IEEE Std. 837 is the change in mechanical pull test requirements. Connectors must now meet UL/CSA pullout requirements instead of the IEEE determined values, which can be seen in a side-by-side comparison in Table 2. The pull test is primarily used to determine if a connector can hold up to tensile forces (intentional or accidental) during installation, but is also another testament to the performance of the connection. Less secure connections can contribute more to resistance or allow for corrosive elements to affect resistance more by penetrating gaps. As discussed previously, this impact on resistance can prove the connection to be less reliable. It is recommended to reference the IEEE Std. 837-2002 requirements for this reason.

It is important to note that pull tests are performed separately from the sequence test and that any difference in secureness resulting from a pulling force may invalidate the sequence testing. If there is ever a concern about a connection, it is always best to replace it with a new connection that will ensure safety and reliability.

Range taking connectors, such as Panduit's StructureGround™ line of GCE E-style connectors, will require different combinations of individual trials to ensure pullout forces can be reached no matter the conductor size. An example of the results of this test can be found in Table 3.

Table 2. Comparison of IEEE Std. 837-2002 and 2014 Pullout Force Requirements.

Conductor Size	IEEE Std. 837-2014 (UL/CSA) pullout force (N)	IEEE Std. 837-2002 pullout force (N)
#6 AWG	445	1,335
#4 AWG	623	1,335
#2 AWG	801	1,335
1/0	1,113	1,335
2/0	1,235	2,225
4/0	2,003	2,225
250 kcmil	2,225	4,450

Note: 1 Newton : 0.225 lbf

Table 3. Results of Mechanical Pull Testing for Panduit GCE250-250 Connector.

Conductor Combination Tested		IEEE 837-2002 Min Pullout (lb)	Trial Number and Pullout Attained			
Main	Tap		Trial 1 (lb$_r$)	Trial 2 (lb$_r$)	Trial 3 (lb$_r$)	Trial 4 (lb$_r$)
250 kcmil	250 kcmil	1,000	1,513	1,516	1,471	1,658
250 kcmil	1/0	300	1,521	1,256	1,408	1,318
1/0	1/0	300	1,732	1,707	1,456	1,225
1/2" Copper Bond Rod	250 kcmil	500	1,708	1,458	1,124	1,346
1/2" Copper Bond Rod	1/0	300	1,712	1,421	1,412	1,258
5/8" Copper Bond Rod	250 kcmil	1,000	1,783	1,383	1,643	1,589
5/8" Copper Bond Rod	1/0	300	1,477	1,488	1,392	1,514
3/8" Rebar	250 kcmil	300	1,683	1,754	1,757	1,718
3/8" Rebar	1/0	300	1,988	1,651	1,757	2,119
1/2" Rebar	250 kcmil	500	1,745	1,747	1,824	1,589
1/2" Rebar	1/0	500	1,561	1,889	1,923	1,355

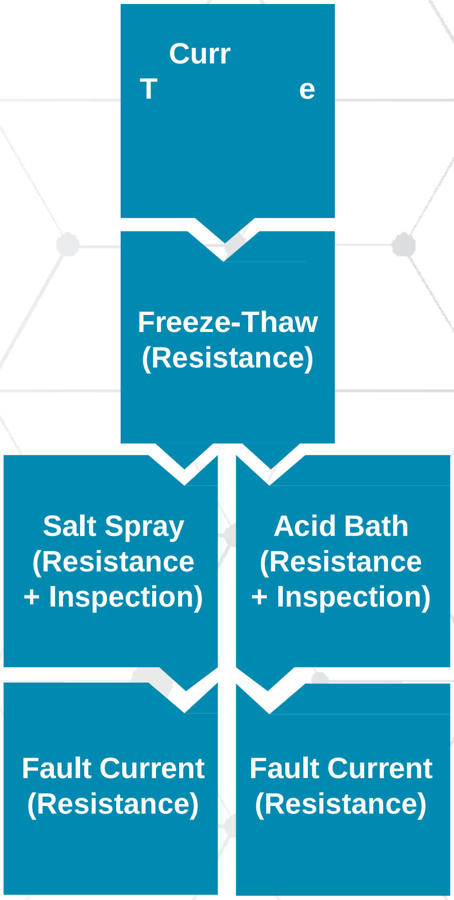


Figure 3. Series of sequential tests with criteria for success noted in parenthesis.

