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GUIDE

PURPOSE

This Grounding and Bonding Guide provides information to assist in the design, construction and maintenance of permanent station grounding and bonding systems. This document is a condensed version of ENG-MAN-002 and has been developed for use by parties external to OPG.

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1. SCOPE

This Grounding Guide (the Guide) provides information on the design, construction, maintenance and system assessment of grounding systems in and around hydroelectric and thermal generating stations and associated switchyards.

The Guide covers the fundamental requirements of grounding systems needed to protect staff, equipment and the public in and around generation facilities. It is intended to help OPG staff review submissions for new or modified installations, designed either by employees or others (including consultants, contractors and subcontractors hired by OPG). The Guide also recommends maintenance procedures to determine whether existing plants require upgrades or more detailed measurements to uncover deficiencies. Finally, the Guide describes a variety of testing options for this purpose.

The main body is prescriptive and avoids mathematical expressions, although two summary tables prompt designers to list design input and output parameters for checking purposes. Modern design techniques rely on commercial software rather than the simplified and approximate expressions commonly seen in older grounding guides. However, the body references the Appendices, which provide formulas and spreadsheet-based tools for checking the reasonableness of a computed result.

This Guide is not a stand-alone document. It complements internal OPG standards, external standards, such as *IEEE Standards*, and the *Ontario Electrical Safety Code*.

The *Ontario Electrical Safety Code (OESC)* has jurisdiction over portions of the plant electrical systems, typically for equipment not directly involved in the production of electricity. Any disputes between this document and the *OESC* are to be discussed with the Electrical Engineering Department of HTO Engineering and Technical Services Division.

2. REFERENCES

The following references are used in this guide:

- Ontario Electrical Safety Code (OESC)
- CAN/CSA Std. B72: Installation Code for Lightning Protection Systems - General Instruction No 1-2
- IEEE Std 80: Guide for Safety in AC Substation Grounding
- IEEE Std 81: Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System
- IEEE Std 367: Recommended Practice for Determining the Electric Power Substation Ground Potential Rise and Induced Voltage from a Power Fault
- IEEE Std 487: Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Locations
- IEEE Std 665: Standard for Generating Station Grounding
- IEEE Std 837: Standard for Qualifying Permanent Connections Used in Substation Grounding
- IEEE Std. 998: Guide for Direct Lightning Stroke Shielding of Substations
- BSI PD IEC/TR 60479-4: Effects of Current on Human Beings and Livestock Part 4: Effects of lightning strokes
- DS DS/EN 62305-3: Protection against lightning - Part 3: Physical damage to structures and life hazard
- NFPA 780 National Fire Protection Association Standard to the Installation of Lightning Protection Systems
- ENG-MAN-001: Temporary Grounding and Bonding Guide
- OPG-M-763 Grounding Systems Standard Technical Specification
- OPG-M-797 Station Grounding System Assessment Standard Technical Specification
- OPG-M-801 Permanent Ground Gradient Control Mats Standard Technical Specification
- Ontario Hydro Transmission and Distribution Grounding Guide 1994
- Ontario Hydro STD5-C-H-57600-002, Design Guide on Grounding Practices for Generating Stations (refer to Figure 25)
- Ontario Hydro STD5-C-H57100-0007, Shielding and Grounding of Shield and/or Metallic Covering
- DS-LP-STD-004 Fences and Barricades, Dam & Public Safety
- OPG-M-762 Fence and Barricade Grounding

3. DEFINITIONS

The following definitions describe the general functions and parameters, which apply to station grounding:

AWG	American Wire Gauge
Bonding	To provide a permanent low impedance path, with adequate current rating, between two objects in order to minimize their potential difference
Electrode	In this document, electrode refers to a buried grounding conductor located outside the fence
Gradient Control Mat	A temporary (or permanently mounted) work surface of closely meshed conductors, (the gaps being smaller than the width of a shoe), bonded to station ground allowing the worker to stand on it in order to control touch potentials
Grounding	To provide bonding between objects and remote earth
Grounding System	All conductors that facilitate grounding
Ground Current	Current that enters a grounding system
Ground Electrode	Buried conductors that dissipate ground current into the earth
Ground Fault	An insulation failure between a phase conductor and the grounding system
Ground Potential Rise (GPR)	The voltage between a grounding system and remote earth during a ground fault
HVAC	Heating Ventilating and Air Conditioning
Isolation Panel	A part of a fence constructed to a specific design from electrical insulating material (e.g. wood, composite material, etc.) and used to provide electrical isolation between sections of the fence.
Redundantly Connected	Connected more than once, typically twice unless indicated or shown otherwise in a drawing
Step Potential	The foot-to-foot voltage during a ground fault, considering that the current through the feet has not reduced the open circuit potential
Tap	In this document, refers to a conductor being connected to a main conductor, such as a tap from the below grade electrode brought up to the inside of a fence post
Touch Potential	The hand-to-foot voltage during a ground fault, considering that the current through the body has not reduced the open circuit potential
Transferred Potential	The voltage between a grounded object that extends exterior to a station and local soil.

Note: For more information on the above definitions, see the latest version of *IEEE Std.80, IEEE Std.665* and the *Ontario Electrical Safety Code (OESC).*

4. OBJECTIVES OF GROUNDING

The primary objectives of grounding are to:

(1) Protect life from the danger of electric shocks by limiting potential differences between touchable objects

(2) Isolate faults as soon as possible by providing a low impedance path to ground in order to activate protection

(3) Redirect fault current and lightning away from equipment and property susceptible to damage by providing multiple paths to remote ground with sufficient current capability and redundancy

(4) Minimize electrical interference by reducing the pickup of noise on control wiring and instrumentation systems.

5. GROUNDING SYSTEM COMPONENTS

A combination of the following grounding system components are required to help achieve grounding objectives:

Component	Description
Grounding Grid	A meshed system of heavy conductors to interconnect the entire station, usually buried by about 500 mm in exterior locations. It safely directs fault or lightning current into the underlying earth or water. It limits step and touch potentials in outdoor areas.
Ground Rods	Vertical rods driven into the soil below frost depth to facilitate the conduction of fault current from the grounding grid to remote earth particularly during the winter when the upper ground layer is frozen and during dry periods when the upper ground may become very dry'.
Auxiliary Ground Electrodes	Copper conductors or vertical rods laid in water or areas of high conductivity near the station, when rock under the station has poor conductivity

Component	Description
Equipment Case and Structure Bonds	Short conductors to direct fault current from equipment or structures to nearby points on the grounding grid. Bonds to equipment in contact with water or earth such as sluice gates, draft tubes and foundations help to dissipate fault current from the grid towards remote earth.
Gradient Control Conductors and Mats	Conductors or conducting mats installed at or below grade to control step and touch potentials.
Personnel Ground Attachment Points	Studs bonded to nearby points of the grounding grid for connecting temporary working grounds applied to phase conductors.
Generator Neutral Grounding Resistor	A relatively high resistance for grounding the neutral of large generators (usually through a transformer) to limit current and thus damage on single phase faults. The connection may include a disconnect switch to allow off-line testing of the generator winding.
Main Output Transformer Neutral Bond	An insulated heavy conductor grounding the neutral of the step-up transformer to limit the potential rise of HV un-faulted phases on single phase transmission system faults. This connection may return a significant split of fault current to the HV phases, thus reducing the ground potential rise of the station
Service Ground	A ground conductor or continuous conduit that runs together with phase and neutral conductors in service wiring to carry fault current in service equipment or station auxiliaries back to the supplying transformer.
Service Neutral Bond	A single connection between the service neutral, the service ground and the grounding grid, usually at the supply transformer or first downstream disconnect. This bond returns fault current in plant auxiliaries to the supplying transformer. A single connection keeps unbalanced (zero sequence or single phase) load current from flowing in the grounding system.
Lightning Protection Systems	Air terminals to intercept lighting strikes, down conductors to direct lightning current in the shortest possible path to the earth, avoiding vulnerable equipment and building components. Earth electrodes to help dissipate the lightning current into the earth. These components may be offset from other grounding system conductors to keep transient current away from sensitive equipment
Instrumentation Circuit Ground	A single point connection to ground on signal circuits to provide a potential reference. Multiple ground connections could bridge different ground grid potentials, causing interference.

Component	Description
Control Wire Shields and Bonds	A grounded concentric conductor on protection and control type circuits to intercept capacitive pickup from adjacent HV conductors. Grounding both ends of this concentric shield also protects signal conductors when transient voltages occur between ends of the control cable. Here transient currents in the shield induce a potential in the signal conductors to neutralize or reduce their local voltage to ground. To achieve significant neutralization, it is essential these bonds be kept very short. Refer to STD5-C-H-57100-0007, Shielding and Grounding of Shield and/or Metallic Covering.
Neutralizing Transformer Grounds	A remote ground connected to the primary winding of a neutralizing transformer with the other winding terminal locally grounded. This raises the local potential of telephone pairs to match the station ground potential rise, preventing operation of over-voltage protectors.
Concrete Rebar/Building Steel	Conductive building materials located between the foot and underlying soil can reduce step and touch voltages.
Overhead Ground Wires	Grounded conductors located above phase conductors on transmission lines to provide shielding from lightning, to limit the potential rise of towers on ground faults or lightning and to provide a return path for fault current
Counterpoise	Buried conductors running under a transmission line connected tower to tower, to limit the potential rise of towers and to provide a return path for fault current.

6. GROUNDING REQUIREMENTS

6.1 General Grounding Requirements

A number of engineering and regulatory standards provide assistance in meeting the grounding objectives of limiting potential differences, providing a low impedance path to remote ground, ensuring adequate current capability in conductors, and allowing for single contingency failures through redundancy and to shield sensitive circuits from interference. Standards pertinent to this Guide are in the Section 2, References, and include the following:

- Grounding systems shall meet or exceed the requirements of *IEEE Std. 80, Guide for Safety in AC Substation Grounding*, and *IEEE Std. 665, Guide for Generating Station Grounding.*
- Grounding systems for all equipment not directly involved in the generation of electricity shall meet or exceed the requirements of the latest version of the *Ontario Electrical Safety Code (OESC).*
- A lightning protection system shall meet or exceed the requirements of *CSA Std. B72, Installation Code for Lightning Protection Systems*, and *IEEE Std. 665, Guide for Generating Station Grounding.*

6.2 Specific Grounding Requirements

The following specific grounding requirements are necessary at a typical OPG facility or location:

(1) All networks shall include a deliberate ground fault return path, so that over current or ground fault protection will trip the supplying circuit breaker (in some 600 V station service systems, an alarm is provided on the first ground fault).

(2) A grounding grid shall be installed under the station to provide contact with the underlying earth. It shall encircle all major equipment so that bonds remain short and touch potentials are reduced. It shall be meshed and current rated for multi-phase faults (except on isolated phase bus generator output circuits) so that its performance is unaffected by any single break contingency in the grounding system.

(3) All equipment and busses with segmented enclosures such as isolated phase bus (IPB) associated with generator output circuits require a dedicated grounding system, bonded longitudinally so these high fault currents tend to bypass the grounding grid. Conductors shall be current rated for multi-phase fault levels. Conductors difficult to inspect visually shall be meshed and current rated so that their performance is unaffected by single break contingencies. This special grounding system shall be bonded to the station ground grid at multiple locations.

(4) Auxiliary equipment rated 600 V and higher shall be grounded through two independent connections: through the service ground running upstream with the supply conductors and through a visible bond from case to nearby grounding grid. The latter shall match or exceed the service ground in sectional area, with minimum size 13 mm^2 (AWG #6) for mechanical robustness. Conductors difficult to inspect visually shall be duplicated and current rated so that their performance is unaffected by single break contingencies. While exceeding the requirements of the *Ontario Electrical Safety Code (OESC)* for industrial applications, the second bond is rationalized by the high fault current, which may flow through undefined paths in generating stations.

(5) All metallic enclosures on equipment and exposed non-current carrying conductive materials capable of becoming energized due to either insulation failure or inadvertent contact with an energized conductor shall be bonded to the grounding grid. Conductors shall be current rated for multi-phase fault levels. Conductors difficult to inspect visually shall be duplicated and current rated so that their performance is unaffected by single break contingencies.

(6) Remote buildings supplied from the powerhouse at 600 V and higher shall be interconnected by a service ground and by separate grounding conductors in contact with the earth, current rated so their performance is unaffected by single break contingencies.

(7) Special attention shall be paid to non-stationary equipment such as cranes. Greased bearings or wheel contact on rails are not to be considered a reliable path for fault current.

(8) Fences, gates, guardrails and other metallic objects remote from the station but in proximity to overhead conductors that can fall shall be bonded. Non-visible conductors shall be duplicated and current rated so that their performance is unaffected by single break contingencies. Alternatively, these remote metallic objects may be isolated with insulating panels breaking the fence into sufficiently short sections so that fallen conductors will not transfer hazardous potentials to locations where the public or personnel are likely to be present, such as at gates.

(9) Objects not bonded to station ground but subject to frequent hand-to-hand contact shall include redundancy on non-visible bonding. Thus posts on either side of a gate shall be interconnected by independent paths below grade.

(10) Bonds that cannot be inspected visually shall be duplicated. The grounding grid shall be looped to provide redundancy for any single break contingency.

(11) All grounding conductors shall be sized to withstand the maximum fault current they will experience over the life of the station with respect to mechanical, thermal and magnetic stresses, as well as corrosion. Aluminum shall not be used below grade or in wet locations. The conductor current rating shall include the contingency of a single break in non-visible locations. All fault types shall be considered, including 1, 2, and 3 phases. All fault locations shall be considered, including within the station and some spans down transmission lines. Faults at all voltage levels shall be considered. However, faults on isolated phase bus generator output circuits shall be attenuated by a dedicated grounding system as described in number (3) above, reducing the impact of this fault on other parts of the grounding system.

(12) All connectors shall be rated to withstand the maximum fault current they will experience over the life of the station with respect to mechanical, thermal and magnetic stresses, as well as corrosion. Connectors below grade or buried within concrete shall meet tests specified by *IEEE Std. 837*, with the preference being the exothermic type. Multiple bolted connections in series on steel equipment enclosures or cable raceways shall not be relied upon for the fault current path; rather, dedicated grounding conductors shall be used.

(13) Where practical, all grounding conductors should be continuous. No switching device shall be inserted in the grounding circuit until discussed with the electrical section of HTO Plant Engineering Services. Structural changes after installation shall not interrupt the grounding circuit.

(14) The grounding grid shall be augmented by auxiliary rods or electrodes to limit the maximum ground potential rise to 5 kV under summer and winter (frozen soil) conditions. If this requirement is impractical to meet, this shall be indicated and both designer and reviewer shall pay special attention to step and touch potentials, and potentials appearing on communication lines leaving the station.

(15) The grounding grid, gradient control conductors and mats shall limit step and touch voltages to the safe body withstand potential when standing on soil, switchyard stone or concrete floors or when touching equipment, structures, building materials, fences, gates, piping or other metallic object. Touch voltages shall include, for example, the stress associated with handling a grounded power tool in any location within any mesh or within the perimeter of the grounding grid.

(16) Cable raceways and trays shall include a grounding conductor bonded to all terminal equipment to help neutralize longitudinal potential differences along control cables.

(17) Communication lines leaving the station shall include isolation or neutralization to prevent the transfer of hazardous potentials to remote locations. Shields on buried telephone cables (including steel jacketed fibre optic cables) shall not bridge this isolation.

(18) For new buildings switchyards, chimneys, radio antennas and other exposed facilities, an assessment shall be performed, as per CSA-B72-M87 (Installation Code for Lightning Protection Systems), to determine if a lightning protection system is required. Lightning protection shall be installed, if deemed necessary per CSA-B72-M87. The system shall provide air terminals to intercept lightning strikes, perimeter conductors to spread the current to multiple down conductors and earth electrodes independent of the power fault grounding system. If practical, maintaining a separation between the lightning protection system and the power fault grounding system may help keep transients away from sensitive equipment.

It should be noted that NFPA 780 (Standard for the Installation of Lightning Protection Systems) offers a more detailed assessment process than CSA-B72-M87 for determining if a lightening protection system is required.

7. GROUNDING SYSTEM DESIGN

7.1 Grounding System Design Input Parameters

Sections 7.1.1 and 7.1.2 may be used to gather necessary data to assess grounding system design by consultants or assist internal design of minor grounding systems. These sections provide the design Engineer with following:

- A description and table to gather pertinent data
- Pointers to formulas and spreadsheet-based tools for checking the reasonableness of a computed result from the design engineer
- The formulas and spreadsheets of Sections 7.1.1 and 7.1.2 may be combined with the system design of Section 7.2 for minor in-house designs, if so desired.

7.1.1 Description of Design Input Parameters

The following information will normally be needed before beginning the design of the grounding system in Section 7.2. Section 7.1.2 provides a summary of input parameters which may be convenient for cataloguing these parameters and checking purposes. The appendices provide further details on simplified ways to estimate these parameters (with preference given to the use of more detailed commercial software by consultants):

(1) List the maximum pre-fault phase-to-phase voltage likely to occur on the HV bus (Vhpp). Given this potential, calculate the maximum resulting fault current that can flow into the ground for a three-phase fault (I3hg), flow from phase B or C for a two-phase-to-ground fault (I2hb), flow into the ground for a two-phase-to-ground fault (I2hg), and flow into the ground for a single-phase fault (I1hg). Include contributions from local generation and from the transmission system. If available, list the positive sequence impedance (Zh1) and zero sequence impedance (Zh0) including the base if in per unit. Indicate the dc decrement time constant (Thd) and backup fault clearing time (Thc). Repeat if more than one transmission voltage level is present. (See APPENDIX A: Maximum Fault Current for Determining Conductor Current Rating).

(2) Repeat above for the station service bus (the bus on the station service side of the station service transformer) (Vspp), (I3sg), (I2sb), (I2sg), (I1sg), (Zs1), (Zs0), (Tsd) and (Tsc). (See APPENDIX A: Maximum Fault Current for Determining Conductor Current Rating).

(3) Propose a general grounding conductor(s) withstanding the above maximum current stress for visible (no redundancy required) locations. State the material, the cross section (Agc) per conductor, and the number of parallel conductor paths (Ngv). Indicate the number of conductors for non-visible (redundancy required) locations (Ngnv). (See APPENDIX B: Conductor Current Capability).

(4) Propose the type of connectors used for splicing and bolting the above conductors to equipment and the standard used in testing their capability. List the tested current capability (Igc), for a dc decrement time constant (Tgd) and fault clearing time (Tgc).

(5) List the maximum prefault phase-to-phase voltage likely to occur at the generator output terminals (Vtpp). Given this potential, state the maximum resulting fault current that can flow into the ground for a three-phase fault (I3tg), flow from phase B or C for a two-phase-to-ground fault (I2tb) and flow into the ground for a two-phase-to-ground fault (I2tg). Include contributions from local generation and from the transmission system. If available, list the positive sequence impedance (Zt1) and zero sequence impedance (Zt0) with bases if in per unit. Indicate the dc decrement time constant (Ttd) and backup fault clearing time (Ttc). (See APPENDIX A: Maximum Fault Current for Determining Conductor Current Rating).

(6) Propose a grounding conductor(s) withstanding the above bus fault maximum current stress for visible (no redundancy required) locations. State the material, the cross section (Abc) per conductor, and the number of parallel conductor paths (Nbv). Indicate the number of conductors for non-visible (redundancy required) locations (Nbnv). (See APPENDIX B: Conductor Current Capability).

(7) Propose the type of connectors used for splicing and bolting the above conductors to equipment. Indicate the standard used in testing their capability. List the tested current capability (Ibc), for a dc decrement time constant (Tbd) and fault clearing time (Tbc).

(8) List the maximum prefault phase-to-phase voltage likely to occur on the HV bus as supplied from the transmission system (Vspp). List the system positive sequence impedance (Zs1) and system zero sequence impedance (Zs0) with bases if in per unit. Given this potential, calculate the maximum resulting zero sequence current that can flow from the system for a two-phase-to-ground fault (I2sg) and a single-phase fault (I1sg). Zero sequence current entering the station contributes to the ground potential rise. (See APPENDIX C: Maximum System Zero Sequence Current for Fault at Station).

(9) List raw soil resistivity data used in determining a two-layer resistivity model for the soil lying under the grounding grid for summer conditions: (ρ1), (ρ2), ... ,(ρ200) etc where 1, 2, ... , 200 are the Wenner probe spacings in m and ρ the apparent resistivity in Ωm. For Schlumberger list the C1-C2 and P1-P2 distances. Indicate the date of the tests and the weather conditions preceding the test. Estimate the frozen soil resistivity (Ωm) and its depth (df) under winter conditions. For hydraulic stations estimate the river water resistivity (ρrw), the head pond depth (drw) and dam area in contact with water (Arw).

(10) Propose a two-layer soil model for the station (ρ1, d, ρ2). Add frozen layer for winter conditions. (See APPENDIX D: Spreadsheet Interpretation of Two-Layer Soil Resistivity Model).

(11) For each transmission line with overhead ground wires connected to the station, list nominal size of overhead ground wire(s), the conductor geometric mean radius (gmro), the conductor ac impedance per km (Ro), the number of conductors (Nohg), their separation distance (doo), the self impedance per km of the overhead ground wire(s) as a magnitude and phase angle (|Zoo|, /Zoo_). List the average tower footing

resistance (Rfm) if measured. List the number of footings (Nf), the distance between footings (sf), the depth of each footing (df) and the footing cylindrical radius (rf). List calculated footing resistance (Rfc). List the average tower span (st). State the driving point impedance (|Zod|, /Zod_) arising from multiple tower footings separated by spans of overhead ground wire. Repeat for all lines and calculate the combined driving point impedance (Zodc). (See APPENDIX E: Driving Point Impedance of Overhead Ground Wires and Neutrals).

(12) For each of the above transmission lines contributing fault current to the station, list the separation of the overhead ground wires from the most distant phase conductor (dop). State the mutual impedance per km between the overhead ground wire(s) and phase conductor (|Zop|, /Zop_), and the shielding factor S for the overhead ground wire(s). This describes the scaled reduction in incoming phase current caused by the "inductive" current component returning on the overhead ground wire(s) due to their proximity to the phase current. Repeat for all lines. List a global shielding factor Sg, by prorating S for individual lines over their varying fault current contributions. (See APPENDIX F: Shielding Factor for Transmission Lines and Cables).

(13) For any multi-grounded distribution neutrals interconnected to the station, list the nominal size, the conductor geometric mean radius (gmrn), self impedance per km (|Zns|, /Zns_), the average resistance of neutral grounds (Rn) and the span between these grounds (sd). State the driving point impedance (|Zdd|, /Zdd_) arising from multiple neutral grounds separated by the span distance. Repeat for all neutrals and calculate the combined driving point impedance (|Zddc|, /Zddc_). (See APPENDIX E: Driving Point Impedance of Overhead Ground Wires and Neutrals).

(14) Investigate single and double line-to-ground faults at various spans (Ns) along the transmission line having the lowest shielding factor (S) due to current supplied from local generators. For each, calculate the reduced ground fault current for single (I1gr) and double (I2gr) line-to-ground faults caused by phase conductor impedance from station to fault location. Subtract the current split returning in the overhead ground wires to obtain the net ground current for single (I1gn) and double (I2gn) line-to-ground faults. (See

(15) APPENDIX G: Maximum Ground Current for Fault along Transmission Line).

7.1.2 Summary Table of Design Input Parameters

Fill in Table 1 of ENG-FRM-GR-001, Grounding Design Input Parameters and Summary, with data accumulated from Section 7.1.1. A sample of the relevant section of the form is shown below. Use additional columns for multiple entries or notes. A copy of this form has been attached to the Guide and is also available on the HTO Plant Engineering Services (PES) website under Governing and Supporting Documents\Forms.

ONTARIO POWER GENERATION	Form Number: ENG-FRM-GR-001 / R 00	Reference Document: ENG-MAN-002	Security Classification: Internal Use Only
	Applicability: Hydro Thermal Operations	Effective Date: Jan. 29, 2013	SCI Number: 57600
	Form Owner: PES Power Equipment Dept.		Page: 1 of 4

Name: Station Grounding - Design Input Parameters and Summary

Table 1: Design Input Parameters

Description from Section 7.1.1 of ENG-MAN-002 (Station Grounding and Bonding Guide)	Symbol	Unit	1	2	3	4	5
1.							
max hv system prefault V	Vhpp	(kV)					
3-phase I stressing conductor	I3hg	(kA)					
2-phase to gnd I from phase	I2hb	(kA)					
2-phase to gnd I into gnd	I2hg	(kA)					
1-phase to gnd I	I1hg	(kA)					
system and local Gen positive seq Z	Zh1	(Ω)					
system and local Gen zero seq Z	Zh0	(Ω)					
dc decrement time constant	Thd	(s)					
backup fault clearing time	Thc	(s)					
2.							
max service bus prefault V	Vspp	(kV)					
3-phase I stressing conductor	I3sg	(kA)					
2-phase to gnd I from phase	I2sb	(kA)					
2-phase to gnd I into gnd	I2sg	(kA)					
1-phase to gnd I	I1sg	(kA)					
system and local Gen positive seq Z	Zs1	(Ω)					
system and local Gen zero seq Z	Zs0	(Ω)					
dc decrement time constant	Tsd	(s)					
backup fault clearing time	Tsc	(s)					
3.							
general ground conductor material							
conductor cross section	Agc	(mm^2)					
number of paths for visible	Ngv						
number of paths for non visible	Ngnv						
4.							
type of connector and test standard							
current capability	Igc	(kA)					
dc decrement time constant	Tgd	(s)					
current duration	Tgc	(s)					
5.							
max Gen terminal prefault V	Vtpp	(kV)					
3-phase I stressing conductor	I3tg	(kA)					
2-phase to gnd I from phase	I2tb	(kA)					
2-phase to gnd I into gnd	I2tg	(kA)					
system and local Gen positive seq Z	Zt1	(Ω)					
system and local Gen zero seq Z	Zt0	(Ω)					
dc decrement time constant	Ttd	(s)					
backup fault clearing time	Ttc	(s)					
6.							
Gen bus gnd conductor material							
conductor cross section	Abc	(mm^2)					
number of paths for visible	Nbv						
number of paths for non visible	Nbnv						

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Form Number:	Reference Document	Security Classification
ENG-FRM-GR-001 / R 00	ENG-MAN-002	Internal Use Only
Applicability: Hydro Thermal Operations	Effective Date: Jan. 29, 2013	SCI Number: 57600
Form Owner: PES Power Equipment Dept.		Page: 2 of 4

Name

Station Grounding - Design Input Parameters and Summary

Description from Section 7.1.1 of ENG-MAN-002 (Station Grounding and Bonding Guide)	Symbol	Unit	1	2	3	4	5
7.							
type of connector and test standard							
current capability	Ibc	(kA)					
dc decrement time constant	Tbd	(s)					
current duration	Tbc	(s)					
8.							
max transmission system prefault V	Vspp	(kV)					
system and local Gen positive seq Z	Zs1	(Ω)					
system and local Gen zero seq Z	Zs0	(Ω)					
2-phase to gnd I0 into station gnd	I2sg	(kA)					
1-phase to station gnd I0	I1sg	(kA)					
9.							
Wenner raw data	(ρ1)	(Ωm)					
	(ρ2)	(Ωm)					
	(ρ5)	(Ωm)					
	(ρ10)	(Ωm)					
	(ρ20)	(Ωm)					
	(ρ50)	(Ωm)					
	(ρ100)	(Ωm)					
	(ρ140)	(Ωm)					
	(ρ200)	(Ωm)					
frozen soil resistivity	ρf	(Ωm)					
frozen soil depth	df	(m)					
water resistivity	ρrw	(Ωm)					
head pond depth	drw	(m)					
area of dam face in water	Arw	(m^2)					
10.							
summer upper layer resistivity	ρs1	(Ωm)					
upper layer depth	ds	(m)					
deep resistivity	ρs2	(Ωm)					
winter surface layer resistivity	ρw	(Ωm)					
frozen depth	dw	(m)					
11.							
circuit(s) designation							
overhead ground wire size							
geometric mean radius	gmro	(mm)					
ac resistance per km	Ro	(Ω/km)					
number of conductors	Nohg						
gmd between conductors	doo	(m)					
self impedance magnitude per km	|Zoo|	(Ω/km)					
self impedance phase angle	/Zoo_	(deg)					
measured tower footing resistance	Rfm	(Ω)					
number of footings per tower	Nf						
distance between footings	sf	(m)					
depth of footing	df	(m)					
footing cylindrical radius	rf	(m)					
calculated footing resistance	Rfc	(Ω)					

DRAFT

ONTARIO POWER GENERATION

Form Number:	Reference Document	Security Classification
ENG-FRM-GR-001 / R 00	ENG-MAN-002	Internal Use Only
Applicability: Hydro Thermal Operations	Effective Date: Jan. 29, 2013	SCI Number: 57600
Form Owner: PES Power Equipment Dept.		Page: 3 of 4

Name

Station Grounding - Design Input Parameters and Summary

Description from Section 7.1.1 of ENG-MAN-002 (Station Grounding and Bonding Guide)	Symbol	Unit	1	2	3	4	5
average tower span	st	(km)					
driving point impedance magnitude	|Zod|	(Ω)					
driving point impedance phase	/Zod_	(deg)					
combined impedance magnitude	|Zodc|	(Ω)					
combined impedance phase	/Zodc_	(deg)					
12.							
separation from most distant phase	dop	(m)					
mutual impedance to phase per km	Zop	(Ω/km)					
shielding factor	S	pu					
global shielding factor	Sg	pu					
13.							
direction of neutral from station							
neutral size							
geometric mean size	gmrn	(mm)					
self impedance magnitude	|Zns|	(Ω/km)					
self impedance phase	/Zns_	(deg)					
average resistance of grounds	Rn	(Ω)					
span between grounds	sd	(km)					
driving point impedance magnitude	|Zdd|	(Ω)					
driving point impedance phase	/Zdd_	(deg)					
combined impedance magnitude	|Zddc|	(Ω)					
combined impedance phase	/Zddc_	(deg)					
14.							
faulted circuit							
shielding factor	S						
spans to faulted tower	Ns						
reduced 1 phase gnd fault current	I1gr	(kA)					
reduced 2 phase gnd fault current	I2gr	(kA)					
1 phase net current into station gnd	I1gn	(kA)					
2 phase net current into station gnd	I2gn	(kA)					

SAMPLE

7.2 General Grounding System Design Guidelines and Requirements

Having gathered system design data in Sections 7.1.1 and 7.1.2, now proceed with the grounding system design as described in the following steps below. The calculations in this section are input into the summary table described in Section 7.2.1.

(1) Sketch out the area to be covered by the ground grid. Surround all buildings, structures, switchyards and equipment with electrical services, such as pump houses, guard houses, cold storage buildings, conveyers, etc by at least 1.5 m, such that a person touching the structure or equipment is standing inside the ground grid. Include longitudinally continuous metallic fences having any portion within the 2 m touch distance of any grounded object. Insulate more remote security fences from interconnected fences by isolating panels. Interconnect non-contiguous grid areas such as a separate switchyard with multiple conductors so that the performance is unaffected by any single break contingency. Run these interconnections under overhead lines (to take advantage of the proximity effect) and along control cable raceways or trenches where practical. Calculate the area covered by the grid (Ag).

(2) Lay out individual conductors within the grid area. Include a conductor to form the perimeter of the grid area. Add interior diameters meshed in two dimensions so that all parts of buildings (including footings for major columns), structures, pedestals and equipment can be grounded through relatively short bonds. Note that at this stage, some meshes may be considerably larger than others. List conductor size (Ac). Ensure that there is sufficient meshing so that all bonds can access the required number of independent grid conductors (Nc) to achieve the required current rating, including single-break contingencies. Use a minimum conductor size of 67 mm^2 (AWG 2/0) for mechanical ruggedness and resistance to corrosion. Provide at least one longitudinal gradient control conductor along the exterior of metallic buildings and interconnected fences to limit touch potentials.

(3) For exterior areas, locate the grid 450 mm below grade as a compromise between reaching remote soil and reducing surface touch potentials, unless another depth provides greater benefits. For interior locations the grid may be installed within concrete pads (non-visible) or around interior walls (visible). Doors may be bypassed overhead (visible) or under the floor slab (non-visible). Specify connectors having the required current rating. Calculate the total length of buried grid as (sg).

(4) Add ground rods to exterior locations having frost depth (df) greater than 300 mm in order to reach unfrozen soil. Locate near elevated equipment, entrance structures and shielding towers subject to lightning. Locate near equipment with high capacitance between phase conductors and ground, such as CVTs. For the preliminary design, specify individual rod length (sr) and sufficient number of rods (Nr) such that their aggregated length is at least 1 % of sg.

(5) Calculate the isolated station grid resistance (Rgs) under summer conditions, preferably using detailed software. Calculate the isolated resistance of any auxiliary

electrodes. For hydraulic stations, calculate the resistance of the dam face in contact with river water. Using the design input parameters of the previous section, calculate the interconnected ground impedance magnitude and phase (|Zgs|, /Zgs_) due to overhead ground wires, distribution neutrals and the dam resistance for hydraulic stations. Select the highest current injected to station ground, either due to a fault at the station supplied remotely by the transmission system (Vgs) or due to the net current from local generation some spans down a line (Vgl) for the fault type (one or two-phase to ground). Calculate the potential rise for summer (Vgs) and the relative (per unit) current splits on the ground grid (|Ig|, /Ig_), overhead ground wires (|Iohg|, /Iohg_), distribution neutrals (|Idn|, /Idn_) and other auxiliary electrode (|Iae|, /Iae_) for comparison to measurements. Calculate the station ground resistance under frozen soil (winter conditions) (Rgw). Find the interconnected winter impedance (|Zgw|, /Zgw_). Calculate the potential rise under winter conditions (Vgw) (see APPENDIX H: Isolated Grid Resistance, Step and Touch Transfer Resistances and APPENDIX I: Ground Potential Rise, Step and Touch Potentials).

