ARMY TM 5-811-3
AIR FORCE AFM 88-9 CHAP. 3

ELECTRICAL DESIGN LIGHTNING AND STATIC ELECTRICITY PROTECTION

DEPARTMENTS OF THE ARMY AND THE AIR FORCE
MARCH 1985

REPRODUCTION AUTHORIZATION/RESTRICTIONS

Technical Manual
No. 5-811-3
Air Force Manual
AFM 88-9, Chapter 3

DEPARTMENTS OF THE ARMY
AND THE AIR FORCE

Washington, DC, *29 March* ***1985***

ELECTRICAL DESIGN

LIGHTNING AND STATIC ELECTRICITY PROTECTION

*This manual supersedes TM 5-811-3, 28 August 1978.

CHAPTER 1
GENERAL

1-1. Purpose. Information and criteria in this manual will guide engineering design personnel in determining the adequacy of lightning and static electricity protection systems for all types of facilities. Policy and procedure of design development and tests are also included. Referenced criteria, codes, and standards are intended to include provisions for normal type facilities, which when integrated with criteria included herein, establish complete provisions for these protection systems. The standards and methods of system protection discussed are intended as the most practical and economical means of accomplishing protection of real property and avoidance of casualties to personnel. These criteria will not provide suitable protection for construction contractors' personnel.

1-2. Scope

a. General. The scope of this manual will include adequacy of engineering design for facilities of Army, Air Force and other agencies in conformance with paragraph 1-3.

b. Limitations. Limitations within continental United States will be subject only to specific provisions of project design directives, deviations included herein or authorized by HQDA (DAEN-ECE-E) WASH DC 20314-1000, for Army projects, and HQUSAF/LEEE WASH DC 20332, for Air Force Projects.

c. Other protection systems. These criteria are not intended to support or implement separate criteria such as furnished for electromagnetic protection or electromagnetic shielding requirements.

1-3. Application. Except as included for facilities of the Army Materiel Development and Readiness Command, criteria contained in this manual will apply to new construction of permanent, fixed type facilities conforming to AR 415-15 within the continental United States. Where conflicts arise with criteria or design guidance of different Army or Air Force agencies, or with Federal organizations other than Army or Air Force, the most stringent guidance will govern. Criteria or design guidance will apply to overseas facilities in conformance with AR 415-36.

1-4. General

a. Separate section of a specification. Inasmuch as provisions for lightning protection involve a special type (steeple jack) trade, contract requirements for lightning and static electricity protection will be included as a separate section in project specifications.

b. Environmental considerations. Design consideration will be given to overall appearance so as to maintain an attractive facility in harmony with area surroundings.

c. System components. Components will conform to applicable NFPA codes, except as otherwise stated or indicated.

d. Penetration of building exterior surfaces. Where roofing, walls, floor and waterproofing membranes are penetrated by components of these systems, adequate waterproofing and caulking of such penetrations will be provided. However such penetrations will be avoided whenever possible.

1-5. Applicable codes and standards. Codes and standards referenced in this manual and listed in Appendix A are to be considered as an integral part of this manual,

1-6. Design development

a. Lightning protection system. When contract drawings comprise more than one sheet showing composite roof and architectural elevation, a separate sheet will be provided showing locations of air terminals, routing of roof conductors, down conductors, and grounding system pattern.

b. Static electricity protection system. Where static electricity protection for two or more rooms or areas is indicated on an architectural floor plan and cannot be shown on an appropriate electrical plan, a separate floor plan sheet showing the complete static electricity protection system pattern will be included in the project design.

1-7. Approved type systems

a. Lightning protection. Selection of the type of protective system will be as prescribed in this manual, NFPA No. 78, and MIL–HDBR-419.

b. Static electricity protection. Selection of system type will be prescribed in NFPA No. 77, MIL-HDBR 419, and MIL-STD-188-124.

1-8. Materials. Materials will conform to applicable NFPA codes, unless otherwise stated. Normally, copper materials will be specified for use below finished grade. Stainless steel grounding devices should be used when there is a potential of galvanic corrosion of nearby steelpipes. UL listed compression-type connectors may be used where such connectors are equivalent to the welded type. Special consideration will be given to selection of materials to compensate for the following conditions as encountered at project locations:

(1) Corrosive soils and atmosphere.

(2) Atmospheric and ground contact corrosion.

(3) Electrolytic couples that will accelerate corrosion in the presence of moisture or ground contact corrosion. This must be prevented by use of same type metals, or by providing junctions of dissimilar metals in air that will permanently exclude moisture.

(4) Equal mechanical strength or fusing capability where conductors of different metals are joined.

CHAPTER 2

LIGHTNING PROTECTION

2-1. Discussion

a. Lightning phenomena. The planet earth is similar to a huge battery continuously losing electrons to the atmosphere. These electrons could be lost in less than an hour unless the supply is continually replenished. It is widely agreed among physicists and scientists that thunderstorms occurring thousands of times daily around the earth return electrons to earth to maintain normal magnitude of electrons at or near the surface of- the earth. The rate of electron loss from earth, called the "air-earth ionic current", has been calculated to be 9 microampere for every square mile of earth's surface. Thunderstorms supply electrons back to earth by an opposite electron potential gradient of perhaps 10 kilovolts per meter within a thundercloud. This feedback forms a potential difference of from 10 to 100 megavolts in a single discharge between the center of a cloud and earth. These lightning discharges carry currents varying from 10 to 345 kiloamperes to earth at an average rate of 100 times per second with duration of less than ½ second per flash. Each flash consists of up to 40 separate strokes, Each stroke of lightning lasting for this brief instant releases about 250 kilowatt-hours of energy-enough to operate a 100-watt light bulb continuously for more than three months at the rated voltage of the lamp. Lightning discharges do not always bring electrons to earth, because so-called positive ground-to-cloud strokes consist of low power energy transmissions from earth to small negative charge pockets in a thunder cloud. However, magnitudes of discharge voltages and currents are approximately the same from cloud to earth, and all occur within the same discharge timeframes. Just before the lightning flash, the ground within a radius of several miles below the cloud becomes deficient in electrons. Repelled by the army of electrons in the cloud base, many of the free electrons on the ground are pushed away. The result is that the ground beneath the cloud base becomes more positively charged. As the cloud moves, the positive charge region below moves like its shadow. As the cloud charge balloons, the pressure becomes so great that a chain reaction of ionized air occurs. Ionization is the process of separating air molecules into positive ions and negative electrons. This air which is normally a good electrical insulator becomes a good conductor and allows the cloud electrons to pierce the faulted insulation and descend this newly created ionized air path between cloud and earth. The lightning flash starts when a quantity of electrons from the cloud heads toward earth in a succession of steps, pulsing forward with an additional step every 50 microseconds creating a faintly luminous trail called the initial or stepped leader. As the leader nears the ground, its effects create an ionized streamer which rises to meet the advancing leader. When the two join, the ionized air path between cloud and earth is completed, and the leader blazes a faint trail to earth. Immediately a deluge of electrons pour from this lightning discharge channel creating the brilliant main or return stroke that produces most of the light we see, The motions of the leader and the main or return stroke appear to move in opposite directions, but lightning is not an alternating current, since the transferred electrical recharge current moves back to earth.

b. Nonconventional systems. Nonconventional and unacceptable systems include the so-called dissipation array, and those using radioactive lightning rods, Radioactive lightning rods have been proven less effective than passive air terminals in storm situations. These systems have not been recognized by NFPA or UL. Use of these systems will not be permitted unless specifically approved by the appropriate using agency. Dissipation arrays consist of two types:

(1) A high tower with top-mounted dissipation suppressor, and radial guy wire array. This type is used on isolated high towers, antenna structures and offshore facilities.

