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MILITARY HANDBOOK

LIGHTNING PROTECTION



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ABSTRACT

This handbook provides basic design guidance developed from extensive re-evaluation of facilities. It is intended for use by experienced architects and engineers. The contents cover electrical design considerations applying to lightning protection systems.

MIL-HDBK 1004/6

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FOREWORD

This handbook has been developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. This handbook was prepared using, to the maximum extent feasible, national professional society, association, and institute standards. Deviations from this criteria, in the planning, engineering, design, and construction of Naval shore facilities, cannot be made without prior approval of NAVFACENGCOMHQ Code 04.

Design cannot remain static any more than can the functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged and should be furnished to Commanding Officer, Chesapeake Division, Naval Facilities Engineering Command, Code 406, Washington Navy Yard, Building 212, Washington, D.C. 20374-2121; telephone (202) 433-3314

THIS HANDBOOK SHALL NOT BE USED AS A REFERENCE DOCUMENT FOR PROCUREMENT OF FACILITIES CONSTRUCTION. IT IS TO BE USED IN THE PURCHASE OF FACILITIES ENGINEERING STUDIES AND DESIGN (FINAL PLANS, SPECIFICATIONS, AND COST ESTIMATES). DO NOT REFERENCE IT IN MILITARY OR FEDERAL SPECIFICATIONS OR OTHER PROCUREMENT DOCUMENTS.

MIL-HDBK 1004/6

ELECTRICAL ENGINEERING CRITERIA MANUALS

<u>Criteria Manual</u>	<u>Title</u>	<u>PA</u>
MIL-HDBK-1004/1	Preliminary Design Considerations	CHESDIV
MIL-HDBK-1004/2	Power Distribution Systems	PACDIV
MIL-HDBK-1004/3	Switchgear and Relaying	CHESDIV
MIL-HDBK-1004/4	Electrical Utilization Systems	CHESDIV
DM-4.05	400-Hz Generation and Distribution Systems	CHESDIV
MIL-HDBK-1004/6	Lightning Protection	CHESDIV
DM-4.07	Wire Communication and Signal Systems	CHESDIV
DM-4.09	Energy Monitoring and Control Systems	HDQTRS
MIL-HDBK-1004/10	Cathodic Protection (Proposed)	NCEL

NOTE: Design manuals, when revised, will be converted to military handbooks.

This handbook is issued to provide immediate guidance to the user. However, it may or may not conform to format requirements of MIL-HDBK-1006/3 and will be corrected on the next update.

MIL-HDBK 1004/6

LIGHTNING PROTECTION

CONTENTS

		<u>Page</u>
Section 1	CODES AND POLICIES	
1.1	Scope	1
1.2	Cancellation	1
1.3	Policies	1
1.3.	Lightning Protection	1
1.3.2	Local Codes	1
1.3.3	National Codes	1
Section 2	SYSTEMS	
2.1	Types	2
2.1.1	Primary	2
2.1.2	Secondary	2
2.1.3	Combination	2
2.2	Primary Systems	2
2.2.1	Lightning Masts	2
2.2.2	Grounded Aerial Conductors	2
2.3	Secondary Systems	2
2.3.1	Air Terminals	2
Section 3	SYSTEM COMPONENTS	
3.1	Masts	10
3.1.1	Material	10
3.1.2	Top Point	10
3.1.3	Height and Location	10
3.1.4	Zone of Protection	10
3.1.5	Joint Design	10
3.1.6	Joint Test	11
3.1.7	Metal Mast Foundation	11
3.2	Grounded Aerial Conductors	11
3.3	Earthed Energy Dissipation Systems	11
3.3.1	Electrodes	11
3.3.2	Ground Counterpoise	11
3.3.3	Radials	11
3.3.4	Plates	12
Section 4	INSTALLATION	
4.1	General	13
4.2	Design Calculations	13
4.2.1	Earth Resistance	13
4.2.2	Soil Resistivity	13
4.3	NAVFAC Design Guides	13
4.4	Ordnance Facilities	13
4.4.1	Storage and Handling Facilities Above Ground	13
4.4.2	Earth-Covered Magazines	13
4.4.3	Cranes on Piers and Wharves	13
4.4.4	Marshalling Yards (Truck and Railroad)	14
4.4.5	Railroad Sidings	14
4.4.6	Electric Service	14

MIL-HDBK 1004/6

	<u>Page</u>	
4.4.7	Exterior Overhead Pipelines	14
4.4.8	Fences	14
4.5	Generating Plants	14
4.5.1	Surge Protection	14
4.5.2	Grounding	15
4.6	Outdoor Substations or Switching Stations	15
4.6.1	Air Terminals	15
4.6.2	Grounded Aerial Conductors	15
4.6.3	Grounding	15
4.7	Transmission and Distribution Lines	15
4.7.1	Distribution Line Clearances	15
4.7.2	Transmission Line Clearances	15
4.7.3	Clearance Calculation	16
4.8	Flagpoles and Chimneys	16
4.9	Towers and Antennas	16
4.10	Aircraft and Aircraft Hangars	16
4.11	Ordinary Buildings	16
4.12	Obstruction Lights	16

APPENDICES

APPENDIX A	Primary Lightning Protection for Ordnance Handling Facilities	17
APPENDIX B	International System of Units (SI) Conversion Factors	37

FIGURES

1	Primary Lightning Protection System	3
2	Lightning Mast Ground Connection Details	4
3	Secondary Lightning Protection or Grounding System	5
4	Bonding and Grounding of Railroad Track	6
5	Concrete and Steel Ground Connections for Secondary System	7
6	Other Grounding Details for Secondary System	8
7	Other Grounding Details	9
BIBLIOGRAPHY		40
REFERENCES		41

MIL-HDBK 1004/6

Section 1: CODES AND POLICIES

1.1 Scope. This handbook presents data and considerations that are necessary for the proper design of lightning protection systems.

1.2 Cancellation. This handbook cancels and supersedes NAVFAC DM-4.6, Electrical Engineering, Lightning and Cathodic Protection of December 1979. Cathodic protection in DM-4.6 is to be covered in the proposed military handbook, MIL-HDBK-1004/10.

1.3 Policies. The policy of the Naval Facilities Engineering Command is to provide the most effective degree of lightning protection.

1.3.1 Lightning Protection. As a minimum, for all ordinary, non-ordnance facilities requiring lightning protection, the requirements of National Fire Protection Association (NFPA) NFPA 78, Lightning Protection Code, should be followed. The requirements of this handbook must be followed for ordnance facilities and those facilities within the scope of NFPA 78. Ordnance facilities, such as magazines and other structures, truck and railroad marshalling yards, railroad sidings, and wharves and piers where ordnance and explosives are handled and stored, shall be provided with special protective measures. Design for these systems shall be in accord with criteria in this handbook; DOD-STD-6055.9, Ammunition and Explosives Safety Standards; MIL-HDBK-419, Grounding, Bonding and Shielding; and NAVSEA OP-5, Vol. 1, Ammunition and Explosives Ashore.

1.3.2 Local Codes. Although the federal Government is not required to conform to local (city or district) building and electrical codes for installations within Government ownership lines, consideration should be given to local standards and regulations wherever practicable.

1.3.3 National Codes. The NFPA and the National Electrical Manufacturers Association (NEMA) have established basic minimum standards of design and installation practice including: NFPA 70, National Electrical Code (NEC); NFPA 70B, Electrical Equipment Maintenance; NFPA 78; and American National Standards Institute (ANSI) ANSI C2, National Electrical Safety Code. These standards shall be complied with in all projects. Approval of the Underwriters Laboratories Inc. should be considered for all electrical materials, fittings, and appliances where possible. Refer to Underwriters' Laboratory (UL) UL 96, Lightning Protection Components, UL 96A, Installation Requirements for Lightning Protection Systems, and UL 467, Grounding and Bonding Equipment.

MIL-EDBK 1004/6

Section 2: SYSTEMS

2.1 Types. Lightning protection systems are either primary, secondary, or a combination of primary and secondary.

2.1.1 Primary. Design primary protection to prevent damage from direct lightning strokes by diverting any charges from structures through a low resistance path to earth.