(6) Consider the following improvements to the grounding system if Vgs or Vgw exceed 5 kV and recalculate:

- (a) Add external auxiliary electrodes or grid in conductive areas or under water
- (b) Add more ground rods (for winter reductions)
- (c) Increase the grid area
- (d) Reduce the mesh size
- (e) Ask the transmission utility to install counterpoise or heavier overhead ground wires
- (f) Accept a potential rise above 5 kV, but pay special attention to step and touch potentials, and consider ground testing of the completed station. To be reviewed by Owner's Engineer.

(7) Find the maximum summer and winter step potential (Vss, Vsw) around the periphery of the grid area and adjacent to grid conductors where meshes are large. Find the maximum structure touch potential within 1 m of pedestals, structures and equipment (Vts, Vtw). Find the maximum mesh potential (Vms, Vmw) near the middle of large meshes when touching grounded equipment such as bucket trucks or grounded power tools. Find the maximum fence potential (Vfs, Vfw) when standing within 1 m of interconnected metallic fences. Find the maximum gate potential (Vgts, Vgtw) when standing within 1 m of the swing area of a gate. Find the maximum fence potential when standing within 1 m of isolated security fences (Vsfs, Vsfw). (See APPENDIX I: Ground Potential Rise, Step and Touch Potentials).

(8) Calculate the allowable step potential for native soil (Vsna) and specified surface treatment (Vssa). Calculate the allowable touch potential (Vtna) for native soil and where surface treatment (specified surface stone, asphalt) will be applied. Compare the above stresses with these safe body withstands and consider the following improvements to gradient control if coordination is not present:

- (a) Extend the surface treatment to areas where native soil does not coordinate
- (b) Increase the depth of the surface treatment

(c) Reduce the mesh size

(d) Add gradient control conductors along linear fences, buildings or equipment

(e) Add gradient control mats or grids under gates

(f) Break isolated metallic security fences into shorter segments using insulating panels

(g) Reduce the ground potential rise as discussed in Section 7 above.

(9) Find the Zone of Influence (ZOI), which is the maximum distance from the edge of the grid to the point where soil potential drops to:

(a) 1 kV (dielectric limit of many communication cable sheaths)

(b) 300 V (causing operation of over voltage protections)

(c) Vtc (allowable touch potential, typically 170 V for 0.5 s fault duration and low soil resistivity).

(10) This result should be communicated to utilities having externally grounded cables or pipes entering the station, such as telephone or gas supply companies, so that their staff will observe special precautions when maintaining their plant within this zone. For example, Bell Canada requires a one-page document “Ground Summary Sheet”. This would be provided by the consultant to OPG who will send to the local phone service provider (typically Bell Canada) after the design is complete.

References for this section:

- *IEEE Std. 80-2000, Guide for Safety in AC Substation Grounding*.
- Ontario Hydro, Grounding Design Standard and Recommended Practices, 1983.
- Ontario Hydro, Transmission and Distribution Grounding Guide, 1994.

7.2.1 Summary Table of Grounding Design Outputs

This section has been intentionally removed.

7.3 Design of Lightning Protection Systems

This section has been intentionally removed.

7.4 Specific Grounding Design Guidelines and Requirements

7.4.1 General

The grounding and bonding methods described in this section are typically supportive of information provided by Technical Standards such as IEEE and the OESC. It is not practical to replicate all the information in those Standards here and the reader is encouraged to refer to the Standards mentioned in each section

7.4.2 Security Fencing and Barricade Grounding Design

7.4.2.1 General

For security and safety purposes, wire station fences and barricades are normally installed on the perimeter of OPG owned property. As well, barricades may be installed inside or outside of perimeter fence enclosures. This section will assist OPG staff in determining the need and methods of grounding and bonding new and existing fences and barriers. Where applicable, it may be used in conjunction with the Lead Plant Document DS-LP-STD-004, Fences and Barricades.

In addition to this section, OPG-M-762, Fence and Barricade Standard Technical Specification provides technical information for grounding fences and barricades projects.

7.4.2.1.1 Fence and Barricade Types

There are three types of fences and barricades:

(1) Station fencing or barricades which enclose OPG sites (containing electrical equipment) and typically require bonding such as in Section 7.4.2.3, Fence Grounding and Bonding Methods. This includes such items as switchyard perimeter fencing or may be a combination of fence and barriers such as headworks access fence and railings. Electrical equipment inside a security fence perimeter may as a result of “Limits of Approach” hazards, be enclosed by a fence.

(2) Security fencing or barricades which are typically more remote from electrical equipment and as a result, is usually not bonded.

(3) Publically owned fences or barricades in close proximity to OPG fence or barricades.

7.4.2.1.2 Development of Hazardous Potentials

The following are conditions under which fences and barricades can develop hazardous touch potentials. Note that these potentials can be transferred to other metallic structures such as ungrounded metal siding on interconnected buildings. Also, excessive touch potentials may be developed between a fence or barricade and grounded items such as metallic siding, bridges, walkways railings and similar items.

7.4.2.1.3 Ground Potential Rise

The ground potential rise due to a fault anywhere at the station can create a touch potential hazard at a fence (or barrier) under the following conditions:

(1) The fence is bonded to station ground and the soil at the remote end rises to a lower potential. The fence is not bonded to station ground but rises due to its proximity to the station and the soil at the remote end rises to a lower potential.

(2) The fence is not bonded to station ground and the adjacent soil close to the station rises to a higher potential.

(3) A bonded object such as a gate telephone is located within the reach distance (2 m) of an unbonded fence, which rises to a lower potential.

(4) A remotely grounded object such as a private fence is located within the reach distance of an OPG fence which rises due to its proximity to the station.

(5) The fence contains a gate, which when opened, contains a potential difference between the gate posts.

Touch potentials due to ground potential rise are checked with current injection testing. Refer to Section 8.2, Reviewing Step and Touch Potential Coordination.

7.4.2.1.4 Insulation Failure

Electrical equipment mounted on fences or barriers (such as gate motors, receptacles, car heaters or light fixtures on dam railings) can be poorly bonded due to corrosion or breakage of conduit fittings. These objects can rise to hazardous potentials due to insulation failure on phase conductors for extended periods without the tripping of upstream protection.

7.4.2.1.5 Capacitive Coupling

Fences or barricades in close proximity to high voltage conductors may develop a hazardous voltage due to the capacitive coupling between the ungrounded metallic object and the

conductor. This situation typically occurs in switchyards due to closer proximities between equipment. This potential is typically dealt with via connection to station ground of the metallic equipment

7.4.2.1.6 Falling High Voltage Conductors

Fences, gates, guardrails and other metallic objects remote from the station but in proximity to overhead conductors that can fall can transfer hazardous potentials to OPG staff and or the public who may be in contact with this equipment during such fault conditions. Here the installation of isolation panels will limit the transfer to points within a short distance of the fallen conductor.

Short handrails and fences which are visible through their entire length, or longer fences located away from high voltage or service conductors, may not require bonding. This includes fences with no chance of dropped conductors, with very small capacitive coupling to high voltage phases and having no contact with service power, as present with gate motors or lighting fixtures.

7.4.2.1.7 Charges on Fences near Transmission Lines

Many OPG hydro electric stations are for located at fair distances from communities. Thermal stations are typically in closer proximity to communities. As communities grow, they more closely approach OPG owned high voltage circuits. In some locations, OPG owned fences cross under or are parallel to high voltage circuits. Fences that cross perpendicularly under transmission lines are subject to little induction, due to the cancellation effect of dissimilar phases, and are rarely a source of complaint. The majority of fences paralleling transmission lines do not present a problem because of natural grounding, distance from the circuits and/or length of fence. However, both electrostatic and electromagnetic induction can affect fences near transmission lines. There are too many scenarios to discuss in this document, so when noticeable charges or currents are identified contact the Electrical Engineering Department, HTO Plant Engineering Services (PES).

The causes and possible effects on fences in close proximity to high voltage circuits are described below:

Electrostatic Induction: The voltage on a transmission line creates an electric field which can induce noticeable charges in objects that are insulated from ground. If a fence near operating transmission lines is poorly grounded, an annoying capacitive discharge may be felt when it is contacted. Occasionally, after contact, a continuing "tingle" current may be felt. The electrostatic effects can be eliminated by additional grounding.

Electromagnetic induction: The current flowing in a transmission line produces a magnetic field which may induce a circulating current in adjacent fences with earth acting as the return path. The effect is most noticeable at openings in very long fences parallel to transmission lines (e.g. gates) where arcs can be drawn when the loop path is broken.

Electro-magnetically induced currents cannot be prevented, but their flow can be minimized and directed to routes that eliminate annoyance and hazard.

Note: In cases of doubt, unusual situations or difficulty in meeting the requirements for grounding or bonding, consult with the Electrical, Protection and Control Department, HTO Plant Engineering Services (PES).

7.4.2.2 Grounding and Bonding Station Fences and Barricades

Two fence-grounding methods that may be found within OPG:

(1) Inclusion of the fence within the main ground grid area as per Section 7.4.2.2, under Fence Ground Connected to Main Station Grounding Grid, below. This situation is found only when:
   (a) The station fence is located within 2 m of grounded station equipment
   (b) When a railway siding is inside the fenced area (Refer to Section 7.4.11.1 for more information regarding railway grounding).

(2) For all cases other than 1(a) and 1(b) above, the fence grounding system is separated from the main grid and connected to its own electrodes as per Section 7.4.2.3, under Fence Grounding & Bonding Methods below. In general, boundary/security fences

remote from the Plant need not be grounded; however some form of isolation from grounded fences and equipment may be required as discussed later in this document.

OPG-M-762, Fence and Barricade Grounding Standard Technical Specification, provides grounding expectations for the installation of fences and barricades.

7.4.2.2.1 Fence Ground Connected to Main Station Grounding Grid

Inclusion of the fence within the ground grid area increases the size of the station ground grid area, thereby reducing the overall ground grid resistance and the maximum ground grid potential rise. As well, by connecting the fence and its grounding system to the main station ground grid, the stations maximum station step and touch potentials will usually be reduced inside the station. However, the touch potential for the public outside the fence may be increased. This touch potential must be determined, as a part of station grounding system assessment and the results compared against acceptable standards, such as IEEE 80. Technical specification OPG-M-797, Station Grounding System Assessment, is available for the assessment.

These fences may require a gradient control or perimeter conductor buried outside the fence, which is redundantly connected to the main grounding grid. A grounding system study or assessment will quantify the touch potential, step potential, GPR, etc., and provide information on whether a gradient control conductor is required. To reduce the station ground potential rise during frozen soil conditions, there may be benefit to placing ground rods along this conductor, equally spaced at 12 m intervals and connected to the station ground grid. Refer to Figure 1, Typical Main Station Ground Grid.

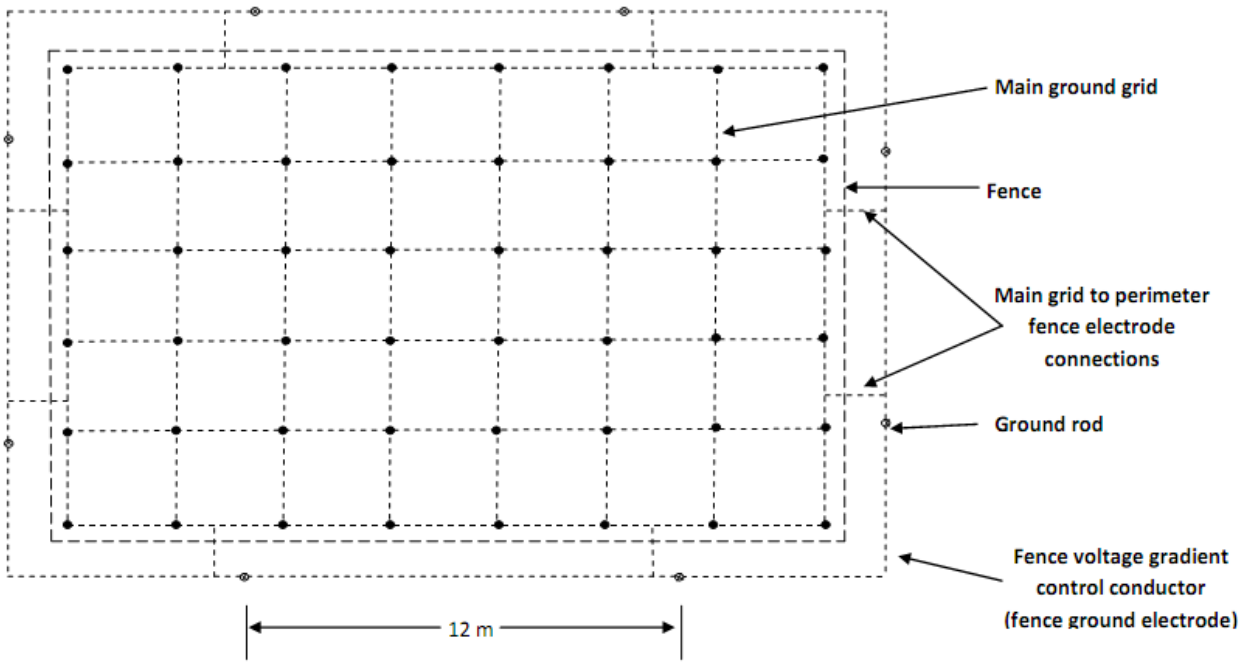


Figure 1: Typical Main Station Ground Grid

In situations where a fence does not encompass a ground grid, as shown in Figure 1, but poses a touch potential hazard, a gradient control conductor shall also be installed on the interior side of the fence.

The fence is then grounded and bonded as per Section 7.4.2.2, under OPG Fences or Barricades under High Voltage Circuits.

Note: Use 3 meter galvanized or copper coated steel ground rods. Where 3 meter rods cannot be driven due to rock, try driving at an angle or driving them as far as possible and cutting them off or laying them horizontal in as deep a trench as possible, with the trench parallel to and as close to the fence as practical.

7.4.2.2.2 Fence Ground Separate from Main Station Grounding Grid

If the station fence grounding system is isolated from the main grounding grid the magnitude of touch potentials to the public may be reduced. This factor is rather important especially for plants where the outside of the station fence is accessible to the public and may more than compensate for the benefits lost by not connecting the fence grounding to the main grounding grid. Grounding software can be helpful in modelling and mitigating such stresses.

Isolating fences from the main ground grid can be difficult, given the possibility that inadvertent electric connections will be present through items such as gate mounted telephones, telephone signal lines and water pipes. If the fence itself is not tightly coupled to the nearby ground by its own adequate ground system, any such inadvertent connections to the main ground grid could create a hazard along the entire length of the fence under fault conditions. Thus, in this method, the fence is not connected to the station's ground grid; rather it has its own grounding electrode. This typically is a 2/0 AWG copper cable buried 150 to 200 mm deep, 1 meter (typical touch distance) on the exterior side of the fence line.

Note: If a fence that is tied to station ground (as per Section 7.4.2.2, under Fence Ground Connected to Main Station Grounding Grid) is being replaced with a fence not tied to station ground and is in the same general location, then all of the original fence ground rods and ties to station ground must be removed. As well, this new fence must not be within 2 meters of any equipment or buildings tied to station ground.

7.4.2.2.3 Expanding an Existing Station Fence

When an existing station yard is being made larger by relocation of an existing fence line, the ground grid may need to be installed within this area depending on whether:

(1) The area will be used by mobile equipment such as aerial devices, oil filters or SF6 processing carts that will be attached to station ground, then the station's grounding grid should be expanded to include that area. If necessary, install a proper grounding point for the above equipment to be connected to station ground. Refer to ENG-MAN-001, Temporary Grounding and Bonding Guide.

(2) Case grounded portable tools or equipment, such as older non double insulated hand tools, test instruments and the like will, be used in the area, then the station's grounding grid should be expanded to include that area.

If the fence is not connected to the main station's grounding grid, then the station's grounding grid extension should not be installed any closer than 2 meters to the security fence. Any new main grounding grid extension must be designed to meet the requirements Section 7.4, Specific Grounding Design Guidelines and Requirements.

Changes to fence grounding shall be reviewed by a Professional Engineer.

7.4.2.2.4 OPG Fences or Barricades under High Voltage Circuits

Circuits operating at 115 kV or higher have much more conductor support hardware that lower voltage distribution class circuits. Lower distribution voltages are typically not a concern; however, local situations and concerns may require similar attention to distribution circuits. There is a chance, albeit small, of a phase conductor falling onto the fence or barricade. If such an incident were to occur, there would be a transfer of potential along the entire length of the interconnected fence with possible harm to anyone in contact with that fence. To limit this potential to the immediate area of the contact, isolation panels (similar to those shown in Section 7.4.2.10, Fence and Barricade Isolation Methods) can be placed on either side of the line crossing (potential contact area).

The probability of a circuit falling are low, so the determining factor to install isolation panels or not, is to determine the average daily human contact. For instance, if the overhead circuit crosses the fence in a tourist area or in a suburban area, then isolation panels are probably necessary. A fence hazard index based on two factors may be helpful in determining which line crossings need this protection. To assist in the decision the following can be used as a guide:

(1) An exposure factor, which may be estimated as the average number of people (staff or public) touching one 3 m panel of the fence per day. Fences near schools, playgrounds, or near paths in busy recreational parks may have an exposure of 1 to 100 contacts per day per panel. Fences away from paths in parks or unoccupied private land may have an exposure of 0.001 to 1 contacts per day per panel. A contact to one panel every three years would have an exposure of 0.001.

(2) A length factor, which is the number of 3 m panels contained in the fence or interconnected neighbouring fences.

The exposure factor F can be calculated by multiplying the numbers from items (1) and (2) above:

F = (exposure factor) x (number of 3 meter affected fence panels)

The product of these factors gives the fence hazard index, F, which can be used to identify fences in greatest need of rehabilitation. As an example, responsible authorities may choose to isolate fences when F exceeds 1.0.

Some fences contain short sections that experience relatively high exposures, for example at gate areas or near pathways, while the remaining fence has less exposure. Here F may be estimated separately for individual sections and the result added together to obtain the overall hazard index.

Scenario 1: Consider a fence under a 230 kV circuit crossing a fence in a busy tourist area. One person a day may approach a given fence panel in a 6 month tourist season (an exposure of 0.5 averaged over the year). The fence runs for 800 m or 270 panels before being crossed by another line. Therefore F is 135 (0.5 x 270), indicating that the fence should be isolated adjacent to both line crossings.

Scenario 2: The same fence runs about 300 m or 100 panels northeast towards two 345 kV circuits. There are picnic tables in this area with heavy natural vegetation indicating a lower exposure factor, say 0.1 person per day per panel averaged over the year. Therefore F is 10, so the fence should probably be isolated adjacent to both line crossings, but with a lower priority.

Scenario 3: At an electric gate, a fence is crossed within 60 m by several 115 kV circuits. The electric gate also extends this fence 20 m southeast where it Tees into another security fence which runs for 220 m before being crossed by other lines. The total interconnected length uncrossed by lines is 300 m or 100 panels. The entire area is posted with signs to exclude the public. Staff have little reason to walk along this fence, so an exposure factor of 0.01 persons per panel per day may be appropriate. The resulting F is 1.0 indicating a borderline case for an isolation panel.

The above scenarios are only to be used as a guide. Individual situations may require isolation panels based on local conditions and concerns.

Isolation panels should be installed 6 m outside of the vertical drop zone of the overhead electrical lines, allowing some distance for wind movement.

The isolation panel function can be defeated by previously installed buried ground conductors. Usually these conductors will be less than 300 mm below grade and they should be removed over the length of the isolating panel. Longitudinal grounds, risers and top rail bonds may be left intact beyond the isolation panel.

7.4.2.3 Fence Grounding and Bonding Methods

This section provides details for the grounding of chain-link fences at OPG facilities.

Notes:

(1) All below grade conductors shall be 2/0 AWG copper.

(2) Aluminum conductor (4/0 AWG) is used above grade as described in this Section, Table 1, Item C and as demonstrated in the pictures of items A, C, D, E, F and G.

(3) All below grade connections shall be exothermic (Cadweld, Burndyweld etc) and shall be done according to manufacturer's instructions.

(4) Copper conductor connections to fence posts and top rails may be exothermic or mechanical (using only approved connectors):

- Exothermic connections are to be immediately painted over with a thick brushed on zinc rich type paint (do not use spray zinc rich type paint).
- All bolted connections above grade shall be coated with an anti-oxidant compound, suitable for the materials used.

(5) All connections shall be on the station side of the fence or barrier.

Referring to Figure 2: The buried perimeter conductor, which is installed 1 m outside the fence, is to be brought up at 12 m intervals by means of 2/0 AWG copper tap to a nearby post and attached to the inside of the post via a clamp as shown in Figure 2, Item A (to be just above grade for easy inspection). From clamp Item A, 4/0 AWG aluminum conductor C is interwoven continuously through the entire vertical fence fabric, making electrical contact between the conductor and the fence fabric (see Item C below). It is then connected to the top rail via clamping arrangement Item D. On the other side of the clamp in arrangement Item D, the

conductor is unravelled so that 2 strands are connected to each of the 3 runs of barbed wire as per Item E. The connection to the barbed wire is made via compression connectors (e.g. Burndy type YC-L thin wall c-tap). If required to ensure good connection, a short piece of barbed wire may be added as filler to the barbed wire side of the connector. Any remaining stands of conductor Item C are clipped off at the horizontal top rail.

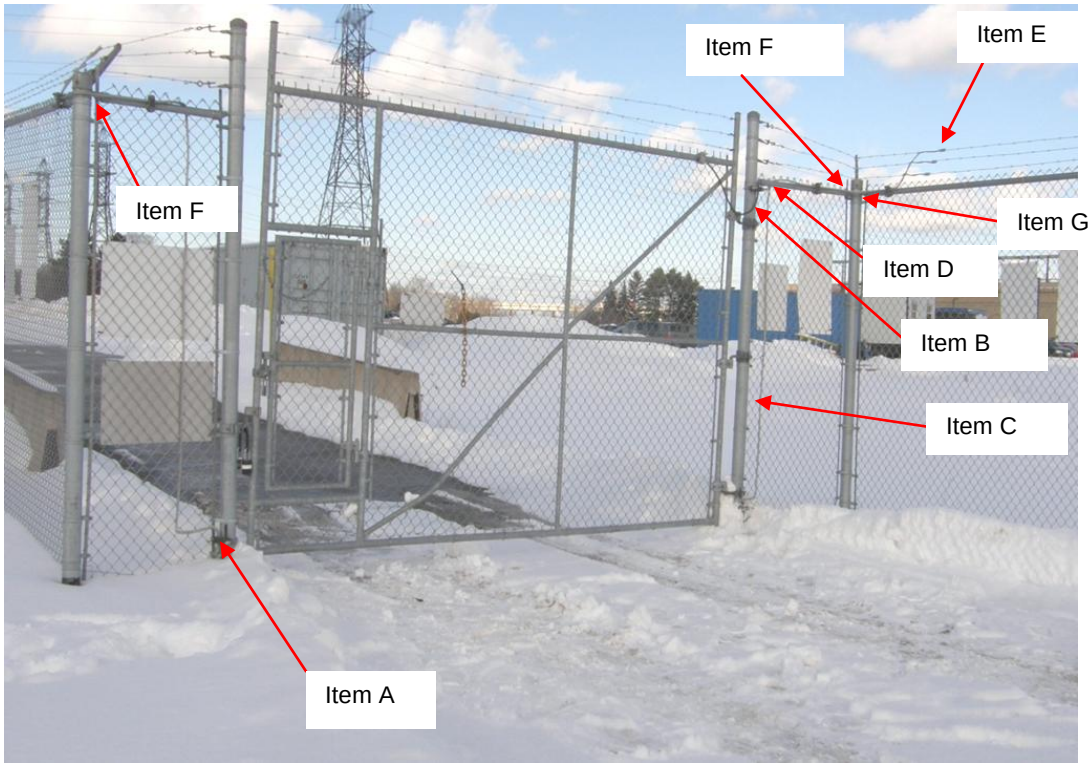


Figure 2: Typical Gate and Fence Area

All top rail corners shall be bonded across by means of jumpers as per Item F. Top rail couplings shall be bonded across per Item G. Some conductor slack (in a slight 'u' shaped bend) should remain to allow for fence rail expansion and contraction. Note the filler pieces used in these particular clamps.

The following pictures refer to the same lettered components in Figure 2.



Item A: Clamp 'A' at Base of Post



Item B: Gate to Post Bonding



Item C: 4/0 AWG Aluminum Woven through Fence Fabric



Item D: Conductor to Top Rail Clamping



Item E: Unravelling of Conductor (Item C) with 2 Strands Clamped to Each Barbed Wire Strand



Item F: Top Rail Corner Bond on an Outside Corner



Item G: Top Rail Corner Bond on an Inside Corner

Note: Split bolt type connectors quite often loosen over time and are not recommended for fence grounding and bonding. Split bolt connectors that are already in the field should be phased out over time.

All top rail couplings for chain link fences shall have a 4/0 AWG jumper installed across them to ensure electrical continuity. Some slack (2 to 3 inches) should be allowed to accommodate fence expansion/movement.

Table 1, below, lists some of the components used in the above pictures. Hardware is per the Burndy Grounding Catalogue. This is by no means a complete listing of the various manufacturers and their components and is only for demonstration purposes. Talk to your local Electrical Supplier or Utility Supplier.

Table 1: Fence Grounding and Bonding Hardware

Item(s)	Information (Typical)
Item A Clamp 'A' at Base of Post	Clamp type GD, for 2 copper cables to tube. Available to fit various O/D posts
Item B Gate to Post Bonding	Clamps type GD as Item A or type GAR (For parallel or 90°copper cable connection to pipe. Conductor is 2/0 AWG extra flex or equivalent flexible braid. If using braid, use clamp type GG
Item C 4/0 AWG Aluminum Woven through Fence Fabric	4/0 AWG 7 strand aluminum
Item D Conductor to Top Railing Clamping	Conductor as per Item C and hardware as per Item B
Item E Unravelling of Conductor	Top rail clamp as per Item B. Conductor as per Item C. Barbed wire crimps are H-CRIMPITs per the Burndy Connector Catalog. Not shown in the picture are the Burndy type YC-L Copper C-Tap, Aluminum to barbed wire connections shall be secured. An additional barbed wire or aluminum strand may be used as filler to ensure well compressed and secure connections. The connection to the barbed wire shall be a secure compression type connector
Item F, Item G Top Rail Corner Bond on an Outside or Inside Corner	Conductor per Item C. Hardware per Item B type GD or GAR

7.4.2.4 Gate Grounding and Bonding

In addition to the methods and hardware used Section 7.4.2.3, Fence Grounding and Bonding Methods, manual and electric gates require extra attention, as discussed in this section.

Manual Gates

For single gates (see Figure 2) or double swing vehicle gates or staff gates (see Figure 3) not solidly bonded across the top, the gate posts shall be connected by redundant underground bonds (2/0 AWG copper). These bond conductors should be brought up to an above grade connector on the inside base of each post as shown in Figure 2, Item A (these redundant bonds shall be buried to the same depth as the fence ground electrode and interconnected underground to the buried fence electrode). From the clamp at the base of each fence post, 4/0 AWG aluminum, is woven through the entire fence fabric in a vertical fashion (Item C) on up to the top rail connector and on to the barbed wire as shown in Item D. The hinged vehicle gate(s) and staff gates shall be bonded to the gate posts or top rails with an extra-flexible 2/0 AWG copper conductor or equivalent size flexible copper braid, as per Figure 2, Item B.

To control the touch potential that a person may experience while opening vehicle station gates, the area under the complete gate swing area of single or double swing vehicle gates require gradient control mesh. Note that in Figure 3 (Person Gate without Post-to-Post Bonding across the Top of the Gate Posts), the gate swings into the station yard. A similar grid would be required for an out swing gate, except that the grid would be installed exterior to the fence. The size of the grid in Figure 4 allows for a gate swing arc of 180°. If the gate swing arc is restricted by stops, then the mesh should be designed to take into account the swing area. If the gate swings into the yard as shown and the fence is isolated from station ground, care must be taken to ensure the gate ground mesh does not come within 2 m of grounded station equipment or structures.

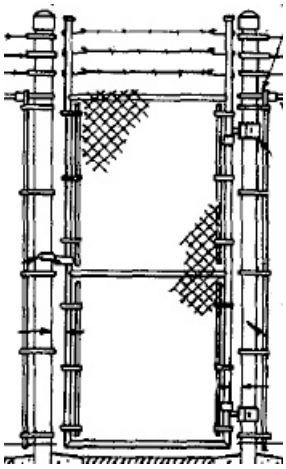


Figure 3: Person Gate without Post-to-Post Bonding across the Top of the Gate Posts

Note: A person gate within a vehicle gate as in Figure 2 (Typical Gate and Fence Area) would be considered bonded via the welded metal frame across the top and bottom of that gate

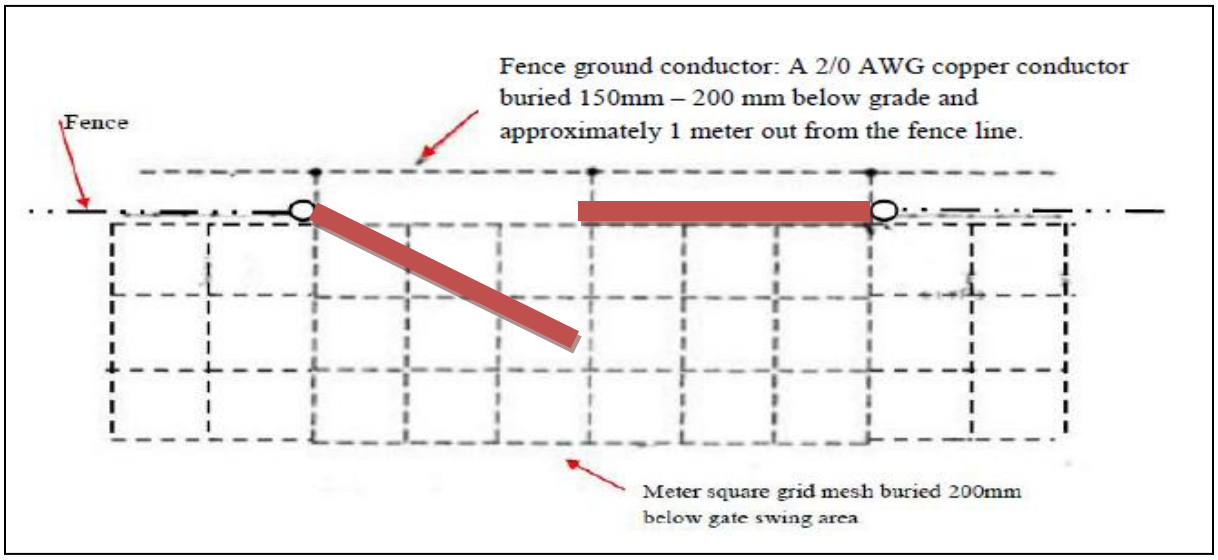


Figure 4: Ground Gradient Mat under Vehicle Gate Swing Area

7.4.2.4.1 Electrically Operated Gates

Electrically operated gates are to be grounded via the service ground that comes with the power supply cable and a separate redundant 2/0 AWG copper ground from the station ground grid. The gate posts are to be bonded together below grade by two 2/0 AWG copper conductors, with each of these redundant bonds connected to the fence ground electrode. These bonds are to

be placed 1 m out from the gate on each side of the gate, each bond acting as gradient control in the gate area. Since these gates do not swing outward from the fence, no further gradient control is required. A 2/0 AWG copper conductor is connected from the motor control enclosure to the below grade fence ground electrodes. If the fence on either side of the gate is not grounded, isolation panels will be required on each side of the gate to isolate the ungrounded fence from the gate and its motor operator.

7.4.2.5 Backfill and Surface Stone

When backfilling over any perimeter conductors (which are typically installed at a depth of 150 to 200 mm) during fence work, cover these areas with a top soil type material having good resistivity to provide gradient control. The soil should be compacted to make intimate contact between the conductor and surrounding soil.

The area around fences and over fence and gate grounding mats is to be covered with specified surface stone. The compacted soil above the buried conductor is also to be covered with specified surface stone. Specified stone is important to reduce step and touch potential hazards in the area around switchyard perimeter fences. These areas should be surfaced with specified surface stone to a depth of at least 80 mm as follows:

(1) For both station perimeter fences connected to the station ground grid and for those not connected to the station ground grid, 1500 mm on the immediate fence exterior and 1500 mm on the immediate fence interior.

(2) The area encompassed by the maximum swing of a gate should be covered with specified surface stone. The areas covered by asphalt or concrete are exceptions, providing they are sloped to minimize pooling of surface water. Excessive water can increase the risk of exposure to hazardous touch and step potential.

(3) Extend coverage 1500 mm beyond all areas occupied by equipment and structures and cable pans.

Specified surface stone should be crushed hard stone/rock, such as dolomite limestone or igneous rock, 16 mm to 22 mm in size - with no fine particles, and have a minimum resistivity of 3000 Ωm.

Any new crushed stone used in a yard should be tested by a certified test lab to assure sufficient resistivity (Kinectrics Inc. has this capability). Once a quarry has been tested, instruct

the quarry that when specified surface stone is requested, it is to be the same material both in type and dimension.

7.4.2.6 Fence Grounding when Fence is Located on Bedrock or Concrete

If part of the fence is installed on bedrock or concrete, move the perimeter ground electrode to the fence interior where it can be buried within the yard material. From the fence interior, continue to bond the fence in the usual manner until conditions permit moving the electrode back to the fence exterior. If the 2/0 AWG copper electrode is exposed during the transition back and forth between fence interior and exterior, protect the electrode from theft and other damage with a well anchored non-corrosive metallic cover.