Sequential Testing

The last section of testing is a sequential set of harsh condition testing that is separate from the high intensity electrical test. The sequence test follows the format shown in Figure 3. The current-temperature cycling and freeze-thaw test will start the test sequence regardless of the path that the sample connectors will follow. After these two tests, the connectors will either be submerged in an acid bath or will be held in a chamber with a salt spray apparatus. The connectors then have a fault current applied to them that ensures the connection can still serve its purpose after being exposed to these harsh conditions.

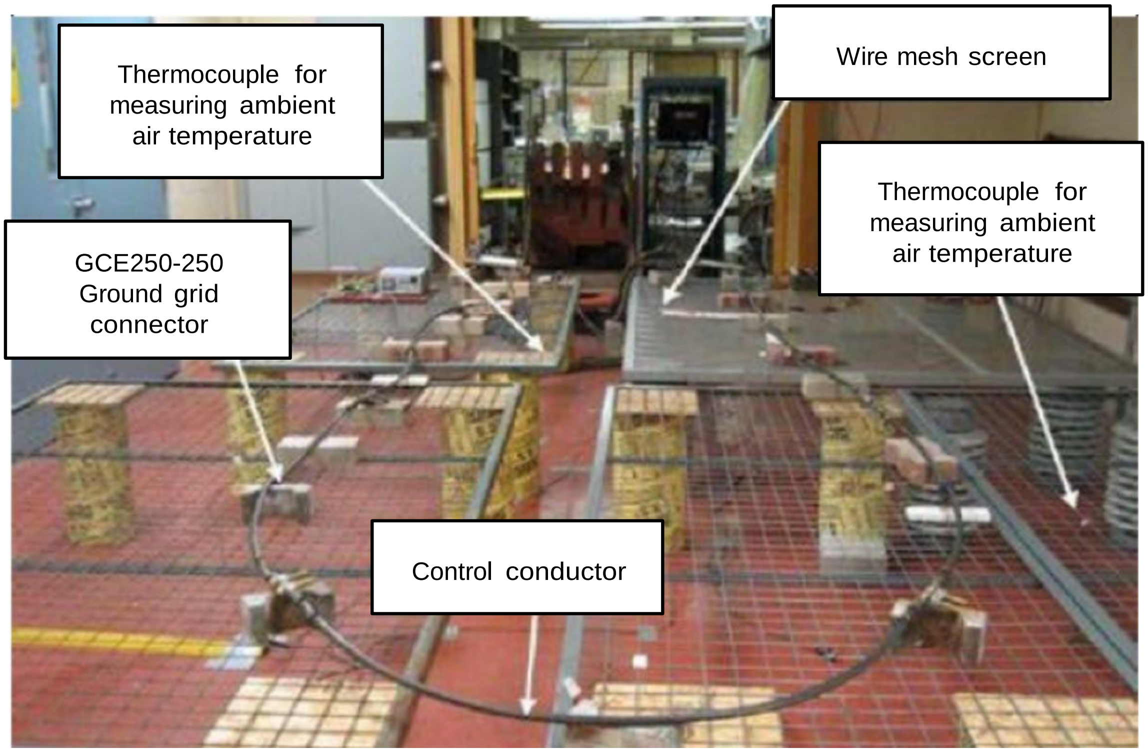


Figure 4. An example of a current-temperature cycling test setup.

