Equipotential Planes

for Stray Voltage Reduction

A SELF-HELP GUIDE FROM...

MREC

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Introduction

The term stray voltage has been used for the past 40 years to describe a special case of voltage developed on the grounded-neutral wiring system on a farm. If this voltage reaches sufficient levels, animals coming into contact with grounded devices may receive a mild electrical shock. At voltage levels that are just perceptible to the animal, behaviors indicative of perception such as flinches may result with little change in normal routines. At higher levels avoidance behaviors may result. You can find out more about the causes and effects of stray voltage by visiting the MREC web site listed at the end of this publication.

A properly installed equipotential plane (EQP) will protect animals and people from stray voltage and other electrical hazards by eliminating contact voltages in livestock confinement areas. An EQP will also improve the electrical grounding and enhance electrical safety on the farm.

An EQP is one way to protect against stray voltage on a farm, but it will not eliminate the source of the voltage. The sources of stray voltage should always be determined before any corrective measures are taken and the safest and most cost-effective solution should always be implemented. Never violate electrical codes or compromise the safety of your electrical system in an attempt to deal with a stray voltage problem!

THIS PUBLICATION WILL:

- Explain the function of an EQP
- Explain how an EQP reduces the incidence of stray voltage
- Provide recommendations for EQP installation.

The installation guidelines in this publication are research-based and comply with the National Electrical Code (NEC). While the examples in this publication are of dairy facilities as examples, the recommendations and procedures apply to any livestock containment facility.

WHAT IS STRAY VOLTAGE?

Low levels of AC voltage on the grounded conductors of an electrical wiring system are a normal and unavoidable consequence of operating electrical equipment. Stray voltage is a voltage that develops on the grounded neutral system of either the farm wiring or utility distribution system. These voltages are termed "stray voltage" when they can be measured between two objects that are contacted simultaneously by livestock. The voltage is a result of the current flow on the neutral wire and the resistance of the grounded neutral network. Stray voltage can be reduced by:

- Reducing the resistance of the grounded neutral system. Proper sizing, installation and maintenance of wiring systems is required to keep the resistance of the grounded neutral system low.
- Reducing the current on the farms neutral system. Current flow on the neutral wire can be reduced by balancing 120 V loads between the phase wires, eliminating fault conditions, and using 240-volt equipment whenever possible.
- reducing contact voltages by improved grounding and/or EQP installation

USDA recommendations for safe exposure levels for stray voltage are expressed in terms of AC voltages (measured as an rms average) because voltage is the easiest and most commonly made measurement. However, animals respond to the electrical current generated by a voltage and not to the voltage directly. To relate voltage measurements to current, a worst case (500 Ohms) or more realistic (1000 Ohms) animal impedance should be used in the animal contact measurement circuit. The USDA suggests that animal contact voltage in excess of 2 to 4 Volts is excessive and should be reduced. Only under the most unusual circumstance can a cow detect voltage less than 0.5 to 1.0 V. Thus attempts to reduce cow contact voltages to below 0.5 to 1.0 V are unwarranted and unnecessary.

...An equipotential plane minimizes the risk of stray voltage in livestock confinement areas...

WHAT IS AN EQUIPOTENTIAL PLANE?

An equipotential plane is an electrically conductive grid that is embedded in a concrete floor and connected to the electric grounding system. The electrical connection between the floor and all grounded metal objects on or near it eliminates voltage differences (potentials) between the floor and these metal objects. If two parts of an animal or person cannot come into contact with a voltage difference then no current will flow through them and they will not receive a shock (like a bird on a wire).

The National Electric Code requires that any conductive object in a livestock facility that could come into contact with a live wire (water pipes, stanchions, metal buildings, etc.) must be connected to the electrical grounding system. This is necessary to maintain the safety of the electrical system. As a result, a small amount of electrical current will be present on these grounded objects. The presence of the current cannot be completely eliminated on a safely wired farm. The best way to protect livestock is to make sure your farm is wired according to the NEC so that the current and voltage on the grounded-neutral system is low enough so that it will not cause a problem. The installation of an EQP reduces the risk by further reducing contact voltages and providing protection in the event that an electrical wiring problem does develop.

Electrical current will only travel through an object if it is in contact with different electrical potentials (voltage levels). This is similar to the way in which water will only flow downhill. If you can measure a voltage between two surfaces, they are at different electrical potentials. When a conductive object (like livestock) touches both surfaces, a path is created for current to flow from one surface to the other. For example, if a voltage can be measured between a water bowl and the stanchion floor – two objects that livestock come into contact with – some electrical current could flow through the animal when touching these two points simultaneously. If enough current flows the animal will experience a sensation.

An equipotential plane causes the water bowl and stanchion floor to be at the same voltage potential. Therefore, no current can flow through livestock when drinking. Current may still be present on the grounding system, but now it has a much lower resistance path to follow – one that does not include livestock.

You can see an example of how this works by watching a bird land on electrical wires. Utility lines are typically energized at 7,200 volts or more and are not covered with electrical insulation. The bird is able to rest on them without harm because everything that it touches is at the same voltage potential. The electrical current stays in the wire and does not pass through the bird. The same is true for livestock standing or lying on a barn floor equipped with an EQP.