7.4.2.7 Card Readers/Phones Outside of the Station Fence

Card readers and telephones are often installed in close proximity to new fences or barricades. When access card readers or phones are installed, they are typically some distance from the station and are thus not situated over the stations ground grid. However, the communication cable(s) from the Station to the reader/phone are connected to station ground, typically via the shield or messenger conductor. If there is a ground potential rise in the station, then the metallic card reader/phone enclosure rises to that voltage. Anyone standing next to or touching the enclosure during this event may be subjected to a hazardous touch potential. The following are some mitigation methods:

(1) Placing a gradient control mesh of 0.5 m grid within 2 m of each side of the metallic enclosure, with the grid connected to the enclosure

(2) Paving the area within 2 m (sloped to minimize water pooling in this 2 meter area). Excessive water can increase the risk of exposure to hazardous touch and step potential.

Note: Fences not connected to station ground, ungrounded fences or barricades should not to be placed within 2 m of the card reader/phone gradient control mesh.

7.4.2.8 Security Fence or Barricades in Proximity to Bodies of Water

If grounded security fences or barricades are within 2 m of these water bodies, it is possible that a person could be in the water or conductive boat and touching the fence at the same time. If the fence or barricade develops a sufficient ground potential rise the person may be subjected

to a hazardous touch potential. For this reason, fences or barricades within 2 m of water bodies (when water is typically highest) are not to be grounded. Note that ungrounded fences/barricades may transfer potential, as described in Section 7.4.2.1 under Ground Potential Rise.

To minimize the touch potentials, all fences or barricades in close proximity to water bodies shall be ungrounded and shall have an isolation panel at any intersections between grounded fences/barricades and the fence/barricade in close proximity to a water body. Depending on the local soil conditions, further mitigation may be required (such as additional isolation panels) along the fence or barricade prior to the water body.

If there are water bodies where OPG staff, contractors or the public launch/remove boats or barges, ensure any approachable fences or barricades are not grounded and have been checked for potentials via current injection testing.

Occasionally it is possible to bridge grounded barricades (handrails, guardrails etc), while OPG staff are working in a boat in the headpond. In some locations, excessive touch potentials may exist between the barricade and the water. This should be considered during job safety planning sessions. One method that can be used to minimize the excessive touch potential hazard in these situations is to use a temporary bonding arrangement between the boat and barricade.

7.4.2.9 Barricades

Guardrails, guiderails and handrails shall be connected to station ground under the following circumstances:

- When located within 2 m of other equipment tied to station ground, such as other stairway, handrail, guardrail or guiderail that are within 2 m of a light standard, motor operated head-gate or sluice-gate or grounded fence
- If lighting, receptacles, or any other electrical equipment are mounted directly on the equipment
- If crossed by overhead high voltage lines.

The size of exposed conductor shall be a minimum of 2/0 AWG for mechanical ruggedness. Also, refer to Section 7.4.2.12, Copper Theft Mitigation.

7.4.2.10 Fence and Barricade Isolation Methods

Fences and barriers that are not required to enclose station yards may be isolated from station ground but can have the following concerns:

(1) Excessive touch potential between these fences / barricades and grounded station equipment or fences.

(2) The transferred potential in item 1 above is transferred along a fence or barricade to within 2 meters of a body of water where staff or public may be in contact with that fence or barricade and the water or staff or public may be in a conductive boat in the water within touching distance of the fence or barricade.

(3) An isolated fence running radially away from a station may bridge soil of varying potential, leading to excessive touch potentials.

7.4.2.10.1 Barricade Isolation Methods

For fences and barricades, the intent of isolation methods is to minimize the risk of touch potentials across two points at different potentials and to prevent the transfer of hazardous potentials.

In Figure 5, the double guardrail on the concrete dam (to the left) is grounded, whereas the single guardrail off the concrete is not. If the rails were bonded together, then any ground potential rise could be transmitted along the total length of the metal rail to the right. Removing the first section on the rail to the left would leave too large of an opening. The following (or similar) solutions may be used:

(1) Remove one section of the guardrail (preferably from the ungrounded guardrail) and replace it with treated wood to provide an isolation panel that is at least 2 m wide. Note that non-conductive composite material, which may be more durable than wood, may also be used.

(2) Remove a section of metallic guardrail and replace it with a concrete Jersey barrier.



Figure 5: Single Gap

7.4.2.10.2 Privately Owned Fences

OPG owned metallic station fences should not approach closer than 2 m to any metallic components of a privately-owned fence.

Private fences shall not be directly attached to OPG fences that are grounded.

When private metallic fences are within 2 m of a grounded OPG fence, the property owner should be contacted and the hazards explained to him/her. Efforts should be made to attain agreement with the owner to allow OPG to install a section of wood/composite fence or isolation panel.

If the property owner requests that barbed wire not be installed on the wood/composite portion of the private fence, then the owner's preference shall be respected.

If the private property owner opposes the installation of an isolation panel on their side of the fence, then one of the following options may be used to achieve isolation:

- For situations where the private property fence is connected at the corner of a grounded OPG fence, install two isolation panels installed at 90 degrees to each other at the corner of the OPG property fence.
- For situations where the private property fence abuts onto a straight section of a grounded OPG fence, install two isolation panels in the OPG fence, arranged longitudinally such that an isolation panel is on either side of the private fence.

7.4.2.10.3 Description of Fence Isolation Panels

Figure 6 and Figure 7 show typical configurations of isolation panels in OPG fences. Isolation panels shall satisfy the following minimum requirements:

- Minimum of 2 m in width
- All vertical and horizontal structural parts shall be wood or composite material
- Barbed wire used on top of isolation panels shall be insulated. Insulators, as shown in Figure 97, should be installed in each run of the barbed wire, approximately 8-12 inches from each barbed wire support bracket on either side of the isolation panel. The barbed wire support brackets on the extension should slope to the same side as the security fence barbed wire.

Refer to Section 2.4.8 of Contract Technical Specifications for OPG Fence Installation for further details on the construction of isolation panels.

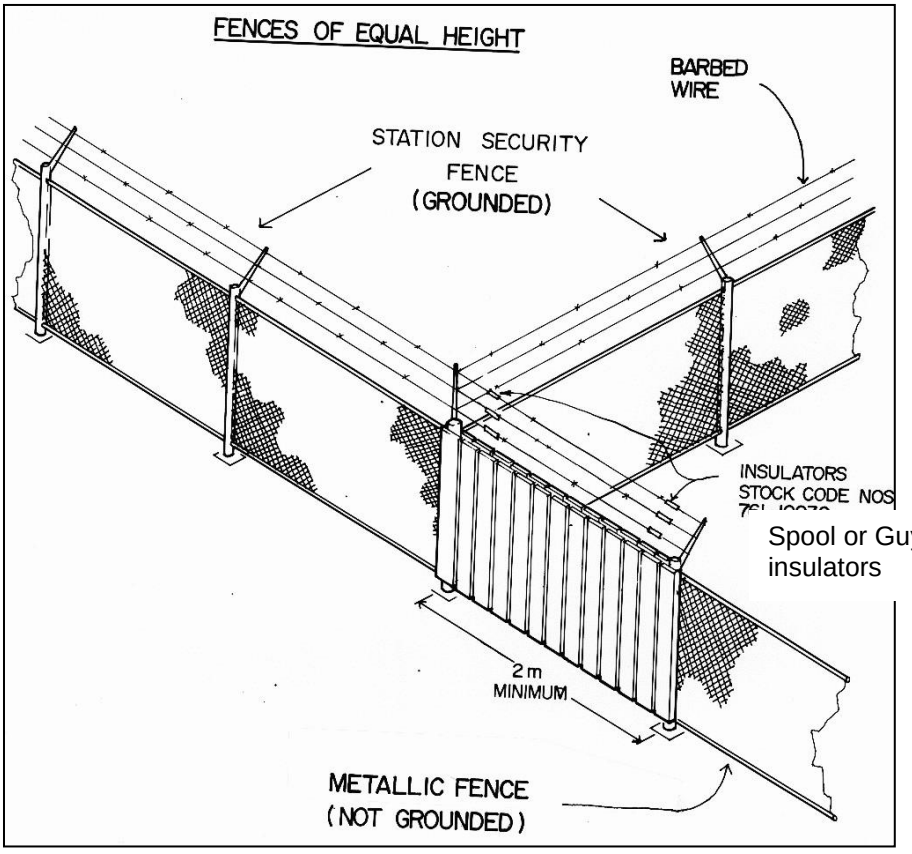


Figure 6: Fences of Equal Height

Note: Maintain barbed wire on same side of fences (i.e. both on inside or both on outside).

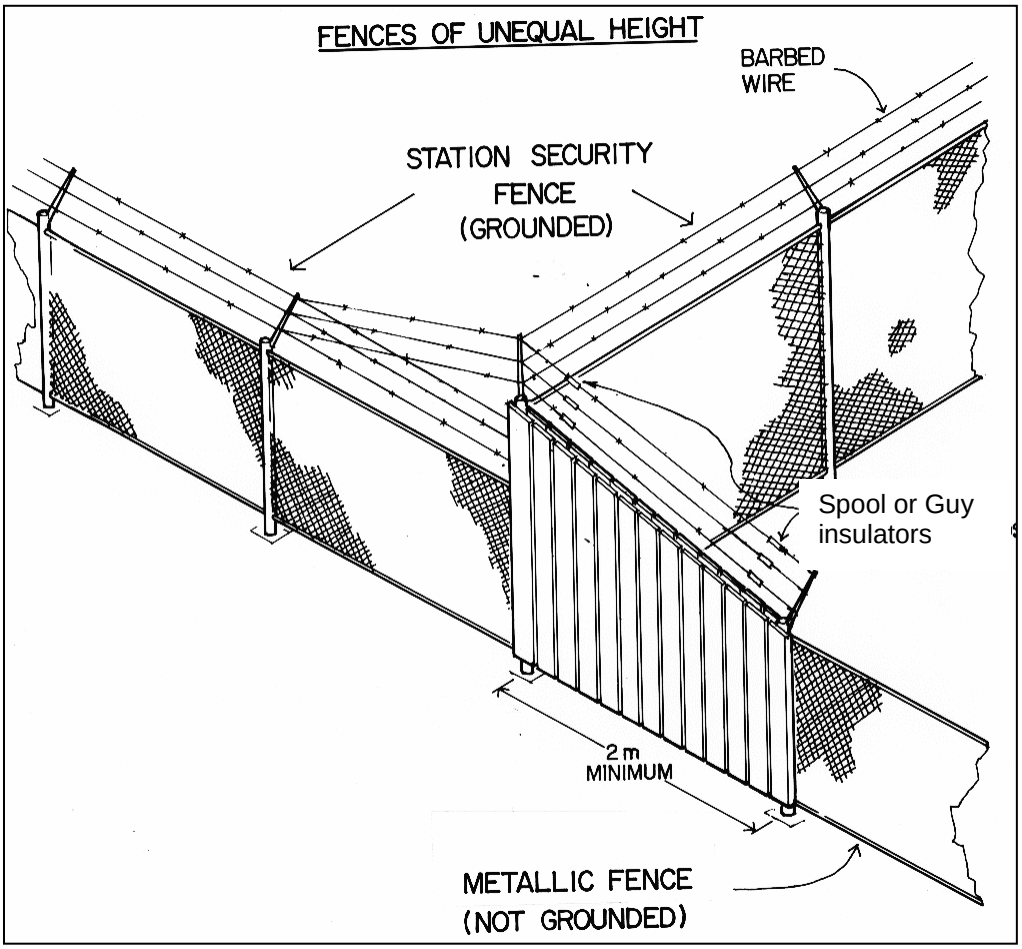


Figure 7: Fences of Unequal Height

Isolation of Ornamental Fences

Wooden or composite material isolation panels of minimum 2 m width and the same height as the ornamental metallic fence may be used to reduce touch potential hazard. An alternative to wooden and composite isolation panel, which improves the aesthetics of the ornamental fence, is described below:

- Gaps of up to 100 mm between metallic panels, of similar design as the ornamental fence, may be used along the fence to break the longitudinal conductivity of the fence.
- Gaps should be located at least every 4 m in the fence where isolation is required.

Refer to Figure 8.

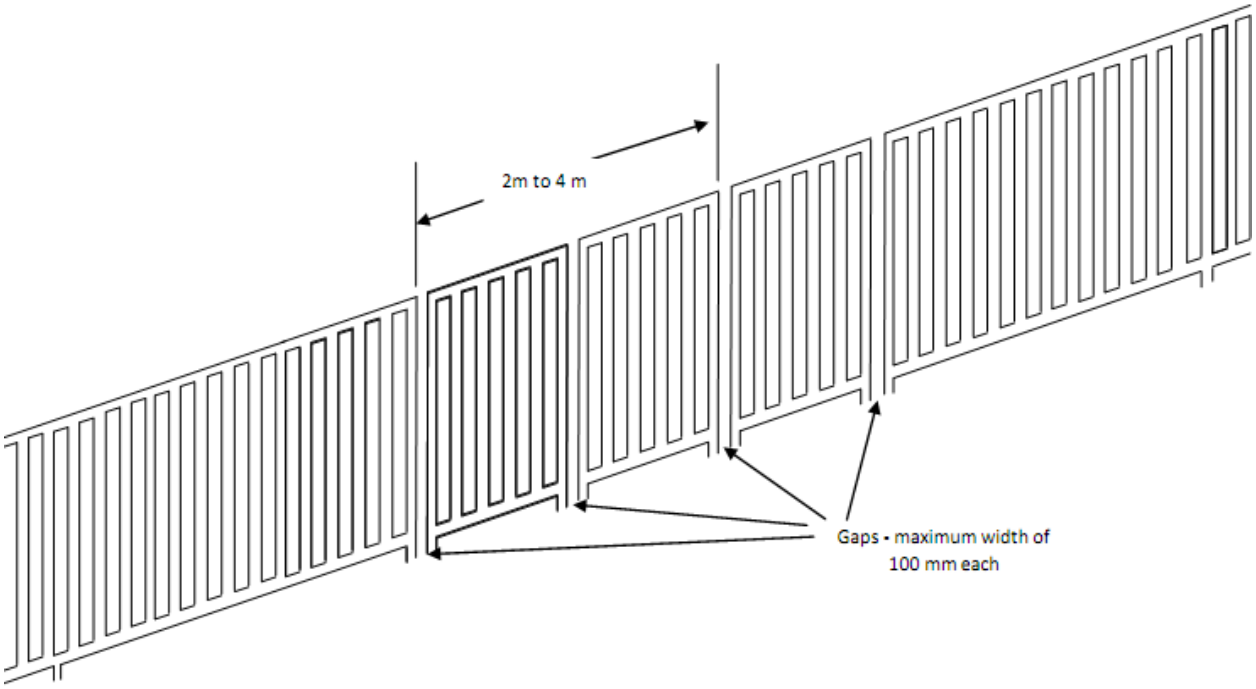


Figure 8: Isolation Method - Ornamental Fences

This arrangement provides sufficient distance to avoid potential transfer along the fence, while maintaining a relatively high resistance to earth for the intermediate section (s). This method results in no significant impact to the appearance or function of the fence.

7.4.2.11 Typical Barbed Wire Isolation Insulators

Typical spool and guy insulators are shown in Figure 9. Porcelain or composite materials may be used provided they are suitable for outdoor use and have a minimum wet rating of 5 kV. Consult your local Utility Supplier.

Note: Maintain barbed wire on same side of fences (i.e. both on inside or both on outside).

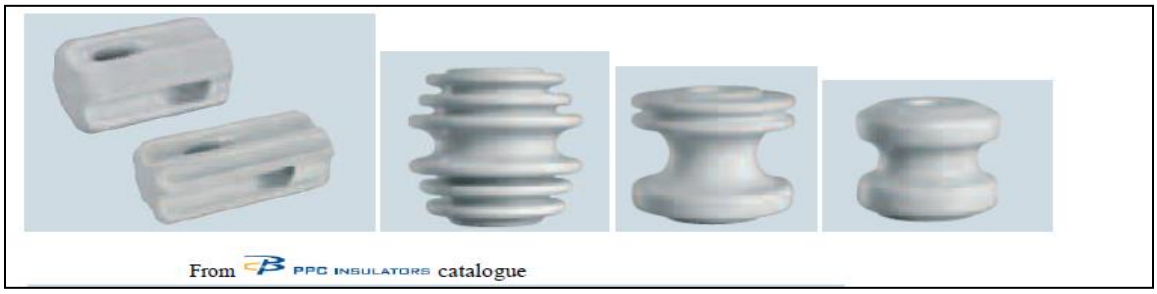


Figure 9: Typical Guy and Spool Insulators

7.4.2.12 Copper Theft Mitigation

Theft of copper grounding and bonding conductors is a both an economic and safety concern. With fences and barriers exposed to the public, they are particularly vulnerable to theft. Prevention methods are to be practiced in conjunction with regular inspections. The following suggestions are by no means complete, but provide some ideas on how to mitigate copper theft.

7.4.2.12.1 The Use of Non-Copper Conductors above Grade

Using an alternative material to copper is the preferred method of above grade fence grounding. Examples:

(1) Stranded 4/0 AWG Aluminum: When using aluminum, all aluminum to copper or bronze connections require the use of an antioxidant compound specifically for this type of junction. Aluminum and zinc are side by side on the galvanic table, so corrosion is not an issue when aluminum is used on galvanized fencing.

(2) Stranded 2/0 AWG Copper Clad Steel: Consists of a copper outer layer bonded to a steel inner core. Because of the construction, it is less expensive to purchase, has little scrap value and is difficult to cut. The downside is it is somewhat stiffer to handle. Copper clad steel is made to the same AWG size as traditional conductors, so the same mechanical connectors as discussed in Section 7.4.2.2, under Fence Ground Separate from Main Station Grounding Grid, may be used. Contact your cable or Utility supplier to discuss the conductor and exothermic connections.

Some suppliers are:

- Composite Power - Telephone: (519) 942-8485
- Anixter - Telephone: (905)-568-8999 or 1-800-268-2357

When discussing with supplier, indicate that conductor flexibility is important.

More of these anti-theft conductors are appearing on the market and should be considered as they become available.

7.4.2.12.2 Disguising or Hiding Copper

Where copper is used above grade, it should be “disguised”. Methods include:

- Painting to make it appear as aluminum or galvanized
- Placing it in a galvanized conduit, or other cover made from non-ferrous or galvanized material.

Figure 10, below, may be used in situations where there is already copper conductors used above grade, this barrier could be used to hide the copper. Paint the hidden and exposed copper to resemble aluminum or galvanized metal.

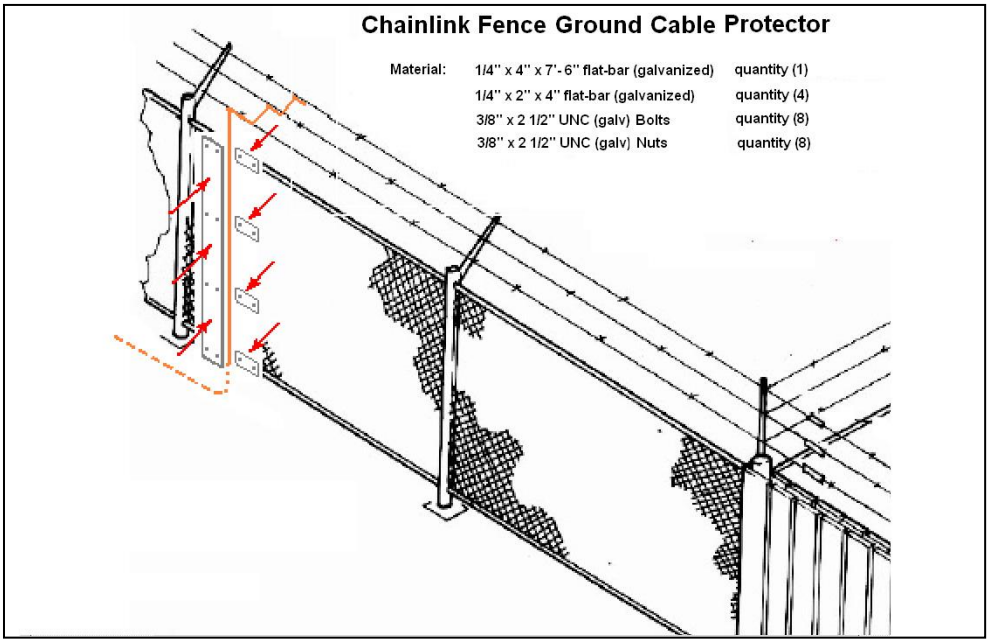


Figure 10: Field Designed Copper Conductor Cover

7.4.3 Switchyard Ground Surface Design

As discussed in Section 8.2, specified stone is important to reduce step and touch potential hazards in the switchyard and around switchyard perimeter fences. The areas surrounding

structures and equipment should be surfaced with specified surface stone to a depth of at least 80 mm as follows:

(1) Along station perimeter fences not connected to the station ground grid, from 150 to 200 mm outside the fence and 1500 mm inside the fence

(2) For fences connected to the station ground, the minimal width of specified surface stone should be 1500 mm on each side of the fence

(3) The area encompassed by the maximum swing of a gate should be covered with specified surface stone. The areas covered by asphalt or concrete are exceptions must be sloped to minimize pooling of surface water. Excessive water can increase the risk of exposure to hazardous touch and step potential.

(4) Extend coverage 1500 mm beyond all areas occupied by equipment and structures and cable pans

The rock should be crushed hard stone or rock such as dolomite limestone or igneous rock, 16 mm to 22 mm in size. See also *IEEE Std. 80, Guide for Safety in AC Substation Grounding, Section 12.5.*

Any new crushed rock used in a yard should be tested by Kinectrics to assure sufficient resistivity.

Over time, this gravel can sink into the earth below, become contaminated with windblown fines (fine organic or inorganic particles such as sand, vegetation or soil) and or weeds will grow up through lessening its effectiveness. Excessive weed growth or sinking rock should have remedial action taken.

7.4.4 Connectors, Grounding Plates, Clamping and Below Grade Corrosion

See Section 6.2, Item 12.

Good aging characteristics of a connector include the ability to maintain:

- Good electrical conductivity (low resistance connection)
- Corrosion resistance
- Required current carry capacity
- Mechanical strength
- Maintain temperature rise below that of the conductor and withstand the effects of heating.

Some connectors (such as the split bolt types) have been found to lose compression and thus have reduced conductivity and current carrying capacity.

Below grade and connections made to non-galvanized steel are to be exothermic (a typical trade name is Cadweld (www.erico.com).

For more information, see *IEEE Std. 80, Guide for Safety in AC Substation Grounding, Section 11.4* and *IEEE Std. 837*, *IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding.*

7.4.4.1 Grounding Plates

Grounding plates or tails bonded to the main ground bus with 107 mm² (4/0 AWG) taps should be installed at the location of most pieces of equipment.

7.4.4.2 Clamping

Above-grade grounding conductors require mechanical restraint to resist magnetic forces, which increase with the square of fault current. Clamps should be placed at least at 1 meter intervals.

7.4.4.3 Below Grade Corrosion

See Section 8.1.1, Item 6.

Refer to *IEEE Std. 665, Guide for Generating Station Grounding, Annex B*.

For information from the Copper Development Association on below grade copper corrosion, open: http://www.copper.org/resources/properties/protection/underground.html.

7.4.5 Generators

Hydraulic generators, their enclosures, generator neutrals and their enclosures, turbine shafts are grounded according to the manufacturer's specifications. Redundant fault current rated provisions are to be included in the grounding system design to accommodate these requirements.

Refer to *IEEE Std.665, Guide for Generating Station Grounding, Section 5.3.3*.

7.4.6 Penstock, Scroll Case and Draft Tube Liners

See Section 5, Item 4.

Metallic penstock liners, scroll case and draft tube liners are to be connected to the main ground grid with conductors sized for the station fault levels as follows:

(1) Metallic penstock liners are connected by at least one point. The number of ground grid connections depends on the liner length and is at the discretion of the designer.
(2) All metallic components of a scroll case must be bonded to the ground grid. The number of connections is at the discretion of the designer
(3) Metallic draft tube and pit liners are connected in at least two places.

The minimum size for mechanical strength is 67 mm² (2/0 AWG).

7.4.7 Head Gate and Sluice Gate Guides

Head-works electrical equipment (hoist drive motors, etc.) rated 600 V and higher shall be grounded through two independent connections. Typically this is achieved by connecting the service cable ground and a visible conductor (no smaller than #6 AWG or the service cable ground conductor) from the main station ground grid. This requirement exceeds the requirements of the *Ontario Electrical Safety Code (OESC)* for industrial applications. The rational for the second bond is the fact that high fault current may flow through undefined paths in generating stations

Head and sluice gate guides are to be connected to the main ground grid with conductors sized for the station fault. It is preferred to use exothermic connections to bond trash racks, head-gate gains and sluice gates. The following shall be observed:

(1) Head gate, trash racks and Sluice gate guides are connected by at least one conductor.
(2) The minimum size for mechanical strength is 67 mm² (2/0 AWG).

7.4.8 Structural Steel and General Steelwork

The base of every steel column should be connected to the main ground bus by means of 107 mm² (4/0 AWG) copper cable. The joints of columns not carrying any ground conductor should be bonded. See Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15 below.