(2) A series of high towers located beyond a given area to be protected and supported by a number of sharp pointed strands of barbed wire for the protection array.

c. Code applicability. NFPA No. 78 is intended to apply to the protection of ordinary buildings, special occupancies, stacks, and facilities housing flammable liquids and gases. The lightning protection code will be utilized where lightning damage to buildings and structures would cause large economic loss or would prevent activities essential to the Department of Defense. NFPA No, 78 does not relate to the protection of explosives manufacturing or storage facilities. Protection for these facilities will be in accordance with paragraph 2–9. Since NFPA No. 78 does not prescribe a comprehensive coverage pattern for each type of facility required by the military departments of the government, additional guidance is given in this chapter. Temporary DOD storage facilities and structure housing operations not regularly conducted at a fixed location and other facilities specifically exempted by the responsible using agency are not governed by the lightning protection code.

d. Effects of lightning discharges.

(1) General. When any building or structure is located within a radius of several hundred feet from the point where a lightning discharge will enter the surface of the earth, the lightning discharge current becomes so high that any building or structure within this radius becomes vulnerable to immediate damage.

(2) Nature of damage. Damage may range from minor defacement to the building to serious foundation upheaval, fire and personnel casualties. Damage control can be effective dependent on extent of fireproofing and lightning protection incorporated into the project design. Although lightning strokes generate static discharges in the form of radio noise, it is generally accepted that these cause only an instant of interference to manmade electronic systems. Increased heating effects are also a factor since a lightning bolt increases the temperature of the lightning channel to about 15,000 degrees C. This sudden increase in temperature and pressure causes such an abrupt expansion of air that any hazard type of atmosphere which comes within the ionized air path of the lightning bolt becomes explosive. The explosive nature of the air expansion of bolt channels can cause physical disruption of structures located near the lightning stroke. Lightning discharges below the earth surface sometimes fuse sand into fulgurates which appear like glass tubes. Trees of 40 feet or more in height are especially vulnerable targets for attraction of lightning discharges, and are susceptible to being totally destroyed.

e. Effective resistance to ground.

(1) The lightning protection system will be designed to provide an electrical path to ground from any point in the system, and that point will be of considerably lower resistance than that otherwise available by use of the unprotected facility.

(2) Low resistance to ground is desirable for any lightning protection system but not essential. This is in conformance with NFPA No. 78 and MI L–HDBK–419. Where low resistance to ground is mandatory, grounding electrode patterns as described herein and MIL-HDBK-419 will furnish ample length of electrical path in contact with earth to dissipate each lightning discharge without damage to the protected facility.

2–2. Limitations in use of lightning protection

a. General. Lightning protection will be installed as part of the initial construction project, particularly in view of long replacement time and high cost of structures. Installation cost of lightning protection systems during project construction is small when compared to the cost of the installation as a whole. Economic and operational considerations will be made in determining the need for lightning protection system, unless otherwise directed by the using agency. Unless lightning frequency at the project site averages five or less thunderstorms per year, as indicated in figure 2-1, lightning protection will be provided for buildings and structures as follows:

(1) Buildings of four floors having elevator or stairwell penthouses or other similar projections above roof.

(2) Buildings of five floors or more with or without projections above roof.

(3) Structures such as steel towers, aluminum and reinforced concrete towers, and flagpoles without inherent grounding, and smoke-stacks and steeples of 50-foot elevation or more above lowest point of contact with finished grade.

b. Other applications. Special consideration will be given in determining need for lightning protection as follows:

(1) Whether building is manned, and there is inherent hazard to personnel.

(2) Whether building contains explosive or hazardous areas or rooms, weapons systems technical equipment, or security communication equipment.

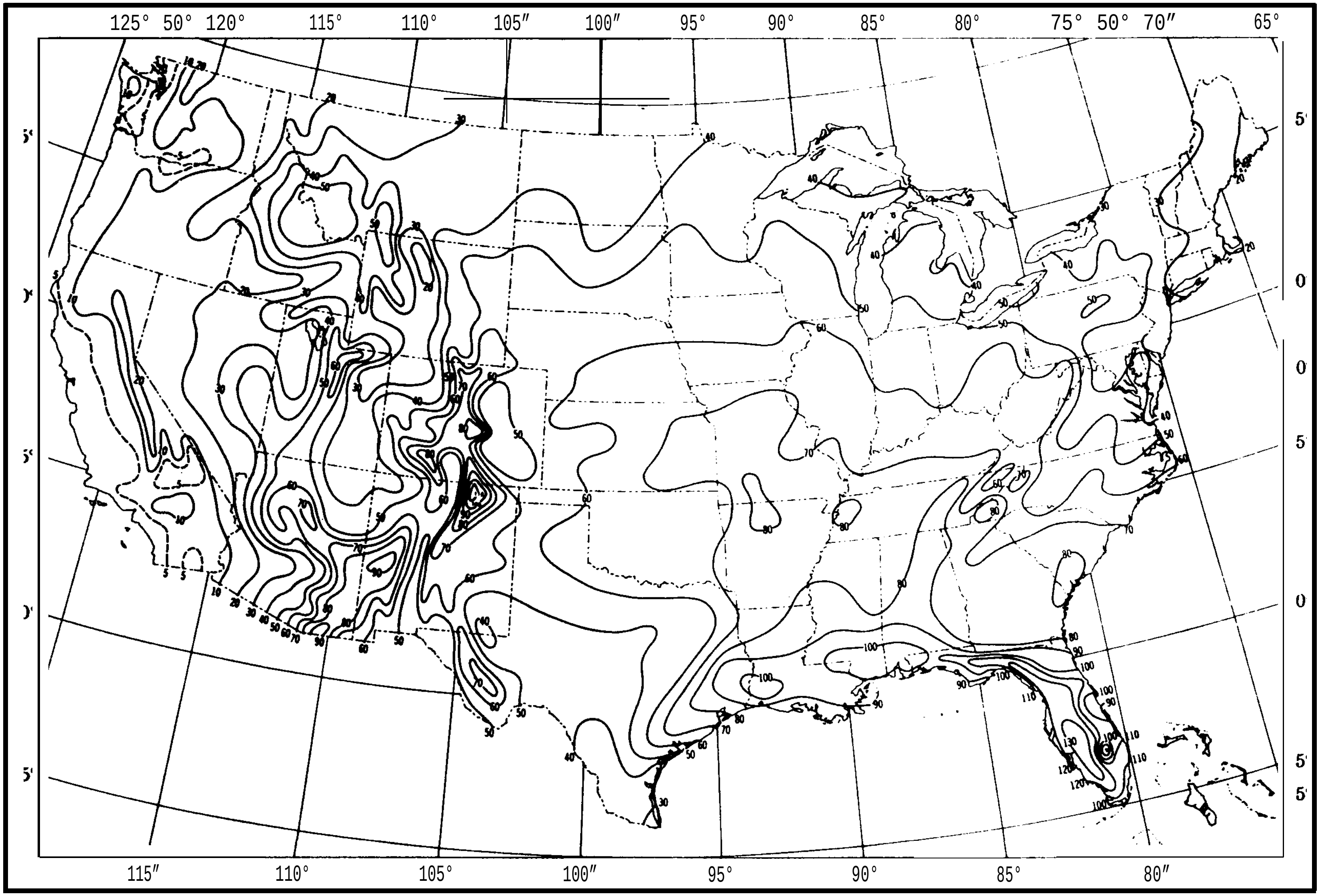
(3) If an unprotected building is destroyed by lightning, the length of outage which can be tolerated until replacement is made. This includes the restoration of high priority facilities such as water supply, weapons systems, police and security intelligence communications, strategic communication system operating components.