2.1.2 Secondary. Design secondary protection to prevent metal parts of buildings, building contents, or other types of structures from accumulating electric charges that can cause sparking or flashover. Sparking or flashover is likely to occur when metal objects are proximate. In the event of a lightning discharge, the potential of independently grounded metal objects can change with respect to nearby objects generating flashover between the objects.

2.1.3 Combination. The installation of a primary and a secondary protection system for the same structure is not always required. A secondary static ground system providing an interconnection of metallic masses within a building or on piers and wharves may also be required with a primary lightning protection system. When a structure is equipped with both primary and secondary systems, interconnect all grounds.

2.2 Primary Systems. Design protection based on 100 ft (30.5 m) lightning strike arc. Design either primary or secondary type and determine mast locations or grounded aerial conductors and their heights. Mast locations or grounded aerial conductors and their heights influence the type of masts along with mast foundation requirements and the location of the ground counterpoise. Primary protection shall consist of lightning masts or grounded aerial conductors as described in paras. 2.2.1 and 2.2.2.

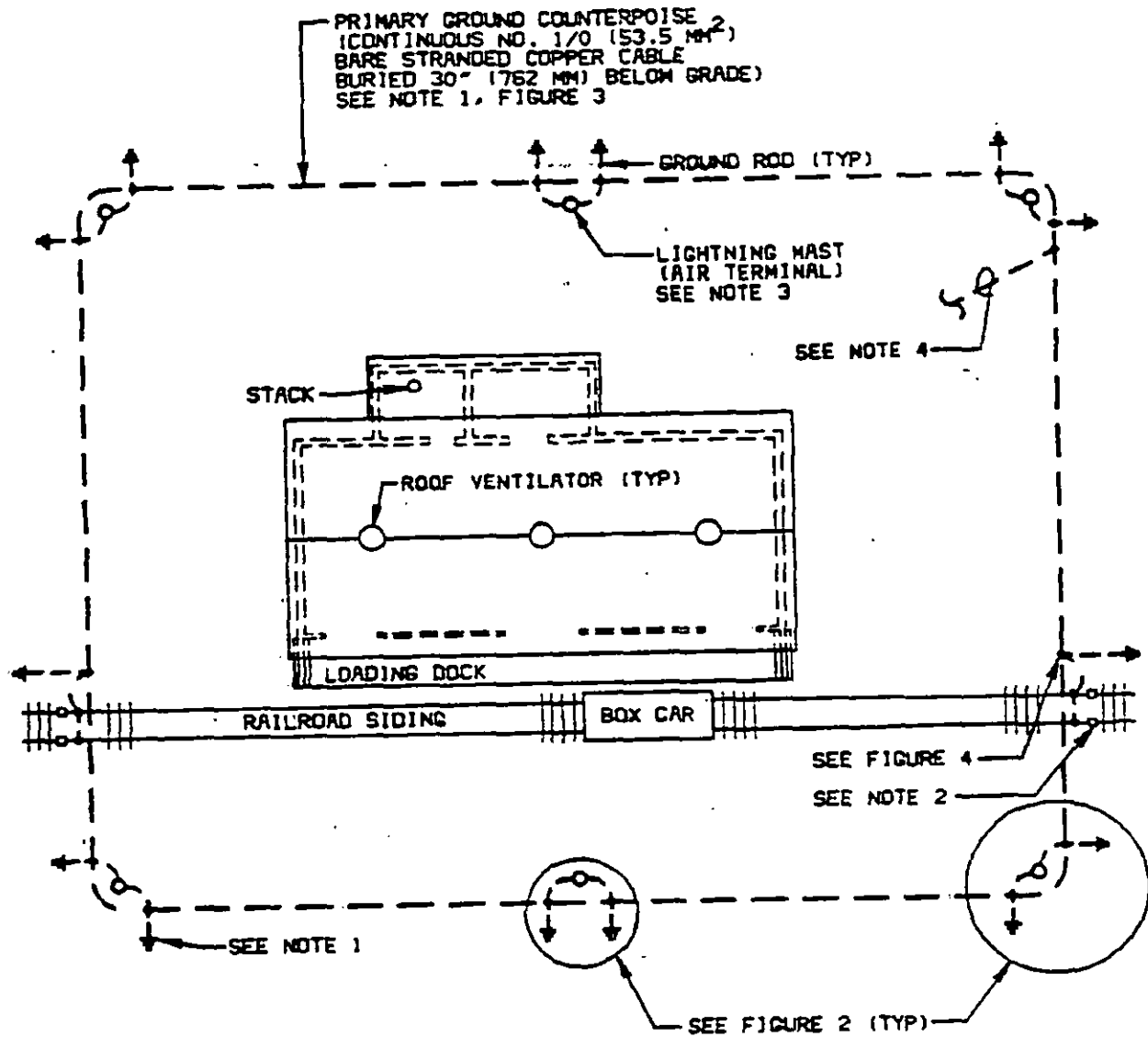
2.2.1 Lightning Masts. Lightning masts (freestanding air terminals) placed around a facility and connected to a buried ground counterpoise (see Figures 1 and 2).

2.2.2 Grounded Aerial Conductors. Overhead conductors spanned above a facility and connected to a buried ground counterpoise.

2.3 Secondary Systems. A secondary system generally consists of a buried ground counterpoise to which all metal parts, including reinforcing steel of the building or other structure, are connected (see Figures 3, 4, 5, 6, and 7). An equipment ground bus may be utilized for the grounding of the building contents. The ground bus shall not form a loop. Connect ground bus to ground counterpoise as shown in Figure 3.

2.3.1 Air Terminals. Points (lightning rods) mounted on the salient parts of facilities and connected to the ground counterpoise may be used for protection for certain specific applications in a secondary system.