Current – Temperature Cycling

The Current-Temperature Cycling test consists of a test loop with a sample connection that will be monitored by thermocouples. A section of the loop that has no connector is termed the “control.” Current is applied to the circuit until it raises the temperature of the control to 350˚C. This temperature is held for one hour, and afterwards the loop is allowed to cool to the ambient temperature before the next current is applied. The test is repeated for twenty-five cycles. A photograph of the test setup is shown in Figure 4.

The objective of the test is to ensure conformance to resistance criteria of connections subjected to temperature changes caused by fluctuating currents. The high temperatures achieved also serve to remove excess antioxidants that could otherwise block corrosive elements from attacking the joint between the connector and the conductor during subsequent tests in the series. Therefore, the sequence is important because it systematically provides exposure to the most difficult conditions.

Freeze-Thaw Test

Ideally, the grounding system is installed below the frost line, but connectors are often installed where they are subjected to freeze and thaw cycles. The IEEE Std. 837 test recognizes and accounts for it by subjecting the samples to ten freeze-thaw cycles. The freeze-thaw test is an attempt to work water into the joint between the connector and the conductor. If water gets into this area and the system is frozen, the water will expand as it turns into ice. This acts as an internal mechanical force that can push open the connection. Failure of this test will result from increased connection resistance that is due to the decreased contact area of the wire-connector joint. Test setup is shown in Figure 5.

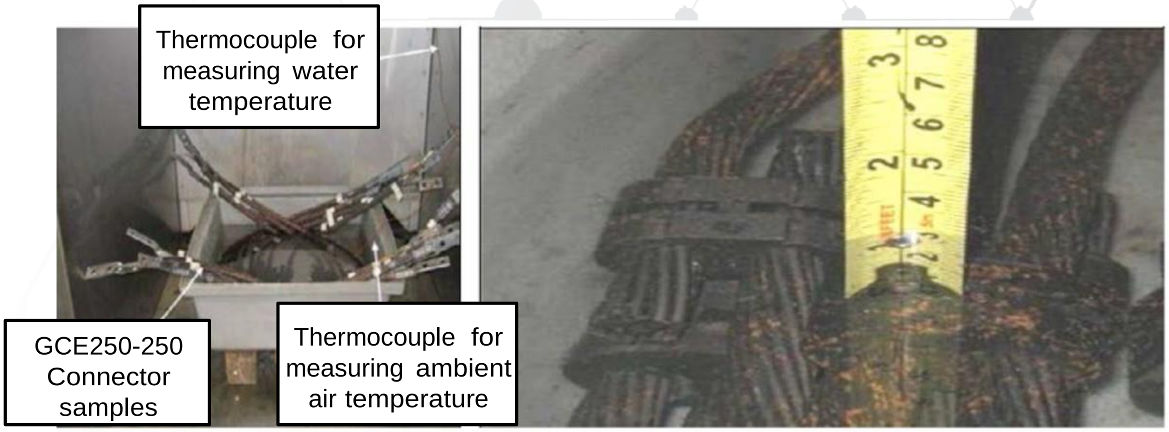


Figure 5. Connectors in water bath being lowered to at least -10°C, and then raised to at least 20°C.

Corrosion Tests: Acid Bath & Salt Spray

After these first two tests, the connector samples are split evenly into two groups. The first connector group is subjected to a salt spray test performed in accordance with ASTM B117-11. The salt spray test emulates connector installation in soils having high salt content. The second connector group is submerged in a solution of nitric acid (HNO_3) and distilled water (10% by volume) until there is a 20% reduction in cross-sectional area (as determined by weight). This test explores the ability of a connector to withstand installation in a highly corrosive environment, and is meant to examine whether the connector will survive the life of the conductor. Test setups are shown in Figure 6.

Figure 6. Testing set-up for salt spray (left) and acid bath (right) sequence tests.