(4) Replacement of building contents and value thereof.

2–3. Air terminals. The purpose of air terminals is to intercept lightning discharges above facilities. Air terminals will be in accordance with UL 96, and 96A, NFPA No. 78 or MIL–HDB-419. Where building roof is not metal and building construction includes steel framing, air terminal connection assemblies will conform generally to figure 2-2.

2-4. Grounding

a. General. Grounding generally will conform to NFPA No. 78, except as required by this manual or by the using agency. Guidance for grounding for purposes, such as electromagnetic pulse (EMP), electromagnetic interference shielding, NASA and HQDCA electronic facility grounding, are subjects of other engineering manuals which govern grounding requirements. Those grounding systems will also serve as grounding of the lightning protection system. Where separate systems are installed such systems will be bonded below grade to any other independently installed exterior grounding system such as for electro-

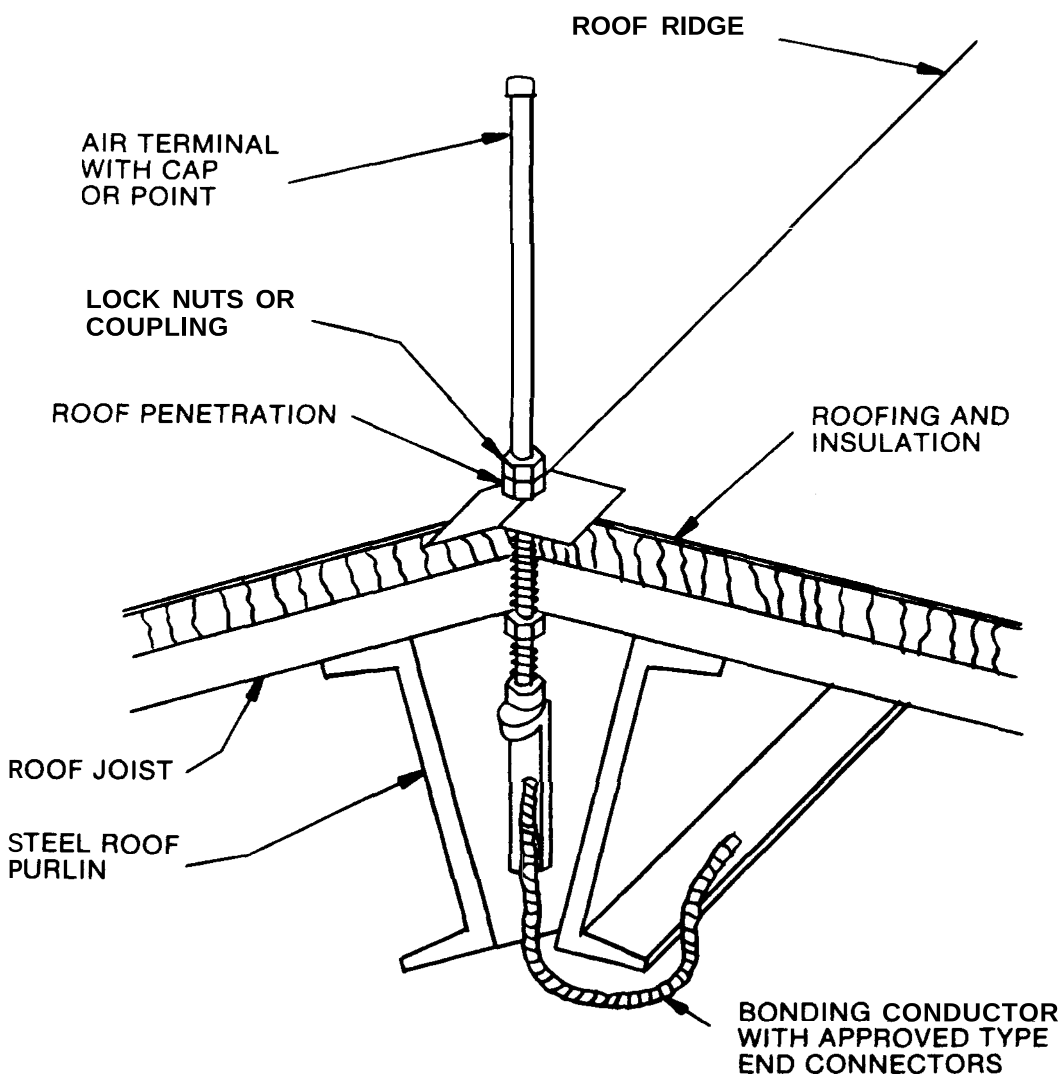


National Oceanographic and Atmospheric Administration

Figure 2-1. Mean number of thunderstorms--annual magnetic shielding not suitable for complete lightning protection system. However, exterior protection grounding system will be bonded to static electricity exterior grounding system.

b. Ground rods. Ground rods will be not less than 10 feet in length, nor less than ¾-inch diameter pipe or equivalent solid rod. Ground rods will be located clear of paved surfaces, walkways, and roadways. Rods will be driven so that tops are at least six inches below finished grade, and three to eight feet beyond perimeter of building foundation. Where ground rods are used with a counterpoise, tops will be driven to same elevation as counterpoise below finished grade. Exact location of rods must give preference to use of moist earth. Contact with chemically injurious waste water or other corrosive soils will be avoided. Where avoidance of chemically injurious or corrosive soils is impracticable, use of stainless steel rods and magnesium-anode protection will be considered. Driving stud bolts will be used for driving, and couplings will be used for sectional rods. Where buried metal pipes enter a building, the nearest ground rod will be connected thereto.

c. Earth electrode subsystem. Each earth electrode subsystem or counterpoise will consist of one or more closed loops or grid arrangement of No. 1/0 AWG bare copper conductors installed around facility perimeter not less than 2 feet below earth surface. Larger conductors should be used when installed in highly corrosive soils. A second loop, if used, should not be less than 10 feet beyond the first and inner loop. At least 2 ground rods should be provided at each corner of each counterpoise loop where earth-seeking current tend to concentrate. Counterpoise