MIL-HDBK 1004/6

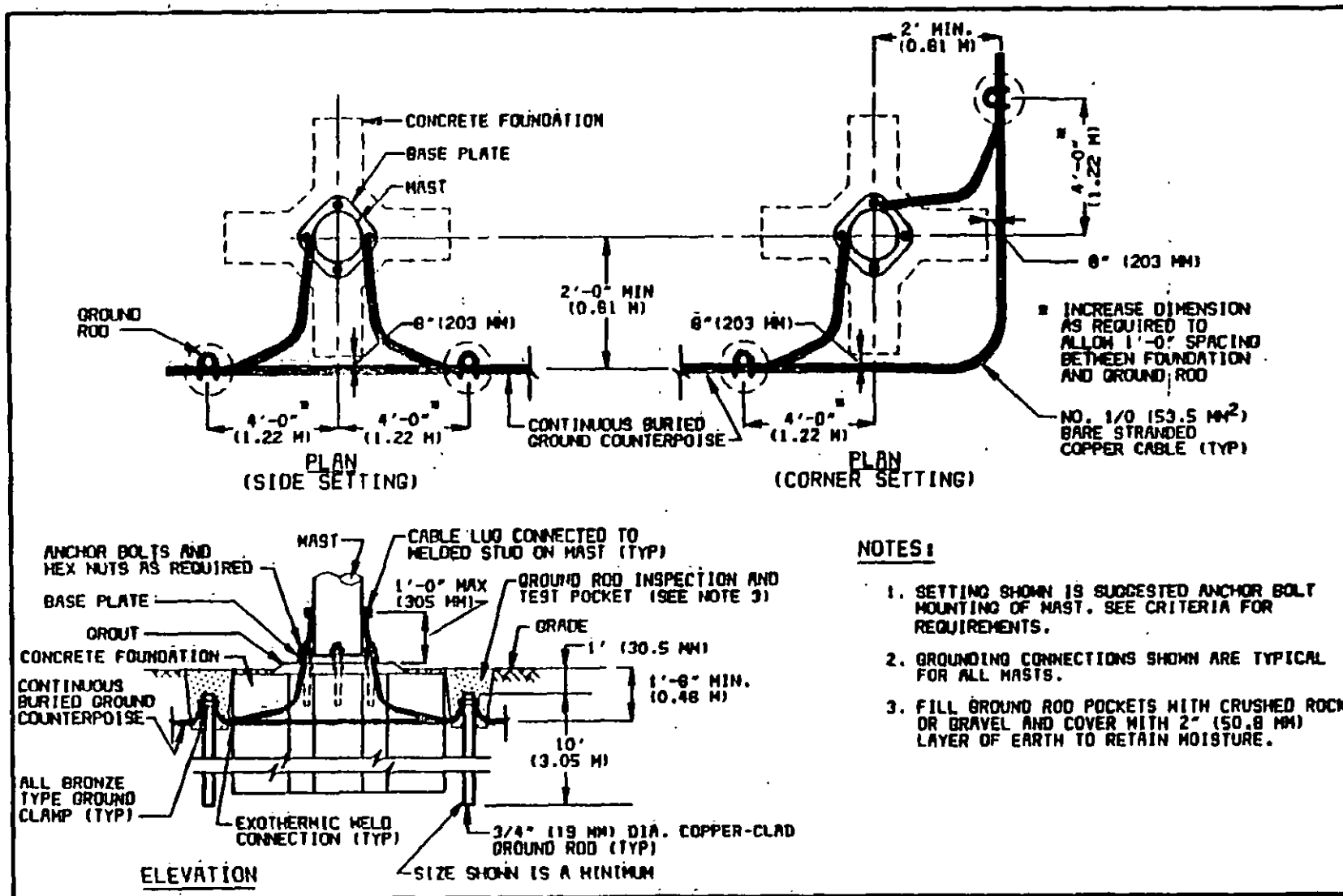
**NOTES:**

1. ADDITIONAL OR LONGER GROUND RODS MAY BE NECESSARY TO PROVIDE THE REQUIRED MINIMUM RESISTANCE.
2. PROVIDE RAIL ISOLATION JOINT IN EACH TRACK AT EACH END OF BUILDING TO ISOLATE BUILDING SECTION FROM REMOTE LIGHTNING SURGES.
3. QUANTITY AS REQUIRED BY SIZE AND SHAPE OF FACILITY TO BE PROTECTED.
4. CONNECTION TO SECONDARY GROUND COUNTERPOISE, IF SECONDARY GROUND COUNTERPOISE IS PROVIDED. SEE FIGURE 3, NOTE 6.

PLAN**ORDNANCE TYPE FACILITY**

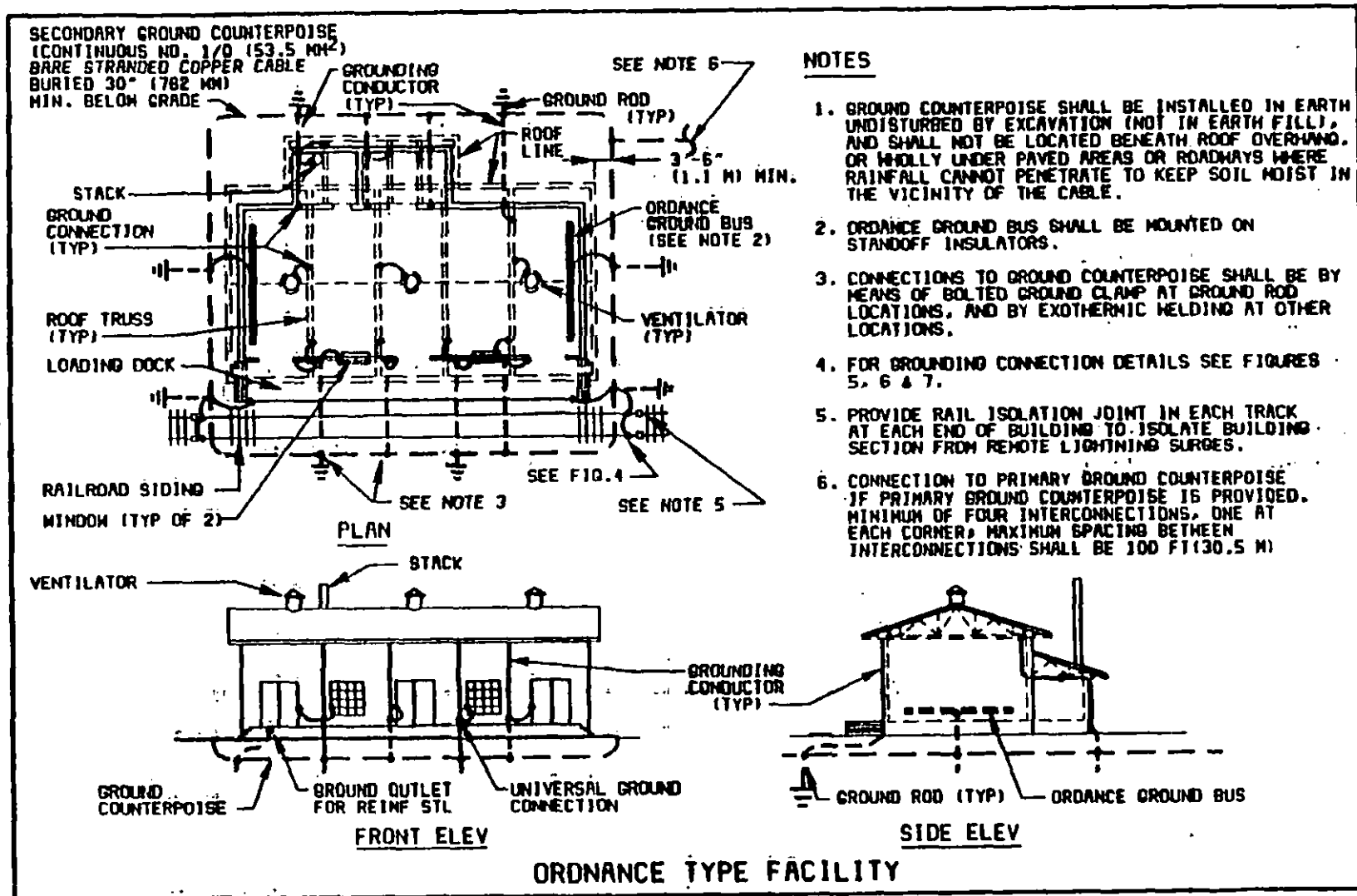
Figure 1
Primary Lightning Protection System