Fault Current Test

The final test in the series is the fault current test. Each group of test connectors is subjected to three surge currents to determine whether the ground system will hold up to substation-type electrical faults after decades of being buried in the ground. Ninety percent of the fusing current is applied for 10 seconds. Between surges, the connectors are allowed to cool to 100°C or less. If the connectors have been damaged by the previous tests, the mechanical jarring created by the application of a fault current will open the joint further, between the connector and conductor, or possibly destroy the connection altogether. Test setups are illustrated in Figure 7. Sample resistance data can be seen in Tables 4 and 5.

Figure 7. Fault current test layout for the acid sequence and salt spray samples.

Table 4/5. Results of 2002 Corrosion Testing for Panduit GCE250-250 Connectors.

Subtest: Acid Sequence	Connector #2 (mΩ)	Connector #4 (mΩ)	Connector #6 (mΩ)	Connector #10 (mΩ)	Connector #11 (mΩ)	Connector #12 (mΩ)	Control #1 (mΩ)
Initial resistance (A)	0.1832	0.1848	0.1849	0.1801	0.1783	0.1811	0.1693
After current-temperature cycling	0.1681	0.1681	0.1670	0.1676	0.1670	0.1675	0.1691
After freeze-thaw cycling (B)	0.2066	0.2096	0.2099	0.1829	0.1915	0.1928	0.1689
Ratio (B/A)	1.13	1.13	1.14	1.02	1.07	1.06	1.00
Outcome	PASS	PASS	PASS	PASS	PASS	PASS	N/A

Subtest: Salt Spray Sequence	Connector #1 (mΩ)	Connector #3 (mΩ)	Connector #5 (mΩ)	Connector #7 (mΩ)	Connector #8 (mΩ)	Connector #9 (mΩ)	Control #2 (mΩ)
Initial resistance (A)	0.1862	0.1807	0.1842	0.1827	0.1840	0.1781	0.1699
After current-temperature cycling	0.1675	0.1683	0.1692	0.1673	0.1683	0.1671	0.1683
After freeze-thaw cycling	0.2166	0.2065	0.2159	0.1964	0.2075	0.1900	0.1676
After salt spray	0.1956	0.2311	0.2465	0.1986	0.2198	0.1887	0.1686
After fault current (B)	0.2238	0.2359	0.2123	0.2473	0.2498	0.2525	0.1703
Ratio (B/A)	1.20	1.31	1.15	1.35	1.36	1.42	1.00
Outcome	PASS	PASS	PASS	PASS	PASS	PASS	N/A

Achieving Results with the Panduit® StructuredGround™ Direct Burial Compression Grounding System

Meeting the appropriate standards are paramount to the success of a project, but ensuring you have the proper materials for the job must be done first.

The key to making a proper connection with the Panduit StructuredGround compression solution lies in the combination of the unique connector designs and crimping process. The result of this crimping process is a tighter connection that provides better resistance to corrosive elements than any other compression system. See Figure 8 for details on the patented installation process and connector design.

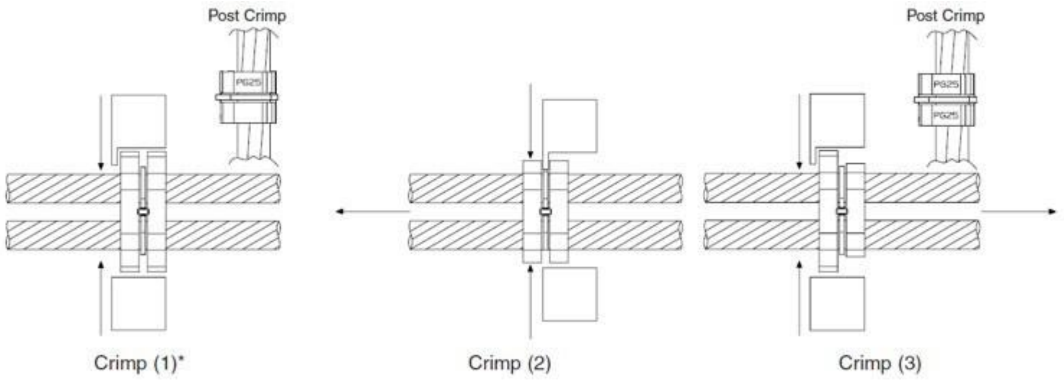


Figure 8. Installation instructions of Panduit E-style connectors.

