Electrical Tech Note — 228

Biosystems & Agricultural Engineering Department
Michigan State University

Grounding, Bonding, and Equipotential Grids

Electrical systems that commonly supply power to areas accessible to the general public are grounded to limit the maximum voltage that may occur and to minimize adverse effects from lightning. This means that one wire of the electrical system serving a building accessible to the general public is grounded to the earth. Theoretically there is no voltage difference between the floor upon which a person stands and the grounded wire of the electrical system. Because there is resistance in conductors, and because wiring and equipment can fail, sometimes there is a difference between a grounded wire and the adjacent earth or floor. This Tech Note is intended to discuss grounding of electrical systems, the terminology associated with electrical grounding, and some of the grounding techniques used to protect humans and animals from harmful as well as annoying electrical shocks and tingles.

All circuits of electrical systems are required to have an effective equipment grounding conductor run to every outlet, appliance, and equipment supplied. This conductor may be a wire or it may be the metal of pipes and enclosures that are a part of the electrical circuit. The purpose of this grounding conductor is to act as a barrier between a person or animal and exposure to live power that can be harmful. Figure 228.1 shows a single-phase circuit breaker service panel typical of the type that supplies power to a dwelling.

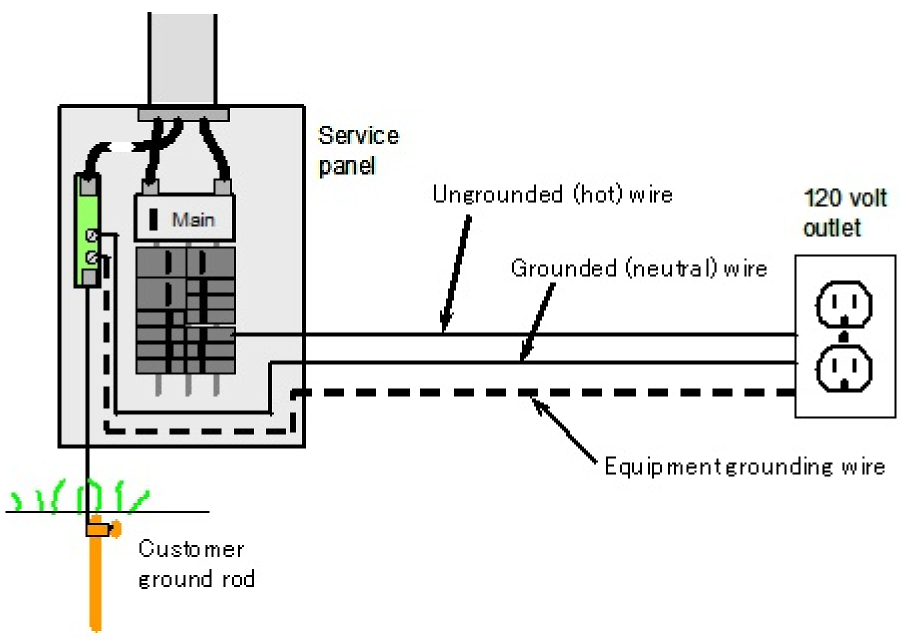

Figure 228.1 *A 120 volt circuit supplied from a single-phase service panel has an ungrounded (hot) wire, a neutral wire (grounded) and a safety equipment grounding wire.*

A typical single-phase electrical service panel like the one shown in Figure 228.1 has two ungrounded or hot wires supplying the service panel. There is 240 volts between the two hot wires, but only 120 volts between each hot wire and the grounded wire which is called the neutral. The diagram shows the wires that are required to supply a 120 volt receptacle. There is an insulated hot wire (usually a black wire), an insulated neutral wire (must be the white wire), and a safety equipment grounding wire which is either bare or has green insulation. Notice that the equipment grounding wire and the neutral wire both terminate at the same location in the service panel. If something goes wrong and the equipment a person is holding develops a voltage, the equipment grounding wire will carry the fault current safely back to the service panel. If the equipment grounding path is broken or not present, the fault current can flow through the person to the earth or floor, possible causing serious injury.