Lightning Mast Ground Connection Details
Figure 2



MIL-STD-1004/6

Figure 3
Secondary Lightning Protection or Grounding System



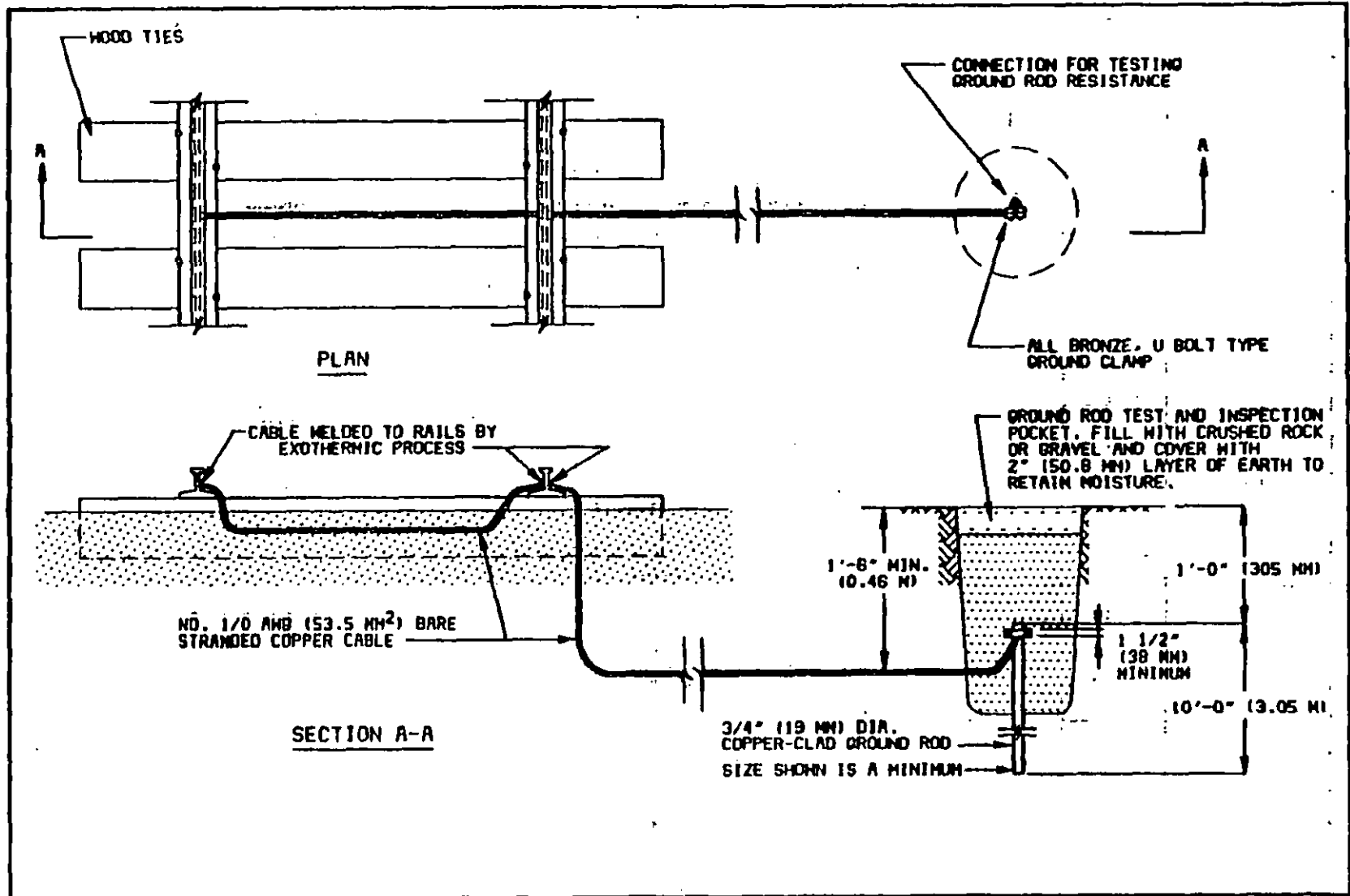


Figure 4
Bonding and Grounding of Railroad Track

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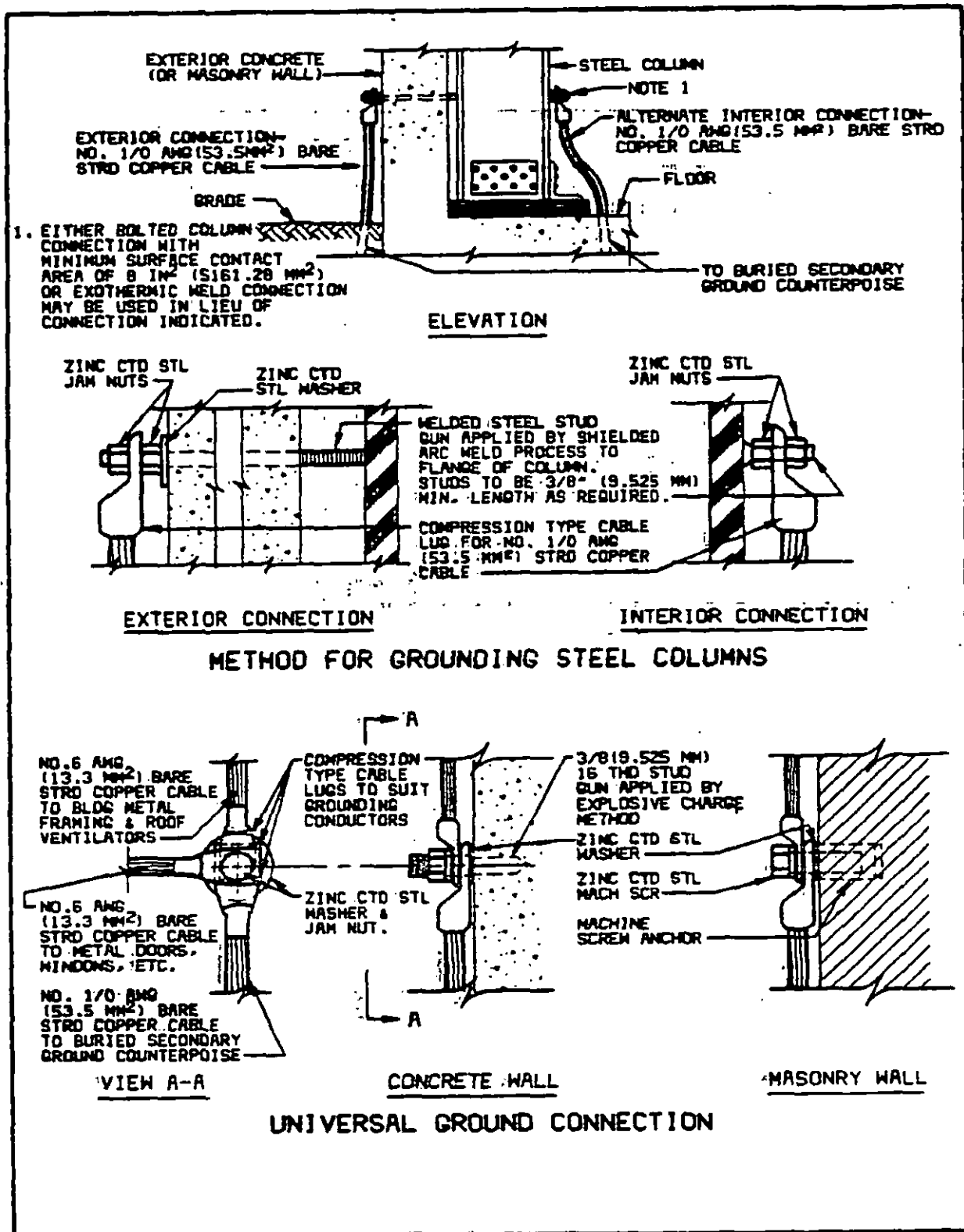