THE NATIONAL ELECTRICAL CODE

Experts who review and adopt changes to the electrical codes recognize the benefits of the equipotential plane. The installation of an equipotential plane is required by the NEC in newly constructed and extensively remodeled livestock confinement areas. Most states have adopted the NEC meaning that EQPs are required. Check with your state electrical inspector if there is any question. The definition of an EQP in Article 547 of the NEC is:

Equipotential Plane: *An area where wire mesh or other conductive elements are embedded in or placed under concrete, bonded to all metal structures and fixed nonelectrical equipment that may become energized, and connected to the electrical grounding system to prevent a difference in voltage from developing within the plane. (NEC, Article 547.2)*

AN EQUIPOTENTIAL PLANE HAS FOUR PARTS:

1. Conductive network in floor (usually reinforcing rod or wire mesh)
2. Bonding network
3. Equipment grounding
4. Transition area (voltage ramp)

1. CONDUCTIVE NETWORK

While the conductive network embedded in the floor is referred to as “wire mesh” in the NEC, there are several materials that can be used:

- Welded-steel wire mesh not smaller than No. 10 gauge
- Reinforcing steel not smaller than No. 3 gauge (3/8-inch diameter)
- Bare copper wire – not smaller than No. 8 AWG (copper wire is easier to install in retrofit applications).

Welded-steel wire mesh generally is available in 6-inch by 6-inch patterns. If steel wire or reinforcing rods are used they should be placed a grid pattern not larger than 18 inches.

Copper wire may serve as the conductive element where fiber mesh or non-reinforced concrete is used. A maximum spacing of 30 to 45 cm (12 to 18 inches) with No. 8 CU or larger conductor is recommended. Multiple interconnections should be used to assure long-term electrical continuity *(ASAE 473.2, Section 6.1.3).*

Make bonds where reinforcing steel or wires cross. The mesh should be embedded at least one inch into the concrete to protect it from corrosion due to moisture and manure.

2. BONDING NETWORK

An EQP must have electrical continuity throughout the wire mesh in the floor as well as metal objects embedded in the floor, such as metallic animal stall posts. Electrical continuity will be interrupted if plastic or non-conductive materials are used to join two conductive elements. The EQP must also be bonded to the ground bar in the service entrance panel. According to ASAE Standards.

A means of bonding the equipotential plane via a copper equipment grounding conductor to the electrical grounding system of the facility should be provided (ASAE 473.2, Section 6.2). The equipment grounding conductor should be located and routed so it is protected from physical damage (ASAE 473.2, Section 6.2).

An electrically conductive bond can be created by using any of the following methods:

- Gas or electric weld
- Chemical weld
- Brazed bond
- Approved clamps
- approved brass, copper or copper alloy compression connectors
- *Exothermic weld (CADWELD)™

* CADWELD™ should be used when bonding copper to any other metal.

Multiple bonding between the wire mesh, reinforcing rods, copper wire, stall pipes, and other metal equipment is desirable. Every 40 to 60 cm (18 to 24 inches), the welded wire mesh should be bonded to the crosswise reinforcing rod where they intersect. Multiple bonds will provide a networking of electrical continuity in case some connections fail. (ASAE 473.2, Section 6.3).

All conductive objects on or near the EQP should be bonded to the wire mesh including:

- Stanchions
- Stall partitions
- Metal posts or columns
- Water lines (if metal)
- Metallic Waterers
- Metallic Feeders
- Livestock crates

Slatted floors, precast concrete troughs, and suspended walkways and floors are considered to be part of an equipotential plane when mounted on concrete foundations or walls in which a grounded conductive element is installed. No further direct bonding of slats, walkways, floors or troughs, including those troughs on slats, is needed.

Where for purpose of good animal husbandry a concrete floor may not be acceptable in a specific area, the equipotential plane can be omitted from that area. Electrically heated waterers and general purpose outlets serving these areas should have ground fault circuit interrupter protection (ASAE 473.2, Section 6.4-6.5).

3. EQUIPMENT GROUNDING

Stray voltage is often attributable to improper wiring and grounding of electrical equipment on farms. Electrical equipment should be wired in accordance with the NEC and properly grounded, especially in animal confinement areas.

Each building service panel must have a grounding electrode system that may include one or more of the following:

- metal underground water pipes;
- grounded metal building frame;
- concrete-encased electrode (building footings);
- a "made" electrode of ground rods.

Refer to the NEC for installation methods to connect the grounding electrode system to the neutral conductor at the electrical service entrance panel.

... be sure equipment is wired in accordance with electrical codes and properly grounded...

The bond between the equipotential plane and the building grounding electrode system must be exposed (not buried in concrete or earth) so that it may be inspected. Any of the following methods can be used to produce an exposed bond:

- Steel reinforcing rods not smaller than No. 3 (3/8-inch diameter) can be bonded to the mesh and left protruding from the concrete. The protruding rods are then connected to the building grounding electrode system to produce the visible bond.
- Bare copper conductors can be bonded to the mesh and left protruding from the concrete. The exposed conductors are then connected to the building grounding electrode system to produce the visible bond.
- Bare copper conductors can be connected between the building grounding electrode system and stanchion metal or other metalwork that has been bonded at numerous locations to the wire mesh.