When a person or an animal feels an electrical sensation, what they are feeling is the flow of current through the body or a portion of the body. Dry skin has a fairly high resistance and it takes a higher voltage to cause a perceptible level of current than if the skin is wet. It only takes a fraction of a milli-ampere (mA) of current (less than 0.001 ampere) for human perception when a person is aware of the possibility of an electrical exposure. Usually it takes about 1 mA of current to get the attention of a human when unaware of an electrical exposure. At a level of 5 mA through a portion of the human body, the shock is generally not pleasant and in some cases is at a level where it may begin to be harmful. The ground-fault circuit-interrupter receptacle required to be installed in many dwelling locations and for all outside 120 volt receptacles trips off the power at a level of 5 mA.

Types of Grounding: One type of grounding is called *system grounding*. This is the intentional grounding of an electrical system to the earth at the service panel. Electrical systems are grounded, usually to the earth, to limit the voltage due to lightning, line surges, or unintentional contact with higher voltage lines. Electrical systems are also grounded to stabilize or fix the level of voltage that can develop under normal conditions between the earth and electrical conductors. A large wire, usually bare copper, runs from the neutral terminal of the service panel to a connection to the earth. One type of earth connection is a metal rod or pipe driven into the earth. The electrical code describes other acceptable ways of making this connection to the earth.

Another type of grounding is called *equipment grounding* and is also shown in Figure 228.1. It connects the metal frames of equipment likely to become energized to a common grounding point which in most cases is the neutral terminal at the service panel. The basic purpose of this equipment grounding conductor is to allow enough current to flow under fault conditions to cause the operation of an overcurrent device such as a fuse or circuit breaker which then de-energizes the circuit. Another purpose of equipment grounding is to limit the voltage on conductors or equipment being contacted by personnel when fault current is flowing. Fault current may flow for a few seconds before the overcurrent device opens the circuit. Or, the fault current may not be sufficient to de-energize the circuit. Under these circumstances, the purpose of the equipment grounding wire is to prevent the voltage exposed to people and animals from getting high enough to cause injury.

Definitions: Terminology associated with the subject of grounding can be confusing. It is important to understand these terms. A *grounded conductor* is an insulated conductor that is intentionally grounded to the earth at the service panel. The electrical code calls it the grounded circuit conductor. For most electrical systems it is the neutral wire. Even though it is grounded to the earth at the service panel, it carries circuit current. An equipment *grounding conductor* is one that connects to exposed metal of the electrical system and to frames of equipment. This conductor does not carry circuit current. It's purpose is to conduct fault current in the event of a problem with the electrical system where a person or animal may become exposed. Most circuits will operate without the equipment grounding wire, but safety is compromised. Even though the equipment grounding wire is not a circuit conductor, some equipment will not operate properly without an equipment grounding connection.

A *fault* is a condition where the electrical current is flowing outside of the intended path. A *ground fault* occurs when there is contact between a circuit conductor that carries current and the earth or the frame of equipment. If this ground fault is to an ungrounded wire (hot) usually the fuse will blow or the circuit breaker will trip. This ground fault can be from the neutral wire in which case the circuit may continue to operate, unless the circuit is protected with a ground-fault circuit-interrupter (GFCI). In that case the GFCI will detect the ground fault and trip off the circuit. A *short circuit* is a fault where current travels directly from one conductor to the other such as when an electrical cable is pinched or penetrated by a screw or nail.

A *voltage gradient* is a difference in voltage across a surface of some material. The gradient voltage can be measured by touching two points on the surface with a voltmeter. Voltage gradients of concern may exist across the surface of high resistance materials such as the earth, a concrete floor, or fresh water such as a fountain or swimming pool water. Utility as well as customer wiring systems are generally grounded to the earth and there will likely be some small amount of current flowing through the earth. Currents flowing through the earth can cause detectable voltage gradients across the earth. Typically a small voltage gradient can be measured across the earth within a few inches of a service panel ground rod. People and animals can sometimes detect these voltage gradients as a slight tingle, but in extreme cases an annoying shock can occur. Within the fenced-in areas near utility equipment, voltage gradients can rise to harmful levels and utility personnel are trained to work safely within these areas.

A *touch potential* is a voltage across a human or animal's body when making contact with metal or another conductive surface. Generally a touch potential is from a hand to the earth such as illustrated in Figure 228.2 for this utility worker. But, small current flowing in the earth can in some cases create small touch potentials around equipment that can be detected by people and animals. A cow at a farm may feel a tingle due to a small touch potential when drinking from some water fountains as illustrated in Figure 228.2.