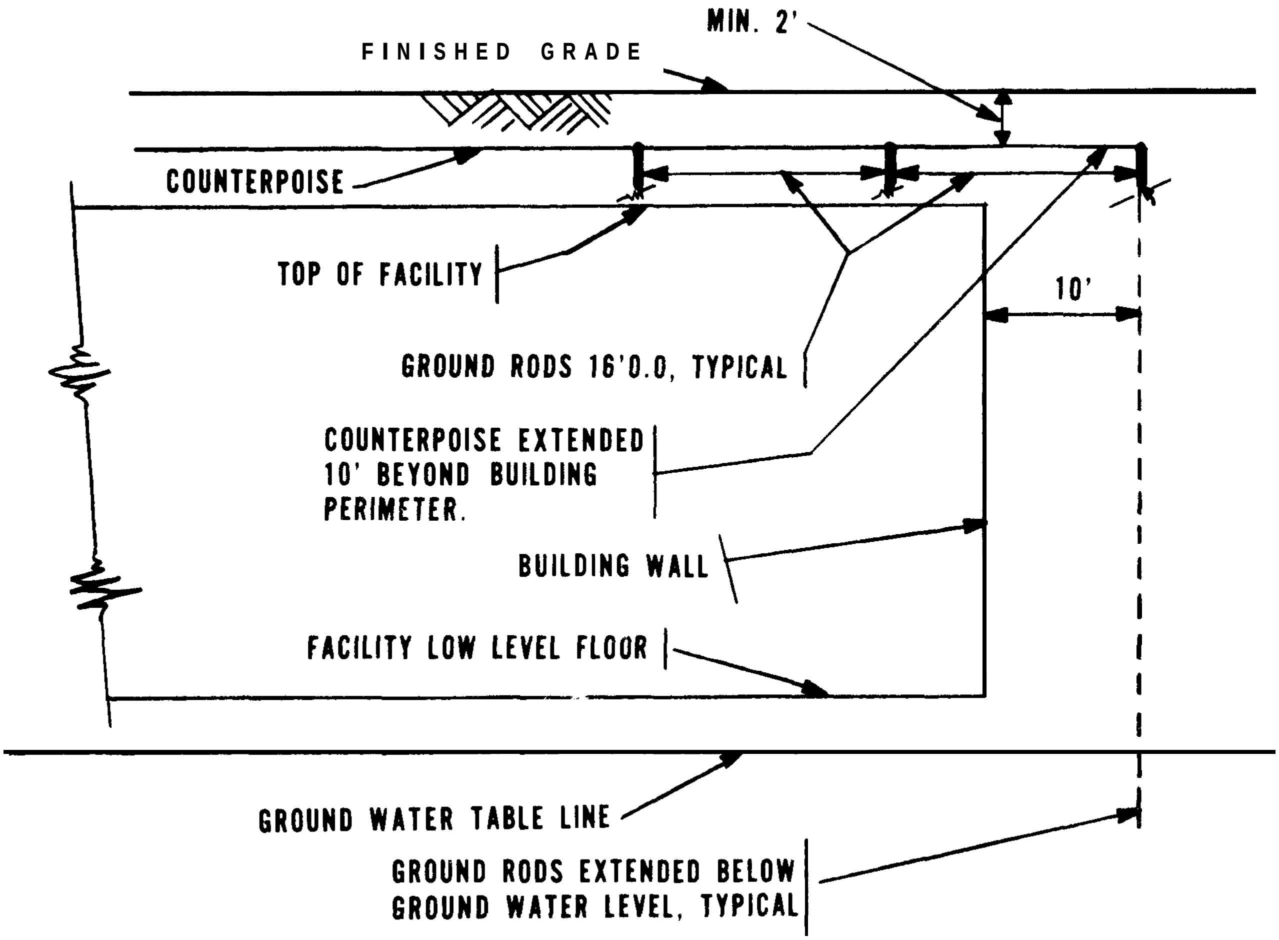
US Army Corps of Engineers

Figure 2-2. Typical air terminal assembly using steel, framing as protective system conductor will extend not less than 3 feet nor more than 8 feet beyond the perimeter of building walls or footings. Conductor ends, connections to down conductors, tops of ground rods, and crossovers will reconnected for electrical continuity. Figure 2-3 illustrates a below grade weapons system facility counterpoise. Pattern will be as required in this manual or as required by using service.

d. Radials. A radial system of grounding consists of one or more No. 1/0 AWG copper conductors not less than 12 feet long, extending away from each ground rod or grounding connection. The use of multiple radials is an effective form of grounding, offering substantially lower reactance to the high frequency of lightning current wave fronts than do single straight conductors. Installation of grounding radials will take advantage of crags and cracks in surface rock formations in obtaining maximum available earth cover. Connections of radials to down conductors will be made so as to insure electrical continuity.

2-5. Nonreinforced concrete or wood frame buildings. Lightning protection will be provided on outside of exterior surfaces without reliance upon components of building for conductors. Fasteners for conductors will be other than aluminum on concrete, and will be selected for attachment to building concrete or wood.

2–6. Reinforced concrete buildings. Reinforcement steel may be used for down conductors in conformance with NFPA No. 78 and if approved by the using agency. Joints should be made in no fewer than every fifth reinforcement rod and at corners of building. Joints will be made electrically conductive and will be connected top and bottom for connections to roof conductors and to grounding electrodes, respectively. Grounding pigtails from bottoms of reinforcement fabric will be connected to exterior grounding system at same or lower elevation as that where pigtails leave walls and footings.



US Army Corps of Engineers

Figure 2–3. Below grade weapons system facility counterpoise, cross section elevation

2-7. Steel frame building with nonconducting roof and sides. Air terminals will be provided and installed in conformance with figure 2-2 and paragraph 2-3. Not less than one steel column will be grounded at each corner of building.

2–8. Metal clad building with steel framing. Steel columns of metal clad buildings will be bonded top and bottom to metal siding. Except for facilities used for storage of propellant type weapons and unless the using service guidelines or requirements differ, air terminals may be omitted from building containing no hazardous areas.

2–9. Building containing hazardous areas. Metal containers of hazardous materials will not be located within 10 feet of lightning protection system. Any metals within hazardous atmospheres having connections to other metals within 10 feet of lightning protection system will be bonded to the nearest lightning protection system down conductor. Metal doors and windows within hazardous areas will be included in such grounding, and doors will be bonded to metal framing by flexible braid-type copper conductors, and connected to lightning protection system.

2–10. Classified communications building. Lightning protection and grounding of communications facilities will comply with MIL-STD-188-124 and MI L–HDBK-419.

2–1 1. Aircraft control-navigation aids.

a. General. These facilities are considered of such importance that aircraft pilots must be assured of reliability, particular when landing during any lightning storm, and when pilot's visibility is severely limited. Counterpoise grid g-rounding system will be provided for each building.

b. Instrument landing system (ILS), tactical air navigation (TACAN) and ground control approach (GCA), facilities. One-floor frame buildings housing equipment for ILS and TACAN facilities and other similar type structures will be protected as described in paragraph 2-5; however no fewer than two air terminals will be provided on each facility. Transmitter and receiver buildings for GCA facilities will be protected as described in paragraph 2-6.

c. Control towers. Protection will be provided independently of antennas and other superstructure. These terminals will be interconnected around top perimeter of control tower for connections to down conductors.