The exposed bonding conductor

from the EQP can be connected directly to the building grounding electrode system at the building's service entrance panel, or to any equipment that is, in turn, electrically connected to the electrode system at the service entrance (e.g., a metal water line).

The NEC specifies the required size of the bonding conductor. The size of this conductor depends on the size (ampacity) of the service entrance, but cannot be smaller than a No. 8 AWG bare copper conductor. The NEC requires that conductors smaller than No. 6 AWG have physical protection, such as a conduit.

Stainless steel milk lines are conductive elements and must have a connection to the buildings grounding system. The connection to the milk line requires a stainless clamp with a copper grounding lug attached or other similar method. Prefabricated stainless steel milk line-bonding clamps may be obtained from dairy equipment dealers. If the milk line is not electrically continuous (some manufacturers use plastic elbows) each section must be bonded. Do not allow copper or steel to come into direct contact with a stainless steel milk line or corrosion may result.

4. TRANSITION AREAS

Install voltage ramps where livestock enter or exit an equipotential plane. Voltage ramps create a gradual change in the voltage potential that minimizes the contact voltage as animals walk on to or off of an EQP. An effective transition area can be constructed by extending the equipotential plane outward and downward. One way to do this is to drive copper-clad ground rods or No. 6 reinforcing rods into the ground spaced 12 inches apart along the width of the transition area. The rods should be driven at a 45-degree angle (1:1 slope) to the surface and bonded to the equipotential plane before the concrete is poured.

Size of largest service entrance conductor		Recommended grounding conductor size
Copper	**Aluminum**	
AWG 1/0 or smaller	AWG 3/0 or smaller	AWG 6-CU
AWG 2/0 through AWG 3/0	AWG 4/0 through 250 kcmil	AWG 4-CU
over AWG 3/0 through 350 kcmil	over 250 kcmil through 500 kcmil	AWG 2-CU

INSTALLATION METHODS

EQP design and installation guidelines for various applications are presented in the figures in the following section.

NEW CONSTRUCTION

The NEC requires that an EQP be installed in all newly constructed livestock confinement facilities. There are several ways to install an EQP. Make certain that the mesh is bonded to all equipment, stalls and partitions that will be embedded in the floor **before the concrete is poured**. Make sure the bonds in the grid have been thoroughly checked for continuity. Also make sure that you have made provision to bond all equipment on or near the EQP that will not be embedded in the floor to the mesh.

RETROFIT CONSTRUCTION

Livestock facilities that were built without an EQP can be retrofit to provide a similar level of animal safety. This may be an appropriate and cost effective method of minimizing existing stray voltage levels. Consult a trained professional for an analysis of the sources and levels of stray voltage. This will determine whether installation of an equipotential plane is appropriate. In addition, this analysis will assist in determining where an equipotential plane is necessary. Once it has been determined that an equipotential plane would be beneficial in an existing barn, there are three difference installation methods that may be used:

1. GROOVE EXISTING FLOOR

Use a concrete saw to cut grooves 1 inch deep by ¼-inch wide in the floor in areas where animals could come into contact with grounded devices or electrical equipment. Next, place bare copper wires – No. 4 AWG are recommended – in the grooves and bond them together at several points along the length of the barn. The number of bonding points and their locations will depend upon the layout of the facility but at minimum, bond the wires at each end of the barn and to the stall work, waterline and any other metal structures in the barn. All bonding should be done by welding or by using pressure-type connections. Use a quick-setting grout to fill the grooves and finish the installation process. An FDA-approved grout must be in feeding areas. This method will cause the least interruption to normal farm operations.

In dairy barns copper wire should be embedded in the feed manger, front- and rear-hoof areas in stalls and, walk alleys. One groove should be located in the feed manger approximately 8-12 inches from the curb, two grooves in the front-hoof area approximately 8-12 inches from the curb and 12 inches apart, and two grooves in the rear-hoof areas approximately 8-12 inches from the gutter and 12 inches apart. Due to the limitations of the concrete sawing equipment, the exact location of the grooves depends on the arrangement of the stall dividers and stanchions.

This method can also be used in milking parlors and holding areas. If a retrofit equipotential plane is installed in a milking parlor, a wire may be required where livestock stand to be milked and also under the worker area of the pit floor and the livestock walk aisles. To ensure all cow contact areas are bonded together, bond the EQP to milking stalls and feeders if present.

2. CAP EXISTING FLOOR

Another retrofit method involves laying mesh on the old concrete and bonding it (as described in the previous section) to all metal components before "capping" the floor, by pouring a new 2-inch layer of concrete.

This method has the disadvantages of being time-consuming to construct, and the level of the barn floor is increased. It also may be inconvenient if livestock require access to the construction area during installation. However, if corroded stanchions are to replaced, this method may be the most cost effective.