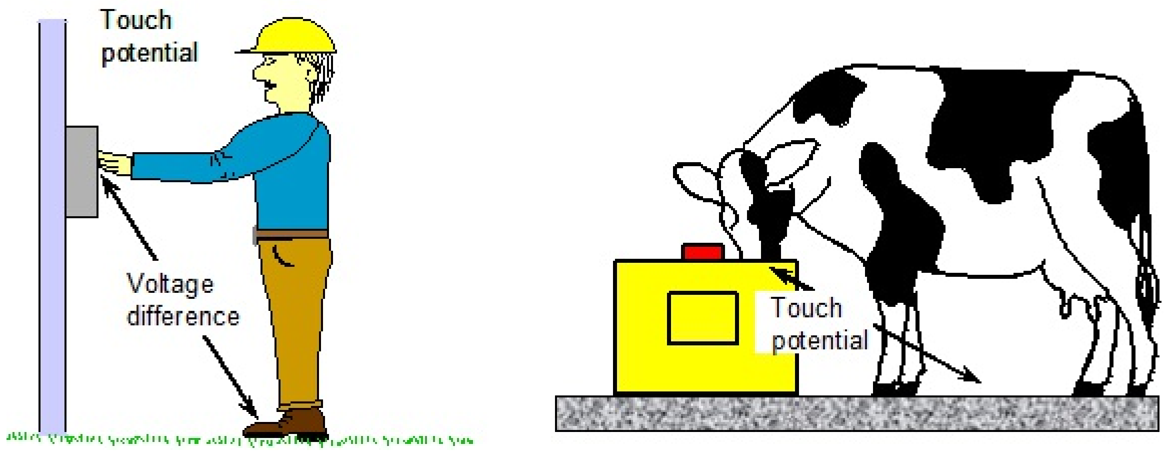

Figure 228.2 *Voltage gradients in the earth or floor can result in the floor being at a different potential than exposed metal equipment resulting in a touch potential.*

A *step potential* is a voltage across a human or animal's body while standing on the earth or some other surface such as a concrete floor. A voltage gradient across the surface of the earth or floor will result in a difference in voltage between a human's or animal's feet. A step potential is illustrated in Figure 228.3. Rarely does a human detect a step potential unless standing on a wet surface with bare feet such as near a swimming pool. If some electrical equipment develops a fault causing an excessive leakage of current into the earth, a voltage gradient will most likely develop in the earth or floor near the equipment and a noticeable step potential can be detected by animals such as the cow in Figure 228.3.

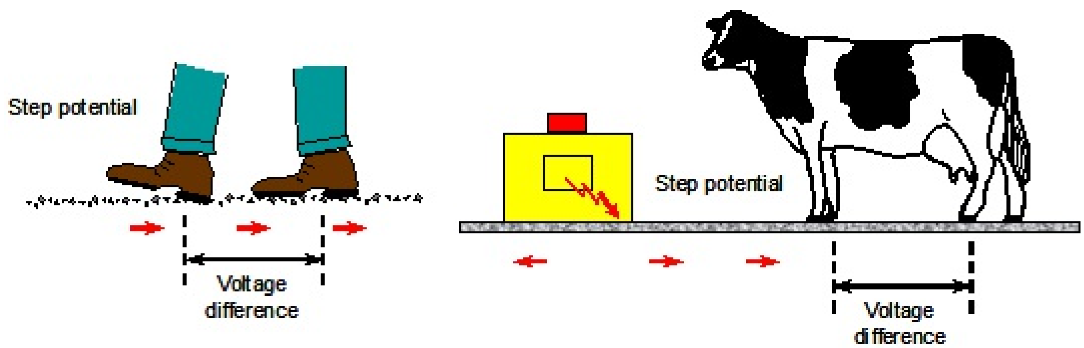

Figure 228.3 *A voltage gradient across the surface of the ground or floor, called a step potential, can expose a person or animal to a difference in voltage between feet.*

An **equipotential bonding grid** is intentionally installed metal elements such as wire, rods, or conductive coatings in the floor, earth, or across the surface with the intention of reducing or eliminating difference of voltage. Metal elements installed in a concrete floor and bonded to exposed metal above the floor will eliminate a difference in voltage between the floor and the exposed metal. The purpose of an equipotential bonding grid is to eliminate or reduce to insignificant levels touch and step potentials for humans and animals. An equipotential bonding grid is illustrated in Figure 228.4 where metal reinforcing mesh embedded in the concrete floor is bonded to the metal that can be touched be humans or animals.

