A Look at Concrete Encased Electrodes

The most basic conceptualization of an electrical grounding electrode is, of course, the driven ground rod. This basic unit is readily expanded to accommodate heightened requirements, either for lower resistances or to overcome hostile soil conditions. The single rod can simply be made longer, i.e., driven deeper, or can be infinitely multiplied into larger and larger grids. In this latter case, the multiplication of electrodes represents a practical application of the law of parallel resistances,

\[ R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n}} \]

where each additional electrode expands the denominator and thereby lowers the total resistance. The former case not only increases the size of the electrical field by enlarging the “footprint” but also endeavors to reach more favorable conditions at greater depths, especially below the water table.

These two basic options, while highly effective in common situations, can also be found wanting in some instances. Sites exist that defy effective installation of traditional grounding electrodes. Such problems include extremely rocky soil, shallow bedrock, and simple lack of space in urban areas. These conditions can make the installation of deep-driven or expanded grounding systems prohibitively expensive. A major breakthrough in solving such problems was the development of the “Ufer ground.” This is emphatically not an acronym involving “ferrous electrode” or any such fanciful concoction, but rather is derived from the name of its inventor, H. G. Ufer. While doing studies in the dry and often inhospitable conditions of the American Southwest, Ufer discovered that the steel reinforcing bars (rebar) in the concrete footings of buildings could serve as effective grounds. This innovation was a great relief from traditional dependence on the water pipe system which was becoming increasingly problematic for two reasons: repairs being performed with new, nonconductive materials like PVC pipe and couplers and protests by various municipal water systems who complained that ground currents promoted corrosion.

Skepticism being such as it is, independent studies were performed to verify and qualify the use of such systems. Interesting and informative research was conducted by E. I. du Pont de Nemours and Co. at building sites around the U.S. Tested items were building column footings typically with vertical reinforcing bars near the column surface for stress relief, horizontal bars in the spread footing, and anchor bolts centrally positioned. As these structures had not been designed for their grounding capabilities, the study was investigating what amounted to an inadvertent application with attendant complications and contingencies. The results yield useful information for the successful design and application of such grounding schemes. Testing proved difficult to implement due to inaccessibility and generally had to be performed via the anchor bolts. Anomalous low readings would crop up and could generally be accounted for by the anchor bolts inadvertently contacting the rebar. Horizontal grade beams, serving as wall supports, could be tied in to connect adjacent footings. This has the same effect as paralleling
numerous ground rods. Wire ties connecting lengths of rebar might have been expected to provide a comparatively poor electrical connection, but evidently there are enough of them so that a serviceable grounding connection can be readily extended from column to column. When tests were performed before and after such connections were made, ground resistance decreased commensurately.

Accordingly, the building footing, or system of footings, can act as an effective grounding electrode. Viewed analytically, a concrete-encased electrode is, in effect, an electrode within an electrode. It amounts to the immersion of a steel bar in a reasonably uniform medium (concrete) of a characteristic 3000 Ω-cm resistivity, which in turn is immersed in the earth, having a resistivity of enormous variability. This can be anywhere from a few hundred to several hundred thousand Ω-cm. Overall ground resistance is contingent upon the surface areas of the rod(s) and the concrete footing and the resistivities of the materials (concrete and earth). Obviously, the concrete is the more “known” of the materials. It is alkaline and hygroscopic, thereby containing effective proportions of the two essentials for current flow in the earth, water, and ions. The rigid molecular structure prevents leaching, so that ions are not lost as they are in many heavily granular types of soil. Also concrete tends to draw moisture from the soil, keeping the proper concentration of water. All this makes concrete an effective medium for enhancing the grounding capabilities of a rod in selected environments.

The basic formula for grounding resistance is

$$ R = \frac{\rho}{2\pi L} \left[ \ln \frac{4L}{r} - 1 \right] $$

where

- $R$ = grounding resistance, Ω
- $\rho$ = resistivity of surrounding medium, Ω-cm
- $L$ = rod length, cm
- $r$ = rod radius, cm

It can be expanded to include a dual medium, such as described above. The formula then becomes:

$$ R = \frac{\rho_0}{2\pi L} \left[ \ln \frac{4L}{r_0} - \ln 1 \right] + \frac{\rho_1}{2\pi L} \left[ \ln \frac{4L}{r_1} - \ln 1 \right] $$

where

- $\rho_0$ = resistivity of concrete, Ω-cm
- $\rho_1$ = resistivity of earth, Ω-cm
- $r_0$ = rod radius, cm
- $r_1$ = concrete radius, cm

This in turn simplifies to:

$$ R = \frac{\rho_0}{2\pi L} \left[ \ln \frac{4L}{r_0} - \ln 1 \right] + \frac{\rho_1}{2\pi L} \left[ \ln \frac{4L}{r_1} - \ln 1 \right] $$

(from F. D. White, Portland, OR)

When soil resistivity measurements were made at the various sites, and the above calculations made using the system dimensions, the calculated resistances compared favorably with those measured. At a number of sites, separate driven ground rods were also installed and measured. It was found that in soils of lower resistivities, i.e., good grounding sites of 5000 Ω-cm or less, rods driven directly into the soil had lower resistances than encased electrodes. The explanation is that these soils have resistivities lower than that of typical concrete, hence there is no advantage to encasement. But at higher resistivities, especially above 10 kΩ-cm, a decided advantage was afforded by the concrete-encased electrodes. The implication of this is that we have here another tool for dealing with difficult conditions. Footings are typically properly spaced, and it may be possible to simply parallel in as many as needed to bring resistance down to an acceptable level. If electrical connection is made between anchor bolts and structural rebar, as by deliberately welding a short section of rebar, capability is significantly improved.

Tests were also made of the current-carrying capabilities in order to ensure a reasonable level of lightning protection. Buried electrodes were subjected to currents of from 2 kA to 10 kA, with rise times less than 5 μsec., without signs of damage. It was further determined that lightning divides at all structural junctures of building steel. At the bottom of a column, if insulation occurred, voltage would double and concrete might burst. But anchor bolts were shown to conduct current safely to earth. A similar study was conducted using sites provided, not surprisingly, by the Los Angeles Department of Water and Power. Even more rigorous current stresses were applied. In one application, normal operating voltages were regularly switched between an encased electrode and a ground rod system for a period of nearly six months. A second application tested surge capabilities by applying high-voltage faults up to 10 kV for a 10-cycle duration. Both driven rods and concrete-encased electrodes stood up well to the high-voltage faults, while the concrete-encased electrodes outperformed the rods on the long-duration tests due to their water-retention characteristics.
These studies and others have demonstrated that building footings properly utilized can be an untapped resource for low cost yet effective grounding enhancement.


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