Figure 5
Concrete and Steel Ground Connections for Secondary System

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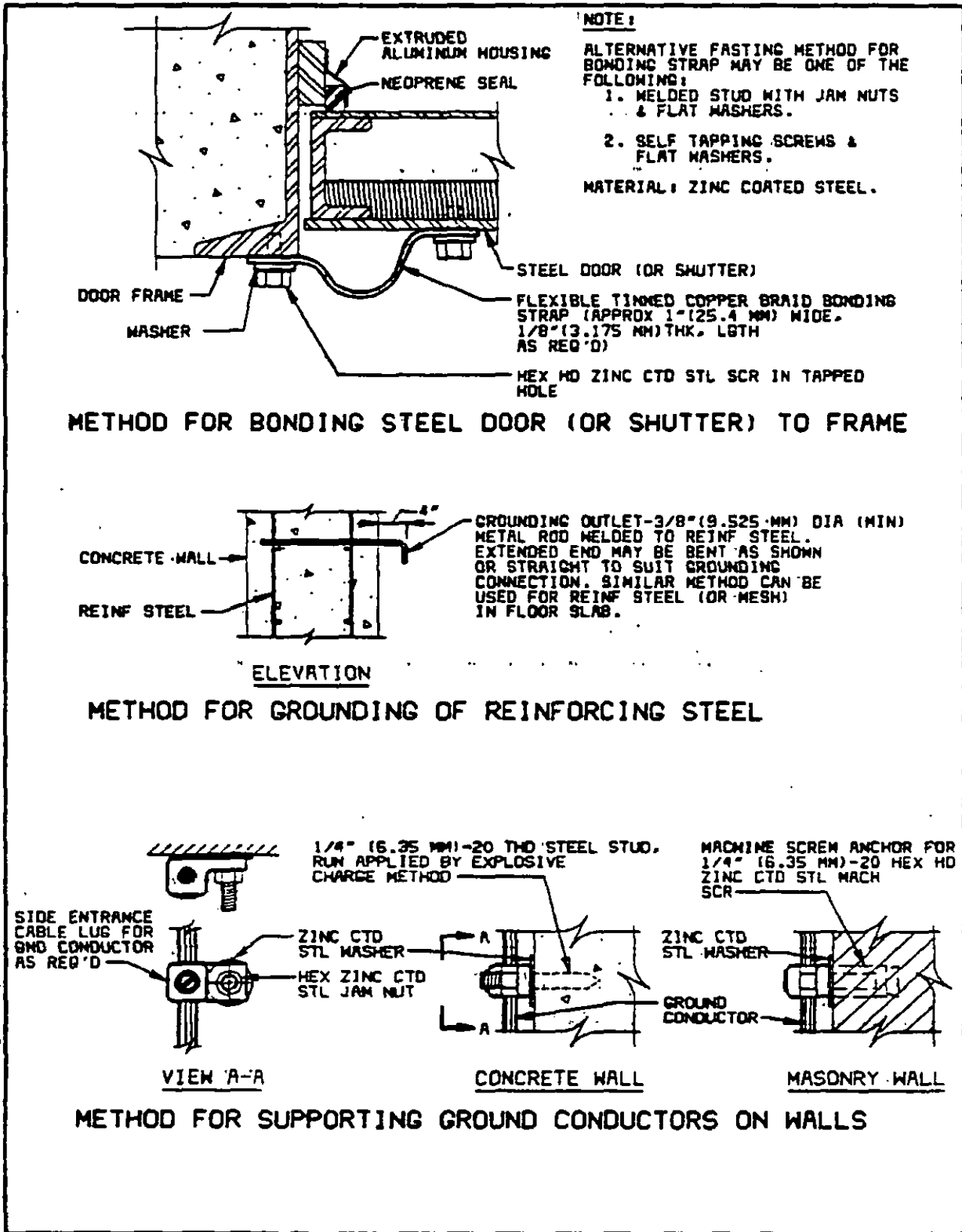


Figure 6
 Other Grounding Details for Secondary System

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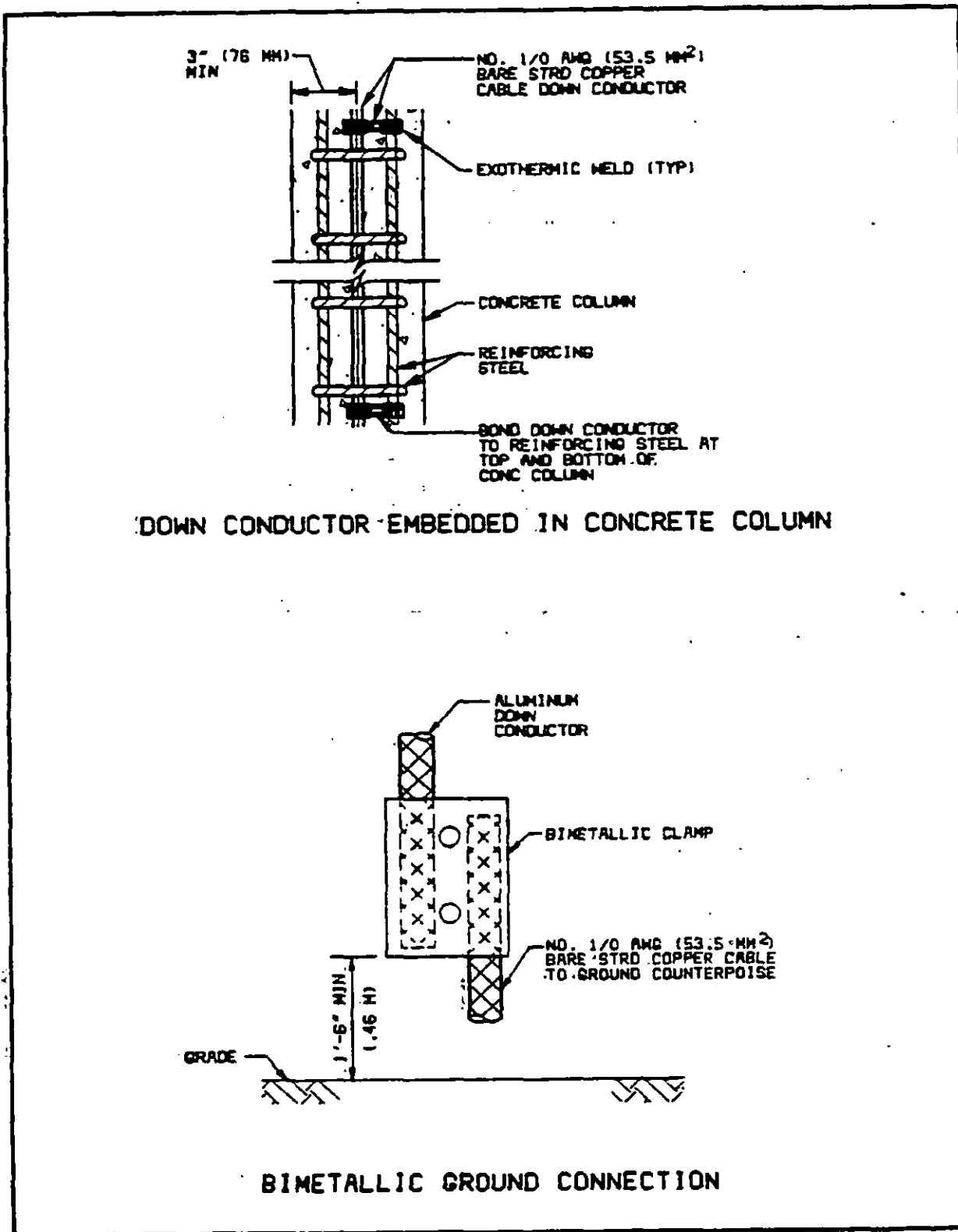


Figure 7
Other Grounding Details

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Section 3: SYSTEM COMPONENTS

3.1 Masts. Lightning masts shall be tapered metal, self-supporting type, (single section design or multisection design) with slip joints, as dictated by total height of mast. The cross-section shall be circular or polygonal, symmetrical about the longitudinal axis, and uniform in configuration throughout the entire length. Wood masts may be used only when heights and structural strength permit and shall be electrical pole line embedded type, topped with a lightning rod or metal cap and with two bare copper ground wires not less than No. 1/0 AWG (53.5 mm^2), run down each side of the pole to the ground system. The ground wires shall have a protective molding extending from grade level to a point at least 10 ft (3.05 m) above grade.

3.1.1 Material. Metal material shall be corrosion-resistant steel, noncorrosion-resistant steel with hot-dipped galvanized finish, or aluminum for single section or multiple section masts with anchor bolt mounting. No combination of materials shall be used that form an electrolytic couple which, in the presence of moisture, causes accelerated corrosion.

3.1.2 Top Point. Mast top shall be fitted with a copper or bronze air terminal or metal cap to take the lightning stroke. The point shall be included in the determined overall height of the mast.

3.1.3 Height and Location. Refer to Appendix A for determination of mast height and for location as related to structure being protected. Masts of heights up to 40 ft (12.2 m) shall be of single section design. Masts 40 to 70 ft (12.2 to 21.34 m) in height should be single-section design if delivery to the site is practical. Design for masts in excess of 150 ft (45 m) receive special consideration.

3.1.4 Zone of Protection. A lightning mast system establishes a zone-of-protection. The zone-of-protection is described by an arc having a radius not greater than 100 ft (30.5 m). To prevent sideflashes, each mast shall be separated from the structure by not less than one-half of the height of the assumed salient plane, but never less than 6 ft (2 m). The maximum distance from the structure shall be 25 ft (7.6 m).