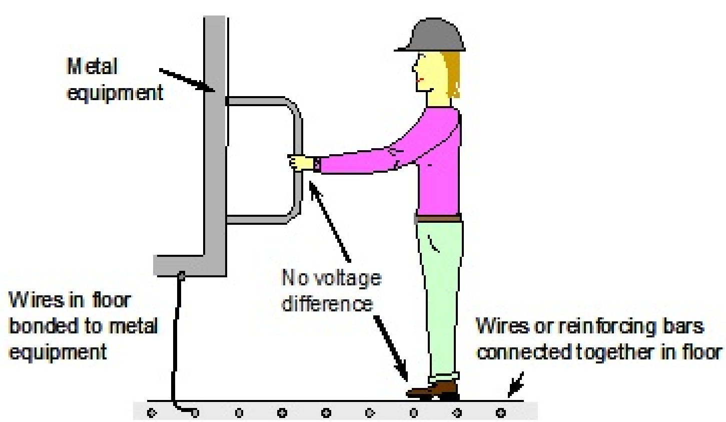

Figure 228.4 *Reinforcing metal installed in a concrete floor and bonded to exposed metal above will result in an equipotential bonding grid where there is little or no difference in voltage between the floor and the exposed equipment.*

Electrical *bonding* is the intentional connecting together of metal or conductive parts of an electrical system. The grounding path created by metal tubing or conduit may be interrupted by a section of nonconductive conduit. For example, to provide flexibility for adjustments, there may be a short length of flexible nonmetallic conduit inserted in a run of metal conduit supplying power to a motor, appliance, or equipment. A copper bonding wire , sometimes called a bonding jumper, is used to connect sections of metal conduit together to form one continuous low resistance path all the way from the service panel to the equipment.

Importance of Equipment Grounding: All equipment required to be grounded is to be connected back to the service enclosure. If equipment grounding is omitted or becomes ineffective, there will not be an effective ground-fault circuit path and the exposed metal of the equipment may develop a voltage that potentially can be dangerous to humans and animals. If the equipment where a fault occurs is making contact with the earth, such as the sump pump in Figure 228.5, current will flow into the earth.