...The National Electric Code requires that an equipotential plane be installed in all newly constructed or remodeled livestock confinement facilities...

3. NEW FLOOR

Another option is to completely remove the old concrete floor and build a new floor with an embedded EQP. The installation method is the same as for new construction. This method is also inconvenient if livestock require access to the construction area during installation. However, may be preferable if barn remodeling is in order.

Several other methods of installing an equipotential plane have been tried. These include conductive concrete, conductive floor/mats and conductive coatings. These methods are presently undergoing study; and, while they may have potential in the future, they are not recommended at this time.

Figure 1. Equipotential Plane Details in a Milking Parlor

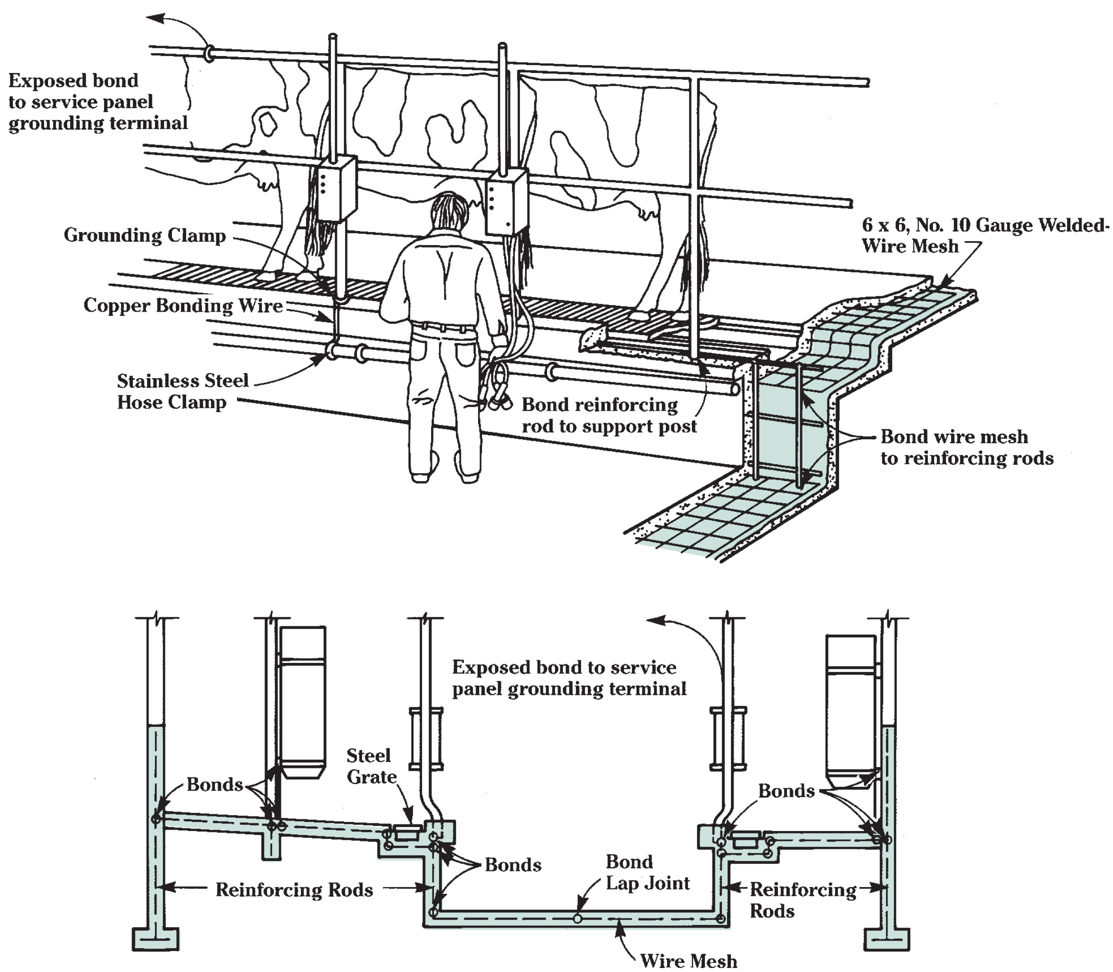


Figure 2. Bond to Stainless Steel Milkline

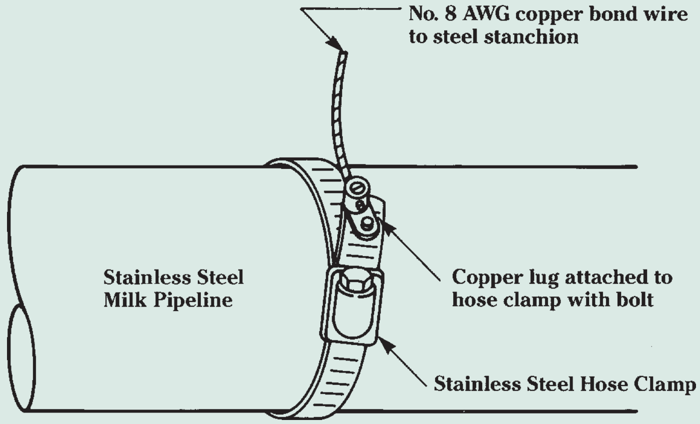


Figure 3. Retrofit Equipotential Plane Layout in a Milking Parlor

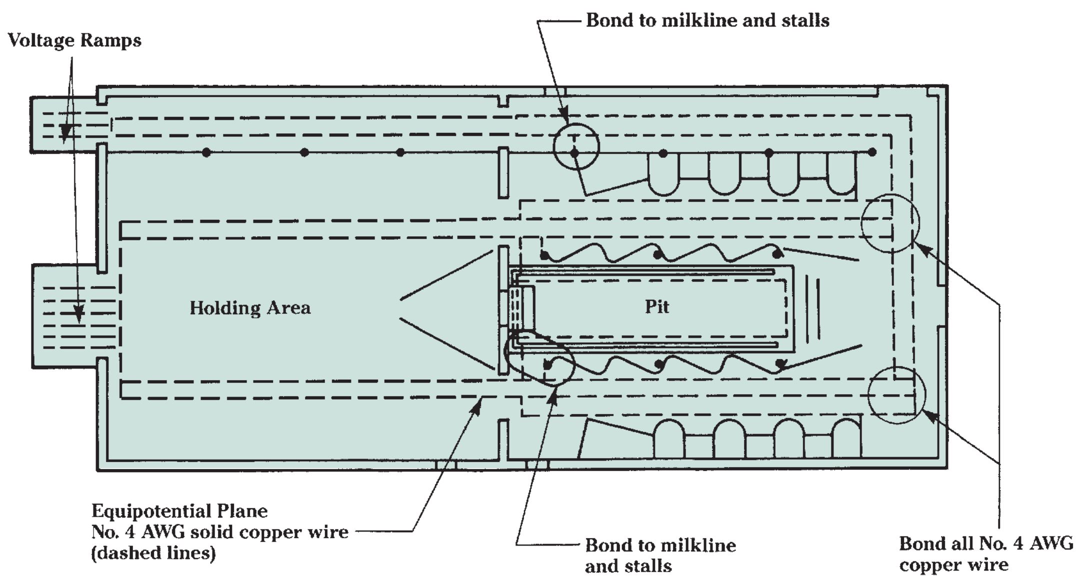


Figure 4. Equipotential Plane in a Milking Parlor/Holding Area

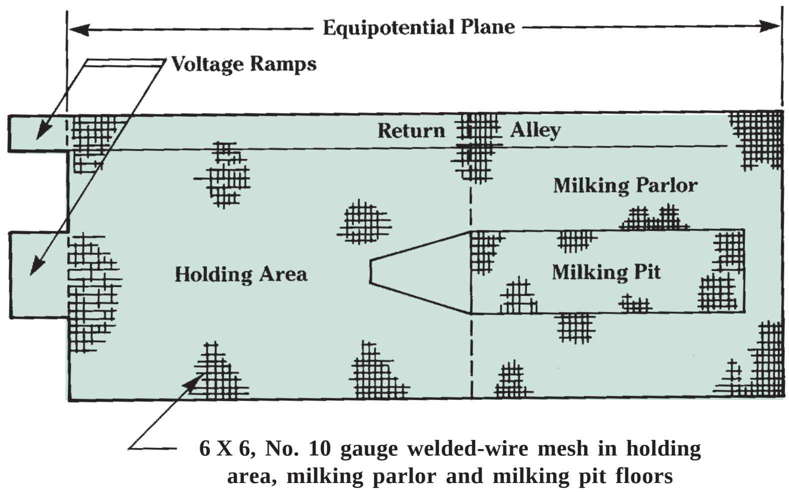