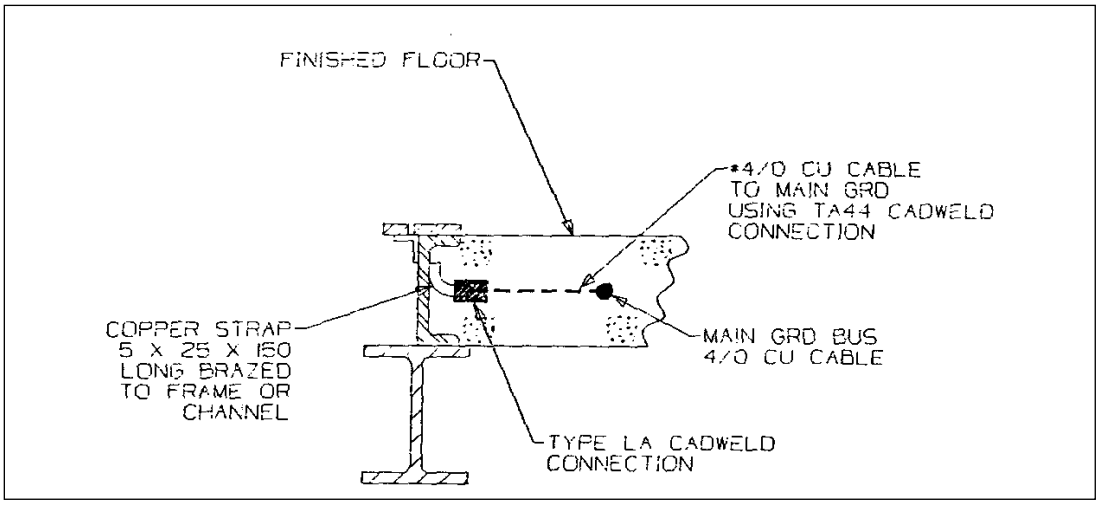


Figure 11: Grounding - Frame Ground

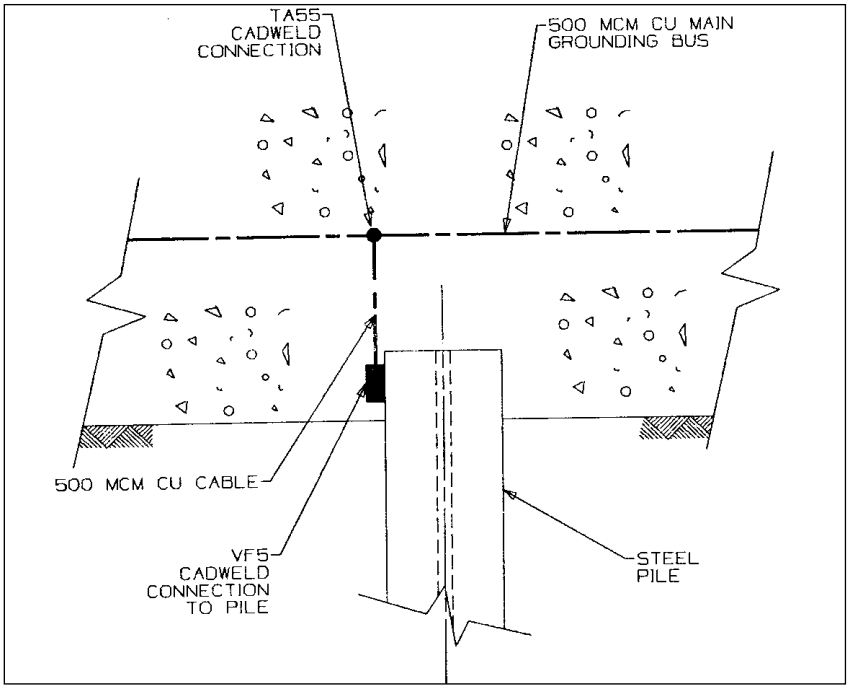


Figure 12: Grounding - Steel Bearing Piles

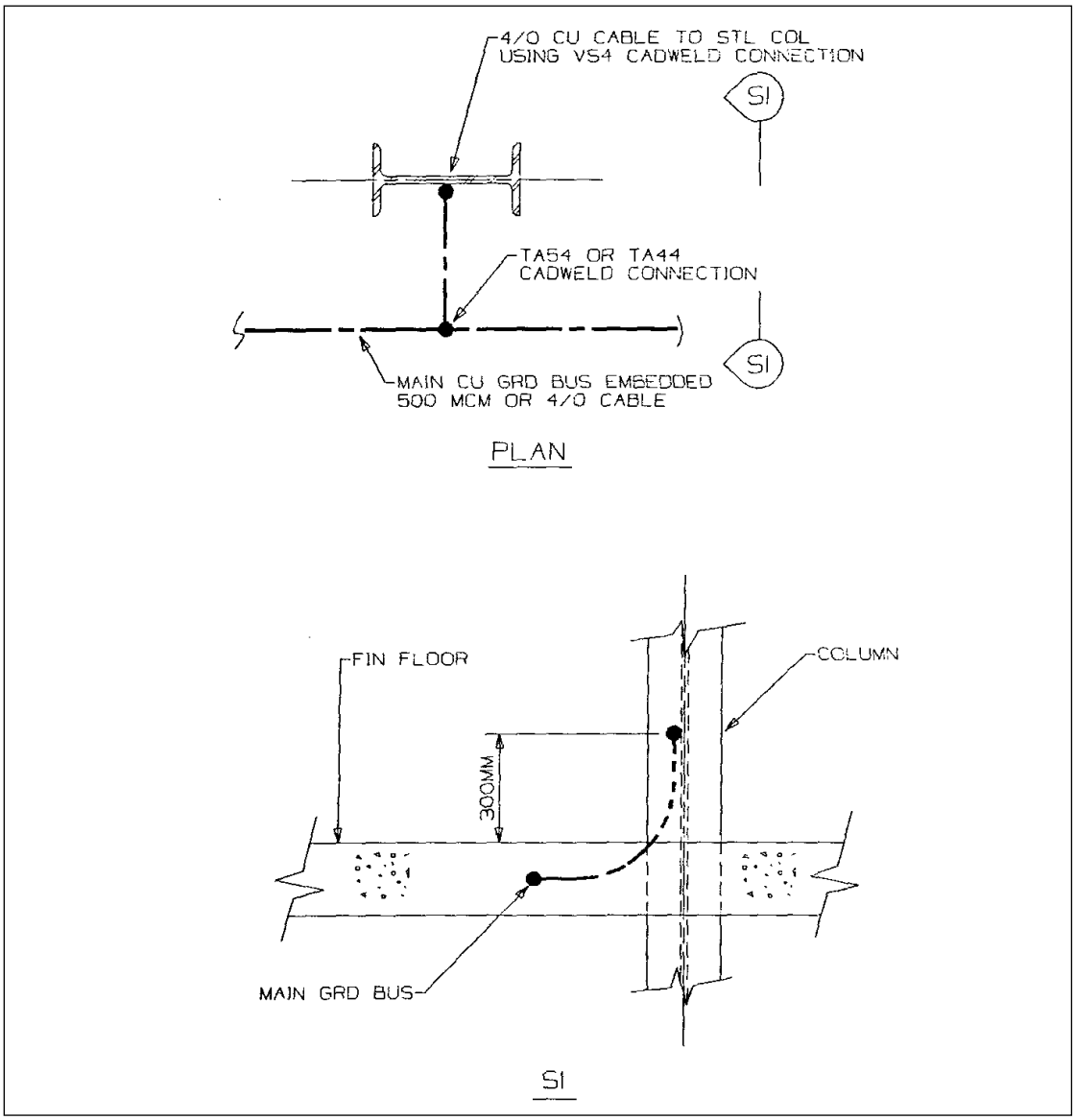


Figure 13: Grounding - Steel Columns

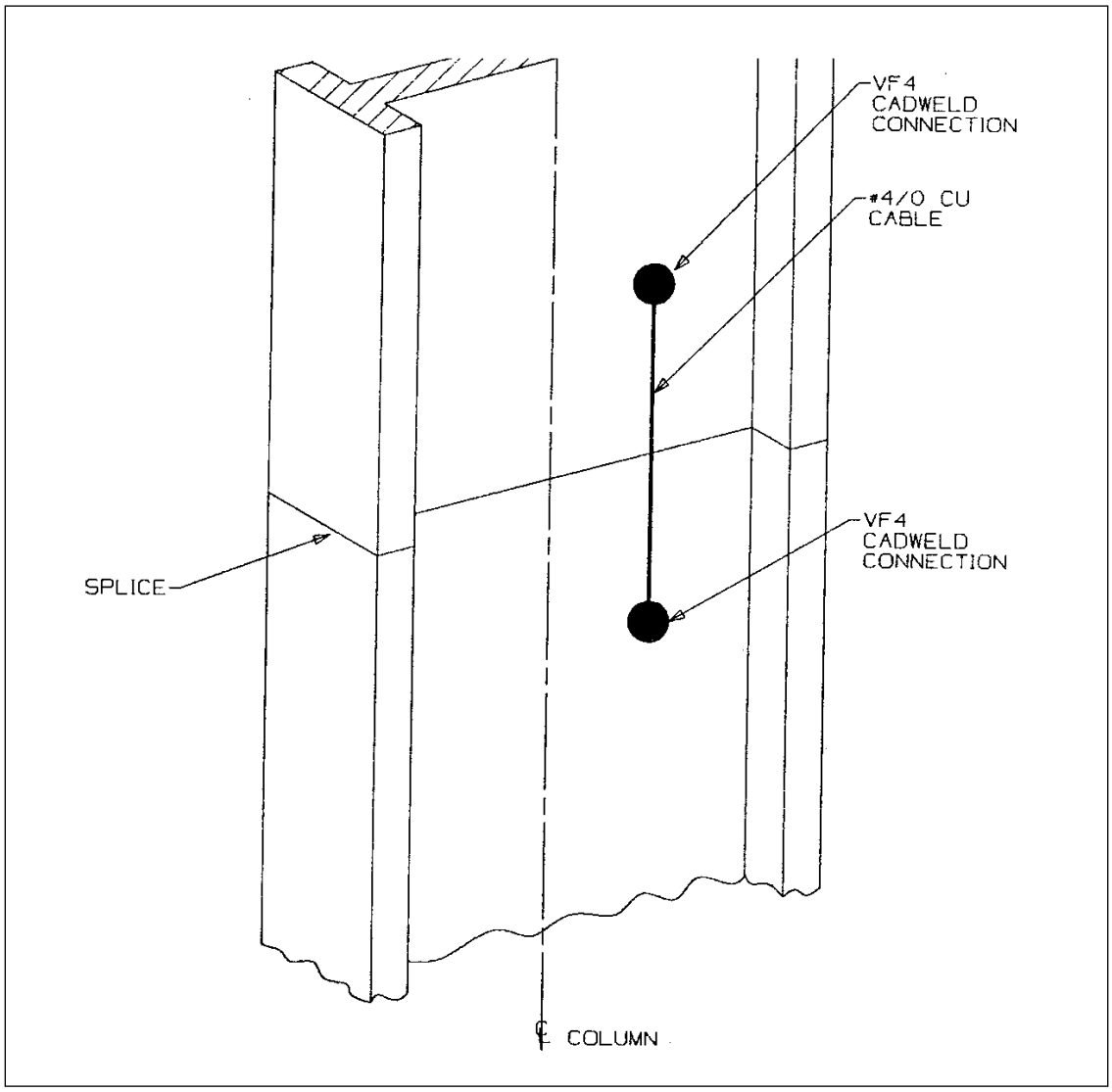


Figure 14: Grounding - Column Splice: Ground Connection

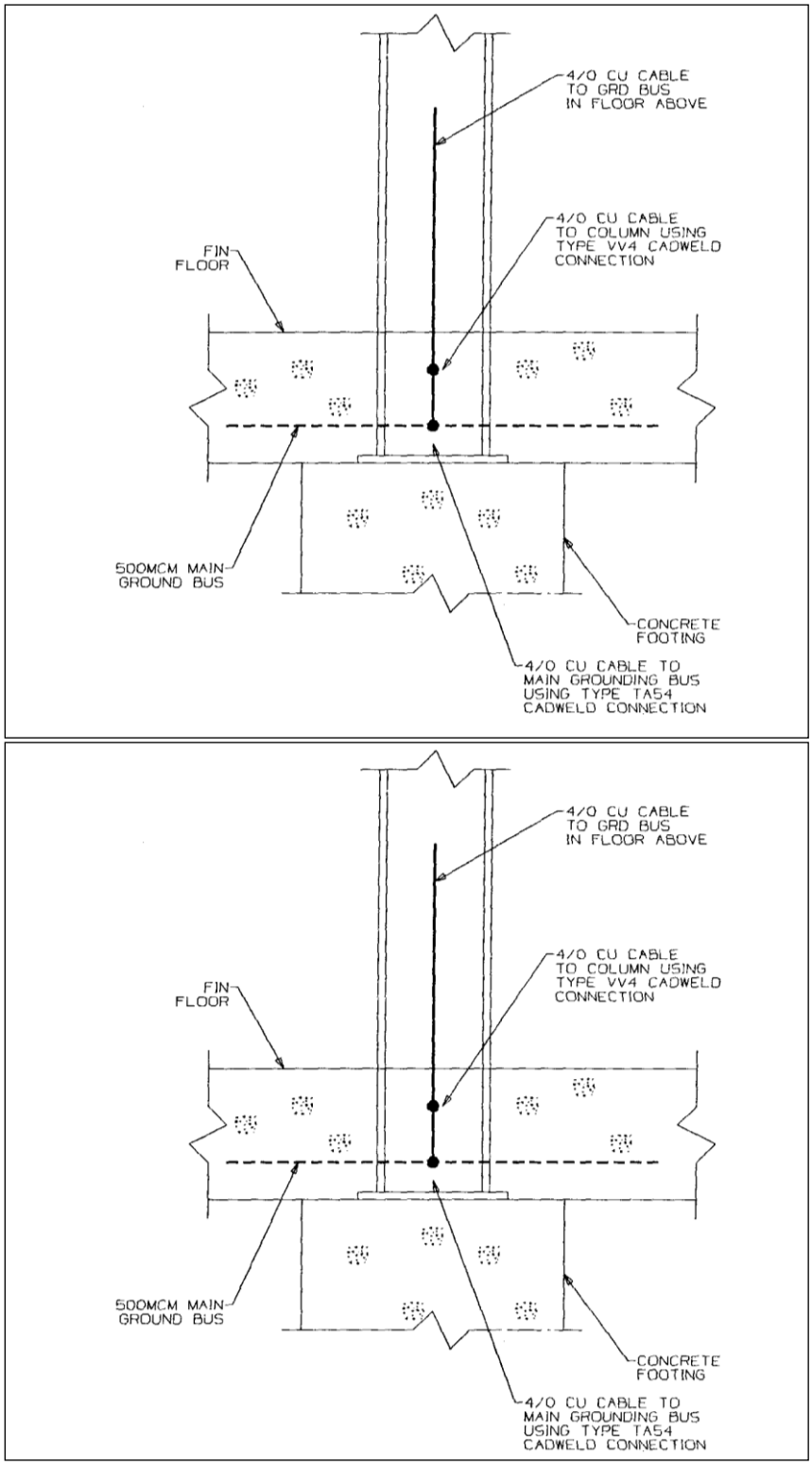


Figure 15: Grounding - Column and Riser

General steelwork such as stairs, door frames (Figure 16), gratings (Figure 17 and Figure 18), etc., should be connected to the main ground bus by minimum size conductor of 13 mm² (6 AWG) copper. Exposed steel should be grounded at locations where a touch potential hazard may exist.

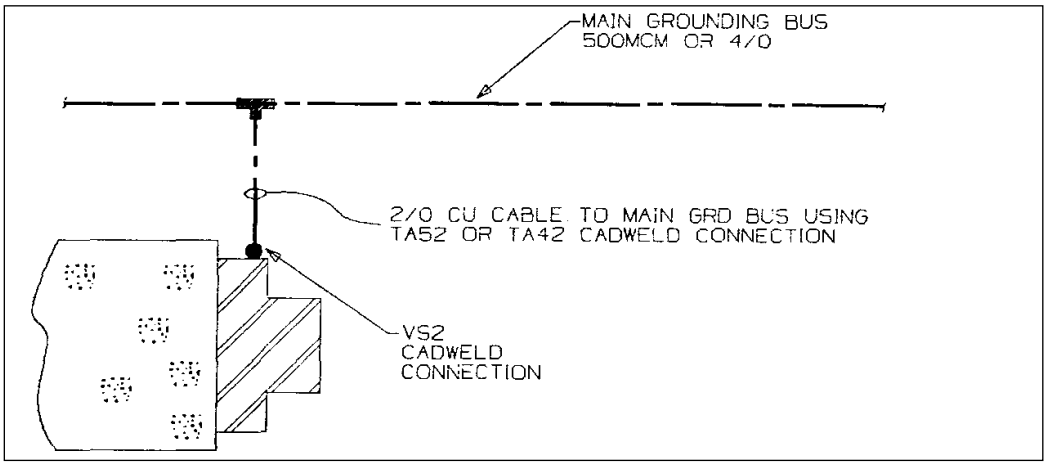


Figure 16: Grounding - Door Frames

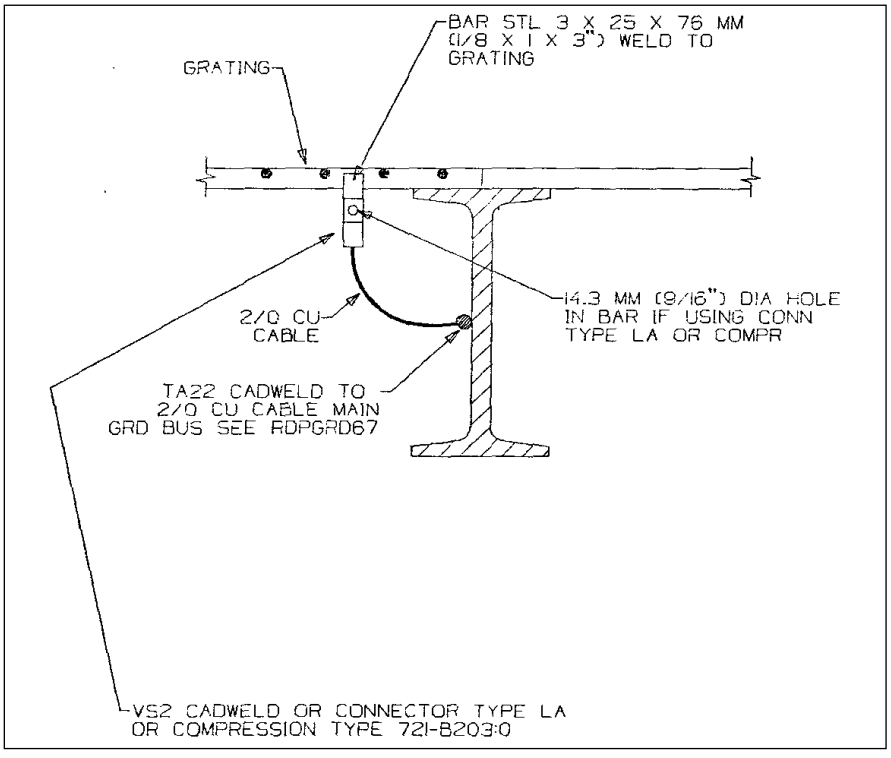


Figure 17: Typical Connection for Grounding Fixed Grating

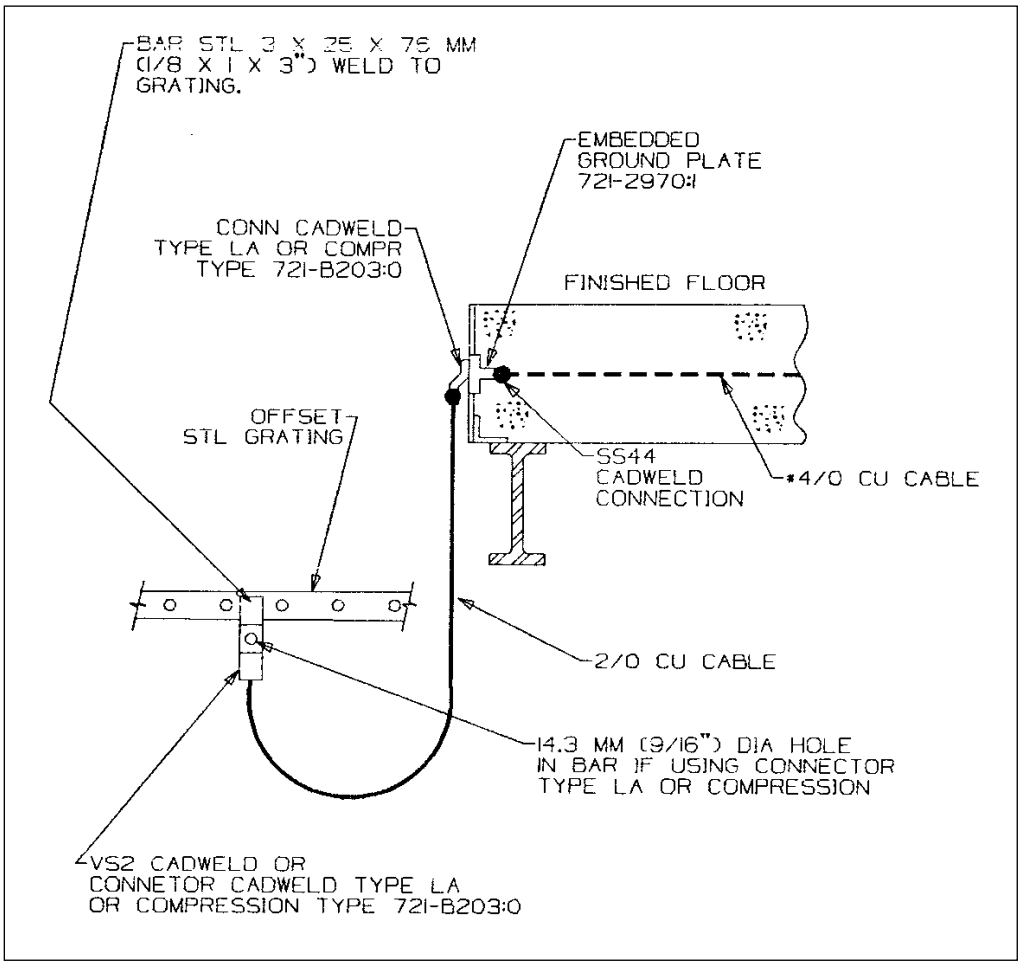


Figure 18: Grounding - Offset Removable Grating

7.4.9 Handrails

Handrails are to be connected to the main ground grid with conductors sized for the station fault levels. The minimum size for mechanical strength is 67 mm² (2/0 AWG). Sectionalized railings are to be individually connected to ground OR bonded together for continuity. Short handrails which are visible through their entire length, or longer handrails located away from high voltage or service conductors, may not require bonding. This includes handrails with no chance of dropped conductors, with very small capacitive coupling to high voltage phases and no contact with service power, for example feeding gate motors or lighting fixtures.

7.4.10 Metallic Gratings

Gratings are to be connected to the main ground bus by minimum size conductor 13 mm² (6 AWG) copper. However, if exposed to mechanical damage, the minimum size conductor is 67 mm² (2/0 AWG). See Figure 17 and Figure 18, above.

7.4.11 Powerhouse, Tailrace, Gantry Cranes and Railway tracks

Powerhouse and Gantry crane rails are to be connected to ground via a 107 mm² (4/0 AWG) conductor. Powerhouse crane rails shall be grounded at more than one point, preferably at each structural steel column.

Each outdoor crane rail is to be connected to ground at least at one point via a 107 mm² (4/0 AWG) cable. Individual rail sections are to be bonded together using 107 mm² (4/0 AWG) cable. All cable-to-rail connections are to be exothermic welds. Newly installed outdoor cranes with overhead rail feeds, are to have a fourth rail to act as ground.

7.4.11.1 Railway Tracks

Plants having railway tracks have part of these rails inside the station fence and the rest outside it. The rails inside the fenced area of the Plant should be grounded to the main ground grid with a 67 mm² (2/0 AWG) conductor. In this case, the system main ground bus is also connected to the fence grounding system. The part of the steel rails outside the Plant ground electrode area should be isolated from the station ground electrode by using several track isolating sections or preferably, remove a section of rail.

See Figure 19 and Figure 20, below.

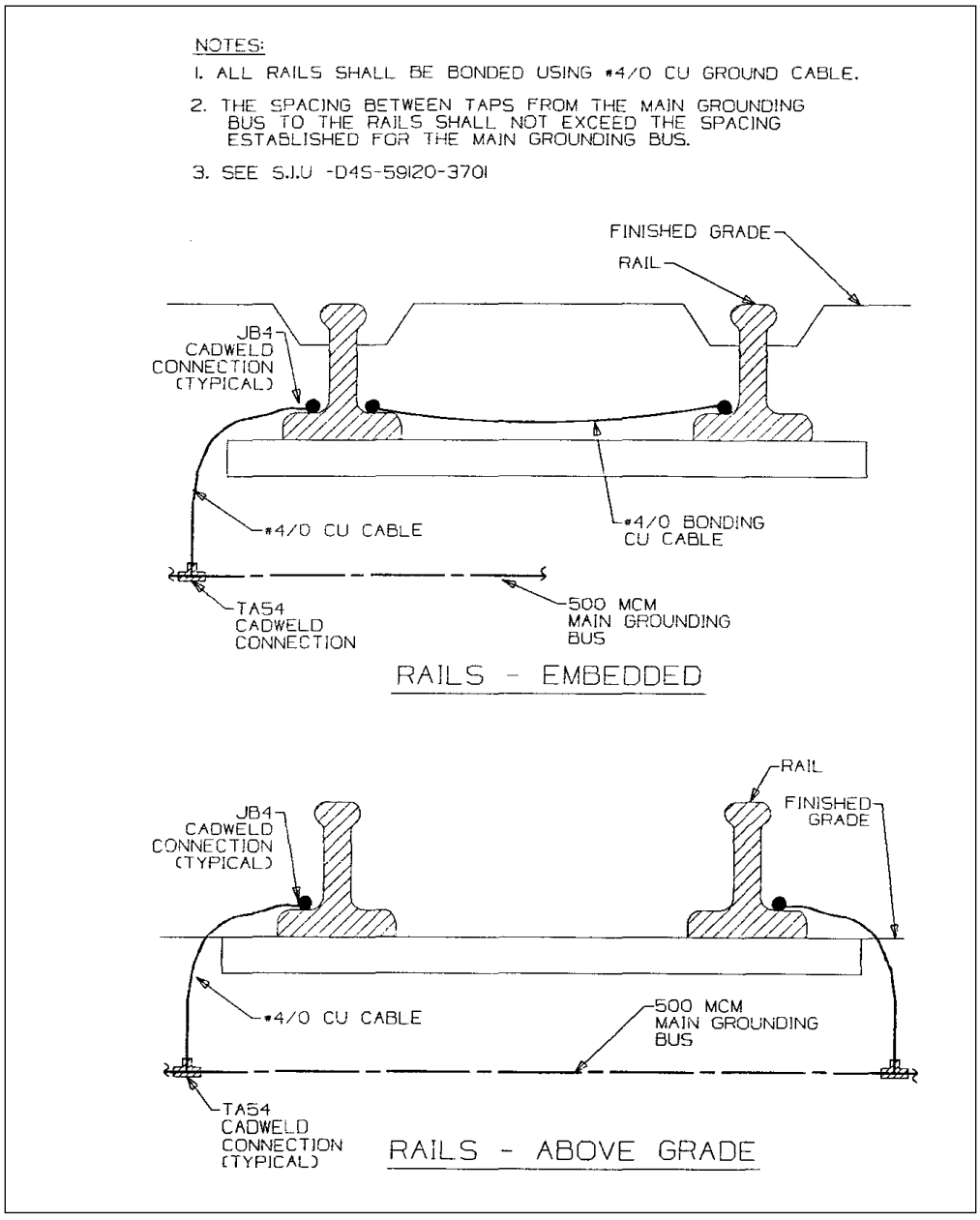


Figure 19: Grounding - Railway Lines and Crane Rails

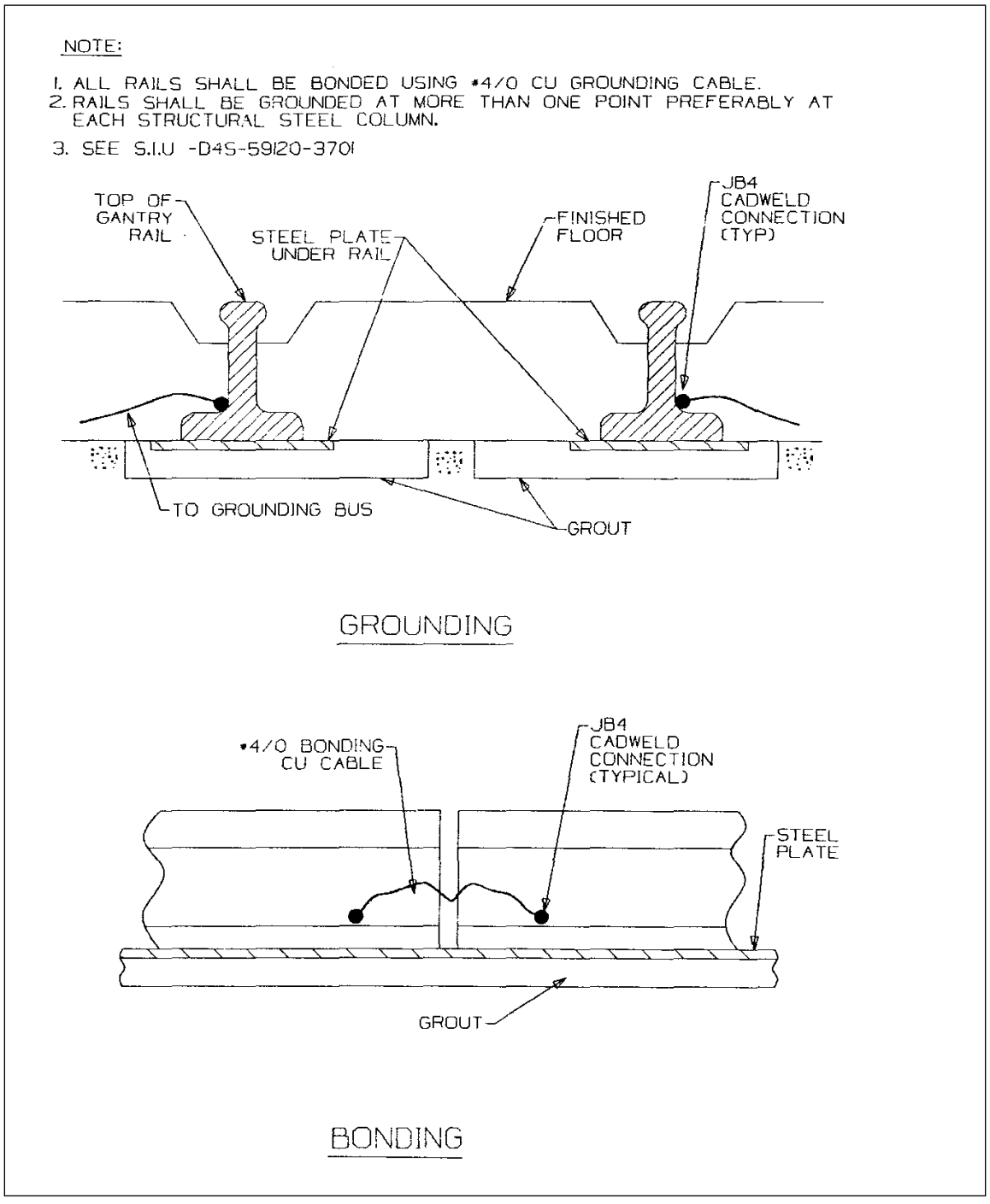


Figure 20: Grounding - Bonding of Crane or Gantry Rails

7.4.12 Metal Duct Work, Roof Flashing, Metal Siding, Piping and Tanks

7.4.12.1 Duct Work

The minimum size for mechanical strength is 13 mm² (6 AWG). See Figure 21 and Figure 22.

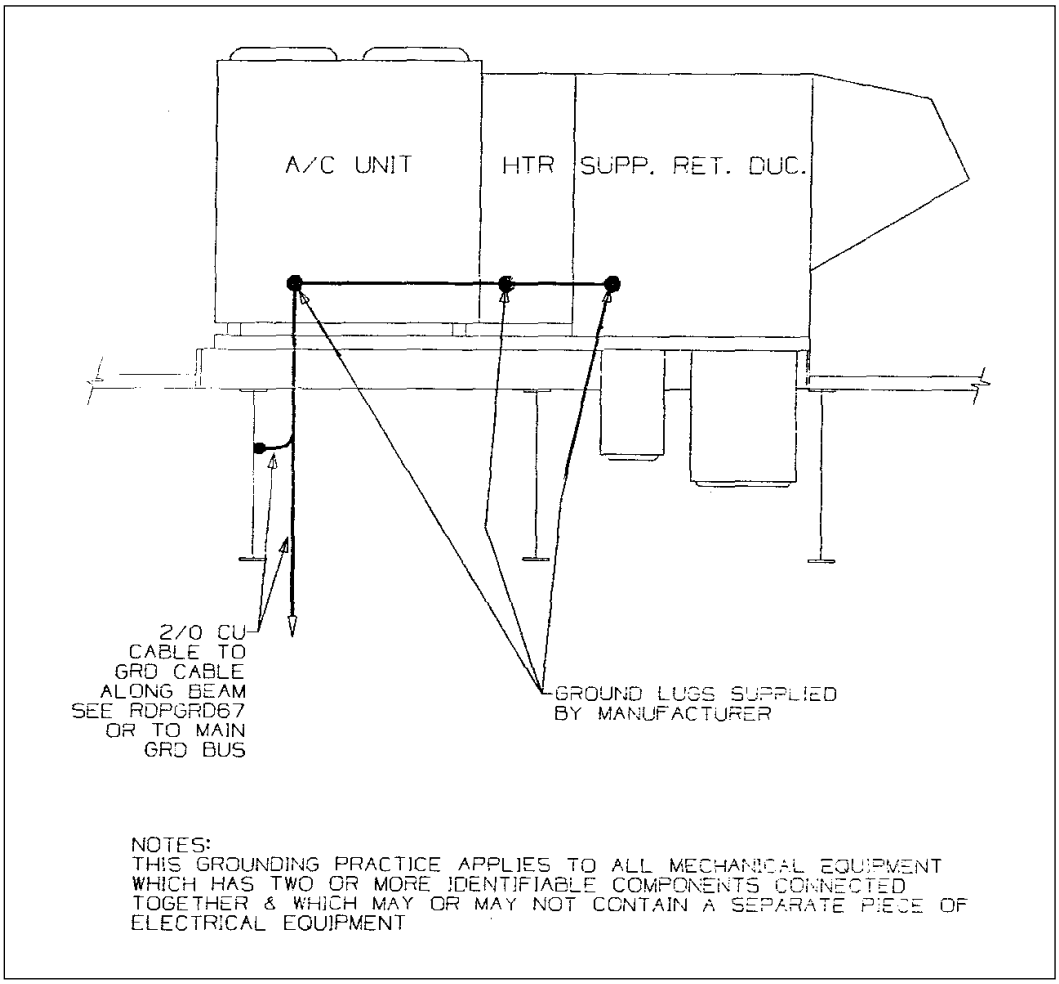


Figure 21: Air Conditioning Equipment Grounding

Note: This grounding practice applies to all mechanical equipment, which has two or more identifiable components connected together and which may or may not contain a separate piece of electrical equipment.

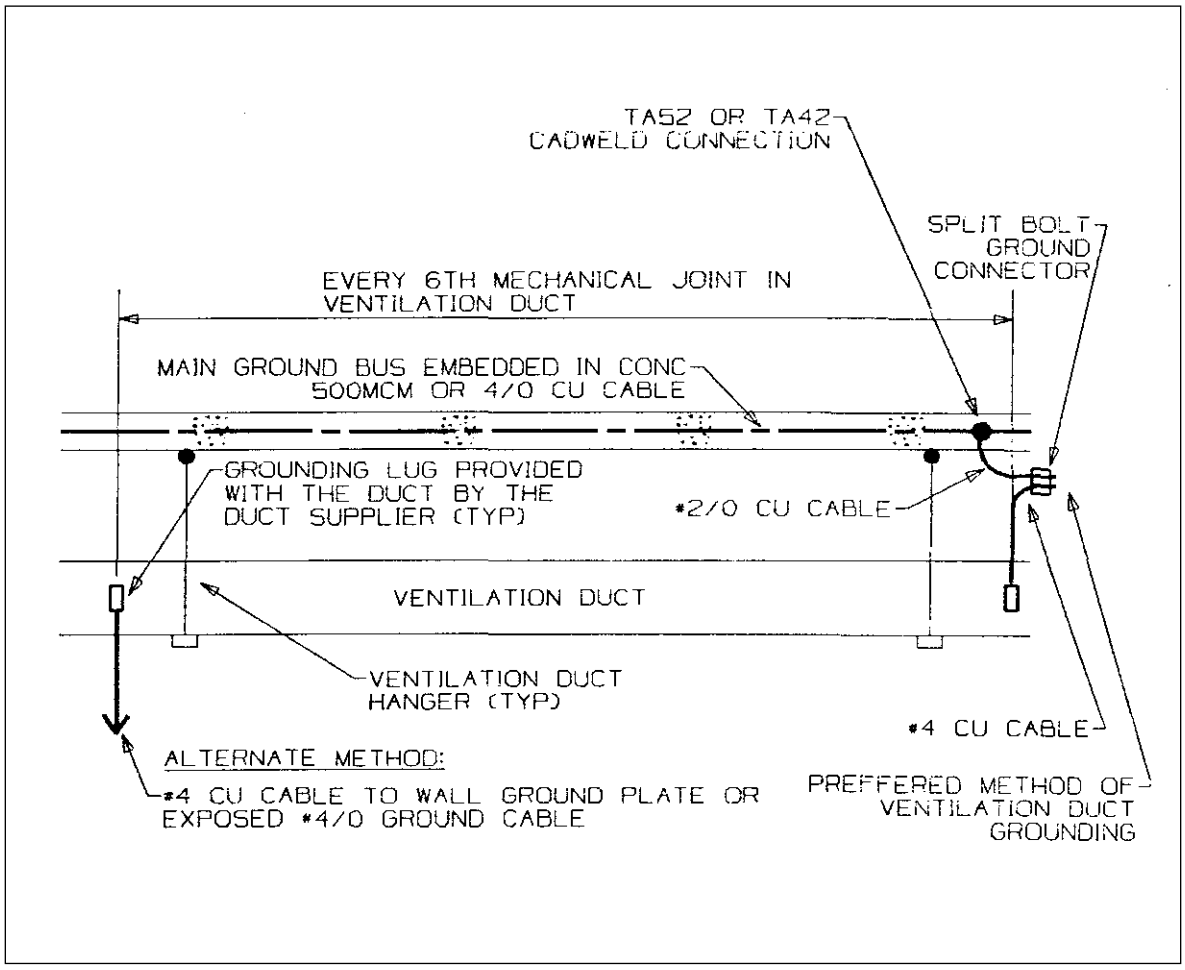


Figure 22: Grounding - Ventilation Duct

7.4.12.2 Roof Flashing

Roof flashing should be connected to ground by a 13 mm² (6 AWG) conductor. See Figure 23 and Figure 24, below.