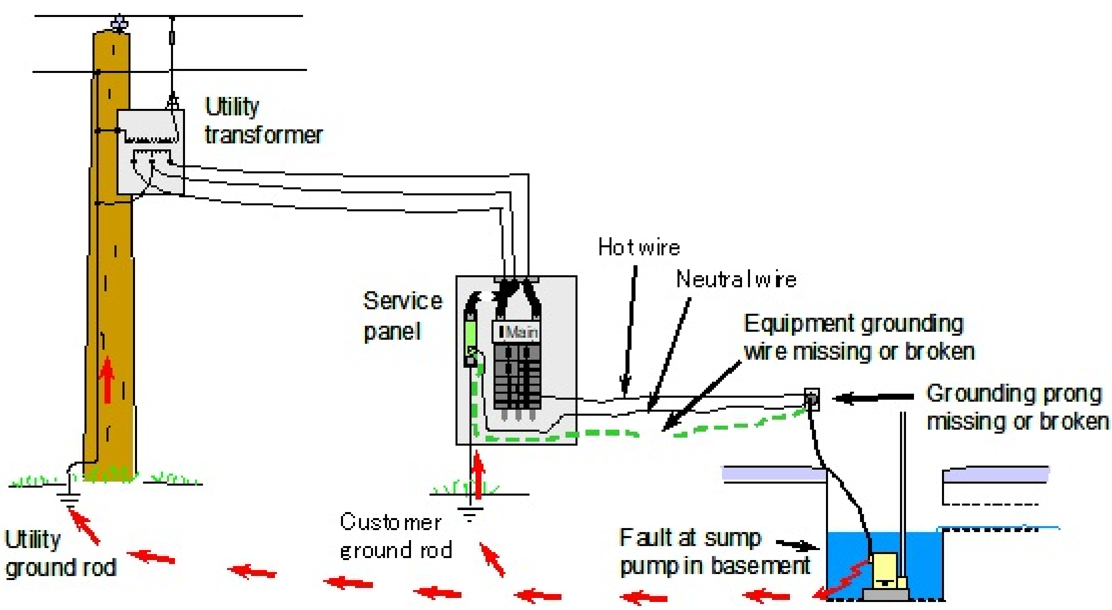

Figure 228.5 *A fault in equipment that is not grounded may result in an earth current that can cause an objectionable or even dangerous voltage to occur in the surrounding area.*

Electrical current flow completes a circuit from the source to the load or point of a fault and back to the source. Contrary to the belief of some individuals, current from an electrical system generally is not seeking the earth. Because electrical systems are often required to be connected to the earth, the earth can become a conductor. Electrical current goes to the earth to seek a path back to the source. Generally the source is the transformer that produces the voltage. Current that goes into the earth will eventually exit the earth at one or more points to get back to the source. Since there is resistance between the earth and a grounding electrode, there will be a voltage set up between the earth and the grounding electrode when current flows on this path. This is called neutral-to-earth voltage and is illustrated in Figure 228.6. Neutral-to-earth voltage creates touch potentials and sometimes detectable levels of step potentials.

This neutral-to-earth voltage is a difference in voltage between some metal object that is grounded to the electrical system and the adjacent earth. Neutral-to-earth voltage can be measured by touching a piece of metal equipment or the service panel grounding wire as in Figure 228.6 with the other probe connected to a short metal rod driven into the earth out in the yard. Best results are obtained by using a digital voltmeter. This voltage is caused by a small level of current (usually a small fraction of an ampere) flowing to earth or from the earth to the service panel neutral terminal.

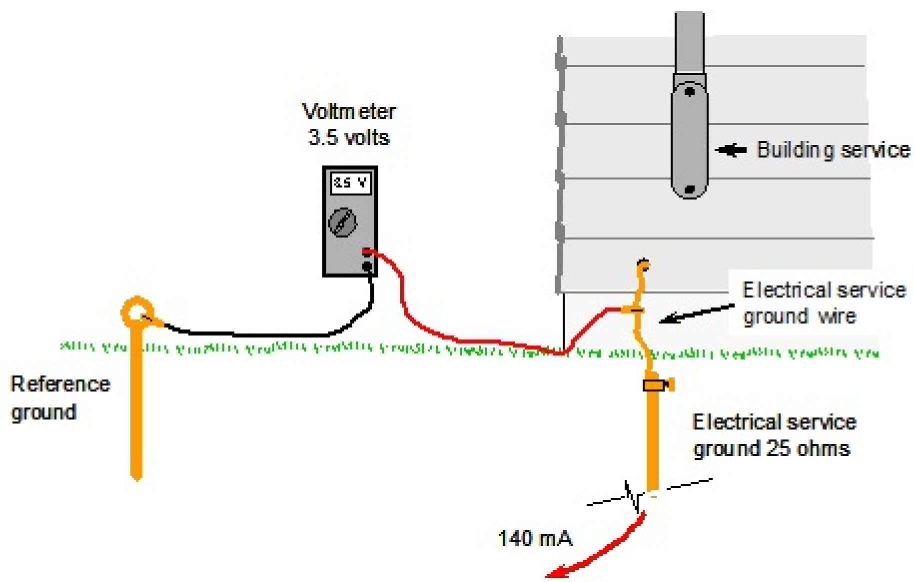

Figure 228.6 *Neutral-to-earth voltage can be measured with a digital voltmeter by touching the equipment or the service panel grounding wire with one meter probe and measuring to a rod pushed into the earth out in the yard.*

Earth Gradients and Ground Currents: Since utility and customer electrical systems are grounded to the earth at multiple locations, the earth acts as a parallel path to the grounded conductor. Usually the resistance through the earth is so high the current flowing in the earth is very small and of no consequence. The lack of a grounding conductor to equipment that is making contact with the earth can result in a significant level of current flowing in the earth. This current flows through the earth in the local area seeking a path back to the source transformer. A high resistance in a neutral conductor of the customer or utility due to a corroded splice or an undersized wire for the load can result in a voltage drop along the wire that increases the neutral current flow in the earth.