Figure 5. Equipotential Plane in a Free-Stall Barn

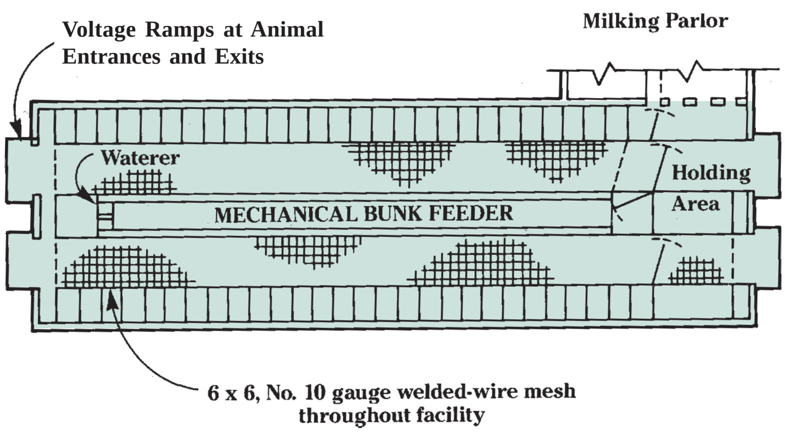


Figure 6. Transition Area/Voltage Ramp

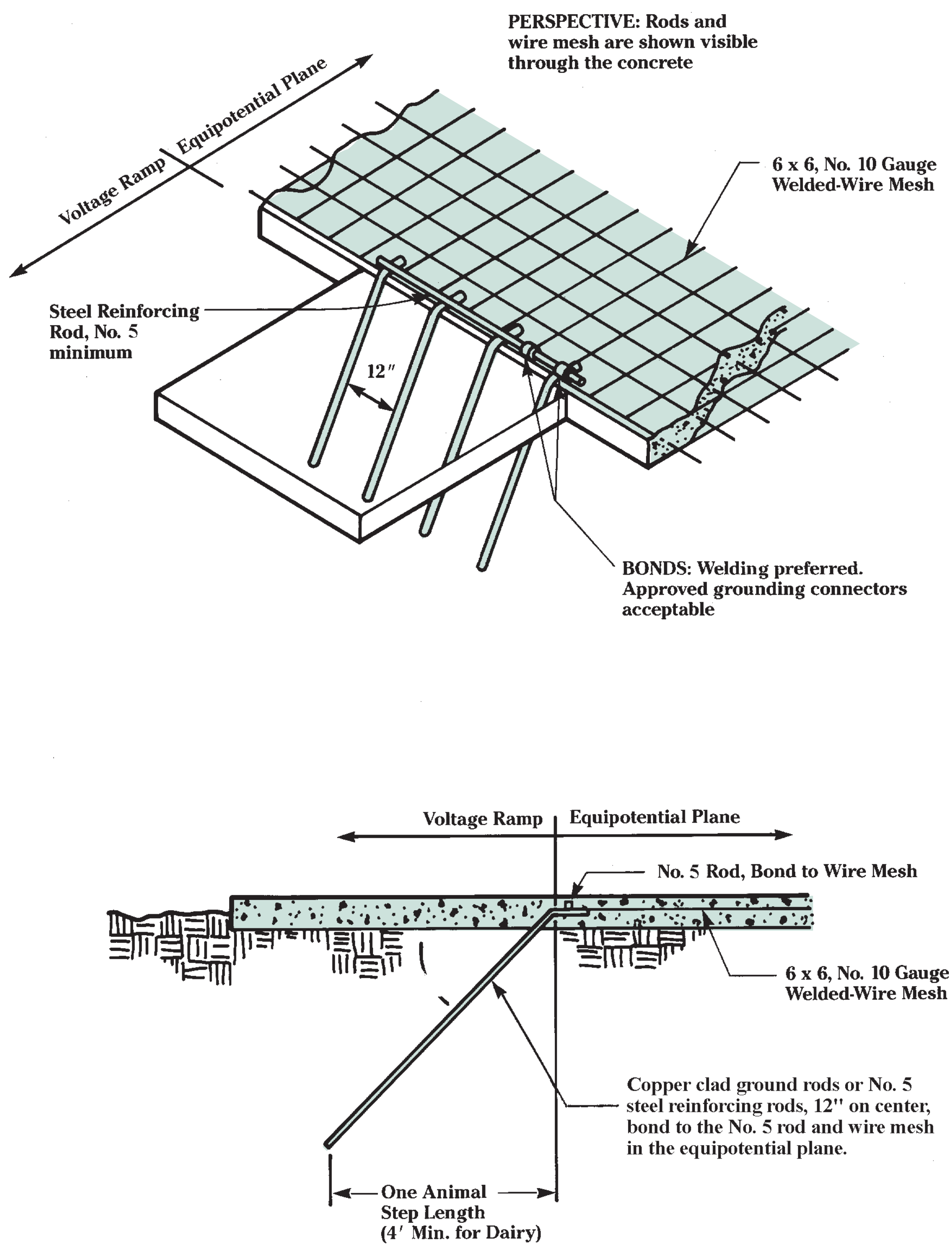


Figure 7. Equipotential Plane in a Stanchion/Tie-Stall Barn

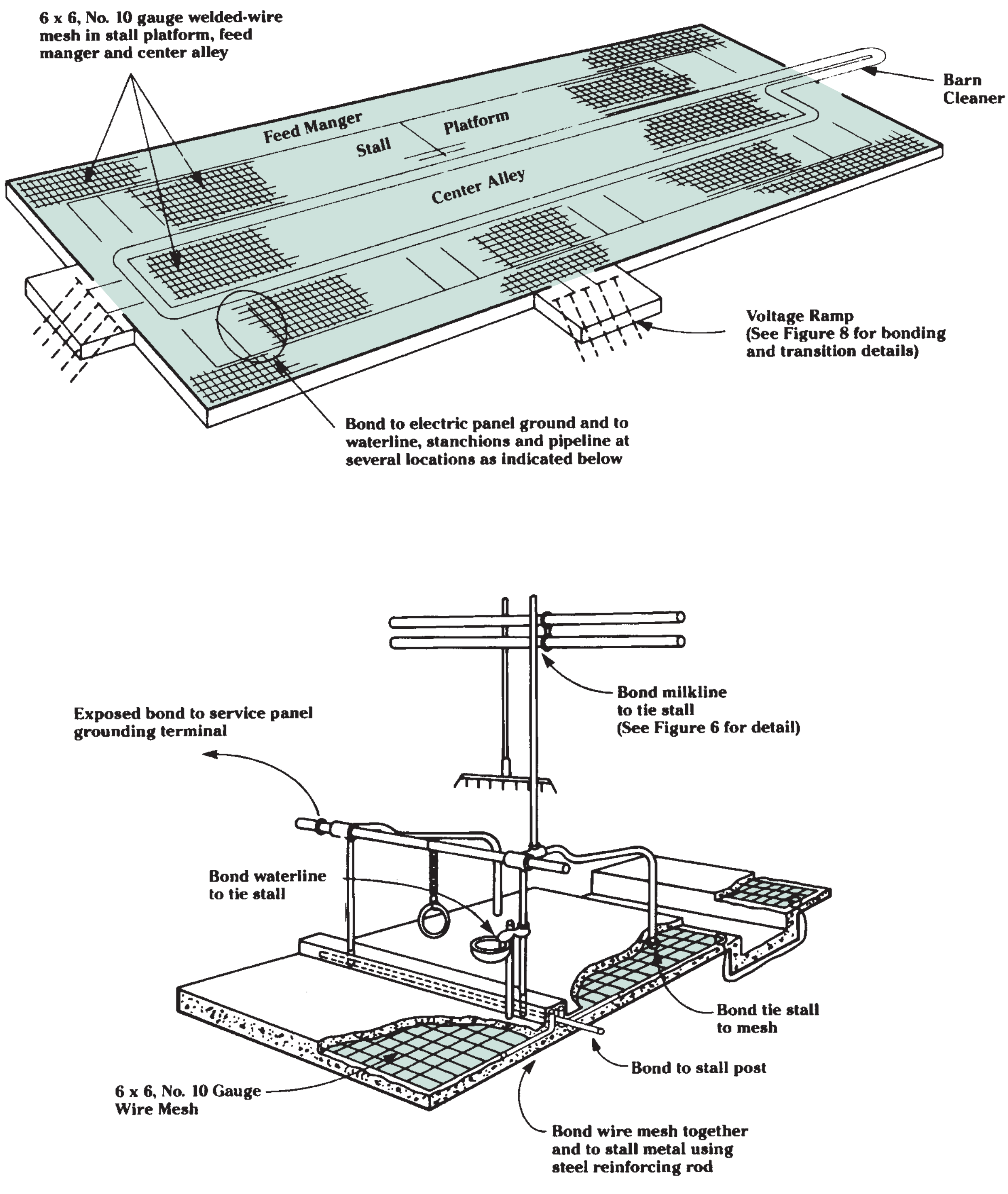


Figure 8. Retrofit Equipotential Plane in a Stanchion/Tie-Stall Barn

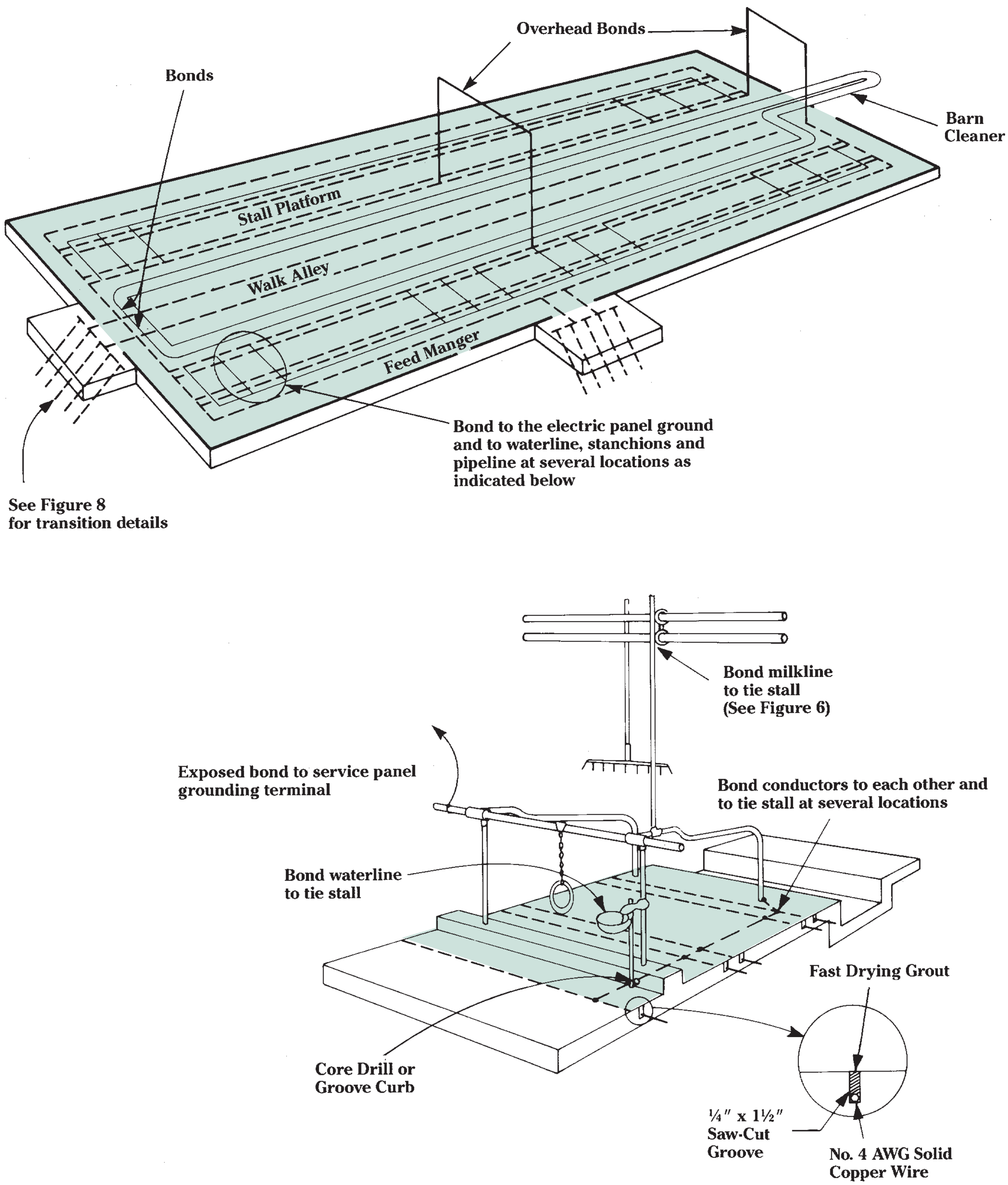