3.1.5 Joint Design. Slip-joint design shall meet the following requirements:

- a) Assure overall structural integrity of the mast.
- b) Include field assembly requirement to assure a snug fit, so that joints of the mast will not loosen when subjected to vibrational modes caused by wind or other means after erection.
- c) Be compatible with field erection requirements to assure ease of installation at the site.
- d) Have good metal-to-metal contact, so that electrical conductivity will be equal to or better than the parent metal used.

MIL-HDBK 1004/6

3.1.6 Joint Test. After assembly, each joint shall be tested at the site and shall be measured by a digital ohmmeter with a 0.01-ohm resolution and an accuracy of 5 percent of the reading, plus one digit. Tests shall consist of comparative measurements across slip joints, with equal spacing of meter probes at least 4 ft (1.22 m) apart. An acceptable joint is one yielding a measurement equal to or less than a similar measurement of the parent metal in a given section of the mast, with the same spacing of the meter probes. The lowest meter range providing an indication in the scale region of greatest accuracy should be used. If the meter reads zero or infinity, an incorrect scale has been chosen or the meter is broken.

3.1.7 Metal Mast Foundation. Foundations for setting metal masts shall be in accordance with the following:

a) Steel or aluminum, mounted by anchor bolts set in a concrete foundation poured in place. Follow manufacturer's recommendations for foundation design and type and for setting of anchor bolts.

b) Steel, mounted by means of a stub set directly into a concrete foundation. Corrosion-resistant steel masts may be set directly into earth where soil conditions permit.

3.2 Grounded Aerial Conductors. Overhead conductors shall be spanned between masts and connected to a ground counterpoise to suit the type of installation. (Refer to Appendix A.)

3.3 Earthed Energy Dissipation Systems

3.3.1 Electrodes. Made electrodes, as defined in the NEC, shall consist of ground rods not less than 3/4 in. (19 mm) diameter and 10 ft (3.05 m) long. Ground rods shall be copper clad steel or solid copper. Connections to ground rods shall be made by bolted clamp type devices.

3.3.2 Ground Counterpoise. Each ground counterpoise shall consist of a No. 1/0 AWG (53.5 mm²) bare copper cable completely surrounding the facility, with its ends connected together to form a closed loop. The size of any strand of the cable shall be not less than No. 17 AWG (1.04 mm²). The counterpoise shall be buried at least 30 in. (762 mm) below grade, external to the structure and away from structural foundations or footings (see Figures 1 and 3). Each counterpoise shall be fixed by driven ground rods. Connection at each ground rod shall be made with a bolted clamp type device to facilitate disconnection of the counterpoise from the ground rod for periodic testing.

3.3.3 Radials. Radial systems shall consist of No. 1/0 AWG (53.5 mm²) bare copper cables arranged in a star pattern with the structure at the center. The size of any strand shall be not less than No. 17 AWG (1.04 mm²). The radials shall be buried at least 30 in. (762 mm) below grade, external to the structure. Each radial shall be fixed by ground rods. Connection at each ground rod shall be made with a bolted device to facilitate disconnection of the radials from the ground rods for periodic testing. Quantity and length of radials shall be as required to provide the required ground resistance. Refer to IEEE 142, Recommended Practice for Grounding, Industrial and Commercial Power Systems, for resistance calculations.

MIL-HDBK 1004/6

3.3.4 Plates. The use of plate electrodes is discouraged due to the high cost of achieving proper grounding effects with this system.

MIL-HDBK 1004/6

Section 4: INSTALLATION

4.1 General. Lightning protection systems shall be provided in accordance with this manual.

4.2 Design Calculations. Design calculations shall consider earth resistance and shall be based upon the soil resistivity for the specific location. Computer programs are available and should be used whenever possible. Project design criteria shall include names of approved computer programs for use in design.

4.2.1 Earth Resistance. Maximum ground resistance for any lightning protection system should not exceed 10 ohms. In high resistance soils or rock formation, it may be necessary to provide ground counterpoises or artificial grounds or to sink ground wells. After installation, each system shall be tested by the single, direct reading instrument method. Where characteristics are unknown, trial grounds should be installed and periodically tested during the course of at least 1 year to include seasonal variations. Refer to para. 4.5.2 for approved grounding methods.

4.2.2 Soil Resistivity. Project criteria will set forth the specific soil resistivity values to be used for grounding system design.

4.3 NAVFAC Design Guides. For specific criteria and sample layouts for systems, refer to NAVSEA OP-5, Vol. I, and Appendix A of this handbook.

4.4 Ordnance Facilities. Ordnance facilities shall be protected in accordance with the following criteria: DOD-STD-6055.9; MIL-HDBK-419; NAVSEA OP-5, Vol. I; NFPA 78; and Appendix A of this handbook.

4.4.1 Storage and Handling Facilities Above Ground. Provide a primary protection system consisting of lightning masts or overhead conductors spaced around the facility. Connect the masts and all metalwork in the vicinity, such as railroad tracks, metal sheaths of underground cables, and metal piping and conduits below ground that do not extend into the building or other structure being protected, to the primary ground counterpoise. All railroad tracks that extend into the building or structure shall also be grounded at a minimum of 10 ft (3.05 m) from the building or structure.

4.4.2 Earth-Covered Magazines. Provide a secondary protection system. Where a metal ventilator provides a salient point above the structure, mount a pointed lightning rod on the ventilator and connect it to the secondary ground counterpoise. A pointed lightning rod should also be mounted on the concrete portal wall and connected to the secondary ground counterpoise. Bond together reinforcing steel by wrapping it with wire and connecting it to the secondary ground counterpoise.

4.4.3 Cranes on Piers and Wharves. Provide a primary protection system consisting of overhead conductors spanned between structural supports and connected to ground rods or to metal plates submersed in water.

MIL-HDBK 1004/6

4.4.4 Marshalling Yards (Truck and Railroad). Provide a primary protection system consisting of overhead conductors spanned between structural supports and connected to a primary ground counterpoise. Ground all metal parts and reinforcing steel of above grade structures to the ground counterpoise. The reinforcing steel of precast concrete slabs should be grounded, but where inaccessible within the slabs, it is permissible to omit such grounding. Ground railroad tracks 10 ft (3.05 m) or more outside of barriers at entrances and exits to the yard and where they cross a counterpoise (see Figure 1).

4.4.5 Railroad Sidings. Provide a primary protection system consisting of overhead conductors spanned between structural supports and connected to ground rods. Ground all metal parts and reinforcing steel of aboveground structure to driven ground rods. Ground all railroad tracks to ground rods located 10 ft (3.05 m) or more outside of the entrance to barrier.

4.4.6 Electric Service. Electric and communication services to explosives operating buildings and magazines shall be run underground in metallic conduit for the last 50 ft (15 m). Services to buildings not containing explosives may be overhead. The line side of the main protective device shall be provided with suitable surge arresters. Surge arresters shall be located at the service transition to underground conduit outside the 50 ft (15 m) limit. A separate ground shall be provided at the secondary electric service entrance. This ground shall be bonded to the facility ground counterpoise. The electric supply to an explosives area shall be arranged so that it can be cut off by switching devices located at one or more control points outside of and immediately adjacent to the explosives areas.

4.4.7 Exterior Overhead Pipelines. Bond overhead pipes which enter a building, storage facility, or area to all metal objects that are within sideflash clearance of the pipes where they are in a zone of lightning protection. Pipe segments shall be electrically continuous.

4.4.8 Fences. Fences shall be grounded on each side of every gate, at points 150 ft (45 m) on each side of high-tension line crossings, and at 150 ft (45 m) intervals along the fence where high-tension lines (as defined by ANSI C2) are directly overhead and run parallel to the fence. Fences shall be grounded every 1,000 ft to 1,500 ft (300 m to 450 m) of length when fences are in isolated places and at lesser distances depending upon proximity of fence to public roads, highways, and buildings. The ground shall be made with a bolted connection at a fence post by the use of No. 2/0 AWG (67.4 mm²) copper cable. Where plastic coated fabric is used, the post shall be bolted, and each strand of the fence shall be brazed to the metallic bare conductors. The conductors shall then be grounded.