Convenience is the hallmark of the design. The easier a connection is made, the higher the rate of successful installation. The middle slot acts as a spot to secure the connector to the conductors with a cable tie before crimping. Securing the connection in place not only turns a two-man job into a one-man job, but it also speeds installation up to four times faster than exothermic welding.

The middle slot also doubles as a guide for the die during the second crimp in the triple crimp process. The locator rib on the Panduit die aids in properly aligning the connection and ensuring that each crimp is done without deforming or damaging the connection.

Convenience does not stop at installation. The Panduit system offers wide range-taking connectors to limit the number of stock keeping units (SKUs) required for a project. The amount of excess tooling and accessories required are also significantly reduced when using this compression system over an exothermic system. In addition, the new Panduit BlackFin™ installation tools are OSHA certified and do not need the permits required for exothermic welding.

If there is any uncertainty about using the proper connector for the job, all pertinent agency approvals, die information, and conductor ranges are listed directly on the connectors. To learn more about the capabilities and key application environments, see Figure 9.

The Panduit E-style connectors also come with a patented antioxidant compound that improves the mechanical and electrical connection of the crimp. A component of this compound adds to the frictional secureness of the pre-crimped assembly and bites through exterior imperfections on rods and rebar. This allows installers to crimp directly onto them, as opposed to pre-crimping the rod, which other systems require.

*One crimp means the connection is listed for UL 467; all three crimps mean the connection is IEEE 837 compliant.

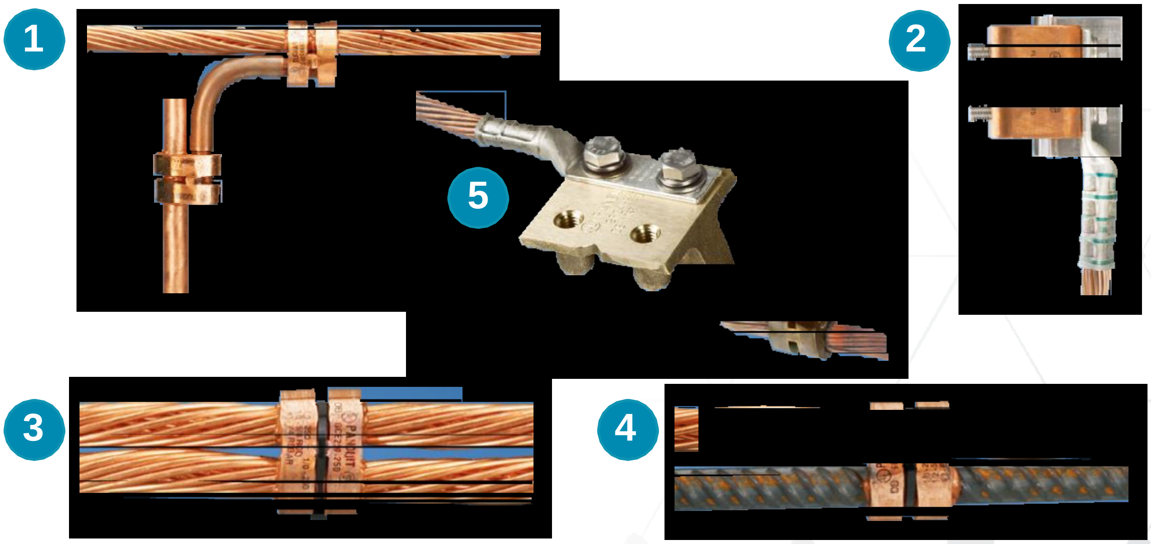


Figure 9. Various Panduit StructuredGround connectors showing the different grounding applications: conductor to (1) rod, (2) building steel, (3) conductor, (4) rebar, and (5) ground plate.