2–12. Igloos. Protection for corrugated steel arch earth-mounted igloos, also called "magazines", will be provided as required by the using agency. Metallic conduits containing electrical conductors will be bonded to steel arch, and all will be grounded in conformance with paragraph 24.

2–13. Fences. Metal fences that are electrically continuous with metal posts extending at least 2 feet into the g-round normally require no additional grounding. Other fences should be made electrically continuous and grounded on each side of every gate. Fences should all be grounded every 1,000 to 1500 feet when located in isolated areas; and every 500 to 750 feet when located within 100 feet of public roads, highways and buildings. All metal fences will be grounded at or near points crossed by overhead powerlines in excess of 600 volts and also at distances of 150 feet on each side of the line crossing.

2–14. Railroads. Rails that are not electrically continuous and that extend within 100 feet of facilities used for storage, manufacturing, processing or handling explosives, explosive ingredients. explosive gases, or flammable liquids will be bonded together with flexible copper cables or straps and grounded. Switches will be bonded to rails. Where overhead power lines in excess of 600 volts crosses railroads, the rails will be made electrically continuous and grounded at a distance of 150 feet on each side of overhead lines. Where tracks are located within 25 feet of structures with a grounding system, the tracks will be grounded to the structural grounding system. This is to effectively discharge potentials generated by static electricity and lightning before such discharges are permitted to accumulate or otherwise cause an air gap spark to ignite loose hazardous materials. Isolation points should be provided in the tracks outside of hazardous areas to avoid stray currents from being conducted into the bonded or grounded area.

2–15. Weapon system electronic facilities aboveground

a. General. This guidance pertains to designs for the protection of radars, antennas, electronic equipment vans, launchers, missile controls, and guided missile batteries when permanently installed. Any lightning stroke may damage or destroy such electronic weapon facilities by blast effect or by creating surges in connecting wiring. A direct stroke could ignite magnesium portions of van walls, cabinets, consoles, and radar antenna castings. When lightning occurs with rain, moisture encourages burning of magnesium and splattering of molten metal. Protection for weapon support buildings is as required by construction types discussed in previous paragraphs.

b. Protection pattern. Patterns will comply with NFPA No. 78. When structure is a van type, pole will be located opposite middle of van's longest side, and not less than 6 inches from concrete base of van to pole. One pole may serve two van units having long sides parallel and located not more than 12 feet apart. Protection equipment will be located and arranged in a manner that will not obstruct the operation of any radar electronic acquisition or tracking beam.

c. Protection system. Down conductors of not less than No. 2 AWG bare copper on pole will be provided from lightning rod to ground rods located not less than 6 feet from van and not less than 6 inches from edge of hardstand. Spiral type grounds under poles (butt grounds) are acceptable. Pole guys will be electrically conductive to ground, and guy anchor will be interconnected to pole ground rod below grade. Each ground rod at pole will be interconnected below hardstand to ground rod of' van grounding system. Where vans are clustered, van ground rods will be interconnected in compliance with MIL-HDBK-419.

2–16. Weapon system electronic facilities below ground

a. Protection included with other protection systems. When external grounding system design is included for electromagnetic pulse (EMP) protection, electromagnetic interference shielding or other protection system, separate lightning protection will not be required.

b. Protection not included in other protection systems. When external grounding system design does not include EMP protection, electromagnetic interference shielding or other protection system, lightning protection counterpoise will be provided including connections to metallic objects below grade, such as the following:

(1) Electrical conduit.

(2) Mechanical piping.

(3) Metal tanks.

(4) Manhole grounds.

(5) Missile cells or equivalent.

(6) Internal grounding system of control buildings and power plants.

(7) Metal ducts for fans.

(8) Tunnels.

The main counterpoise will be installed above each buried weapon system building, at least 2 feet below finished grade, and will extend beyond the building perimeter not less than 3 nor more than 8 feet. Main counterpoise will be connected to ground rods located as in figure 2–3, and driven to a point at least 6 inches below normal ground water table level, where earth is available for driving. See also above for building reinforcement system grounding. Metal equipment extending above ground will be grounded to protection system counterpoise.

2–17. Electrically-controlled target training system

a. General. Reliability of continuous operational availability of electricallty-cont rolled target systems for rifle squad tactical ranges is of such importance to infantry training in the scheduling of firing periods and to morale of' large numbers of troops that provisions of lightning protection is warranted. Lightning protection for rifle range support facilities need not be provided.

b. Control tower. Complete protection system will be provided. The system should have at least two air terminals installed on roof.

c. Target control system. Where a control relay is separately provided at each target mechanism box assembly station of such rifle ranges, lightning protection counterpoise or grid will not be required for protection of down range target area. Where such control relays are not provided, grounding counterpoise or grid will be provided above wiring in trenches below grade to all targets from control tower.

2–18. Petroleum oil lubricants (POL) facilities

a. Storage tanks. Generally, protection for storage tanks will depend on their inherent contact with earth. Where steel storage tanks are constructed on foundations of concrete or masonry, grounding will be provided in accordance with grounding schedule show-n in table 2–1, regardless of tank height. Where steel tanks are constructed in direct contact all around the perimeter with not less than 18 inches of earth, grounding will not be required. See AFM 85-16 for additional requirements pertaining to Air Force facilities.

Table 2-1. Fuel Storage Tank Grounding Schedule

Tank Circumference—Feet	Ground Connections Minimum Number
200 And Less	2
201 Through 300	3
301 Through 400	4
401 Through 500	5
501 Through 600	6
601 Through 800	7
801 And More	8

b. Pump house. Protection for POL pump house will be provided complete as required for the applicable type of building construction.

c. Fill stands. Protection for fill stands will conform to NFPA No. 78.

CHAPTER 3

STATIC ELECTRICITY PROTECTION

3–1. Discussion

a. General. While the practice of grounding electrical systems is well established, the full implications of static electricity protection are not always understood. The object of static electricity protection is to provide a means whereby static electricity charges, separated by whatever cause, may recombine harmlessly before sparking charges are attained. In order for a static electricity charge to become a source of trouble, the following conditions must be considered:

(1) There must be a means of static generation.

(2) There must be a means of accumulation of a static charge capable of producing ignition.

(3) There must be a means of spark discharge of the accumulated charge.

(4) There must be an ignitable mixture or atmosphere at location of spark discharge to constitute an explosive or fire hazard.

(5) The static potential must be maintained to constitute a hazard to personnel.