4.5. Generating Plants. Commercial type, metal-oxide, surge arresters shall be provided on all overhead feeders adjacent to a plant as described in paras. 4.5.1 and 4.5.2.

4.5.1 Surge Protection. Surge protection shall be provided between the aerial surge arresters and generator or on a bus for several generators. Where a generator is connected to an overhead line through a transformer, provide a station type surge arrester on the high voltage side of the transformer.

MIL-HDBK 1004/6

4.5.2 Grounding. Provide protection for smokestacks as described in para. 4.8, and ground all steel columns, beams, trusses, and equipment frames at their lowest points to a low resistance station grounding system.

4.6 Outdoor Substations or Switching Stations. All overhead feeders shall be provided with surge arresters at the station which shall be connected to their own ground rod system. The ground rod system shall be connected below grade to the station ground mat. Refer to IEEE 80, Guide for Safety in Substation Grounding, and IEEE 81, Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System. Additional protection shall be as described in paras. 4.6.1 through 4.6.3.

4.6.1 Air Terminals. On distribution metal station structures, provide lightning rods at each corner of the station, extending rods above the structure and the electric conductors. Connect the structure and all equipment frames, transformers, tanks, and bases to a low resistance grounding system.

4.6.2 Grounded Aerial Conductors. In areas where lightning storms are prevalent, install overhead ground conductors above the transmission and distribution system conductors to form a ground wire network over distribution stations. Extend the overhead ground wires out over transmission lines for a minimum of 1/2 mile (0.8 km). Aerial ground wires shall be grounded at the station and at each pole.

4.6.3 Grounding. Provide a ground system of No. 2/0 AWG (67.4 mm²) copper cable, welded to the columns and equipment frames and connected to a ground system. Provide a ground mat for stations supplying distribution voltages and a counterpoise for substations supplying utilization voltages. A ground mat shall consist of a system of bare conductors located on or below grade throughout the station and connected to a counterpoise to provide protection from dangerous touch voltages.

4.7 Transmission and Distribution Lines. Overhead aerial lines shall be provided with lightning protection coordinated with NFGS-16302 and in accordance with standard utility practice at the project location. Acceptable shielding results when a perpendicular line from grade to the ground wire and when a line from the ground wire to the conductor protected do not result in an angle greater than 30°. Overhead ground wires may be steel, copper, aluminum, or copper clad steel, with sizes dependent upon mechanical requirements but not smaller than No. 1/0 AWG (53.5 mm²) copper-equivalent. Ground the overhead ground wires at each pole. Where an overhead electric transmission and distribution line transitions to underground, the underground cable shall be provided with lightning protection.

4.7.1 Distribution Line Clearances. The towers or poles supporting distribution lines operating at less than 69 kV, and unmanned electric substations operating at less than 69 kV, shall not be closer to ordnance facilities than public traffic route distances as defined in DOD-STD-6055.9.

4.7.2 Transmission Line Clearances. For transmission lines operating at 69 kV and above, and for electric substations operating at 69 kV and above which are part of a system serving a substantial off base area, both the towers or poles supporting the lines and the stations shall not be closer to

MIL-HDBK 1004/6

ordnance facilities than inhabited building distances, as defined in DOD-STD-6055.9. When failure of the lines and stations will not cause serious hardships, both the towers or poles supporting the lines and the stations may be located at public traffic route distances.

4.7.3 Clearance Calculation. Line clearance distance calculations shall be based on airblast over pressure only. Fragment distances will not be used.

4.8 Flagpoles and Chimneys. Provide grounding at the bases of metal chimneys or flagpoles at the lowest points in accordance with NFPA 78. Provide protection for other chimneys and flagpoles in accordance with NFPA 78.

4.9 Towers and Antennas. Provide grounding at the bases of metallic towers or at the lowest points in accordance with NFPA 78. At least two columns should be connected to an adequate ground by No. 2/0 AWG (67.4 mm²) copper cable. Provide the same grounding for metallic watch/surveillance tower structures. Structures adjacent to metallic towers and within their zone of protection do not require primary protection, but all metal frames, ventilators, doors, and window frames shall be bonded together and adequately grounded. Provide antenna lead-ins with spark gap protection connected to ground adjacent to supporting structure of antennas.

4.10 Aircraft and Aircraft Hangars. Provide aircraft and aircraft hangars in accordance with NFPA 78. Grounding receptacles shall be located in accordance with DM-21.1, Airfield Geometric Design, and DM-21.9, Skid Resistant Runway Surface.

4.11 Ordinary Buildings. Provide protection in accordance with NFPA 78. Health care facilities are included under ordinary buildings, except protection for flammable liquids and gases shall apply as appropriate. Where air terminals are located on flat roofs, either near mechanical equipment or in areas traversed by maintenance personnel, special consideration must be given to preventing injury from tripping over air terminal points, such as installing longer or elevated air terminals.

4.12 Obstruction Lights. Provide air terminals 1 ft (0.3048 m) above the top of the obstruction lights. Provide surge arrestors connected to the lighting circuit conductors and bonded to the lightning protection system.

MIL-HDBK 1004/6

APPENDIX A

PRIMARY LIGHTNING PROTECTION FOR
ORDNANCE HANDLING FACILITIES

1. Scope. The following design method will provide adequate primary lightning protection for ordnance handling buildings with vertical masts, or overhead aerial wiring, in the vicinity of the building to be protected. This method can also be used to provide protection for a group of closely associated structures or complexes.

2. General. Experiments have indicated that under certain assumed test conditions, a vertical conductor will generally divert to itself direct lightning strikes which might otherwise fall within a cone shape or wedge shape space zone-of-protection space in which the apex is the top of the vertical mast, or the overhead horizontal ground wiring of the wedge. In this case, the base is approximately two times the height of the mast or the overhead horizontal ground cable.

2.1 Lightning Protection System. The lightning protection system employed herein is based on the zone-of-protection as determined by clearance arcs and a 100 ft (30.5 m) lightning striking distance. All masts and overhead ground wiring that is used for the protection of a structure must be adequately grounded. If the structure being protected is of metal, grounding must also be bonded to the structure. The ground resistance should not be over 10 ohms. A sufficient number of masts or overhead ground wires must be used so that the entire structure is covered by their zone-of-protection.

3. Application of Criteria. The following criteria apply to primary lightning protection:

a) Basic requirements are an adequate design for lightning protection and economical cost of the system provided.

b) All three dimensions, the length, the width, and the height, of a structure to be protected by a primary lightning protection system are of major importance in determining the height, number, and location of the masts or the overhead aerial wiring which will be used to protect the structure.

c) The spacing of the masts along the length of the structure shall be a minimum of 1-1/2 times the height of the masts and a maximum of 200 ft (61 m).

d) The distance "C" of the masts from the structure shall be one-half the height of the assumed salient plane (S/2) but never less than 6 ft (1.8 m) or more than 25 ft (7.6 m). In cases where a minor readjustment may be necessary to accommodate road clearance, an exception shall not grossly exceed the limits.

MIL-HDBK 1004/6

e) The height of the masts is determined by the Equation:

$$\text{EQUATION: } D = \sqrt{[(L + 2C)/N - 2]^2 + [(W + 2C + B)/2]^2} \quad (1)$$

and the set of curves as shown in Appendix A, A-1, this set of curves is plotted from

$$\text{EQUATION } M = S + 0.293 \sqrt{2D^2} + P \quad (2)$$

where "M" is the height of the masts, "S" is the height of the assumed salient plane, "D" is the mast spacing on the diagonal axis as determined by Equation (1), with C = 40 ft (12 m). "P" is given an empirical value (see Appendix A, A-1) according to the value of "D" as calculated from Equation (1).