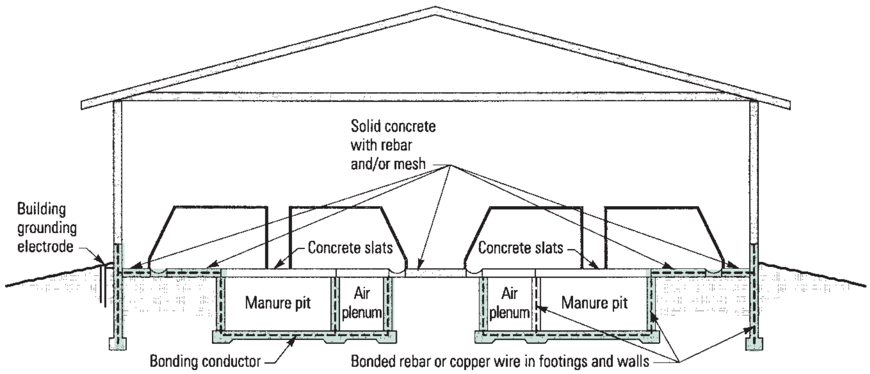


Figure 9. Equipotential Plane in a Building with Partly Slatted Floors



Equipotential Plane in a Building with Fully Slatted Floors

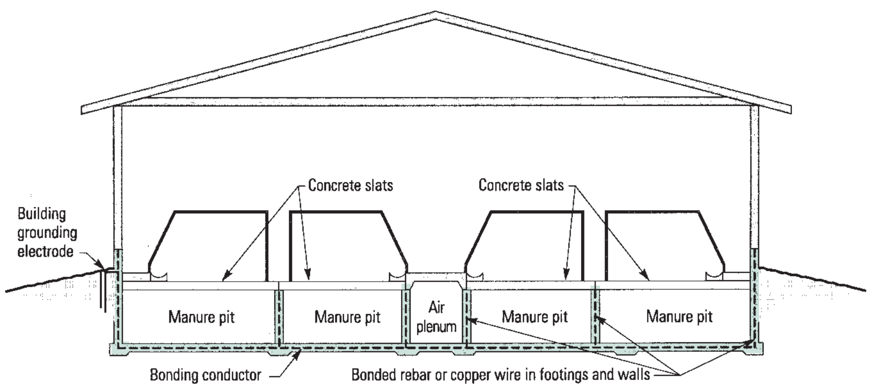
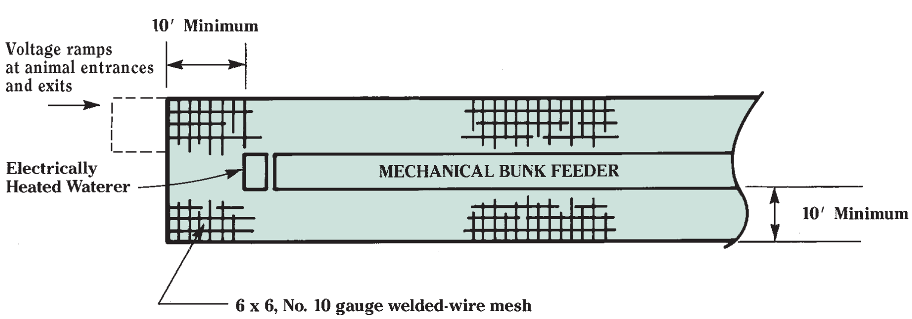


Figure 10. Equipotential Plane in a Water and Bunk Feeder Area



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