(6) The static charge must be continuously conducted to constitute a compromise of classified communications. It may be impracticable to attempt mitigation or control of all static charges. Furthermore, most static charges normally do not accumulate sufficient charge to supply enough energy to produce a spark capable of causing ignition. It should be recognized, however, that when static electricity accumulates, it becomes a potential hazard, and therefore must be controlled as required. Electrostatic electricity charges are generated by friction or contact between dissimilar conductive, semiconductive or nonconductive moving objects, materials, liquids or air particles. Obviously, we live in an electrostatic environment containing constant movement of molecules, none of which is inherently grounded. When two solids move into contact, a voltage difference or contact charge occurs. In most cases it is very small, but with tin and iron, as specific examples, it is nearly a third of a volt. The tin is electropositive in this case. Moreover, if a piece of plastic is merely pressed—not rubbed-against a metal plate and taken away, it will have a charge where actual contact was made. Whereas if the plastic is rubbed on the metal, the charges will be increased in proportion to the number of little areas which actually make contact. The plastic, being a nonconductor, tends to retain that state at any little area of contact. When an insulating solid becomes charged, the charge tends to remain anchored to the area where it was developed. Good insulators having clean dry surfaces in low atmospheric humidity can hold their charge for quite a while. A poor insulator quickly loses its charges to surrounding areas, and a good insulator having surface contamination will become somewhat conductive regardless of humidity, and will permit leakage to take place. A volume of relatively dry space which is normally a good insulator containing neutral molecules can also become charged by radioactivity andl cosmic rays. However, since there are no known perfect insulators, isolated charges of static electricity always eventually leak away. The problem is to provide instant control of hazardous accumulations of static charges without reliance upon natural bleeding or leaking away of such charges. For static electricity to discharge as a spark, the accumulated charge must be capable of jumping through a spark gap. The minimum sparking voltage at sea level is generally accepted as approximately 350 volts for the shortest measurable length of gap. Characteristics of the gap are also a limiting factor. For discharge to constitute a fire hazard, the gap must exceed a critical minimum length to permit the buildup of a sufficient energy level for an incendiary spark to result. Of course, there must be an ignitable mixture in the gap where the spark occurs. This energy level is estimated to be in order of 10^{-8} joules minimum. An example of sparking voltages required to break clown various air gap spacings is furnished in table 3–1. For calculating ignition energy, refer to NFPA No. 77.

Table 3–1. Static Electricity Sparking Voltages

Air Gap	Needle Points	½″ Square Rods Cut Square	Air Gap	Needle Points	½″ Square Rods Cut Square
CM	Volts	Volts	CM	Volts	Volts
0.01	(*)	(**)	1.0	12500	(**)
.05	(*)	(**)	1.5	17800	(**)
.1	(*)	(**)	2.0	23000	26000
.2	(*)	(**)	4.0	41000	47000
.5	8000	(**)	6.0	55000	62000

*Varies between 350 and 600 volts depending on air gap characteristics.

**Varies between 450 and 22,000 volts depending on air gap characteristics.

b. Sources of static electricity charges. For purposes of this manual, static electricity charges should be considered as being generated by three classifications of sources.

(1) Magnetic inductions.

(a) office equipment with moving parts as in data processing systems, having integral electric motor-driven parts assembled in a ferrous metal fireproof enclosure where the motors are grounded into the building electrical distribution system.

(b) Portable, normally ungrounded, electric motor-driven equipment having a ferrous metal enclosure exposed to operating personnel. Induced charges from magnetic induction sources could be of continuous duration at utilization voltage of electric motors.

(2) Electrostatics as defined in NFPA No. 77.

(3) Lightning static results from accumulations of extremely high voltage discharges, as discussed in paragraph 2–la. These magnitudes of potentials are sufficient to break down the dielectric strength of air for distances upwards of 3,000 feet, It will suffice to note here that lightning discharges can and do by their so-called side effects break down the dielectrics of many man-made condensers (ungrounded insulated metals, for example) existing within most of our buildings, and thereby very rapidly generate hazardous and explosive accumulations of static electricity energy in these condensers.

c. NFPA No. 77. This code suggests special studies for determining the need to provide means of preventing accumulation of static electricity in the human body. These studies include such means as: conductive flooring, use of nonmetallic supports and hardware for personnel assistance, and tie-down rings for aircraft and hydrant refueling. These means of static control are included below, as appropriate.

d. Effects of static electricity discharges. There are many reasons why concerns for protection against static electricity charges are important. Most of the everyday, normal types of static charges find a quick natural means of dissipation without any hazardous effects. However, because static charges of instantaneous magnitudes greater than 10 kilovolts may be encountered, it is mandatory that potential effects from accumulations of these charges be considered. This is particularly essential where personnel are involved and where such static discharges may occur in hazardous areas with sufficient strength to produce ignition. It is not the intent herein to provide a listing of effects of discharges of static electricity, as many are already well known. It is the intent, however, to place every electrical designer on the alert to use every reasonable precaution for including static electricity protection in each project specification when such protection is required.

e. Resistances to ground. Resistance to ground for dissipation of static electricity charges is not critical in order to provide adequate leakage path to ground and to equalize static electricity charges as fast as they are generated. Resistance to ground for static electricity dissipation may be as much as 1,000,000 ohms. However, resistances to ground of less than 25,000 ohms should be avoided when used with the usual g-rounded electrical distribution system in order to avoid increased electric shock hazard to personnel which may result in using lower resistances to ground. Maintaining an average range of between 25,000 to 100,000 ohms resistances, to limit the current magnitude to ground, is complicated by ambient wet or dry conditions, such as: atmospheres, building materials, and foundations of concrete or earth, Resistance to ground limitations will be established for corresponding applications herein.

3–2. Applications

a. Conditions. It is not the intent of this manual to attempt to furnish a listing of all applications where static electricity protection should be provided. The electrical designer must analyze suspected potential static electricity charges and decide what conductive paths will be available between them, particularly in the following conditions:

(1) Hazardous locations as listed in the NFPA No. 70.

(2) Locations containing hazardous materials which will be handled or stored.

(3) Movable and portable equipment having static electricity generating capabilities which will be dangerous to personnel,

b. Hospitals. Static electricity protection in intensive care, and surgical and obstetrical sections of hospitals will conform to NFPA No. 56A.

c. Other facilities. Static electricity protection for other facilities will be in conformance with provisions included below, unless otherwise requested on a project-by-project basis by the using service. Where criteria of other Federal agencies conflict with criteria contained below, the most stringent criteria will govern.

3–3. General. Building areas where static electricity protection is required will be identified on the contract drawings in conformance with classifications contained in NFPA No. 70. A listing of hazardous materials, containers, and operating units will be included in the design, and fixed operating equipment locations indicated on the drawings. Portable and movable equipment requiring static electricity grounding will be distinctively identified by location and with type of grounding locations required.

3-4. Bonding

a. Bonding is the process of connecting two or more conductive objects together by means of a conductor. Bonding is done to minimize voltage differences and impedances of joints. Bonding conductors normally will be uninsulated. When bonding conductors are used between movable objects, and connections are disconnected frequently, they will be of the flexible conductor or strap type. When concealed or mechanically protected, bonding conductors may be No. 10 AWG copper wire; otherwise No. 6 AWG copper wire or larger will be used. Bonding for other facilities will conform with NFPA No. 70, and U L 467, unless otherwise required in paragraph 3-9. The following guide will be used for determining objects to be bonded, in conformance with paragraph 3-2:

—For permanently installed underground built-in equipment having metal housing and movable or portable equipment having ungrounded metal housing; bond to attached or unattached fixed adjoining metal.

—For movable or portable equipment normally having ungrounded metal housing located in room or area where protection of operating and maintenance personnel is required regularly; provide conductive flooring as described below.

—For movable or portable normally ungrounded equipment having nonconductive housing and no accessible grounding terminal; provide bonding terminal for portable type connection.