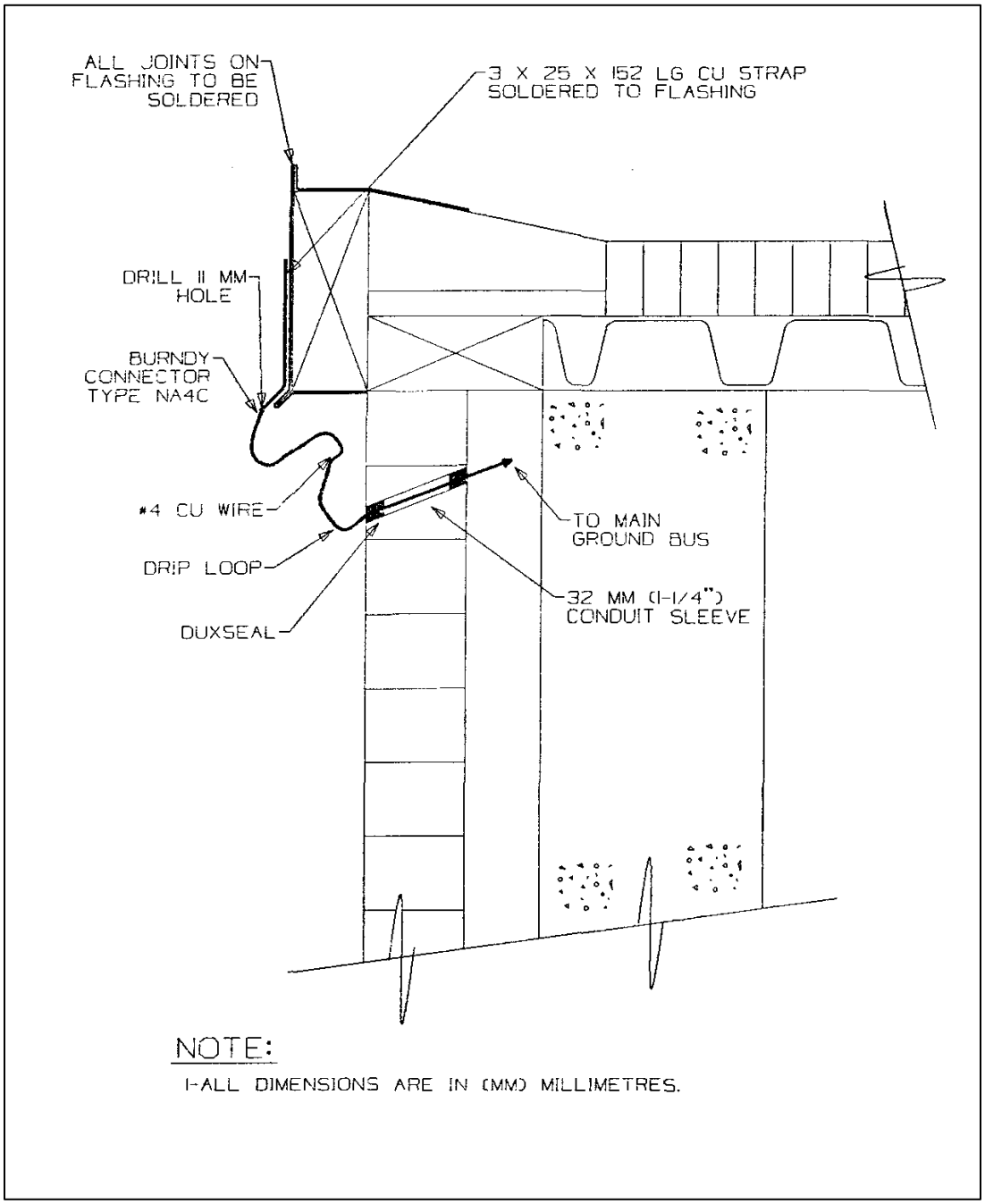


Figure 23: Grounding - Roof Flashing

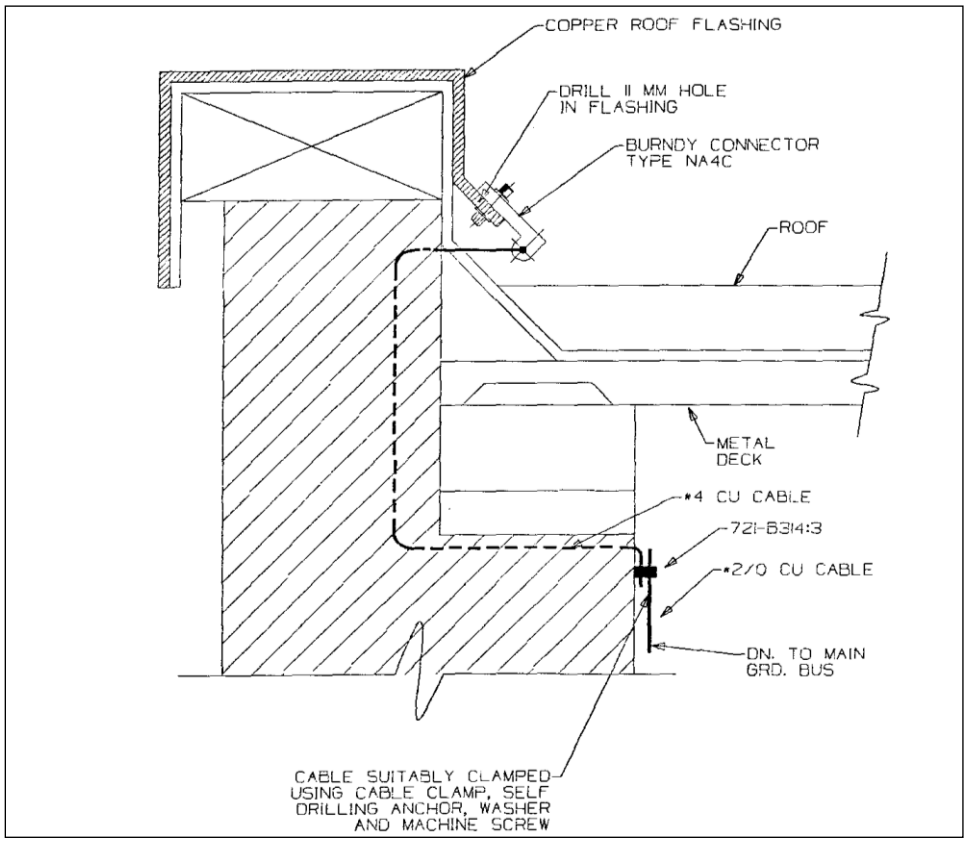
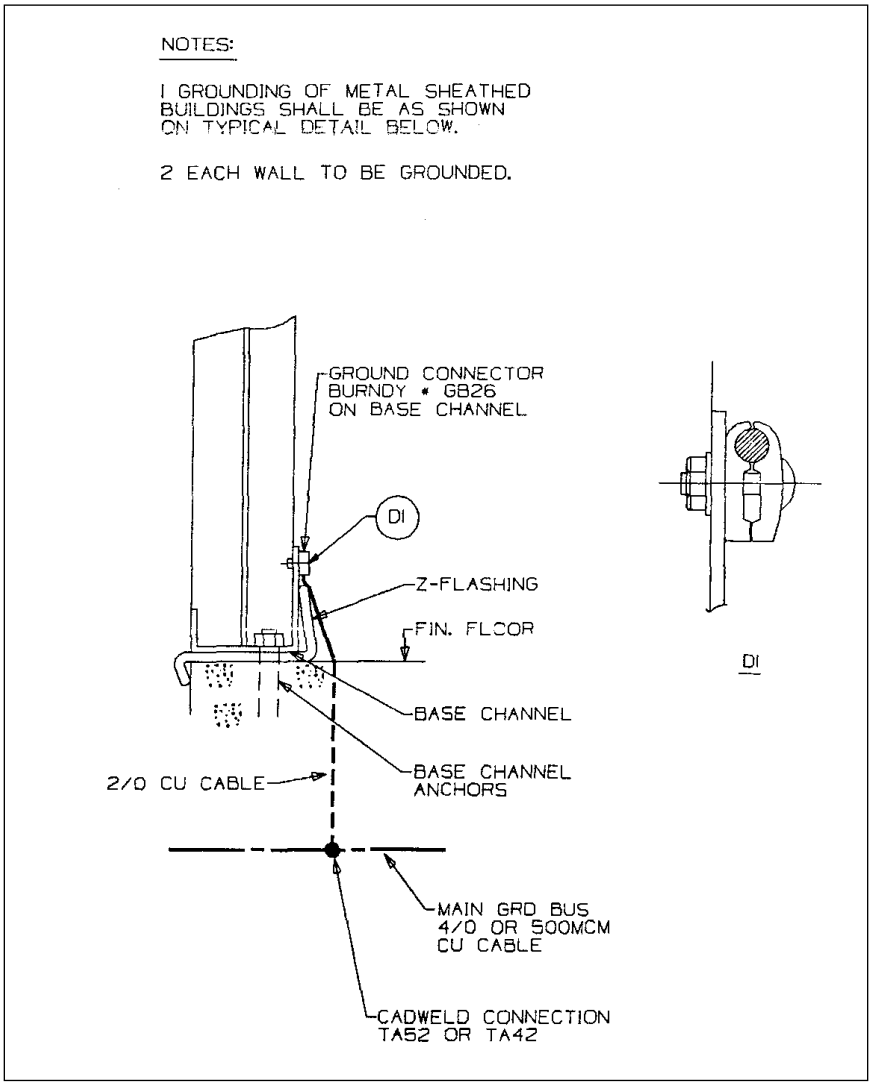


Figure 24: Grounding - Internal Roof Flashing

7.4.12.3 Metal Siding

Metal siding not connected to the building structural steel (that is connected to ground) should be connected to ground at least once, by a 13 mm² (6 AWG) conductor on each side of the building. See Figure 25.



(Ontario Hydro STD5-C-H-57600-002, Design Guide on Grounding Practices for Generating Stations)

Figure 25: Grounding Metal-Sheathed Buildings

7.4.12.4 Piping and Tanks

All piping tanks, heat exchangers or any vessel in a system in which liquids or gases are stored or transported should be connected to the main ground bus at one point. Piping in each process is grounded in each building served and also in areas traversed by the piping. High velocity steam or gas pipes and associated metal jackets should be grounded at more than one point to prevent static discharge build up.

The minimum size for mechanical strength is 67 mm² (2/0 AWG).

See Figure 26, Figure 27, Figure 28, Figure 29 and Figure 30.

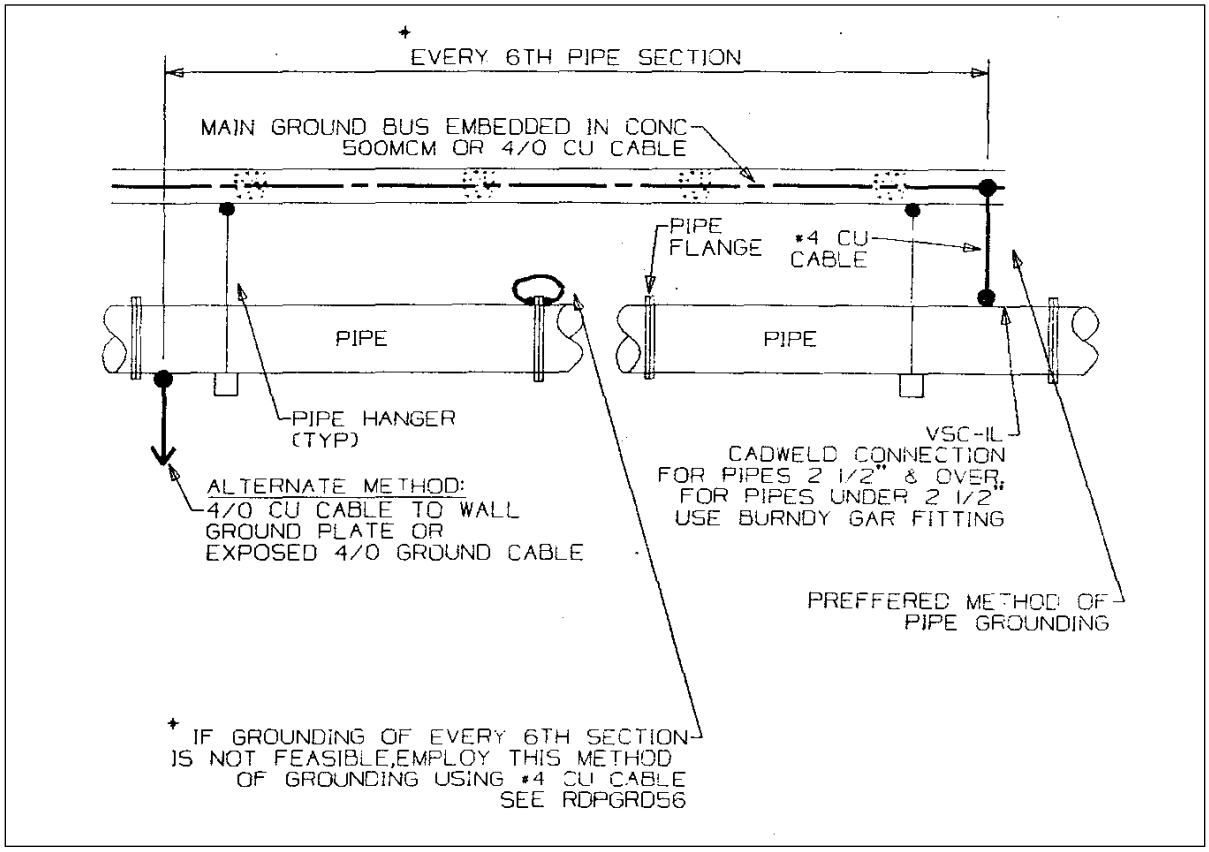


Figure 26: Grounding - Piping

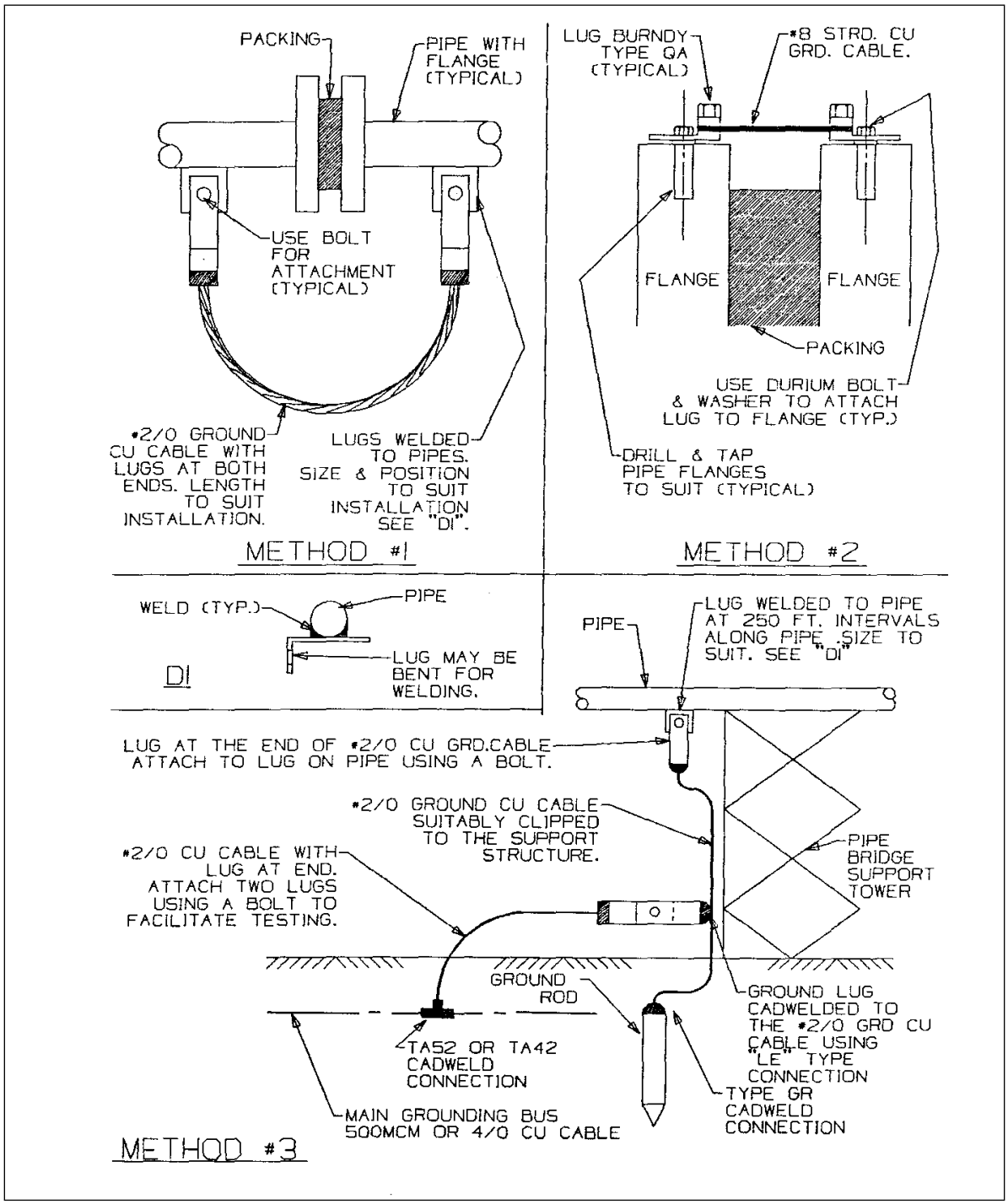


Figure 27: Grounding - Pipe Bridges: Bridge Connections at Flanges and Ball Joints

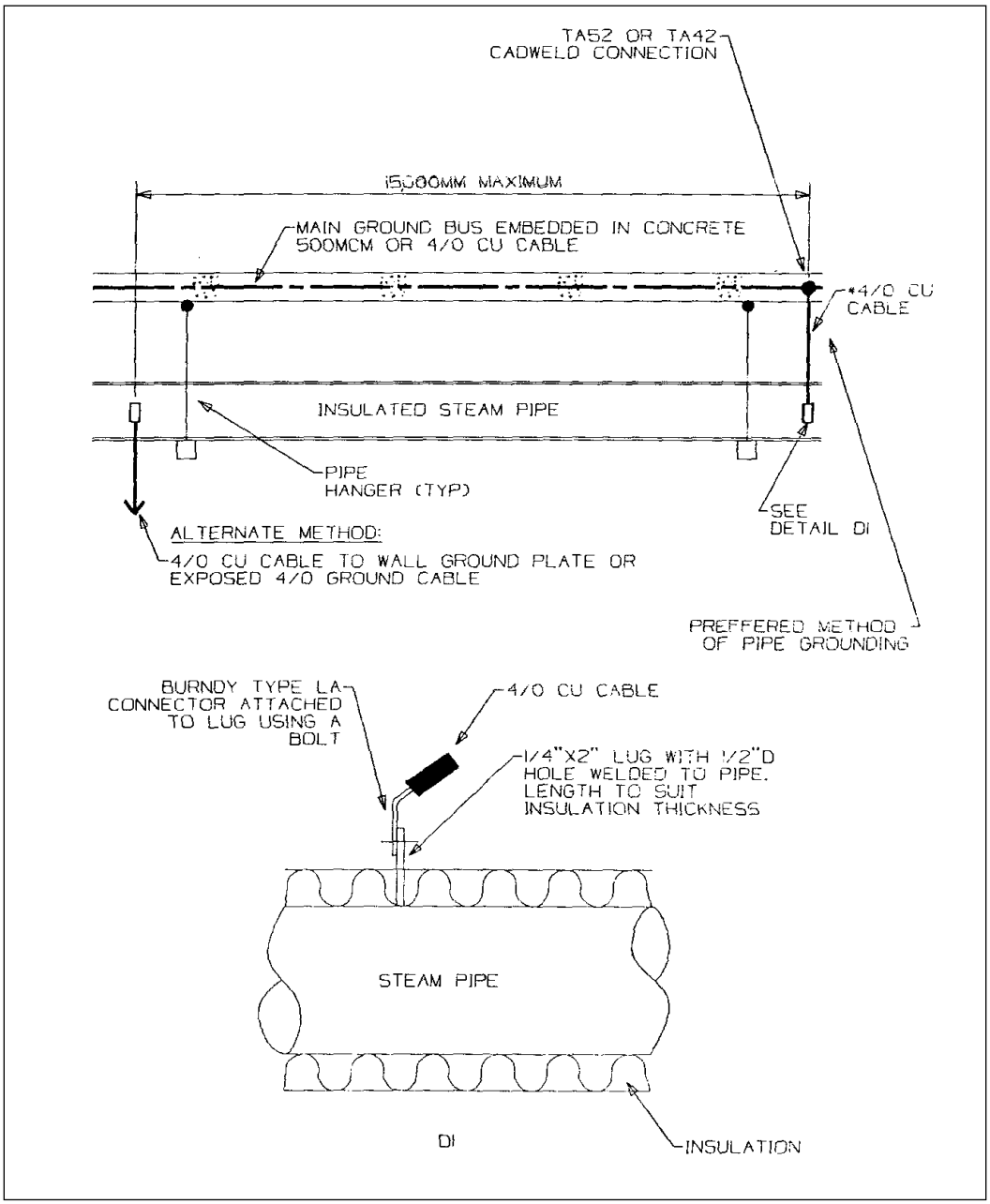


Figure 28: Grounding - Steam Pipe

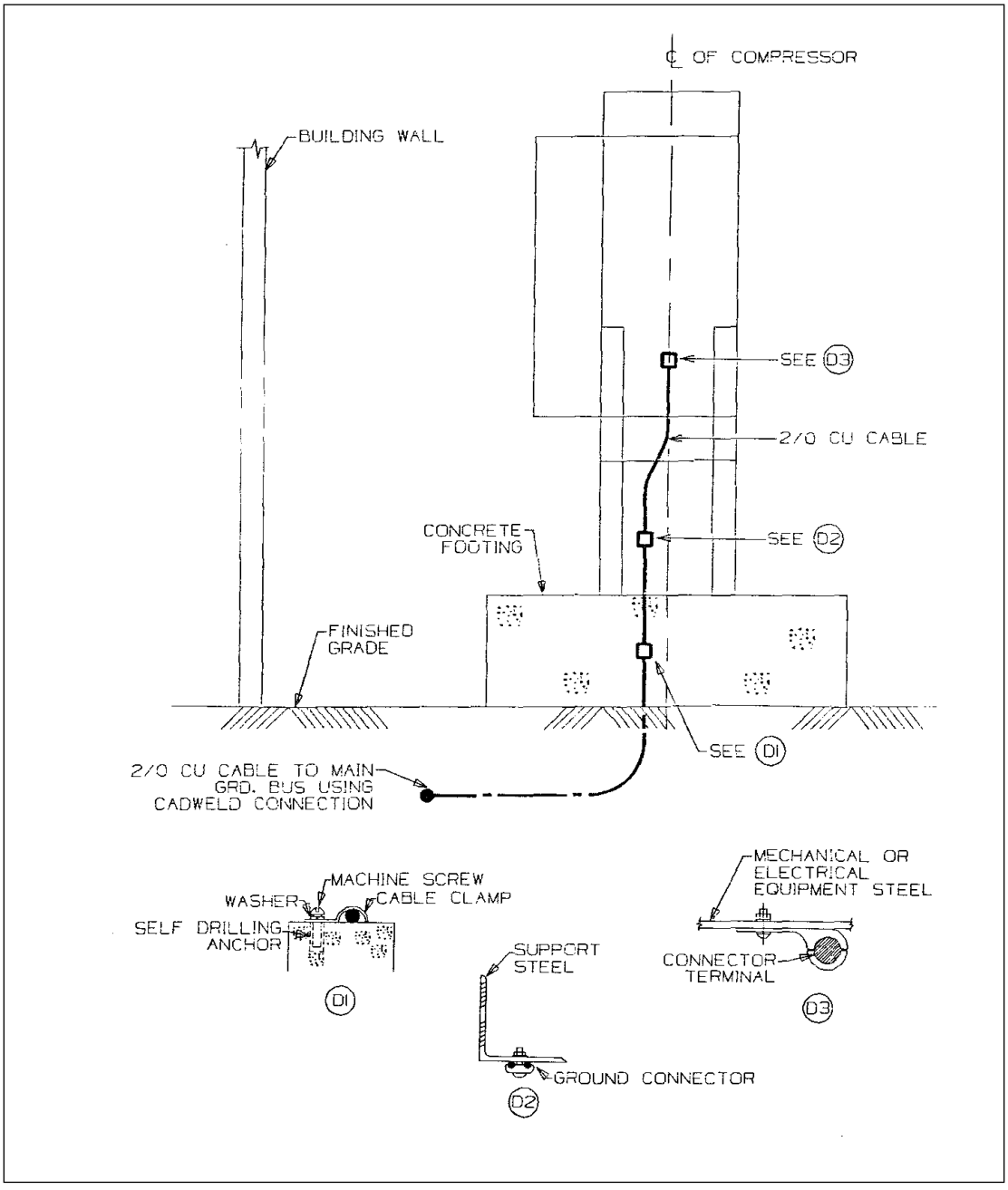


Figure 29: Grounding - Compressor Cooler

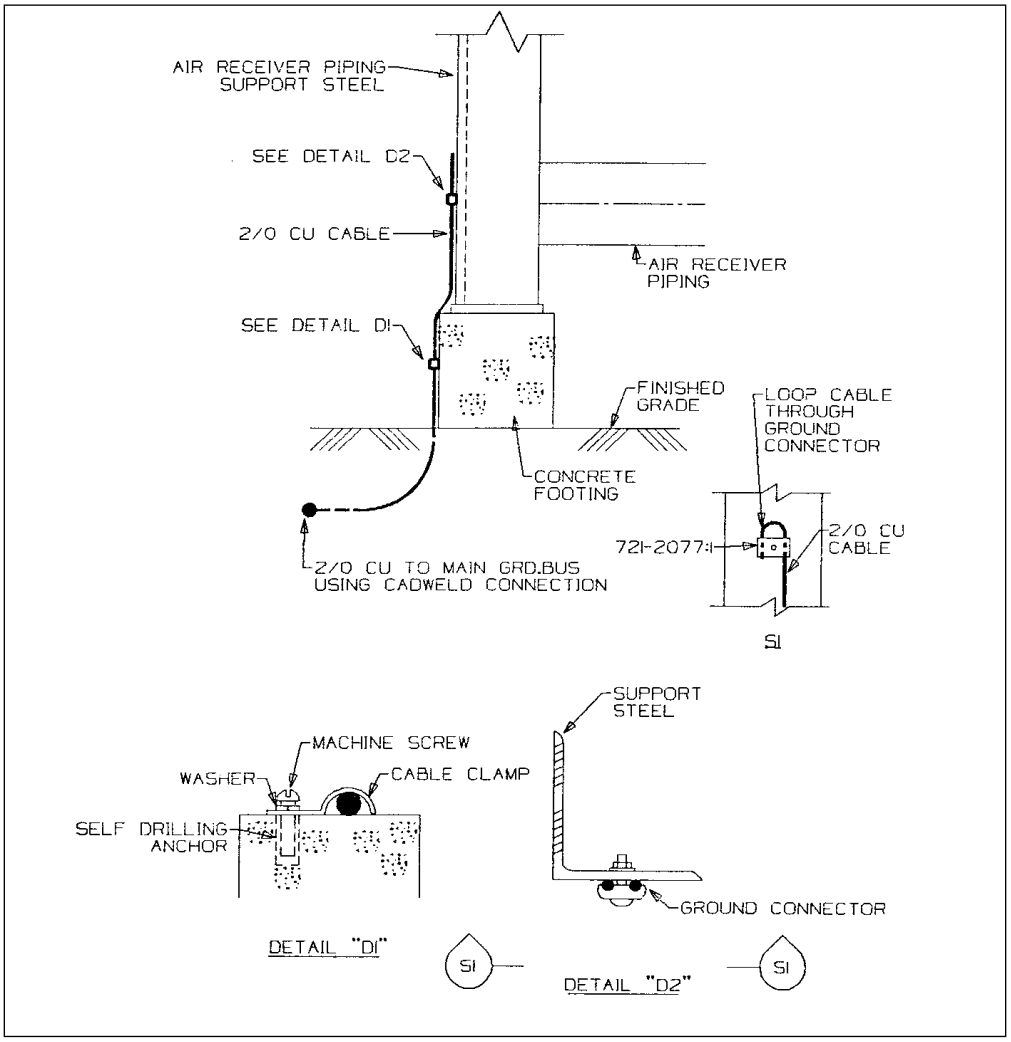


Figure 30: Grounding - Support Steel for Air Receiver Piping

7.4.13 Instrumentation, Control and Sensitive Electronic Equipment

See Section 5, Item 12.

Good grounding practices can minimize interference on instrument/control circuits. Low frequency (60 Hz) interference on low-level circuits (e.g. on thermocouples, analogue current loops, network connections) can result from inductive coupling between these conductors and parallel power cables carrying heavy current.

Mitigation involves a combination of:

- Go and return conductors run within the same cable (a balanced twisted pair optimizes this strategy),
- Transducers and instrumentation use differential inputs / outputs with balanced impedance and high common-mode voltage immunity,
- Circuits have a connection to ground at only one point (usually the receiving instrument),
- Shields on these circuits have a bond at only one end.

Bonding a shield at both ends may cause it to pick up 60 Hz current, again due to parallel power conductors. Shield current can induce slightly different potentials into a twisted pair due to manufacturing tolerances, causing a differential interference potential.

Circuits carrying low-level high-frequency signals (e.g. video, radio receiving antennas) often use coaxial cable in order to match impedances (to prevent spurious signal reflections). Here 60 Hz interference is usually attenuated with high-pass filters.

High frequency interference on instrumentation / control circuits may be caused by:

- Lightning (even when striking hundreds of metres from the powerhouse)
- HV switching (especially disconnect switches) and faults
- Switching of dc inductive loads (e.g. electromechanical relays)
- Switching of plant loads (especially tripping of breakers during motor starting)
- Operation of radios or cell phones
- Arc welding.

Mitigation may involve a combination of:

- Use of coaxial cable (the shield is efficient at high frequencies)
- Instruments attenuate high frequency interference with low-pass filters and varistors
- Shields on multi-conductor cables are bonded at both ends to neutralize interference.

Bonding the shield at both ends causes a high frequency current to flow in the shield. Mutual coupling to the internal conductors induces a potential that exactly cancels (neutralizes) the high frequency potential difference between the ends. This benefit is not available for controlling 60

Hz interference because the shield resistance is significant compared to shield reactance at this low frequency.

Note the above conflict between bonding shields at one and both ends. Circuits contained within one metallic building tend to have little coupling to the worst high frequency interference sources (lightning and HV switching or faults). Here single-end shield bonding is correct.

Circuits running outdoors (especially within switchyards) or between separated buildings can have significant coupling to lightning and HV switching or faults. Here shield bonding at both ends is correct. External circuits usually contain higher level signals (e.g. from CVTs or CTs), so the increased risk of interference due to 60 Hz shield currents is not a problem.

Refer also to *IEEE Std. 1050, Guide for Instrumentation and Control Equipment Grounding in Generating Stations*, *IEEE Std. 1100, Recommended Practice for Powering and Grounding Sensitive Electronic Equipment*, and equipment manufacturer's recommendations.

7.4.13.1 Signal-Sensing Device Grounding

The frames of all instrumentation and control devices such as transducers, servo-mechanisms, dc motors, solenoids, detectors, etc., should be connected to the main grounding point by 3.3 mm² (12 AWG) copper conductors

7.4.14 Instrument Transformers

Each freestanding instrument transformer case in a medium or high voltage switchyard (13.8 kV and up) should be connected to a ground loop on the support structure. The ground connection and each half of the ground loop should be capable of carrying the primary voltage maximum ground fault current at that location during the time required to clear the fault. Cases of instrument transformers less than 13.8 kV should be connected directly to the ground grid by means of a single conductor sized for the maximum ground fault current at the location and the time required to clear the fault In both cases, the minimum conductor size is 67 mm² (2/0 AWG) for mechanical strength.

7.4.14.1 Instrument transformer Secondary Circuits

See Section 5, Item 12.

There should be only one grounding point on any instrument transformer secondary. The secondary circuits for current and voltage transformers should be grounded at a load termination point near the relay room cable entrance, not at the instrument transformer connection box. Grounding at the point of cable entry will reduce the level of transient voltage rise reaching the load equipment. The size of ground conductor should be the same as the circuit conductors but under no circumstances less than 10 mm² (No. 8 AWG).

See Figure 31 and Figure 32.