Most of the resistance of a path through the earth is located at the grounding electrode where the electrical system makes contact with the earth. Electrical codes indicate that the resistance to earth should be kept as low as practical, and below 25 ohms if possible. Since low resistance of a grounding electrode is dependant upon the resistivity of the earth at that location, low resistance in many places is not possible to achieve. According to the Ohm's law, current flow across a resistance will result in a voltage difference. The product of current and resistance is voltage. This is illustrated in Figure 228.6 where 140 milliamperes (0.14 amperes) is flowing into the earth at a ground rod that has a resistance-to-earth of 25 ohms. A voltmeter connected to the grounding wire and connected to the earth about 10 ft from the ground rod will measure about 3.5 volts caused by this current flow. A person or animal standing on the earth and touching the grounding wire will have a voltage across the body. The voltage will be less the closer a person or animal stands to the ground rod. This difference in voltage in the earth is called a gradient. Usually this gradient is so small it cannot be detected. In recent years it was discovered that livestock on farms and people in swimming pools can detect this gradient or neutral-to-earth voltage.

Equipotential Grid: An equipotential bonding grid is the intentional installation of metal in the earth or floor near exposed metal equipment with the purpose of making the earth or floor at the same electrical potential as the exposed metal equipment. The theory is that a person or animal near the equipment will not experience a detectable voltage difference across the body by touching the equipment (touch potential). This is illustrated in Figure 228.2 and Figure 228.4. Equipotential bonding grids are required by the Code to be installed in some agricultural locations, at permanent swimming pools, and near electrical equipment associated with some artificial bodies of water.

A typical means of creating an equipotential grid in the floor of a livestock area is illustrated in Figure 228.7. Sheets of reinforcing metal are put in place prior to pouring a concrete floor. The sheets consist of steel wire factory welded at each wire crossing point. The sheets of reinforcing steel are fastened together with tie wires to form an electrical bond between the sheets. This method of bonding the reinforcing metal is acceptable by the electrical code. A copper wire connected to one of the reinforcing sheets is required to be connected by means of a pressure connector or exothermic welding. This copper wire is required to be size 8 AWG or larger. In the case of a permanent swimming pool with conductive poured walls and floor, this connection is to the equipotential bonding grid wire in the concrete. The wire is to be solid copper wire not smaller than size 8 AWG. As this copper wire emerges from the concrete it should be protected from damage by a nonmetallic conduit sleeve. Rigid nonmetallic conduit provides a durable corrosion resistance means of protecting the copper wire. This wire is then connected to all of the other metal equipment associated with the swimming pool. Bonding the wire directly to the grounding conductor of the exposed equipment is recommended. Make sure this bonding connection is not in such a location that it will experience physical damage or corrosion.

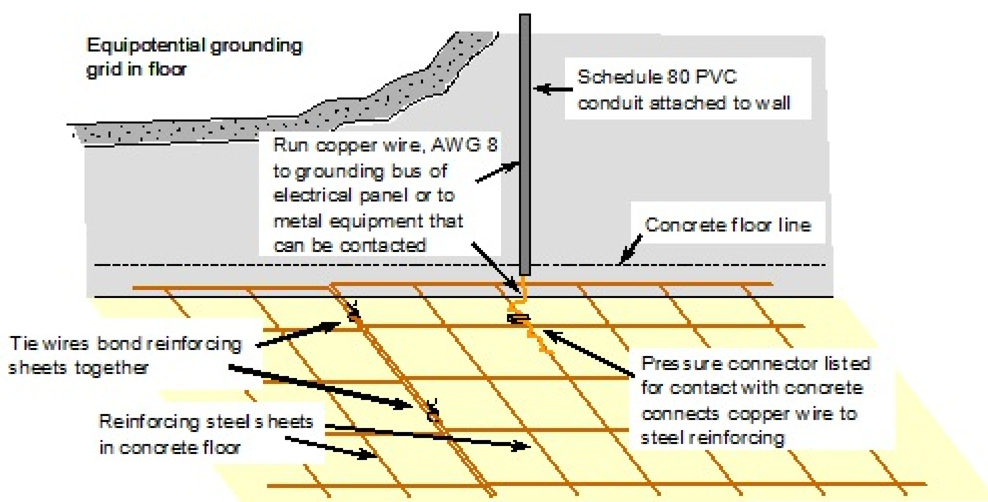

Figure 228.7 *A typical means of establishing an equipotential grid is to insure that reinforcing bars or wire mats installed in concrete floors are connected together and a wire brought out of the concrete for connection to exposed metal equipment or to the grounding bus of the electrical supply panel.*