—For classified equipment; bond in conformance with paragraph 3–9. Electrically conductive containers with explosive and flammable contents shall be grounded. In bonding explosive and flammable contents of containers, including nonconducting liquids stored in electrically insulated containers, it may be necessary to insert a conductive electrode having a bonding terminal on the exterior of the container. The electrode material will be chemically inert to the stored ingredients and the container. Such an arrangement will be specified only by the using service. Whenever such electrode is used, it will be of a designed which will preclude its being broken off during handling of containers.

b. Before securing any bond, it is necessary to insure electrical continuity by removing any paint, oil, dirt or rust to present an electrically clean contact surface. In providing a bond for a frequently moving body such as a metal door, hinged shelf or table, not less than two separated flexible bonding straps will be provided. Bonds will not be made to gas, steam, oil, air, or hydraulic lines, nor to sprinkler system piping or metallic bodies connected to lightning protection system, except as required below finished grade, as described below.

3–5. Grounding. Grounding is the process of connecting one or more metallic objects and g-rounding conductors to a ground electrode or system. A metallic object also may be grounded by bonding to another metallic object that is already connected to the ground. Grounding conductors within the building will be bonded separately to static electricity bonding jumpers or other bonded metals, and connected below finished grade to an appropriate grounding electrode or system. No fewer than two grounding conductors will be provided for connection to grounding electrodes at opposite corners of any building. For buildings having more than a total of 1,600 square feet of protected area, one grounding conductor-electrode arrangement will be provided at each corner of the building. Steel framing members of the building and metal sides that are electrically bonded and not used for lightning protection may be as part of the grounding conductor system. Ground rods will be not less than 5/8 inch in diameter, 8-foot long copper or copper-clad rods driven so tops are not less than 6 inches below finished grade, except as otherwise required herein. The electrical power grounding system will be extended and connected to the static electricity grounding system.

3–6. Hazardous locations. Electrical design will incorporate the requirements of the using service relative to hazardous materials, equipment and containers to the extent that information is furnished to enable the construction contractor to proceed with full understanding of static electricity protection provisions. Classifications will conform to NFPA No. 70, unless otherwise authorized by the using service. For Air Force facilities, classifications of hazardous areas of hangars, docks and POL areas will conform to AFM 88-15. For Army facilities, classifications for POL areas will conform to AR 415-22.

3–7. Petroleum oil lubricants (POL) facilities. This paragraph pertains to static electricity protection for pumping, distribution, fueling and refueling storage and miscellaneous handling facilities for Army facilities. Fueling and refueling of fixed wing aircraft on the ground is discussed in paragraph 3–11. Recommendations contained in NFPA No. 77, will be included in each project design of these facilities as appropriate. Prior to and during fueling of other than fixed wing aircraft, the refueling hose nozzle must be bonded to the plane by means of a short bond wire and clip, without reliance upon a separate static electricity grounding system. Air Force designs will be in accordance with the requirements of AFM 85-16.

3–8. Weapon systems. Where electromagnetic pulse (EMP) or electromagnetic sheilding protection is included in the design of any weapons system, grounding conductors of the static electricity protection systems, when required, will be bonded to these other protective systems at convenient locations below finished grade. Separate static electricity protection is not required for static producing units such as doors, fixed or movable equipment, electric motors, and storage containers, when these items are bonded electrically to other grounding type of protection system. When question arises whether static electricity generating sources may be controlled, these units will be bonded to a grounding system to assure safety of personnel and prevent malfunction and breakdown of weapons system tactical control functions. Weapons system support facilities provisions for static electricity protection will conform to above general requirements.

3-9. Classified communications buildings. Classified communications cannot risk being compromised and endangered by permitting ungrounded static electricity discharges. Static electricity generating equipment used in classified communications operations will be bonded to a grounding system separate from other grounding systems in accordance with MIL-HDBK-419 and MIL-STD-188-124. This is required to insure complete invulnerability to intelligence countermeasures from any possible potential static electricity discharge, No fewer than two shielded grounding buses will be provided within each classified room or area. Not more than two such grounding buses will be connected by shielded conductor to one electrode below finished grade, Grounding buses will be arranged with a number of shielding one-wire grounding receptacles to provide a plug-in grounding jack (telephone type) connection for each classified unit of equipment, Grounding of other than classified equipment to these grounding buses will be permitted. Ground rods will be driven into earth so that tops and connections thereto will be not less than 2 feet below finished grade.

3-10. Corrugated steel arch type igloos for storage of MB-1, GAM-87 and GAR cased propellant type weapons. Static electricity grounding of case will be bonded to the lightning protection grounding electrodes. This arrangment will permit no space between cased weapons and storage racks for possibility of any static spark.

3-11. Airplane parking aprons. Static electricity grounding in new construction for airplane parking-hydrant refueling areas will be accomplished with a closed metal tie-down ring, 1% inch inside diameter, welded to the reinforcing steel in the concrete, Parking apron will be provided with a recess cavity at each ground rod location, permitting top of tie-down ring to become set below apron surface. The recessed cavity will be wide enough to permit static grounding temporary connections to metal tie-down ring. Resistance to ground of each tie down ring connected to the reinforcing steel can be anticipated to be less than 10,000 ohms. In hydrant refueling areas one static grounding tie-down ring will be installed between each refueling hydrant and electrical cable control box. Tie-down ring grounding electrode interconnections between hydrant and cable housing will not be required. Static grounds are not designed for aircraft lightning protection.