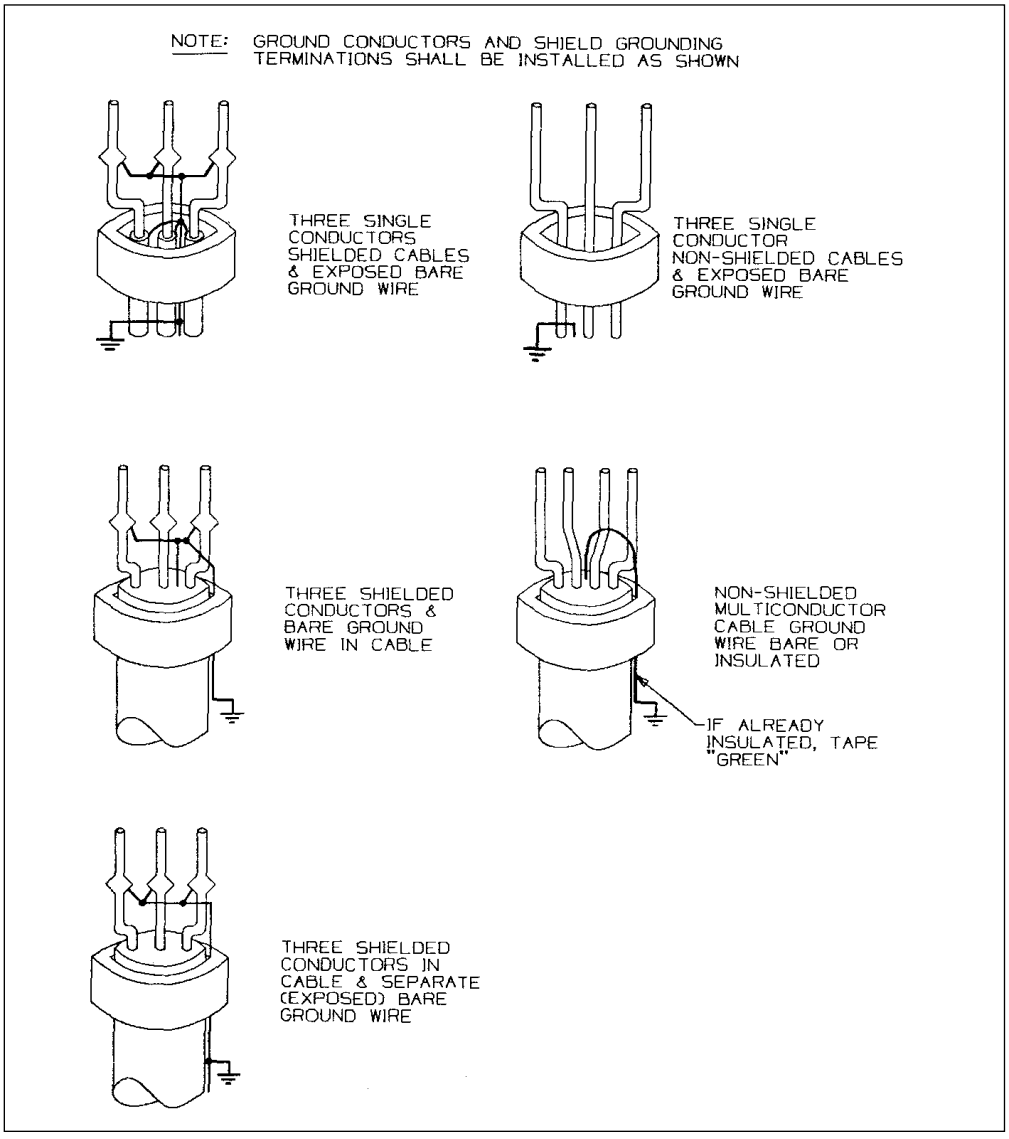


Figure 31: Grounding - Core Balance Current Transformers

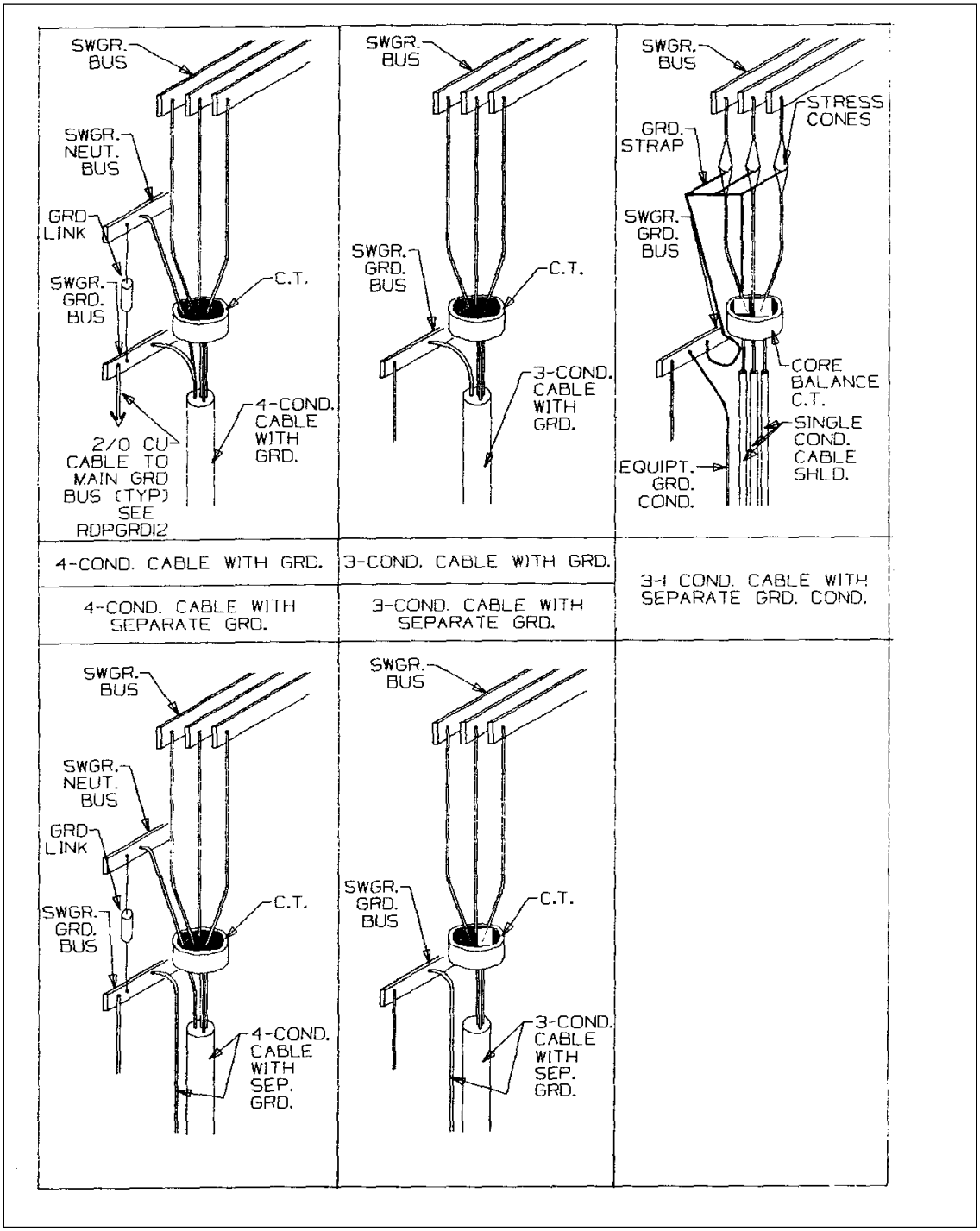


Figure 32: Grounding Core Balance Current Transformers with Switchgear Neutral Bus

7.4.15 Racks for Control, Metering, Relaying and Annunciation

All racks should be individually equipped with a grounding bar at the bottom or top of the rack, and connected to a common ground bus.

See Figure 33.

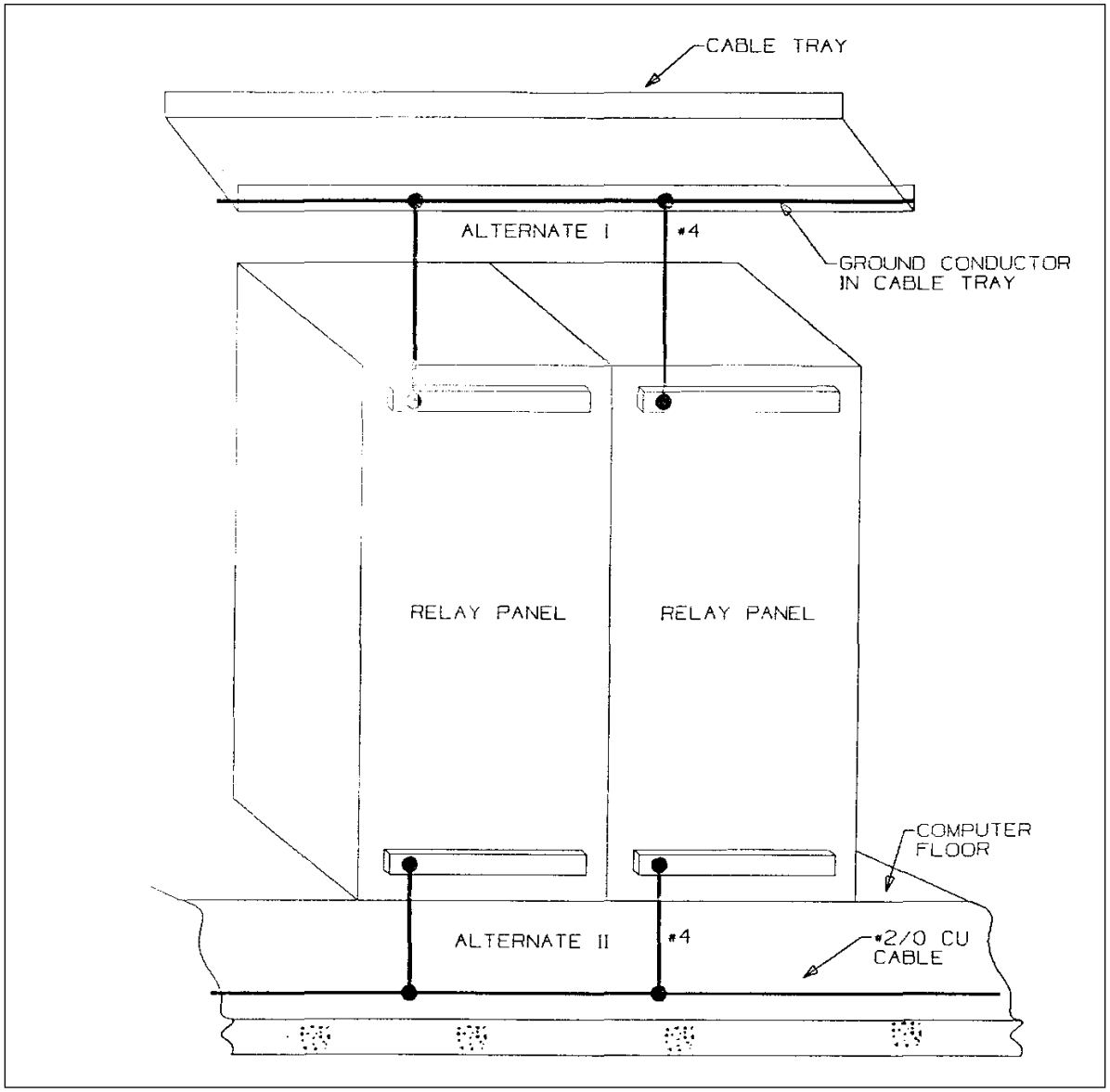


Figure 33: Grounding - Relay Panel

7.4.16 Battery Bank Racks

Battery bank racks should be anchored to the floor and be connected to the ground grid with a removable 21 mm² (#4 AWG) conductor.

7.4.17 Standby Generators

The frame of permanent standby generators should be connected to the ground grid by two 107 mm² (4/0 AWG) conductors. Also discuss with manufacturer/supplier.

7.4.18 Disconnect Switches (Medium and High Voltage)

See Section 6.2, Item 5.

If a disconnect is mounted on a steel structure common to all three poles, its grounding should consist of at least a ground loop at the base of the structure plus a ground conductor connecting all three switch bases together. Such a conductor should be capable of carrying at least 50 % of maximum ground fault current at the station.

If each switch pole is mounted on its own steel structure, each structure should be grounded separately.

Grounding switches should be grounded by means of a conductor connected to the ground blade, adequate to withstand the maximum ground fault current expected at the station

Operating rods of manually operated switches and motor driven switches should be grounded by means of a conductor clamped to the rods, adequate to withstand at least 50 % of the maximum ground current. In cases of switches with a high gear reduction ratio, the operating rod should be grounded by means of a conductor connected to a multi-revolution grounding device mounted on the rod. The multi rev device may be used on manually operated switches as well. See Figure 34.

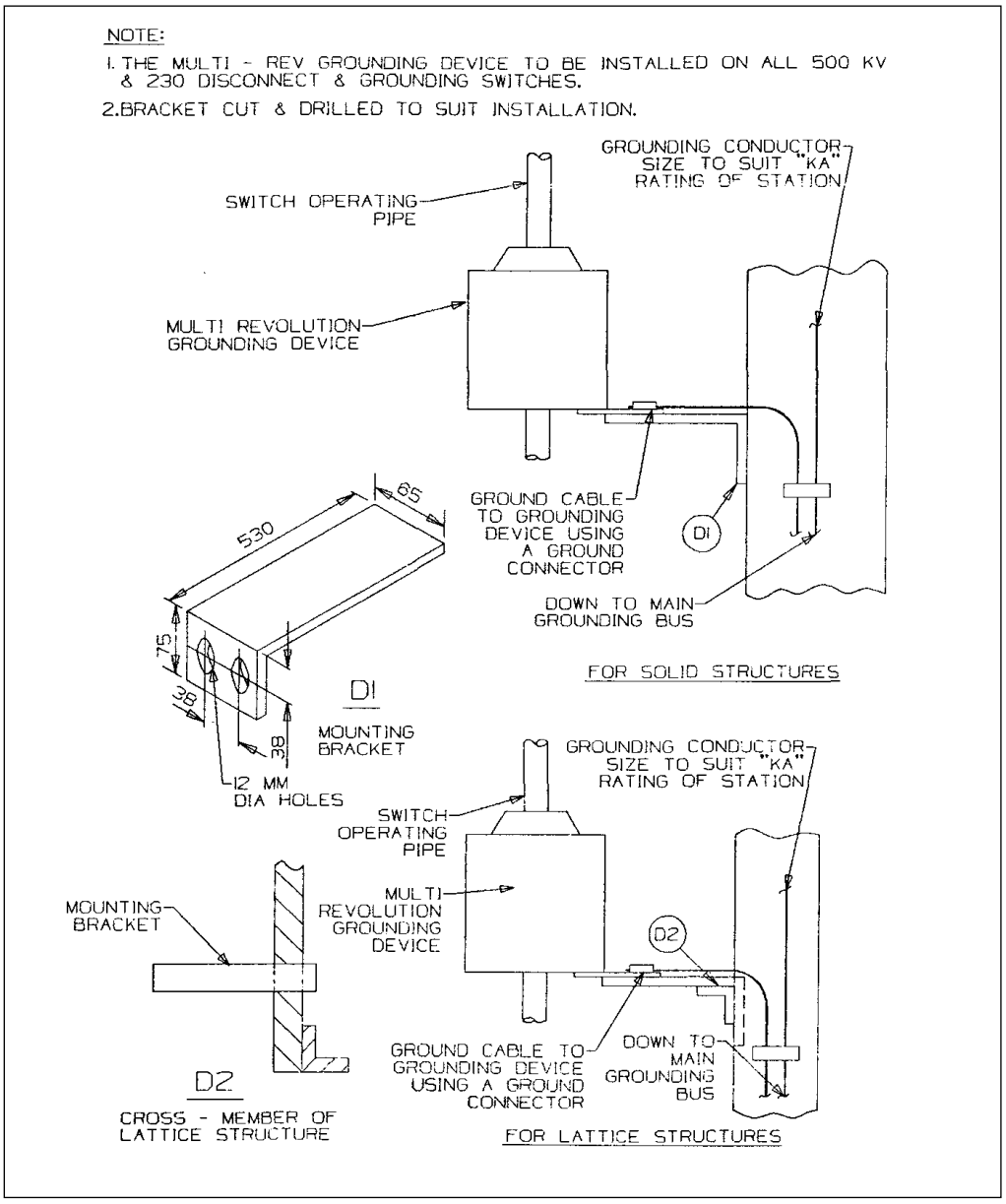


Figure 34: Grounding - Multi-revolution Grounding Device for Switch Operating Pipe

Ground gradient control mats should be installed at the operating handle locations of manually operated disconnects and ground-switches (indoor and outdoor). The mats should be connected to the structure supporting the switches and to the ground grid by means of copper conductors of suitable size. Portable ground gradient control mats can be used in lieu of permanent mats at motor operated disconnects.

Equipment with grounded metal operating platforms does not require a separate ground mat.

See also *IEEE Std. 80, Clause 17.2*.

7.4.19 Ground Gradient Control Mats

Ground Gradient Control Mats (GGCMs) are to be installed under the operating handle of all manually and motor operated gang-operated disconnect switches including grounding switches, operating at 1000 volts and above. Fuses and non-gang operated disconnects that are operated using a live line stick do not require GGCMs.

To purchase a permanent GGCMs refer to Technical Specification OPG-M-801, Ground Gradient Control Mats.

7.4.19.1 Installation

7.4.19.1.1 Locating the Mat

The center-line of the GGCM is to be installed under the centerline of the disconnect switch operating handle. To ensure the operator's feet are always completely on the GGCM, typically the edge of the GGCM should be no further than 300 mm from the structure footing.

For torsion operated disconnect handles, the mat may be moved in the direction of handle swing to ensure the operators feet are both on the mat during the entire disconnect operation.

To ensure the above 2 conditions are met, the mat should be positioned with an operator simulating the disconnect operation prior to final location.

The outer perimeter of the mat must be a minimum of 1.5 meters from station fences or any other structure not connected to station ground.

The mat is to be level (30 mm per meter tolerance) and evenly supported via the specified surface stone of the yard.

The entire area is to be vegetation free at all times.

7.4.19.1.2 Connection to Station Ground

The GGCM has 2-bolt NEMA holes pre-drilled on opposite sides to accommodate connection to station ground. These connections include:

- One to the station ground connected to the steel structure supporting the disconnect switch. This connection is to be exothermic or an *IEEE Std 837 Standard for Qualifying Permanent Connections Used in Substation Grounding* compression connector such as the Burndy HYTAP Connector. Below grade connection shall be exothermic. Note that galvanized surfaces shall be cleaned with wire brush or emery cloth. For extra heavy galvanized steel, clean with a rasp.
- One to station ground grid, typically below grade in the immediate area below the mat if outdoor. Below grade connections shall be exothermic.

The conductor is to be bare copper, sized the same as the station ground conductors in the yard.

The ground cable should be routed/buried as much as possible to minimize tripping hazards.

To minimize damage to the GGCMs galvanized surface, bolted connections may be used via the 2 bolt NEMA pad holes. The ground conductors are to be attached to these predrilled holes using 2 bolt compression lugs and stainless steel hardware. Stainless steel lock washers shall be used in all bolted connections. The hardware shall be torqued to ensure the long term secure connections. Anti-oxidant paste, suitable for the materials, is to be used between the compression lugs and the GGCM.

Extreme care shall be taken not to expose the base steel under the galvanize coating. If this occurs, 3 coatings of brush applied ‘zinc-rich’ type coatings shall be applied over the area.

7.4.20 Surge Arrestors

7.4.20.1.1 Surge Arrestors and Gaps 115 kV and Above

Arrestors and spark gaps, whether or not isolated from the steel supporting structure, should be connected to the ground-conductor loop located at the base of the structure, by a grounding conductor sized to take the maximum ground fault current expected at the station. If ground rods installed as part of the station grounding electrode are not in the immediate vicinity, a driven rod grounding electrode of not less than 4 rods 3 m apart should be located close to each arrestor or spark gap installation and be connected to the main ground grid.

In situations where the arrestors and spark gaps are located on building structures where it is impractical to install grounds rods, it is recommended that they be connected directly to the ground grid. The integrity of the ground grid should be verified periodically.

7.4.20.2 Surge arrestors 46 kV and Below

These arrestors should be connected to the station ground grid by the shortest possible route. The grounding conductor should be capable of carrying the maximum ground fault current expected at the Station. See also *IEEE Std. 80, Clause 17.7*.

7.4.21 AC or DC Control Cables including CVTs

See Section 5, item 13.

Control cables should include grounding conductors in cable trays or PVC conduit. All shielded type cables running exterior to buildings should have their shields grounded at both ends. Control cables running within a building may have the shield bonded at one end. It is particularly important for Capacitance Voltage Transformer control wiring to have the shield bonded at both ends. At the CVT, the shield bond is to be as short as possible and connected directly to the CVT case. Switching operations and lightning cause transient potential rise on CVT cases which is then most effectively neutralized by the cable shield.

7.4.22 Cable Sheaths, Terminations, Trays and Conduits

Surge arrestors may be installed for high voltage cable sheath protection. These should have their grounds connected to the cable sheath as near as possible to the arrestor. The above connection should include a warning sign.

Cable termination bodies are to be connected to ground as per the manufacturer’s instructions.

All metallic trays should be grounded at one end if the run is less than 8 m and at regular intervals no greater than 16 m for longer runs. See Figure 35.

Metallic conduits terminating at sheet metal enclosures, pull boxes, or cable trays should be fitted with ground bushings at both ends. Conduits terminating to hubs should not be fitted with ground bushings. Ground bushings should be bonded to the enclosure or to the cable tray with

a 21 mm² (4 AWG) conductor for conduits 40 mm and larger and with an 8.4 mm² (8 AWG) conductor for conduits less than 40 mm.

Refer also to the *OESC* for more information on the above items.

See Figure 36, Figure 37, Figure 38 and in Piping from External Sources.

In order to prevent transferred potential from leaving the Plant to the outside world, piping (natural gas, water etc) should be fitted with insulating joints or equivalent at the point of entry into the station. Touch voltage immediately outside the grid, may be reduced by burying a conductor one meter outside the fence line and connecting it to the fence. Additional protection can be provided, by covering the surface inside and outside the fence by a thick layer of crushed stone.

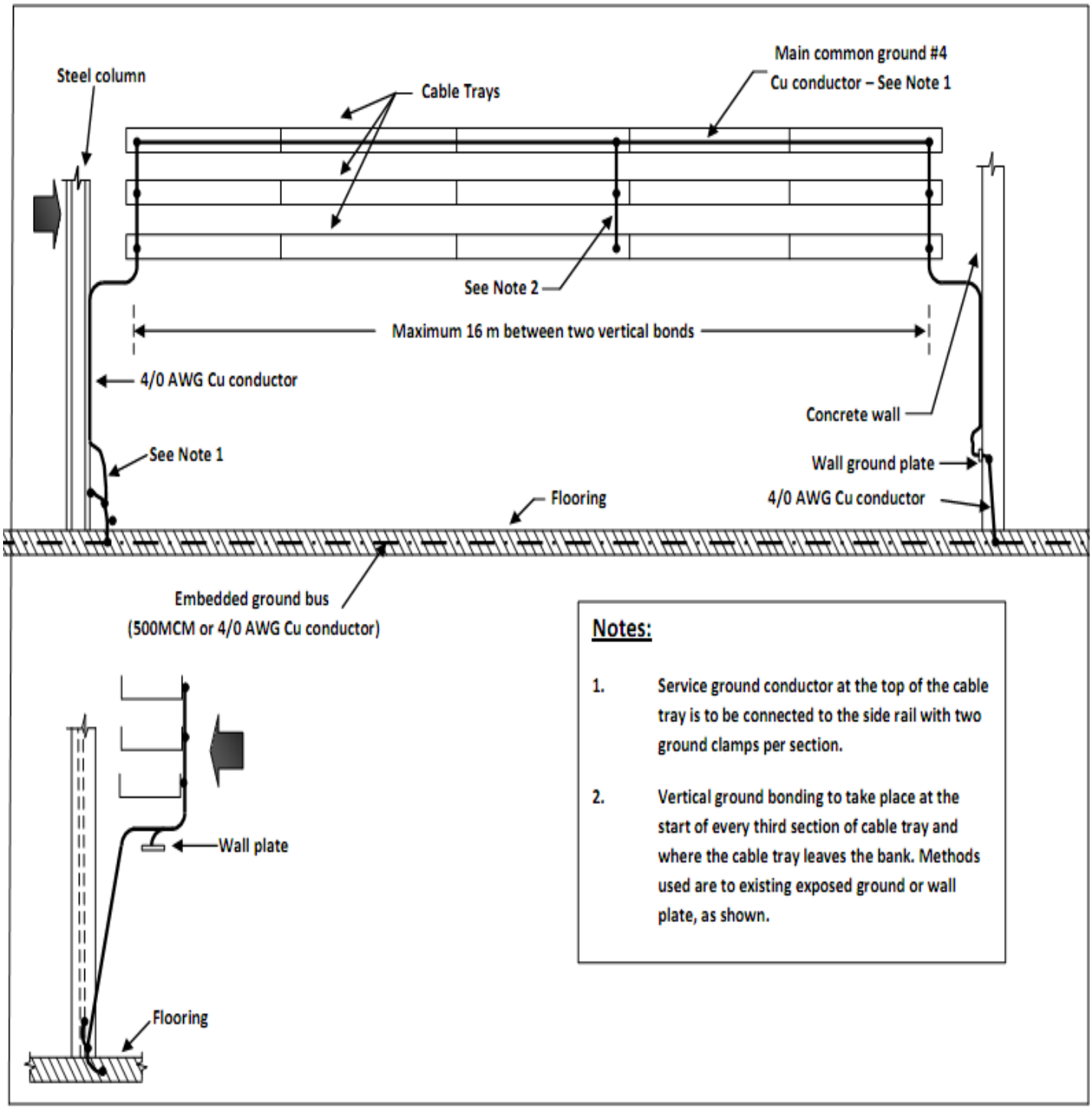


Figure 35: Grounding - Cable Tray

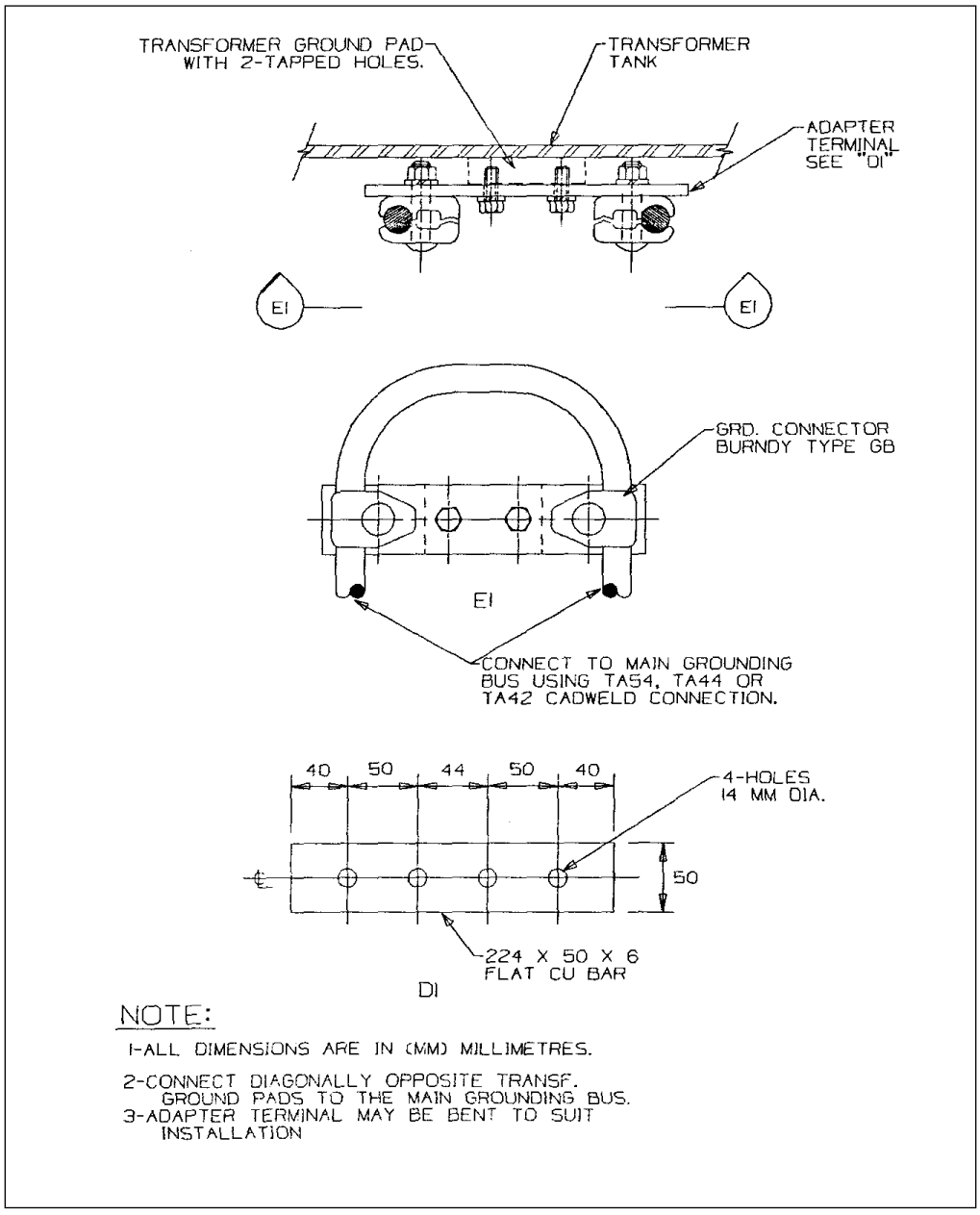


Figure 36: Grounding - Power Transformers

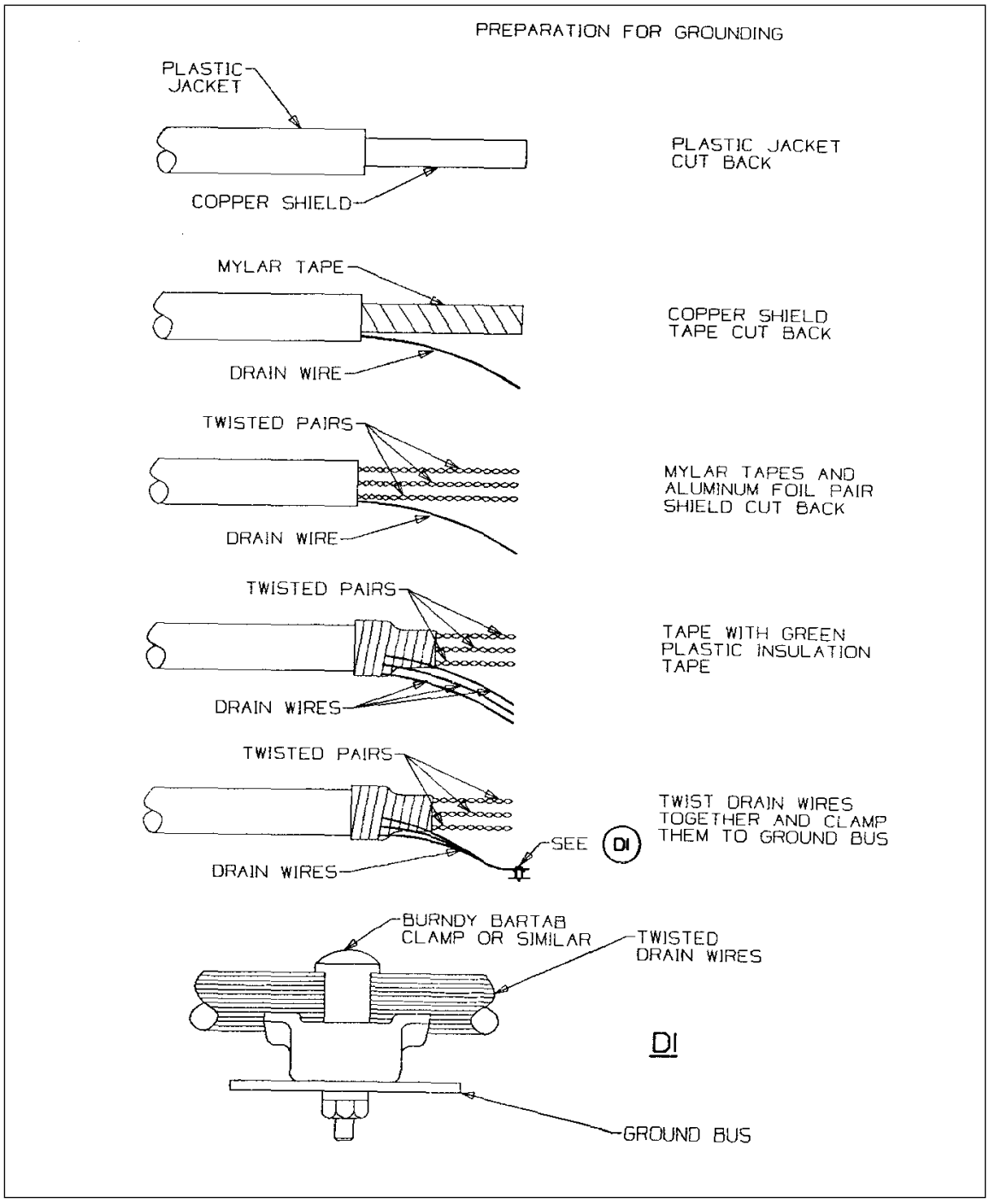


Figure 37: Grounding - Control Cable Shields

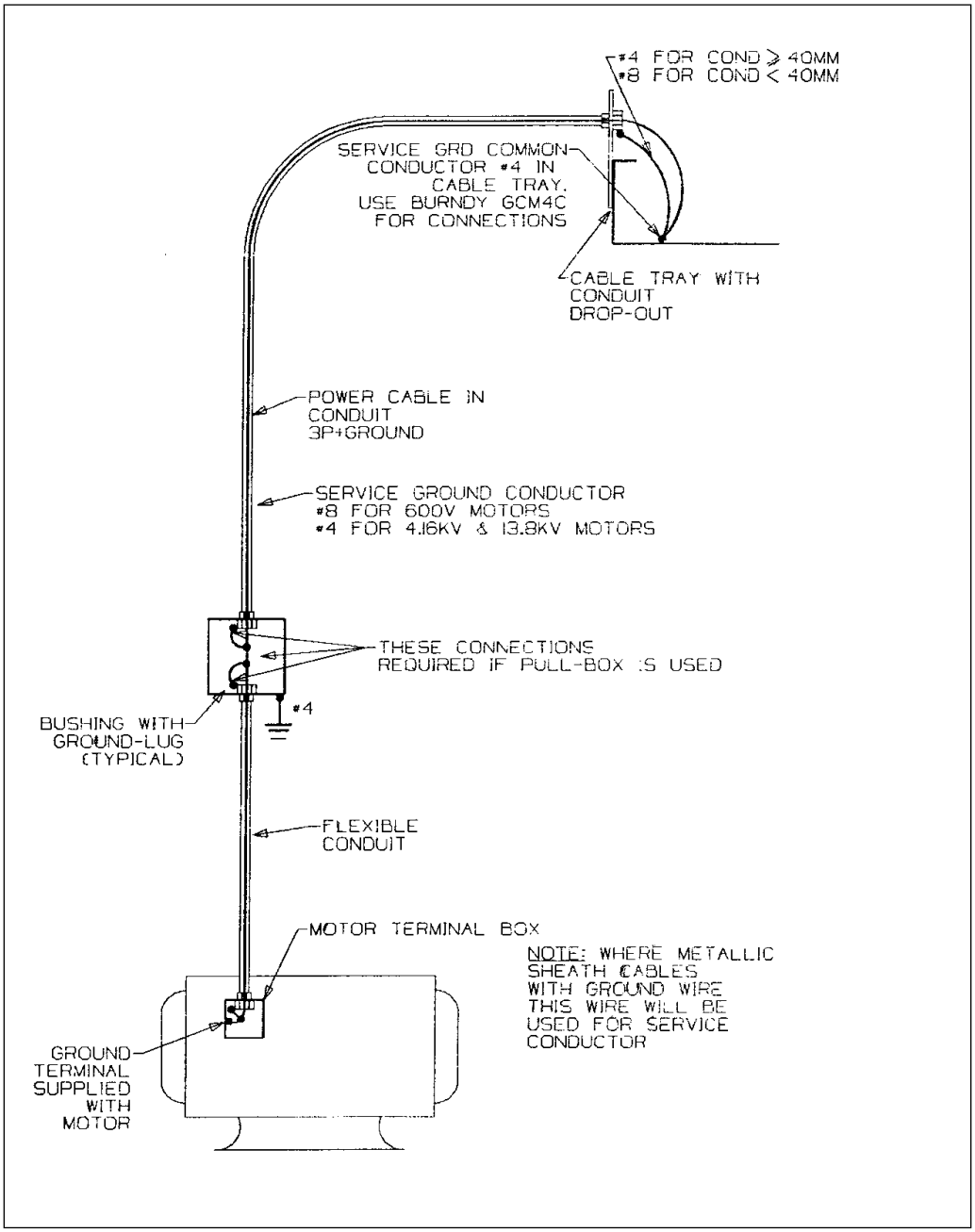


Figure 38: Grounding - Motor and Cable Tray

7.4.23 Switchgear

600 V and up to 13.8 kV switchgear should have a ground bus installed in an accessible location for the total length of the switchgear. This ground bus should make contact with each section of the switchgear. It is connected to the plant main ground bus at each end with a suitable sized looped conductor. Minimum size is 67 mm² (2/0 AWG) for mechanical strength.