Swimming Pool Equipotential Grids: Specifications for the installation of an equipotential grid are provided in the *National Electrical Code*®. When a concrete walkway is provided around the perimeter of a pool, metal reinforcing mesh should be installed in the concrete walkway out a distance of not less than 3 ft from the edge of the pool. This is illustrated in Figure 228.8. Metal reinforcing mesh should also be installed in a concrete pool wall and floor. This metal reinforcing is required to be bonded together and to all metal equipment associated with the pool. The wire used to bond the reinforcing together and to metal pool equipment is required to be copper, solid, and not smaller than size 8 AWG.

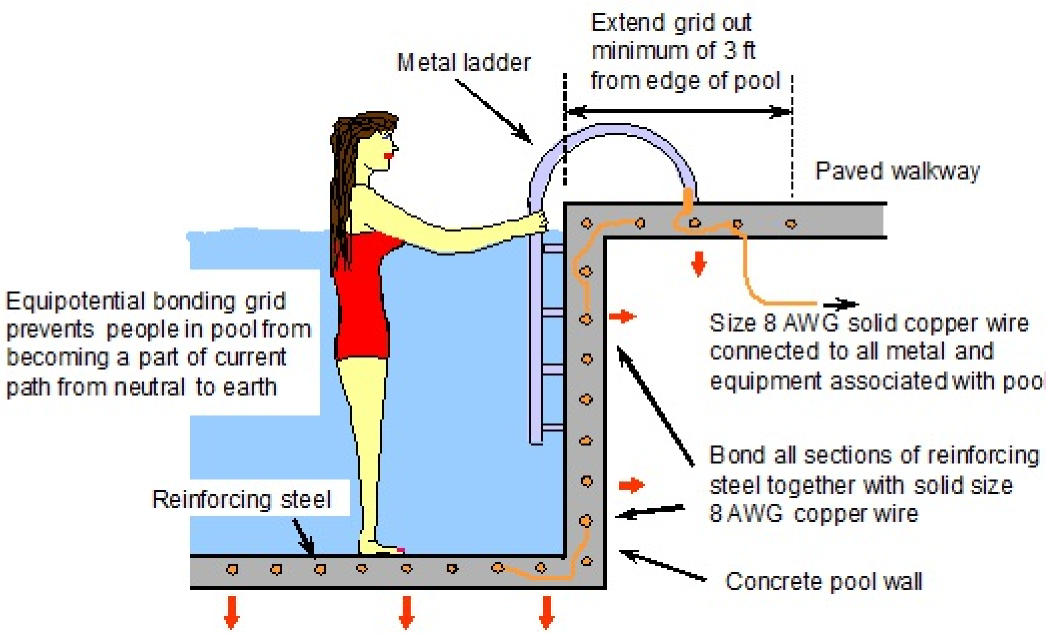

Figure 228.8 *Paved walkways around pools and concrete pool walls and floor are required to have an equipotential grid that is bonded to all metal associated with the pool using a solid copper wire not smaller than size 8 AWG.*

Without an equipotential bonding grid in the walls and floor of a conductive poured permanent swimming pool, a person becomes a part of the circuit path to earth from metal equipment such as a ladder. With metal reinforcing steel in the walls and floor of a swimming pool and bonded to all other metal accessible from the pool, an equipotential grid or plain is established. When a person enters the pool, the floor, walls, and metal that can be contacted is at the same potential. A person is not part of a circuit path to earth and does not feel an electrical tingle or shock.

More Information: More information on the purpose of equipment grounding and levels of current that have an effect on humans can be found in Tech Note 216. For more information on grounding, bonding, and equipotential grids refer to the most recent edition of the National Electrical Code® available from the National Fire Protection Association, One Batterymarch Park, Quincy, MA 02169-7471.