Inspection is the last and one of the most important pieces to the advantage of the Panduit compression system. Using either the single or triple crimp process, an inspector's job is made easy when reviewing a Panduit installation. As opposed to hitting the connection with a hammer, like the traditional exothermic welding technique for inspection, the die index number of the die is embossed on the connector during the crimping process. A single embossed number from one crimp implies the connector is safely secure and meets the Underwriters Laboratories standard UL 467. After the triple crimp process is complete, two die numbers will appear embossed on either finger of the connection that implies compliance to the IEEE 837 standards. An example of these markings can be seen in Figures 8 and 10.

Figure 10. Isolated view of Panduit GCE250-250 with IEEE 837 die number embossment verification.

Conclusion

Connection reliability is critical to the long-term integrity and performance of a grounding and bonding system. This white paper explains the key aspects and requirements of IEEE Std. 837, which proves its importance and relevance at defining what reliability looks like for permanent connections in subgrade grounding applications. The harsh mechanical, electrical, and sequenced corrosion testing of this standard together become a testimony for the quality of a connection. Panduit's StructuredGround system is further highlighted, as it exceeds the testing requirements of the 2002 and 2014 revisions of IEEE Std. 837. Panduit's system proves to be vastly superior to exothermic welding systems, and more convenient than other compression systems. With all of the system's features and benefits being taken into account, it is recommended to specify compression grounding on all future projects.

Referenced Standards

- IEEE Std. 837-2002, "IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding," 2002.
- IEEE Std. 837-2014, "IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding," 2014.
- Ontario Hydro Technologies, "Substation Grounding Connectors, IEEE Std., 837-1989 Test Series"
- ASTM B-1 "Standard Specification for Hard-Drawn Copper Wire," 2007
- ASTM B117-11 "Standard Practice for Operating Salt Spray (Fog) Apparatus, 2011
- UL 467, "Grounding and Bonding Equipment," 2007

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IEEE Std. 837 Revision Comparison Chart.

	IEEE 837-2002	IEEE 837-2014	Change
Mechanical Pullout Test	Minimum Values per Table 2 of the standard	Requirement Eliminated	↓
EMF Test	Largest-to-Largest and Smallest-to-Smallest Conductors (Panduit did Large-to Small)	Largest-to-Largest and Largest-to-Smallest Conductors	↔
	Loop with 1 to 4 Connectors Being Tested (Panduit tested 2 in loop)	1 Connector Tested at a Time	↔
	3 Surges Applied	2 Surges Applied	↔
	No Visible Movement Allowed	<10mm or OD of Conductor Movement Allowed	↓
	Final Resistance < 1.5 times initial Resistance	Resistance Requirement (for the EMF portion) Eliminated	↓
	Minimum X/R ratio of 20	Minimum X/R ratio of 30	↑
	Minimum 12 Cycles	Minimum 15 Cycles	↑
	kAmp Test Current (per calc in Annex C)	2 times kAmp Test Current (values per Table 3)	↑
	No minimum Conductor Size (Panduit Tested #6 AWG)	Minimum Conductor Size #2 AWG	↔
Current Cycling Test	No Change		↔
Freeze-Thaw Test	No Change		↔
Salt Spray Test	No Change		↔
Acid Test	Final Resistance for reference only (Panduit Already Passed < 1.5X Resistance)	Final resistance < 1.5 times final control resistance	↑
Fault Current Test	No Change		↔

Since 1955, Panduit's culture of curiosity and passion for problem solving have enabled more meaningful connections between companies' business goals and their marketplace success. Panduit creates leading-edge physical, electrical, and network infrastructure solutions for enterprise-wide environments, from the data center to the telecom room, from the desktop to the plant floor. Headquartered in Tinley Park, IL, USA and operating in 112 global locations, Panduit's proven reputation for quality and technology leadership, coupled with a robust partner ecosystem, help support, sustain, and empower business growth in a connected world.

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