Refer to OPG Switchgear Technical Specification OPG-M-760-07. See Figure 39 in Motor Drives.

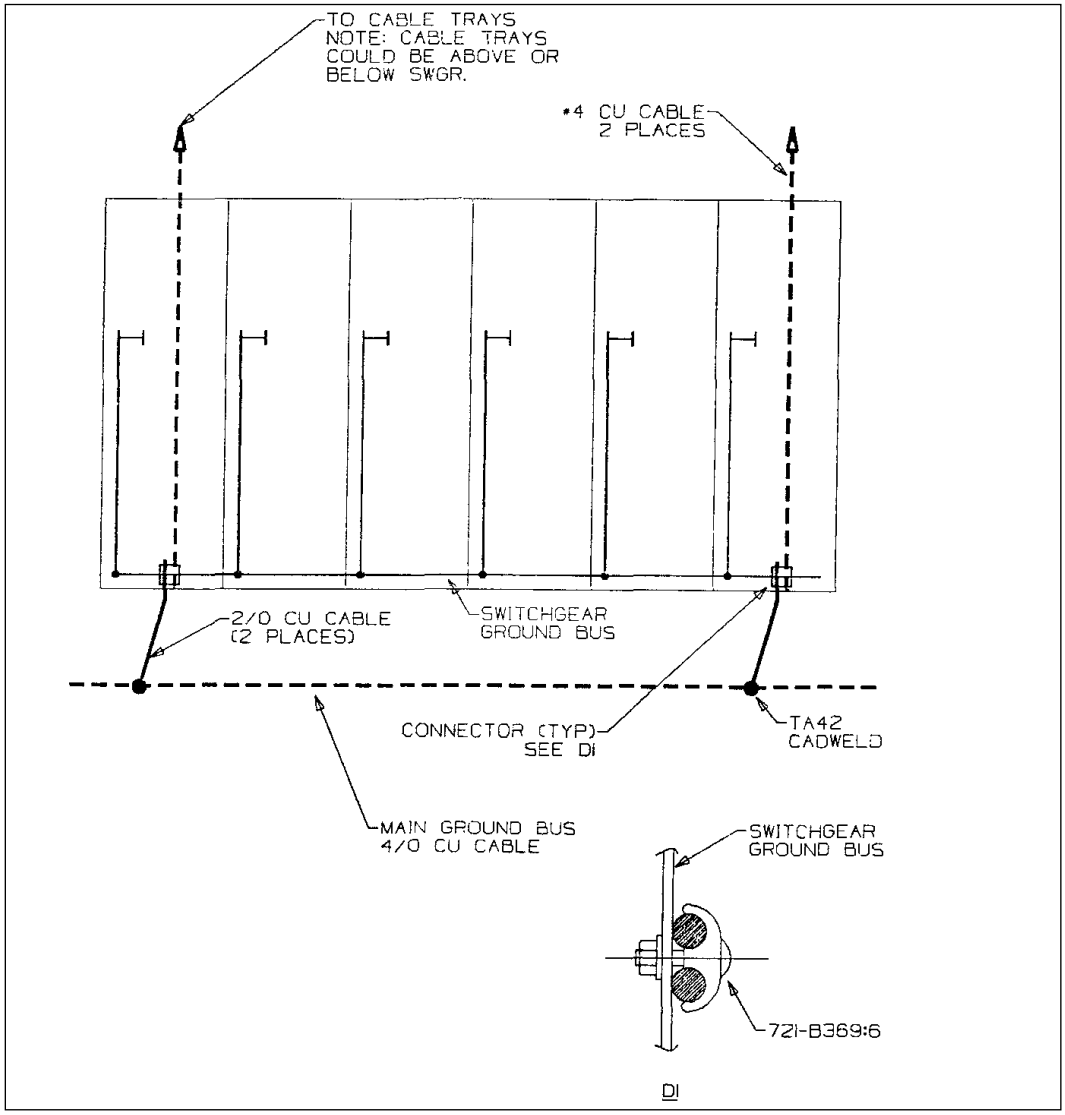


Figure 39: Grounding - Typical Metal-Clad Switchgear

For rotating equipment supplied from 4.16 kV or 13.8 kV system, the frames should be connected to the main ground bus by a 67 mm² (2/0 AWG) copper conductor. See Figure 40.

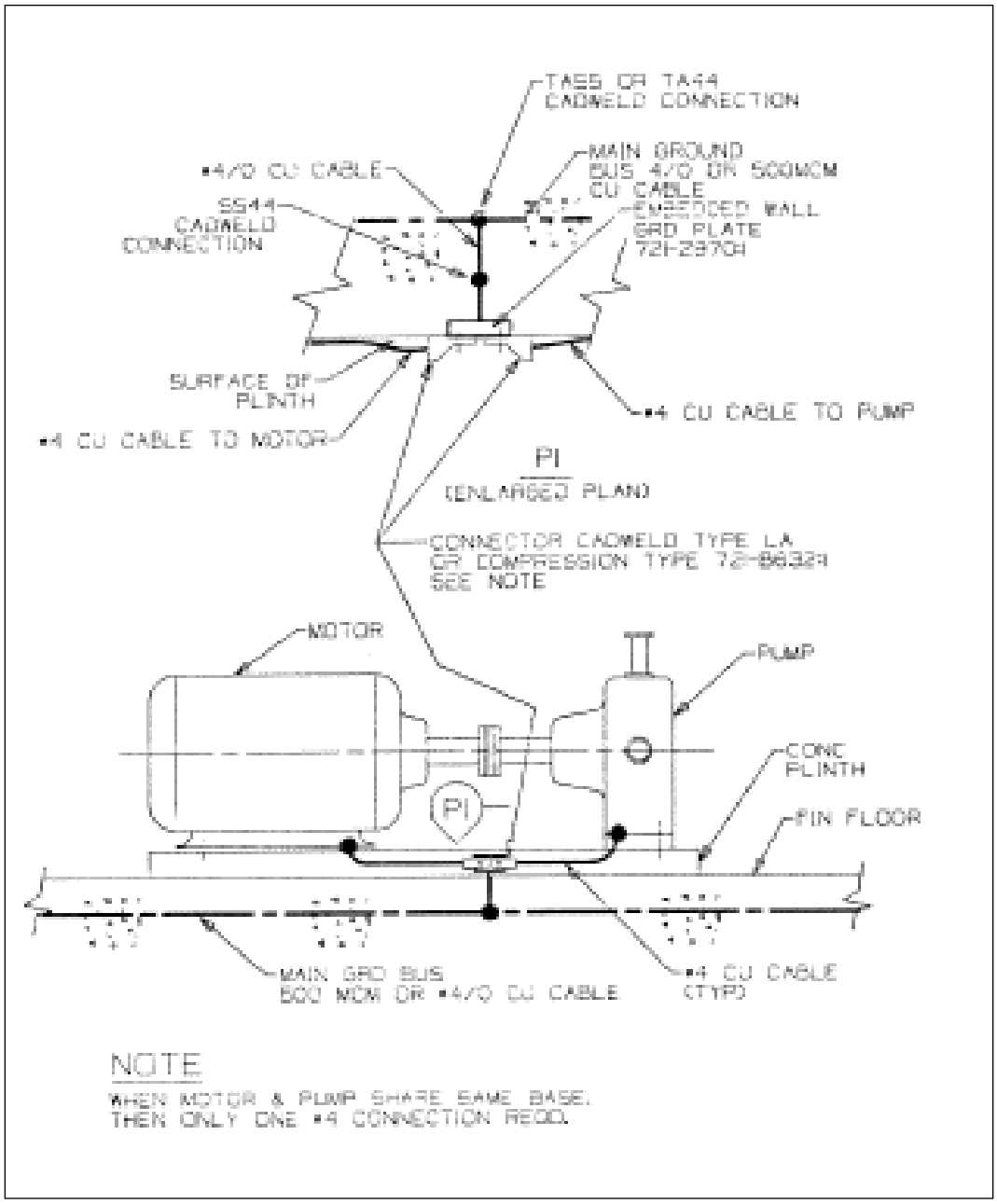
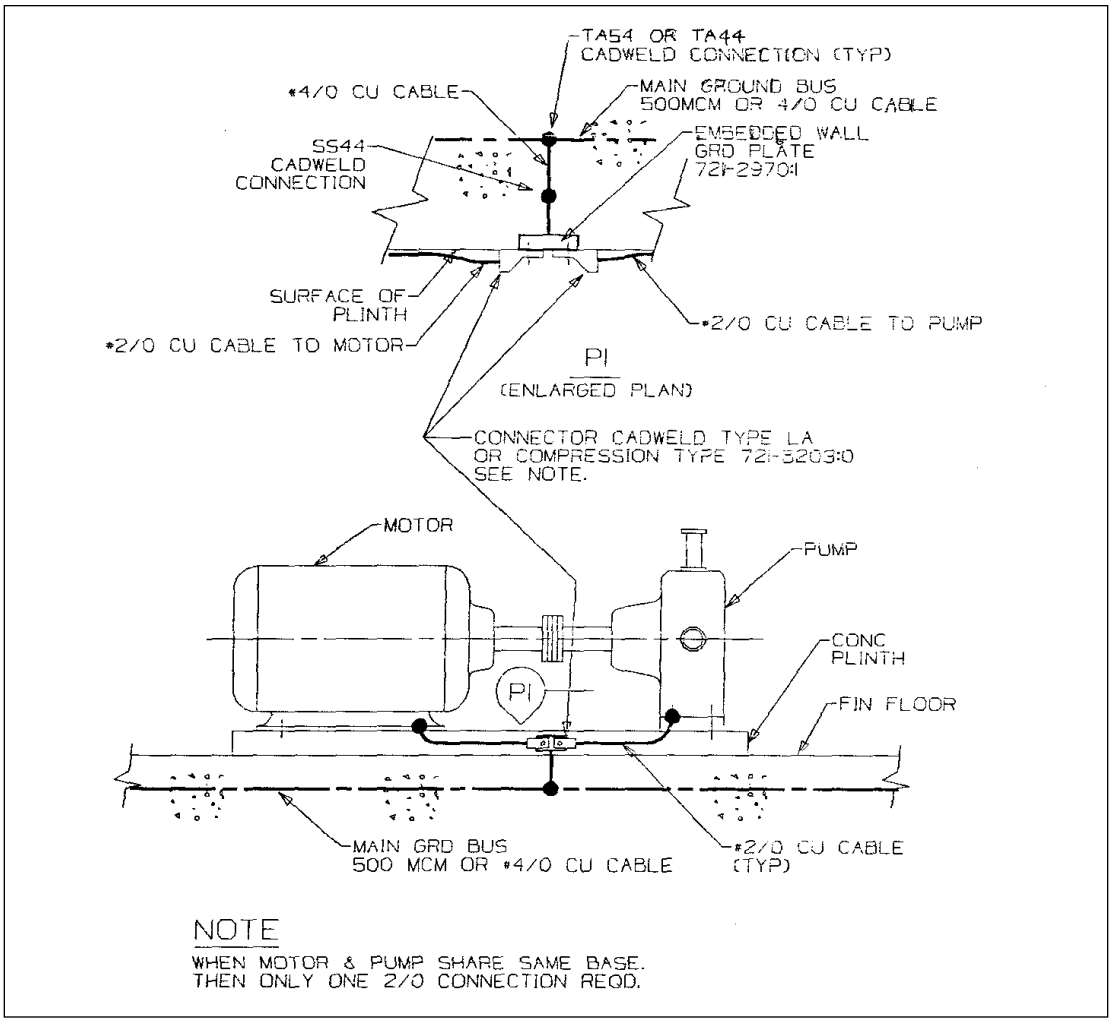


Figure 40: Grounding - Motor and Pump Greater Than 600 V

For rotating equipment supplied from the 600 V system, the frames should be connected to the main ground bus by a 21 mm² (#4 AWG) copper conductor. See Figure 41.



(Ontario Hydro STD5-C-H-57600-002, Design Guide on Grounding Practices for Generating Stations)

Figure 41: Grounding - Motor and Pump 600 V and Less

If a motor and its driven equipment share a common frame, only one ground connection need be used. Hold-down bolts are not used for ground connections. The connection should be made to a pad or where necessary, drill and tap the frame.

See also the *Ontario Electrical Safety Code (OESC)* for additional references.

7.4.24 Motor Control Center (MCC)

MCC grounding shall be similar to that in section 7.4.23. A ground bus should be provided to span all sections of the assembly with each section of the steel enclosure connected to the ground bus. This bus provides a convenient location for connection of incoming and outgoing cable ground conductors. See also the *Ontario Electrical Safety Code (OESC).*

See Figure 42.

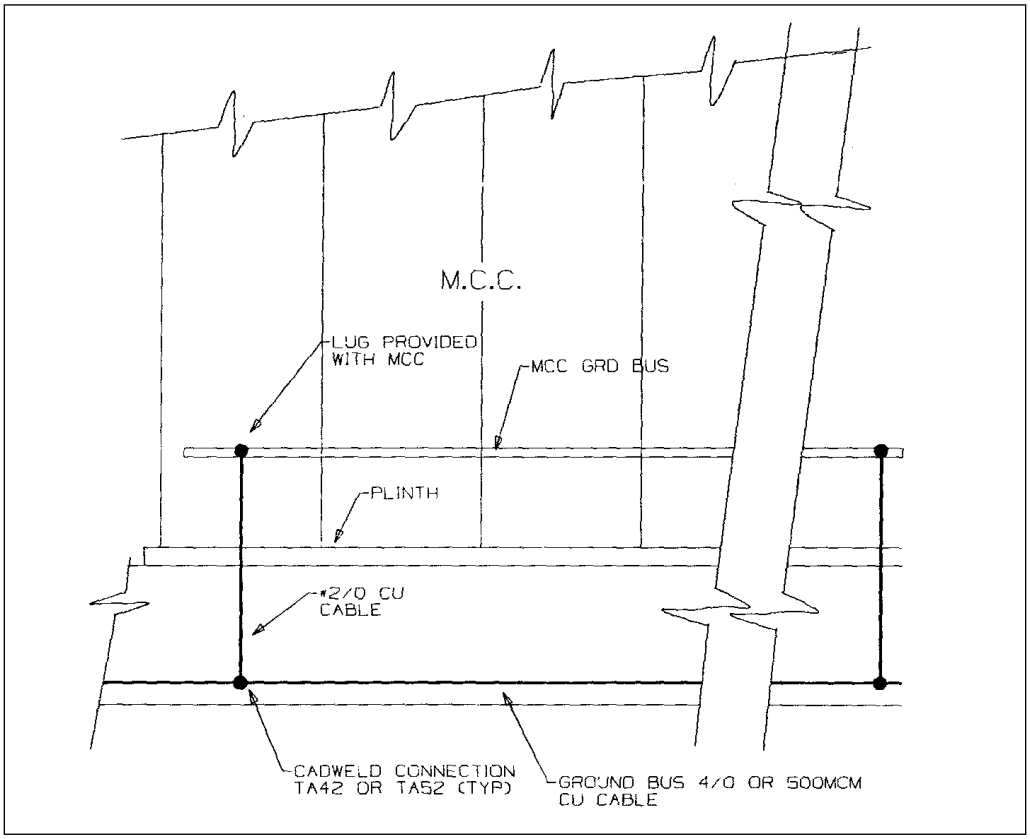


Figure 42: Grounding - MCC Bus

7.5 Grounding Systems Standard Technical Specification

Standard Technical Specification OPG-M-763, Grounding Systems, covers the technical requirements for the design and installation of grounding systems at OPG generation stations. The specification is available on the Plant Engineering Services (PES) webpage under Governing and Supporting Documents/Specifications/Electrical.

7.6 Grounding Systems Design/Construction Checksheet

A checksheet is available for the Owner's Engineer to track various components of the grounding system design and construction. ENG-FRM-GR-002, Checksheet for Grounding System Design & Construction, is available on the Plant Engineering Services (PES) webpage under Governing and Supporting Documents/Forms/Grounding. A sample copy of the form has been provided in APPENDIX P for reference.

8. GROUNDING SYSTEM MAINTENANCE

Maintaining the grounding performance of a station requires vigilance in two areas:

- Review the integrity of visible and non-visible grounding conductors (Section 8.1)
- Review the coordination of step and touch potentials against the safe body withstand (Section 8.2).

8.1 Review the Integrity of Visible and Non-visible Grounding Conductors

This section has been intentionally removed.

8.2 Reviewing Step and Touch Potential Coordination

This section has been intentionally removed.

APPENDIX A - MAXIMUM FAULT CURRENT FOR DETERMINING CONDUCTOR CURRENT RATINGS

This Appendix has been intentionally removed.

APPENDIX B - CONDUCTOR CURRENT CAPABILITY

Copper is commonly used for grid and bonding conductors because it has high conductivity, and ductility to withstand mechanical damage and relative freedom from corrosion. Aluminum is sometimes specified on fences where theft can be a problem, but only above grade. The minimum size is usually 67 mm^2 (AWG 2/0) for mechanical ruggedness.

The transient temperature rise on fault duty should be limited to 450 °C for copper. Table 2 lists the equivalent symmetrical rms current, which would lead to this temperature. This assumes an ambient temperature of 40 °C, a system X/R ratio of 30 and fault initiation at a voltage zero crossing for maximum current asymmetry.

Table 2: Fault Duration Limits for Copper Conductor

Wire Size (AWG)	Area (mm^2)	Fault (rms current n kA)	
		0.5 s duration	***1.2 s duration***
2/0	67.4	19.3	13.0
4/0	107.	30.7	20.7
250 kcmil	127.	36.3	24.4
350 kcmil	177.	50.9	34.2
500 kcmil	253.	72.7	48.9
750 kcmil	380.	109.	73.4
1 000 kcmil	507.	146.	97.9

APPENDIX C - MAXIMUM SYSTEM ZERO SEQUENCE CURRENT FOR FAULT AT STATION

This Appendix has been intentionally removed.

APPENDIX D - SPREADSHEET INTERPRETATION OF TWO-LAYER SOIL RESISTIVITY MODEL

This Appendix has been intentionally removed.

APPENDIX E - DRIVING POINT IMPEDANCE OF OVERHEAD GROUND WIRES AND NEUTRALS

This Appendix has been intentionally removed.

APPENDIX F - SHIELDING FACTOR FOR TRANSMISSION LINES AND CABLES

This Appendix has been intentionally removed.

APPENDIX G - MAXIMUM GROUND CURRENT FOR FAULT ALONG TRANSMISSION LINE

This Appendix has been intentionally removed.

APPENDIX H - ISOLATED GRID RESISTANCE, STEP AND TOUCH TRANSFER RESISTANCES

This Appendix has been intentionally removed.

APPENDIX I - GROUND POTENTIAL RISE, STEP AND TOUCH POTENTIALS

Using complex arithmetic, calculate the interconnected station ground impedance Zgs as the parallel combination of the summer isolated grid resistance Rgs, the driving point impedance of all overhead ground wires Zod, the driving point impedance of interconnected multi-grounded neutrals Zdd and any auxiliary electrodes. Find the highest shielded zero sequence current injected to this impedance due to one and two phase faults from either the transmission system or due to local generation. Calculate the summer ground potential rise Vgs from the highest current times the interconnected station ground impedance. Find the split of ground current into the station grid Ig, the overhead ground wires Iohg, distribution neutrals Idn and any auxiliary electrodes Iae by dividing Vgs by the respective impedances as complex numbers.

For the winter grid resistance Rgw, calculate the winter interconnected ground impedance Zgw and ground potential rise Vgw. Normally one may assume that the deep footings associated with line towers and distribution neutral ground rods will not change appreciably for winter frozen soil conditions.

Calculate the step and touch potentials (mesh, structure, fence and gate swing) from the product of grid current Ig and the transfer resistances calculated in the previous section. Do for both summer and winter conditions.

APPENDIX J - ALLOWABLE STEP AND TOUCH POTENTIALS

This Appendix has been intentionally removed.

APPENDIX K - CALCULATION OF ZONE OF INFLUENCE

This Appendix has been intentionally removed.

APPENDIX L - TESTING ISOLATED ELECTRODE RESISTANCE

This Appendix has been intentionally removed.

APPENDIX M - TESTING INTERCONNECTED STATION GROUNDING IMPEDANCE

This Appendix has been intentionally removed.

APPENDIX N - CUSTOM MICRO OHMMETER TO MEASURE GRID INTEGRITY

This Appendix has been intentionally removed.

APPENDIX O - MODELLING POINT-TO-POINT RESISTANCE IN GRIDS

This Appendix has been intentionally removed.

APPENDIX P - CHECKSHEET FOR DESIGN & CONSTRUCTION OF GROUNDING SYSTEMS

The following form, ENG-FRM-GR-002, provides the Owner's Engineer a method to track various components of the grounding system design and construction. If the item is not applicable, insert NA under 'Notes'.

ONTARIO POWER GENERATION

Form Number: ENG-FRM-GR-002 / R 00	Reference Document: ENG-MAN-002	Security Classification: Internal Use Only
Applicability: Hydro Thermal Operations	Effective Date: Jan 29, 2013	SCI Number: 57600
Form Owner: PES Power Equipment Dept.		Page: 1 of 3

Name: **Checksheet for Design and Construction of Grounding Systems**

This Checksheet should be filled out in accordance with ENG-MAN-002, Station Grounding and Bonding (see Section 7.6). Refer also to OPG-M-763, Technical Specification for Grounding Systems.

Station:	
System:	
Owner's Engineer:	
Consulting Engineer:	

Stage of Project	Completed Date	Notes		
DESIGN				
Designer using software and it is equal to or better than *CDEGS* Software?				
Are fault all currents up to date? In the notes section indicate where the data was obtained from?				
Has designer used all fault scenarios - 1, 2 and 3 phases to ground?				
Have faults several spans out of the station been considered?				
Are fault clearing times based on breaker backup?				
Has the proposed grid area soil / water been assessed for acidity?				
Has the head pond water conductivity/acidity been established?				
DESIGN REVIEW				
Coordination margins achieved?				
Redundant grounding of main power equipment, state for each item in rows below:				
1. Margin between safe body withstand and step potential		Volts:		
2. Margin between safe body withstand and mesh touch potential		Volts:		
3. Margin between safe body withstand and fence touch potential		Volts:		
4. Margin between safe body withstand and gate touch potential		Volts:		
All gate guides (head gate, sluice gate and tailrace grounded properly?				
Fence grounding and bonding to standard including gate swing areas?				
Smallest margin between conductor size and conductor duty is?		Amps margin is:		Amps

SAMPLE

ONTARIO POWER GENERATION

Form Number:	Reference Document	Security Classification
ENG-FRM-GR-002 / R 00	ENG-MAN-002	Internal Use Only
Applicability: Hydro Thermal Operations	Effective Date: Jan 29, 2013	SCI Number: 57600
Form Owner: PES Power Equipment Dept.		Page: 2 of 3

Name

Checksheet for Design and Construction of Grounding Systems

Fence isolating panels sufficient?				
Penstock, scroll case, turbine pit grounded properly?				
All construction steel grounded (columns etc)?				
All non current carrying metallic components grounded?				
Generator grounding points are redundant and match manufacturer's requirements?				
Metal clad switchgear grounding layout correct for configuration?				
Cable tray grounding?				
Portable grounding locations correct?				
Has conductive cement and or backfill been avoided?				
Have protections, controls and instrumentation grounding been addressed? (See Section 7.4.13, Instrumentation, Control and Sensitive Electronic Equipment, of Station Grounding and Bonding Guide)				
CONSTRUCTION INSPECTION				
Grid layout matches the design?				
Non-accessible connections checked before covered with earth/cement to ensure isothermic connections and that they are properly made?				
Actual installed depth of grid is?		Depth is		mm
Head gate, sluice gate, penstock liners, draft tube liners and turbine pits connected to ground as per requirements?				
All building steel columns including column splices grounded?				
IPB has its own grounding bus, with connection to ground at each end?				
Metal clad switchgear has a sufficiently sized continual ground bus, connected to station ground at each end with suitable sized conductors?				
Redundancy grounding of Power Transformers?				

SAMPLE

ONTARIO POWER GENERATION

Form Number:	Reference Document	Security Classification
ENG-FRM-GR-002 / R 00	ENG-MAN-002	Internal Use Only
Applicability: Hydro Thermal Operations	Effective Date: Jan 29, 2013	SCI Number: 57600
Form Owner: PES Power Equipment Dept.		Page: 3 of 3

Name

Checksheet for Design and Construction of Grounding Systems

Redundancy grounding of Station Service Transformers?		
Outdoor manually (and motor that can be hand operated) operated disconnects have operating linkages bonded above hand-wheel?		
Outdoor manually operated disconnects have permanent potential gradient mats have redundant exothermic grounding?		
All piping, metallic door frames, handrails, flashing and other metallic non current carrying items are bonded to ground?		
Crane rail, indoor and out grounded as per requirements?		
Fence gates have grids in the swing area connected to the fence ground?		
Cranes with overhead rail supplies have a ground rail?		
Lightning protection installed?		
Transformer surge arrestors installed and grounded?		
Perimeter ground is around the outside perimeter of fences connected to station ground?		
Security fences outside the grid have isolating sections?		
Outbuildings (garages, storage, data gathering sheds, head-works buildings grounded?		
Yard gravel tested and to sufficient depth including perimeter fence?		
POST CONSTRUCTION		
Current injection and interconnect testing completed as per Sec. 8.2 of ENG-MAN-002?		
Current injection and interconnection testing have verified acceptable touch potentials on isolated fences?		
Recommendations arising from current injection and interconnection testing, if any completed by Consultant?		

SAMPLE

APPENDIX Q - ADDITIONAL REFERENCE FIGURES

The drawings in this appendix, taken from Ontario Hydro STD5-C-H-57600-002, Design Guide on Grounding Practices for Generating Stations, have “stock code” numbers that may no longer be applicable. Where possible, use these figures in conjunction with applicable Technical Standards.