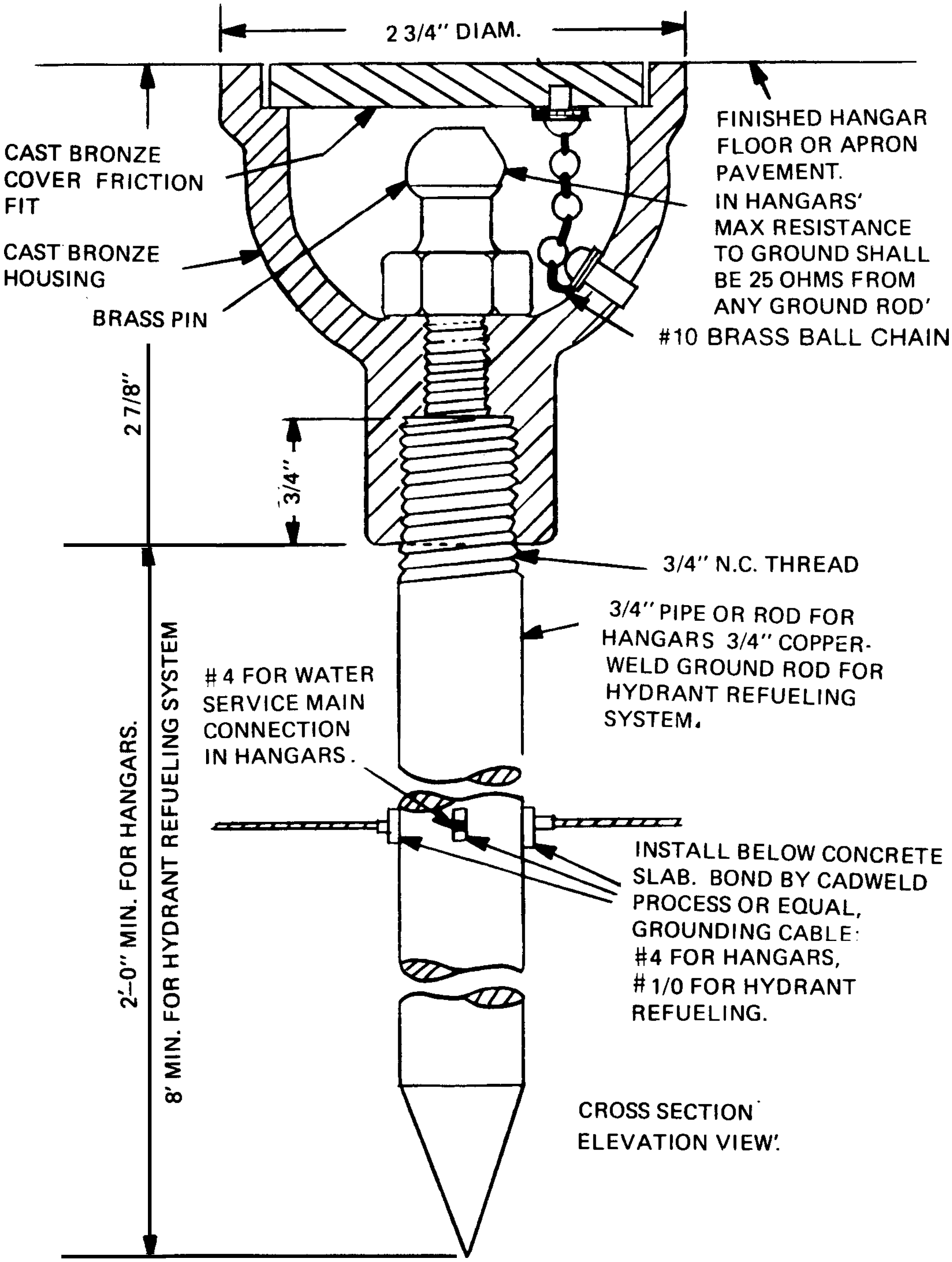
3-12. Airplane hangar floors. Grounding devices installed in floors are intended to serve for airplane static and equipment grounding. A static grounding system conforming to NFPA No. 77 is suitable for dissipation of any aircraft static electricity to ground. However, inasmuch as NFPA No. 70 requires a maximum of 25 ohms resistance to ground for equipment grounding, the 25-ohms requirement will govern for this dual-purpose grounding system. Floor grounding systems electrodes will be interconnected below concrete, and interconnection also will be made to hangar electrical service grounding system. Interconnections will be of not less than No. 4 AWG bare copper. Each floor receptacle will consist essentially of a housing, grounding connection stud, housing cover, and ground rod as illustrated in figure 3-1. Floor layouts for receptacles will be essentially as follows:

a. Where hangars will be used for a specific number and type of aircraft, one grounding electrode will be provided for each aircraft space approximately 10 feet from the centerline of the aircraft space in the vicinity of one of the main landing gears.

b. For general purpose hangars, electrodes will be provided for each aircraft space approximately 10 feet from centerline of the aircraft space, and will be installed at 50-foot intervals. Spacing of electrodes from wall lines or columns will not exceed 50 feet.

3-13. Conductive flooring. Where conductive flooring is provided in an area of a room, it is not necessary to provide separate grounds for metal frames of nonelectric equipment located on that flooring. Conductive floors are provided essentially to protect operating and maintenance personnel from hazards of shock where personnel may otherwise become exposed to low resistances to ground (less than 25,000 ohms), at voltages of electrical distribution system, or other hazardous area system, The following guide may be used in identifying hazardous conditions and materials requiring conductive flooring for protection of personnel from static electricity:

a. Areas containing units of operating equipment hazardous to operating and maintenance personnel.



US Army Corps of Engineers

Figure 3-1. Static grounding receptacle *b. Hazardous materials including the following:*

(l) Loose unpacked ammunition with electric primers.

(2) Exposed electro-explosive devices such as: squibs, detonators, etc.

(3) Electrically initiated items with exposed electric circuits such as rockets.

(4) Hazardous materials that could be easily ignited or detonated by a static spark such as—

Lead styphnate.	Ethyl ether.
Lead azide.	Ethyl alcohol.
Mercury fulminate.	Ethyl acetate.
Potassium chlorate-lead styphnate mixtures.	Tetrazene. Diazodinitrophanal.
Grade B magnesium powder.	Igniter composition.
Black powder dust in exposed layers,	Acetone.
Dust of solid propellants, uncased.	Gasoline.
Dust-air mixtures of ammonium picrate, tetryl, and tetrytel.	Anesthetics.

c. Storage areas containing exposed explosives, such as—

Primers.	Igniters.
Initiators.	Tracers.
Incendiary mixtures.	Detonators.

Information in connection with specific hazardous materials as listed above and units of hazardous equipment will be obtained from the using service for each project. Hazards of dust-air or flammable vapor-air mixtures can be reduced substantially by providing for adequate housekeeping, dust collection, ventilation, or solvent recovery methods.

APPENDIX A
REFERENCES

Government Publications.

MIL-HDBK-419	Grounding, Bonding, and Shielding for Electronic Equipment and Facilities, Volume 1 and 2.
MIL-STD-188/124	Grounding, Bonding and Shielding for Common Long Haul/Tactical Communications Systems.

Departments of the Army and the Air Force.

AR 415-15	MCA Program Development.
AR 415-22	Protection of Petroleum Installations and Related Facilities.
AR 415-36	Peacetime Planning and Construction In Overseas Base Rights Areas Garrisoned On Temporary Basis.
AFM 88-15	Air Force Design Manual Criteria and Standards for Air Force Construction.
AFM 85-16	Maintenance of Petroleum Systems.

Nongovernment Publications.

National Fire Protection Association [NFPA], Publications Department, Batterymarch Park, Quincy, MA 02269

No. 56A-1978	Inhalation Anesthetics.
No. 70-1984	National Electrical Code.
No. 77-1983	Static Electricity.
No. 78-1983	Lightning Protection Code.

Underwriters' Laboratories Inc. [UL] 333 Pfingsten Rd., Northbrook, IL 60062

UL 96	Lightning Protection Components. (May 25, 1981, 2nd Ed.; Rev May 26, 1981)
UL 96A	Installation Requirements for Lightning Protection Systems. (Apr 9, 1982, 9th Ed.; Rev Ott 5, 1983)
UL 467	Grounding and Bonding Equipment. (Nov 7, 1972, 5th Ed.; Rev thru Mar 26, 1982)

The proponent agency of this publication is the Office of the Chief of Engineers, United States Army. Users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) direct to HQDA (DAEN-ECE-E), WASH DC 20314-1000.

By Order of the Secretaries of the Army and the Air Force:

JOHN A. WICKHAM, JR.
General, United States Army
Chief of Staff

Official:

DONALD J. DELANDRO
Brigadier General, United States Army
The Adjutant General

CHARLES A. GABRIEL, ***General USAF***
Chief of Staff

Official:

JAMES H. DELANEY, ***Colonel, USAF***
Director of Administration

Distribution:
Army to be distributed in accordance with DA Form 12-34B, requirements for TM 5-800 Series: Engineering and Design for Real Property Facilities.
Air Force: F

●U.S. GOVERNMENT PRINTING OFFICES : 19930-342421 (62332)