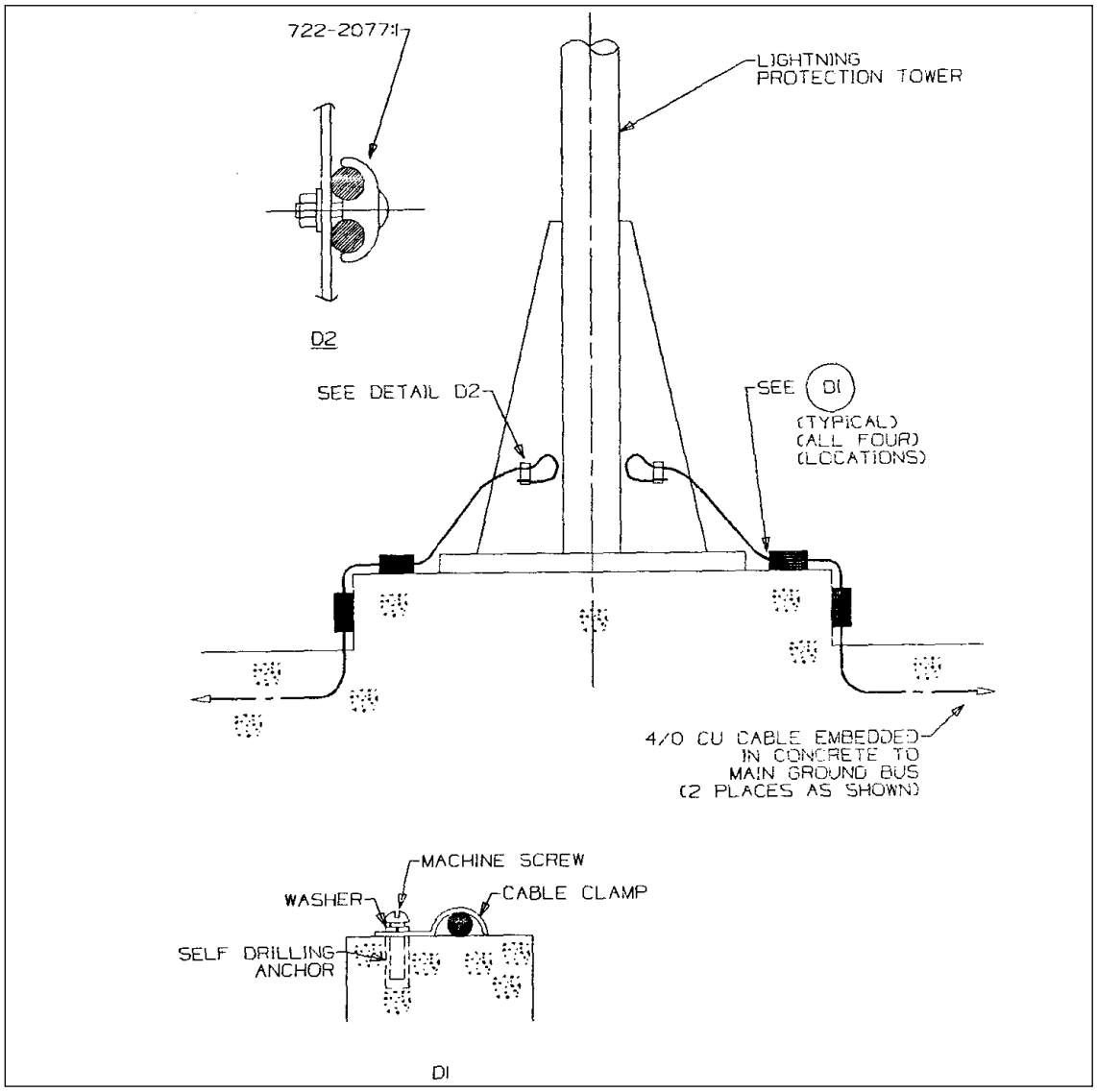


Figure 43: Grounding - Lightning Protection Tower

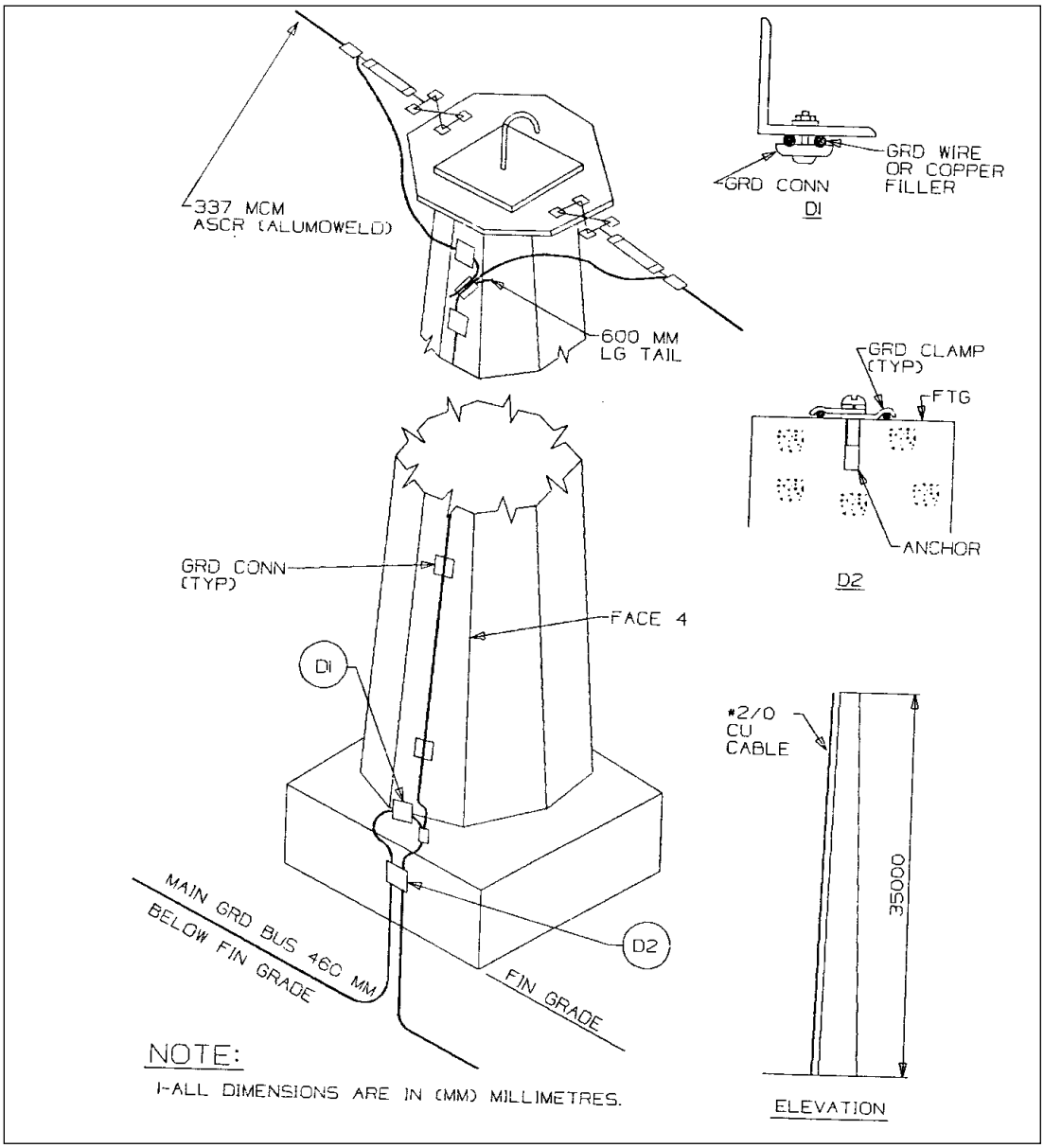


Figure 44: Grounding - Skywires: Lightning Protection Tower

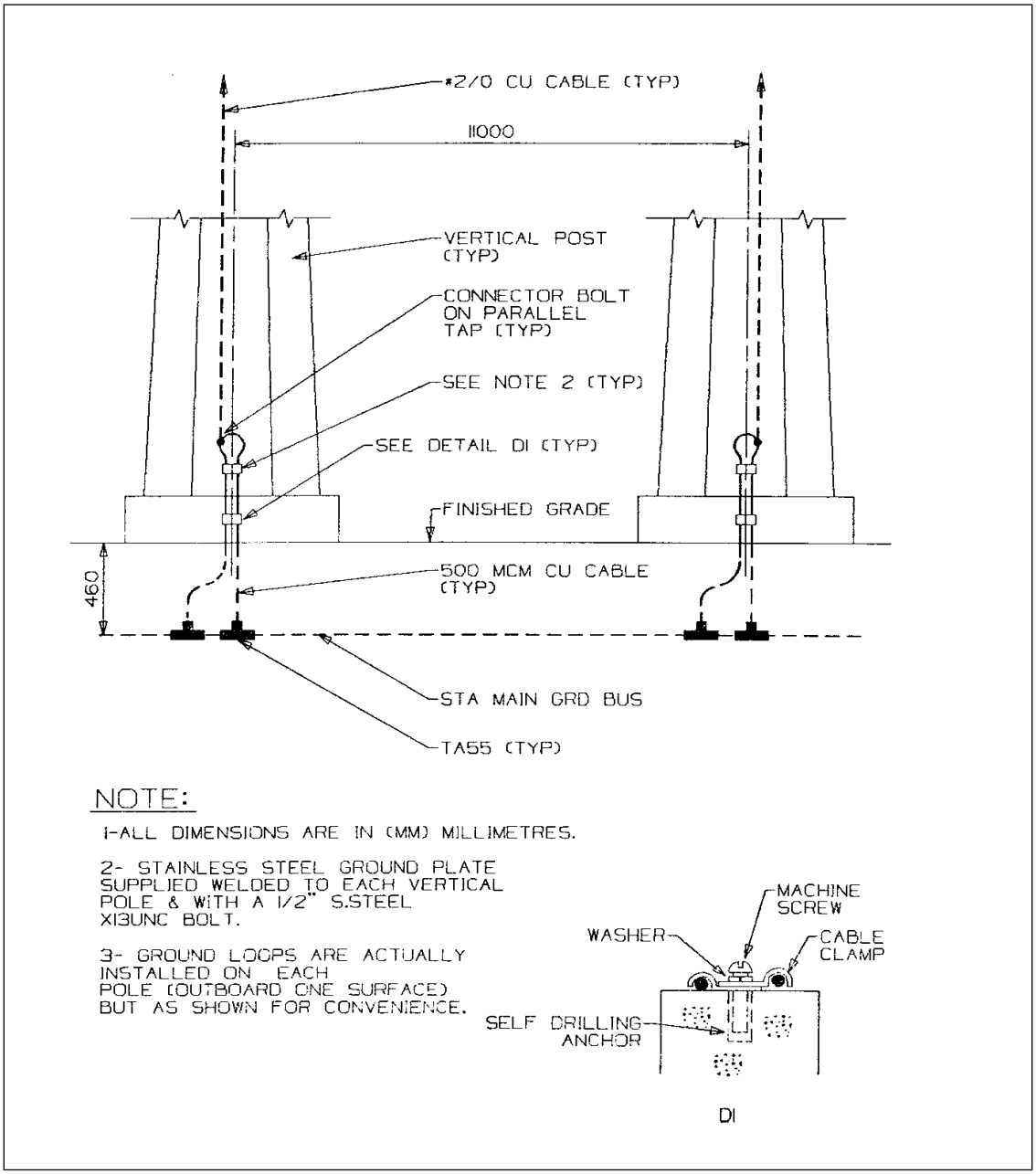


Figure 45: Grounding - 500 kV Transmission Structure Ground

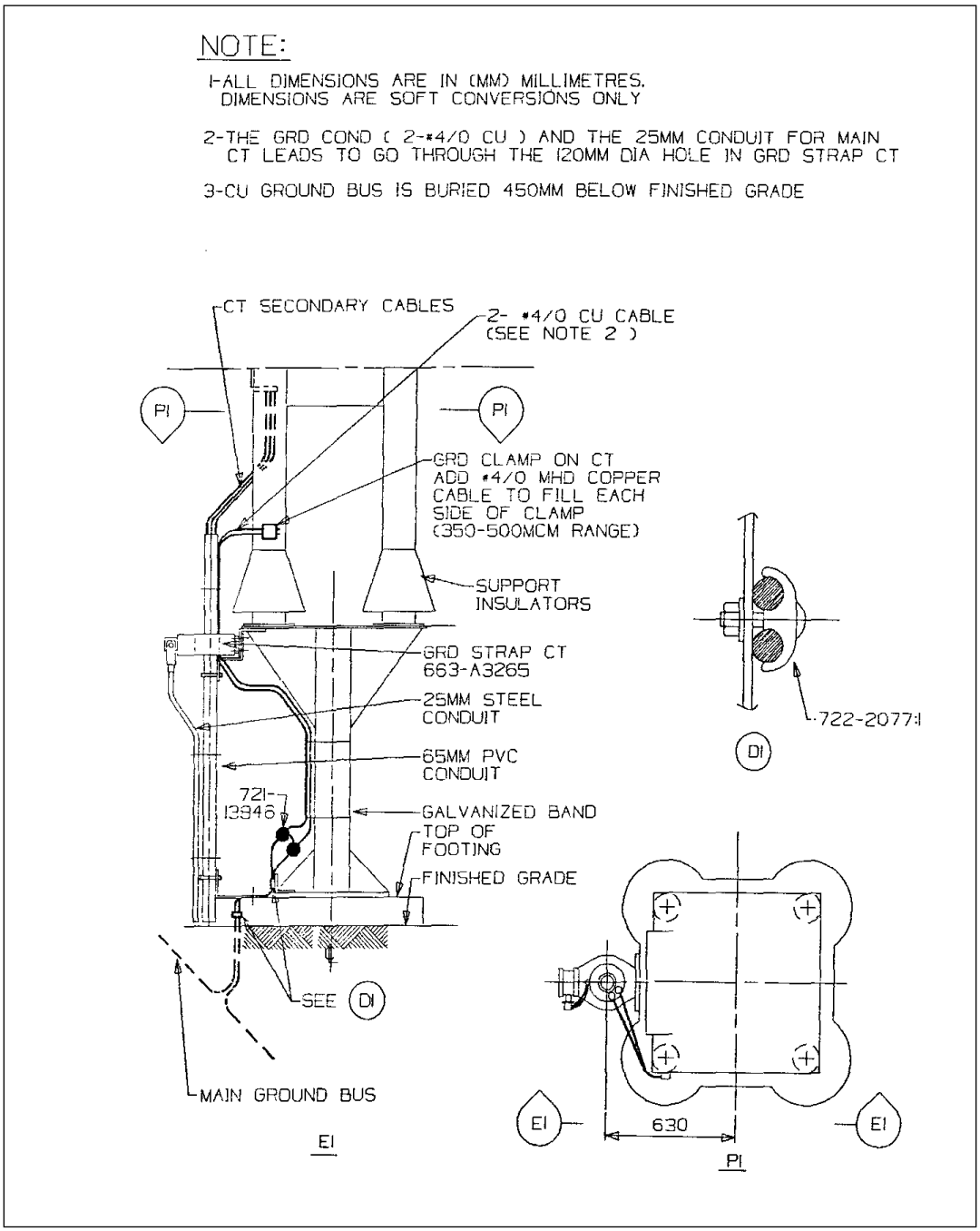


Figure 46: Grounding - 500 kV Switchyard Current Transformer

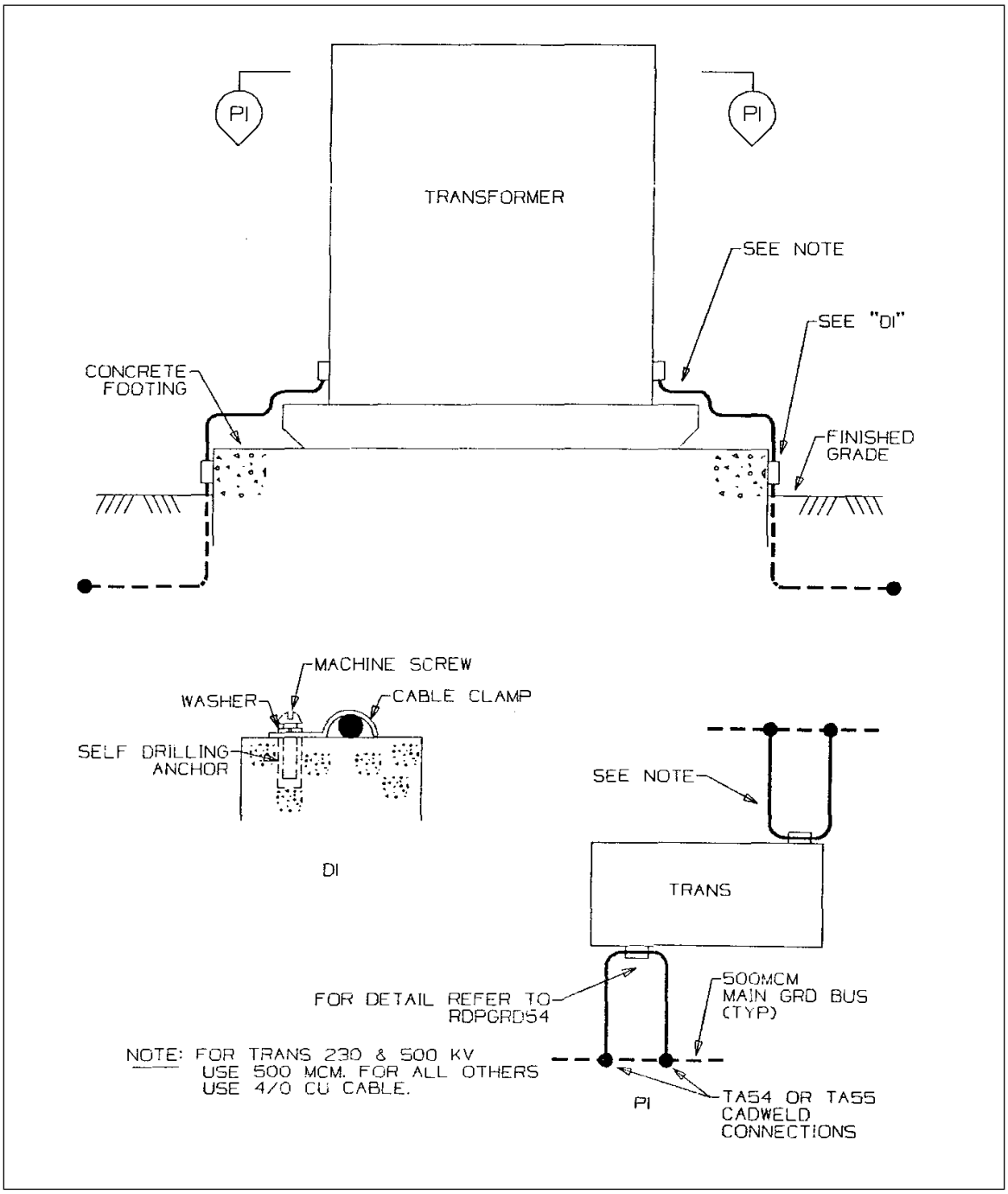


Figure 47: Grounding - Transformers

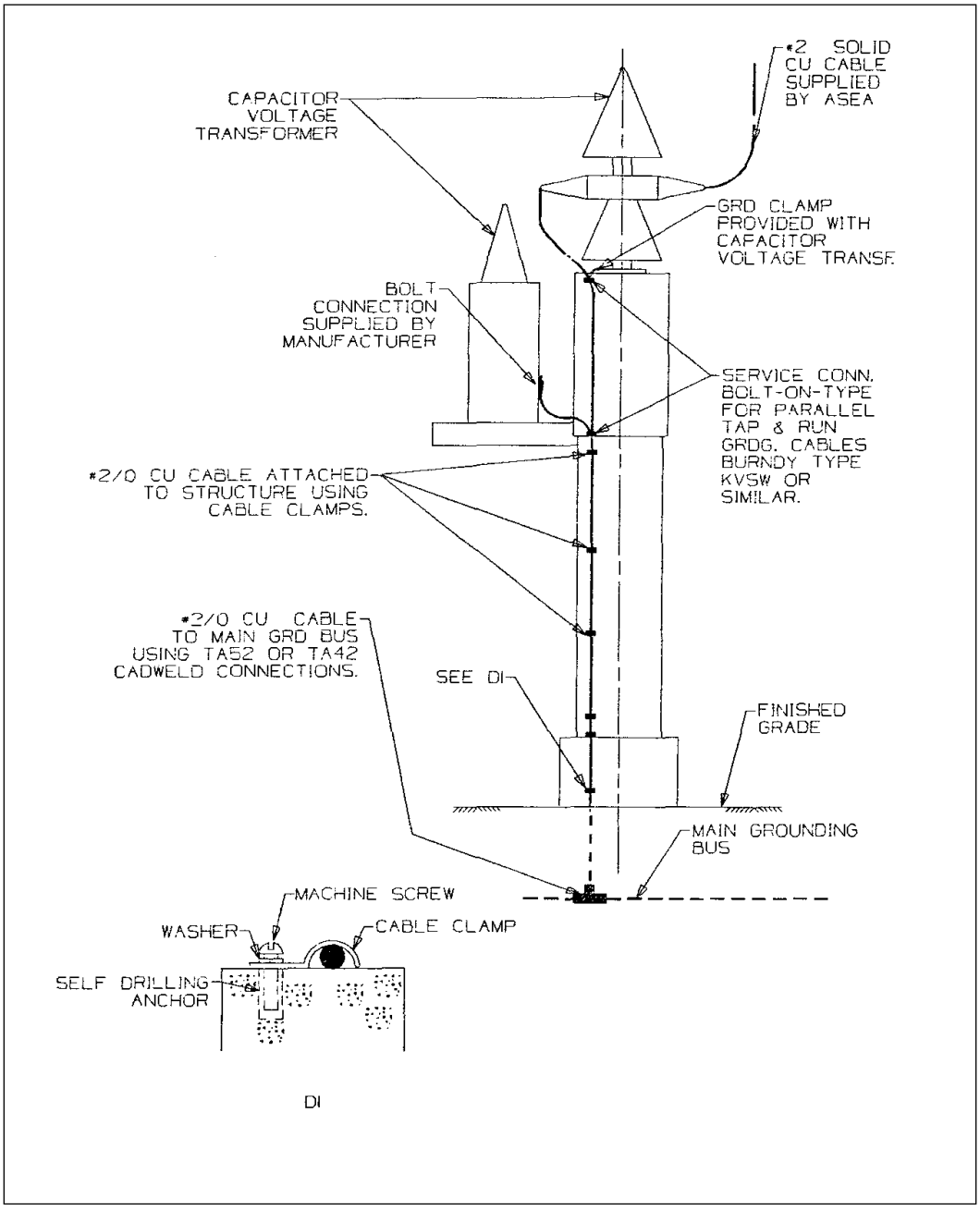
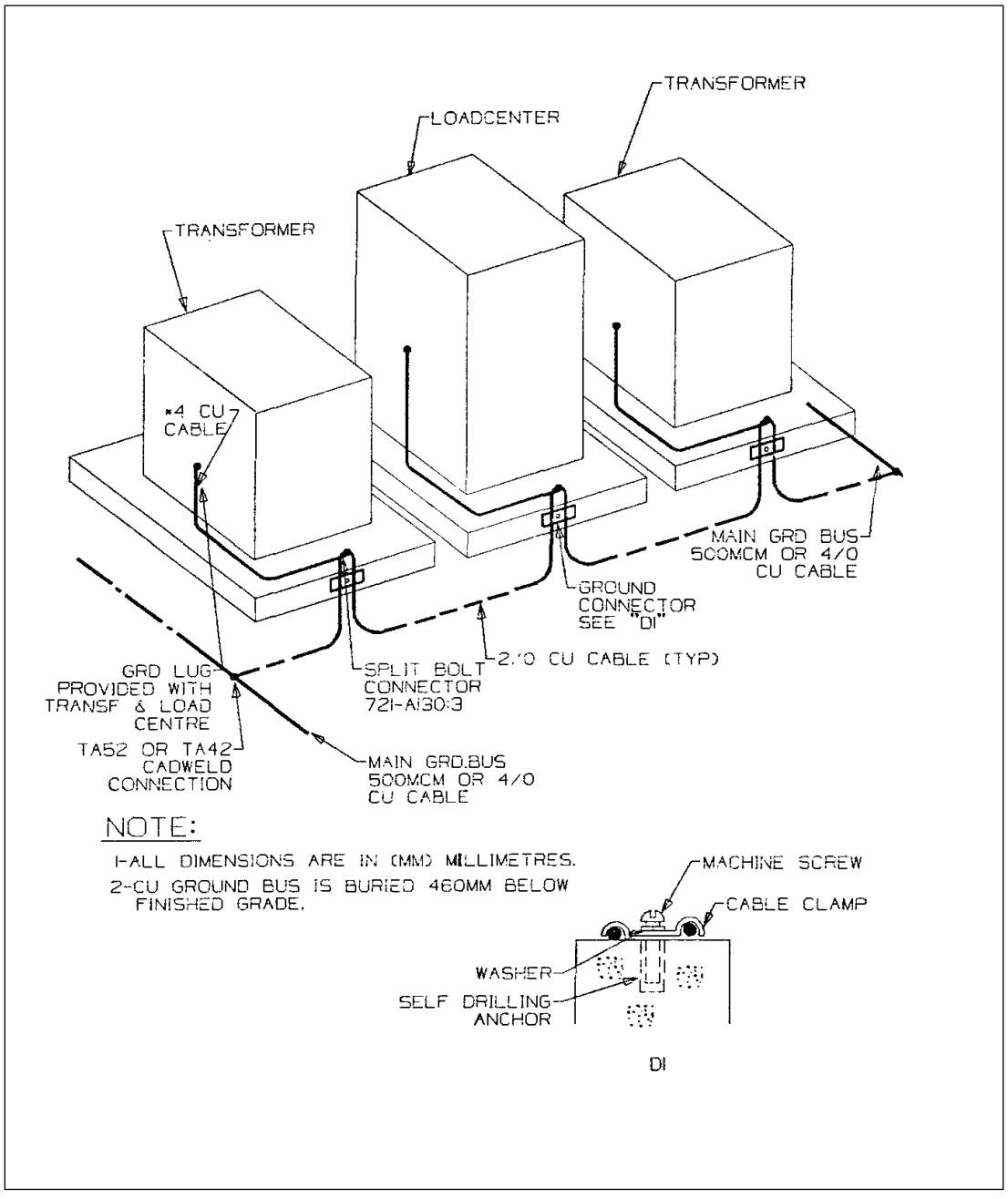


Figure 48: Grounding - 230 kV Capacitance Voltage Transformers



(Ontario Hydro STD5-C-H-57600-002, Design Guide on Grounding Practices for Generating Stations)

Figure 49: Grounding Connections for 600V Load Centers on Concrete Footings

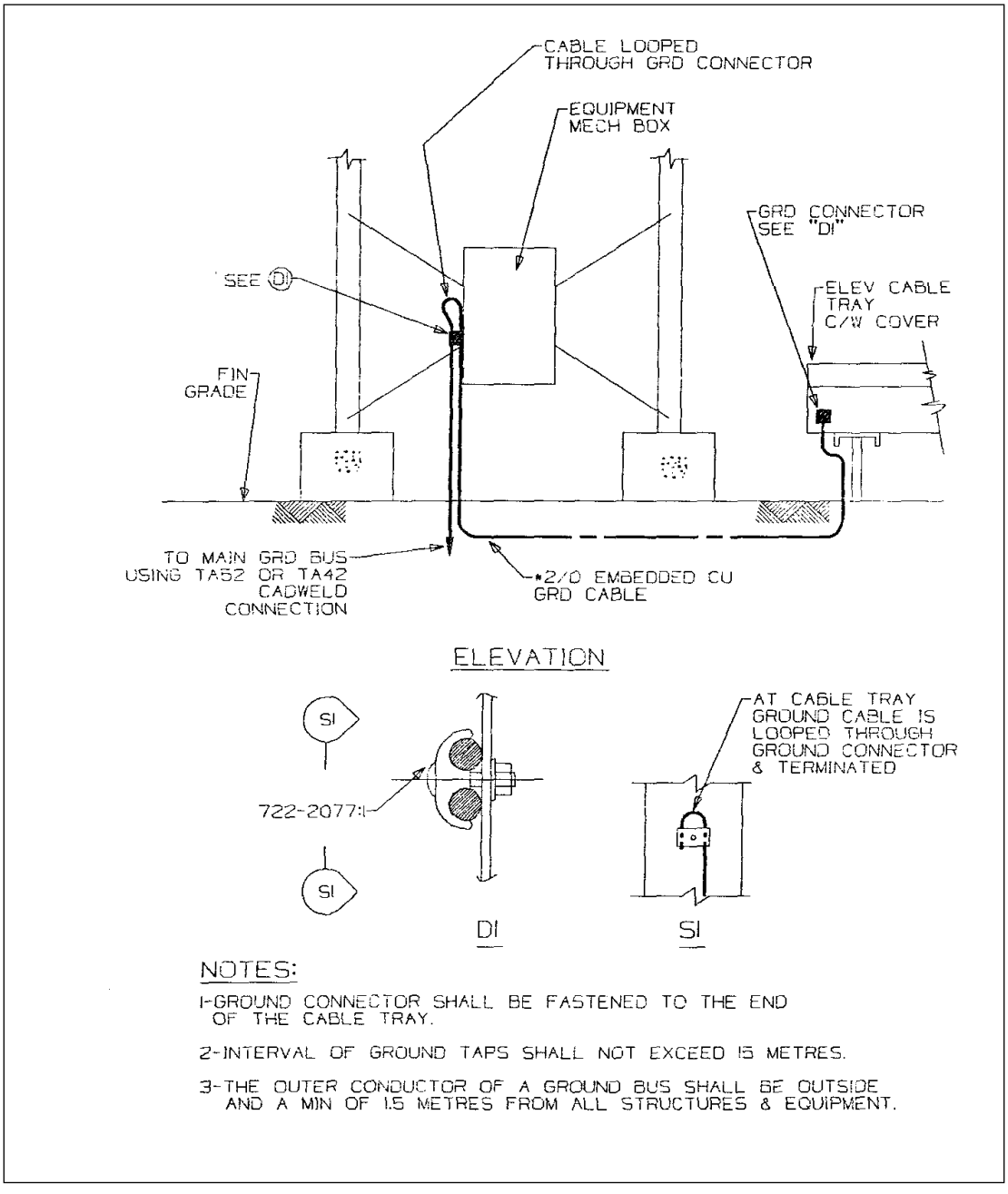


Figure 50: Ground Connection between Elevated Cable Tray & Equipment Mechanical Box

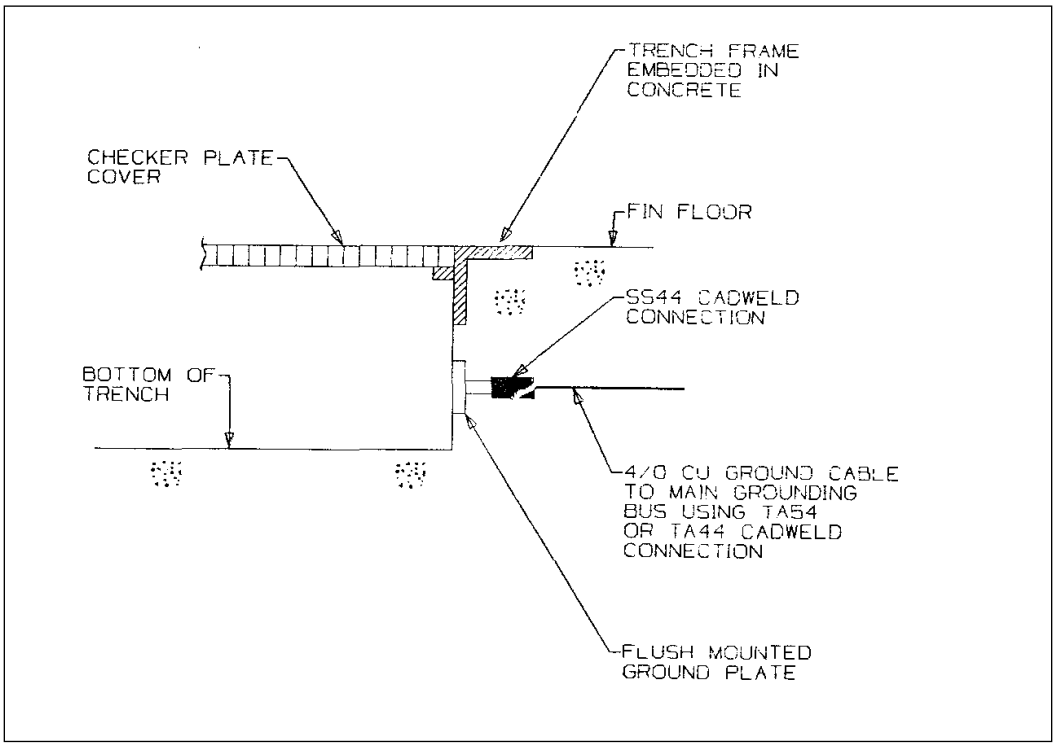


Figure 51: Ground Plate Installation Inside Trench

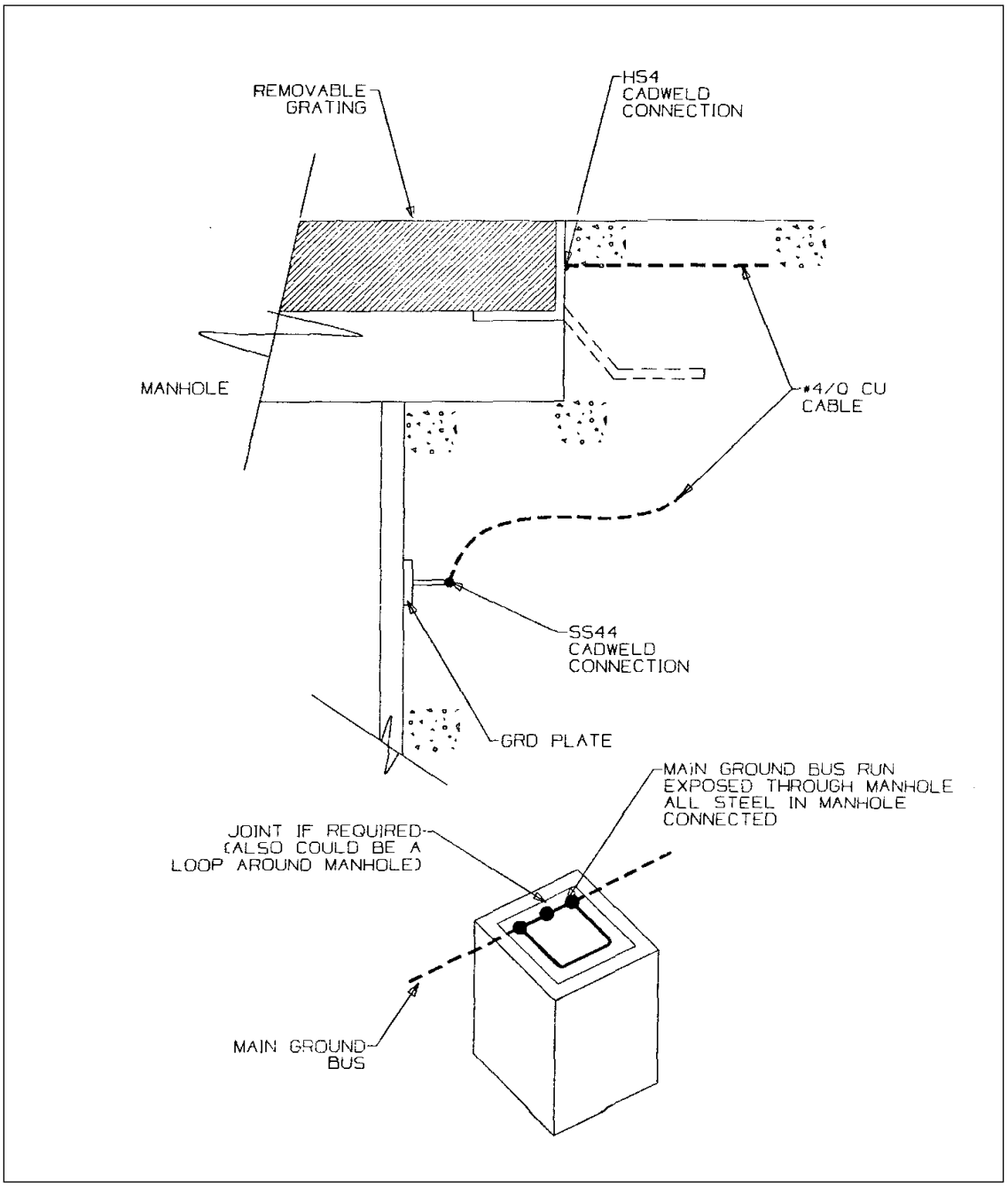


Figure 52: Grounding - Removable Grating

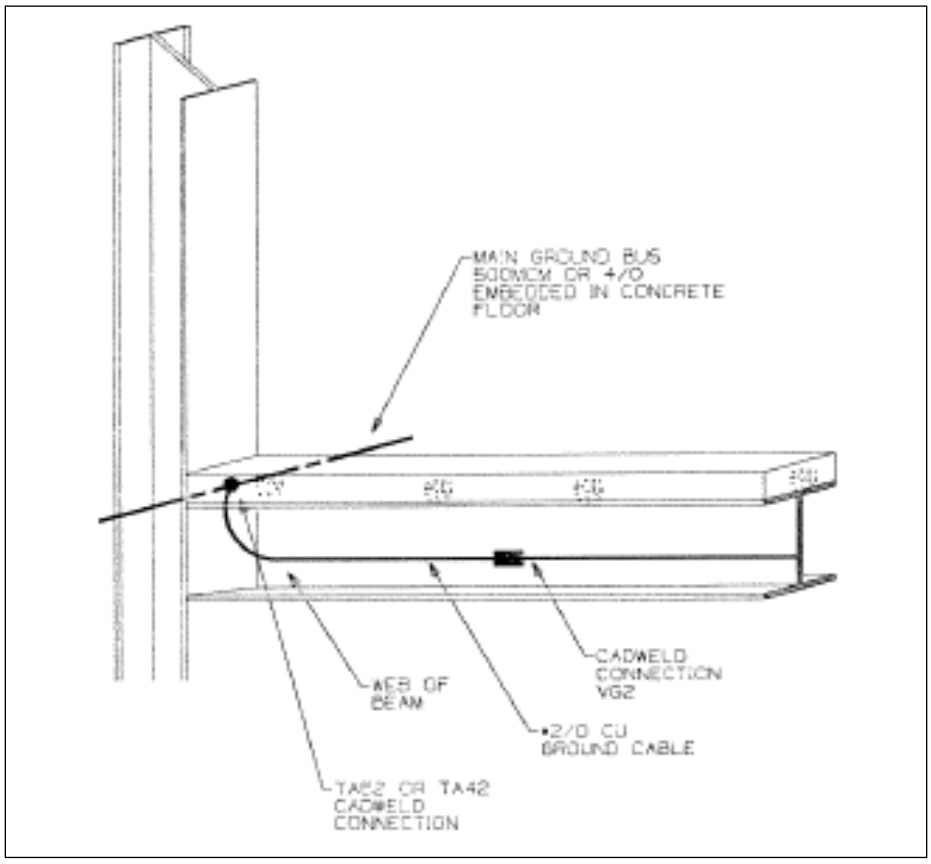


Figure 53: Cross Beam Ground

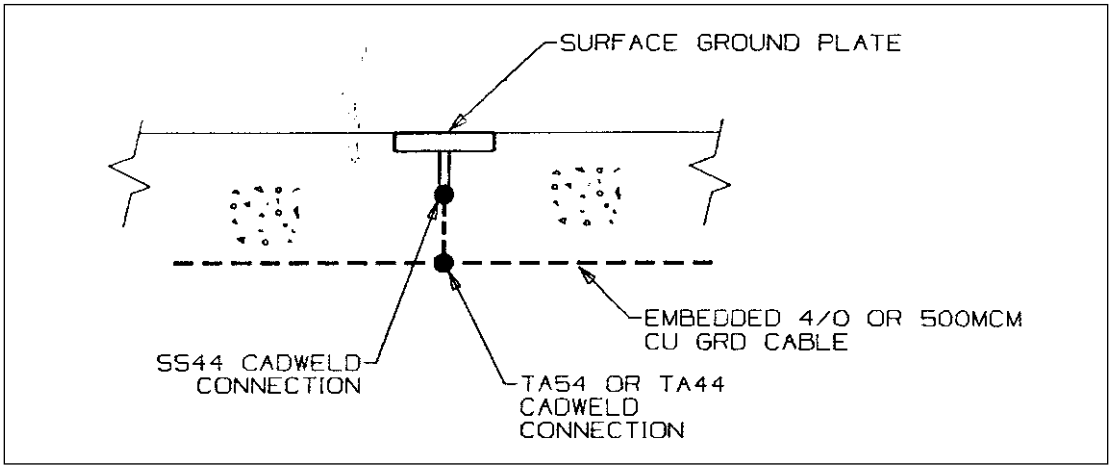


Figure 54: Grounding - Methods of Connecting Ground Plates Using Different Cable Sizes