The height of the masts as determined by the formulae is based on the condition that the structure to be protected is located between two parallel rows of masts. To determine the height of the masts, use Equation (1), and using C = 40 ft (12 m), calculate for D, and then determine M by using the curves of Appendix A, A-2, Chart No. 1.

f) The protection of a structure by self-standing vertical masts dictates that the distance from the center line of the structure or complex to the masts on the normal or the diagonal axis must not be more than 100 ft (30.5 m). When this condition cannot be met, the protection of the structure or complex will be by overhead ground wiring. To determine the final distance, D₁, along the diagonal axis, use Equation (1) substituting D₁ for D, with C values between 6 ft (1.8 m) minimum to 25 ft (7.6 m) maximum. D₁ shall not exceed 100 ft (30.5 m).

g) When overhead ground wiring are used for protection, support the overhead ground wiring on masts located at the vicinity of the protected structure at distances from the structure established as 6 ft (1.8 m) minimum to 25 ft (7.6 m) maximum. The lowest point of mid-span sag in the overhead ground wiring above the salient plane of the protected structure is to be no less than 10 ft (3.05 m). Increase the distance of cable which is run parallel to the structure by 1 ft (0.3 m) for each 10 ft (3.05 m) of horizontal cable greater than 50 ft (15 m). Determine mid-span sag of the overhead ground wire from the curves of Appendix A, A-2.

4. Graphic Examples. In Appendix A, A-3, Example 1: L, W, and S are known, C is given the value of 40, B = 18 ft (explained in Appendix A, A-1, Definitions of Terms), and N is equal to 6. In Equation (1) substitute these values and D is found to equal 98.5 ft. In Appendix A, A-1, refer to the curves at point 98.5 ft (30 m) on the horizontal scale, then extend vertically to the 50 ft slant line, and carry horizontally to the vertical scale, again using Equation (1) and substituting actual distance C = 6 ft (1.8 m) minimum to 25 ft (7.6 m) maximum, this will show a mast height of 95.5 (29 m).

MIL-HDBK 1004/6

In accordance with para. 3, Appendix A, determine actual D1 distance from the center-line of the building or complex to row of masts on the diagonal axis. With $C = 25$ ft, D is equal to 82 ft.

After the height and location of the masts have been determined, proceed as follows:

a) Draw a plan of the building to scale. Locate the masts at distances which are determined by the method shown in Appendix A, A-3, Example 1, Figure 1.

b) Draw an elevation of the building to scale. Locate the masts at distances which are determined by the method shown in Appendix A, A-3. Draw a 100 ft striking distance radius from the apex of the masts to the center-line of the building or complex as shown. Draw two arcs (the normal axis and the diagonal axis clearance arcs) as shown in Appendix A, A-4, from the point of intersection with the center-line of the building. These arcs must clear the salient plane.

c) Draw a lengthwise scale elevation of the building. Locate the masts as shown in Appendix A, A-5 (refer to para. 4b, Appendix A). No part of the protected building should lie outside the zone-of-protection. Appendix A, A-6 through A-11 provide examples which illustrate application of this principle.

5. Facilities Other Than Structures. The following criteria apply for facilities other than structures.

a) This type of facility can be protected by using overhead ground cable spanned between two metal towers or poles which are effectively grounded and meet criteria in para. 3, Appendix A.

b) In this system, the overhead cable will intercept lightning strikes and the resulted electrical current will be safely carried to ground via the cable and supporting towers or poles.

c) The design method establishes the height of the horizontal ground cable at mid-span to provide the required zone-of-protection for a specific facility.

d) The mid-span sag of the overhead cable must be included when the height of the supporting towers or poles is determined (see Appendix A, A-2).

e) Selection of cables is based on mechanical strength rather than electrical considerations. The overhead ground cable should be stranded, non-corrosive, copper coated steel wire. Minimum size shall be 3/8 in. (9.5 mm) high strength (7 No. 8 strands).

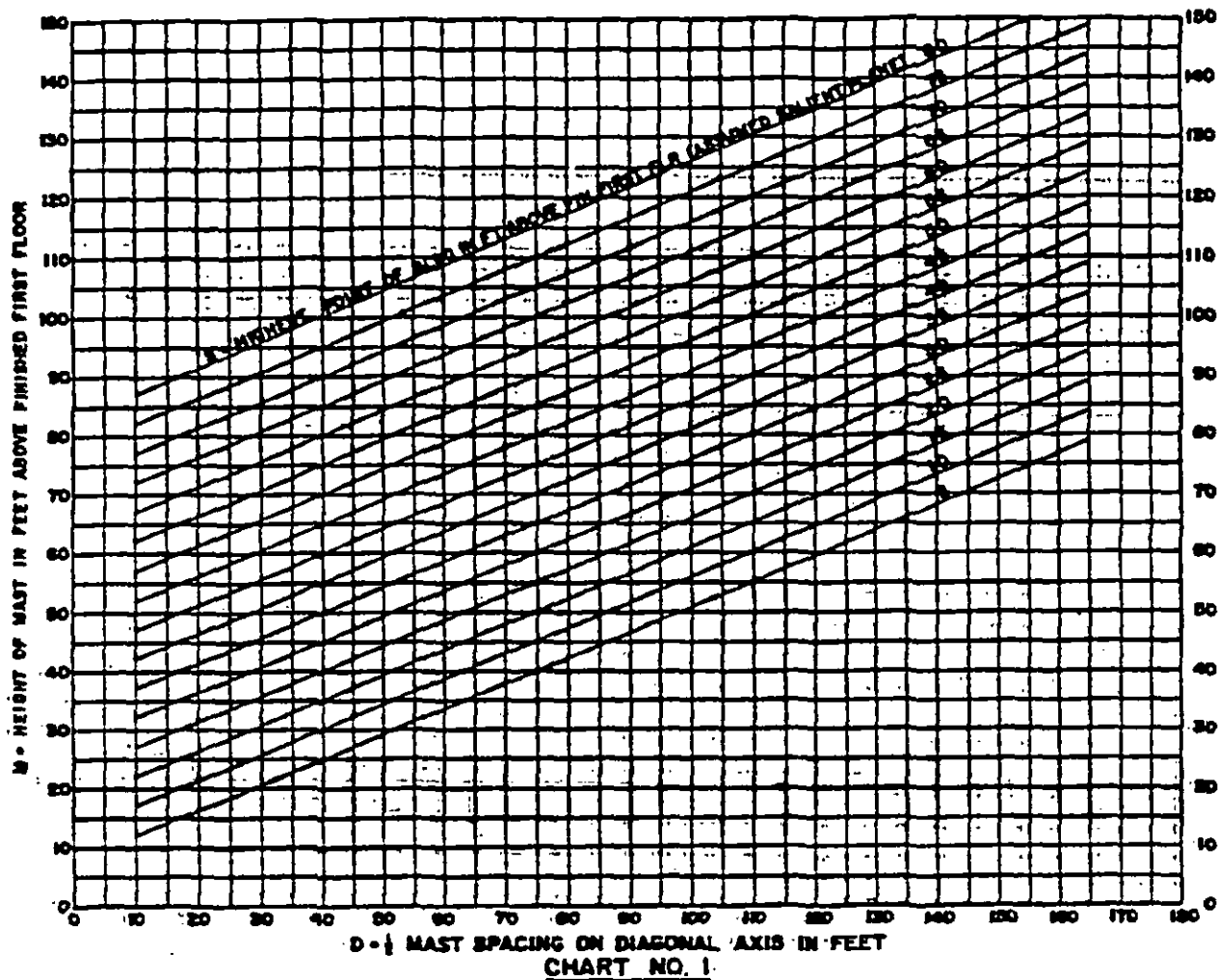
f) The construction of the towers and their structural members or the class of poles should be based on considerations of mechanical and wind loading stresses.

MIL-HDBK-1004/6

g) Appendix A, A-12 and A-13 illustrate primary lightning protection by overhead ground cables for railroad and truck marshalling yards, railroad siding and detail of overhead ground wire supporting poles and counterpoise. Piers and wharves should be protected by meeting requirements stated in paras. 1 and 3, Appendix A.

h) To check the adequacy of the zone-of-protection when the height of supporting towers or poles is determined, draw sketches to scale as shown in Appendix A, A-12 and A-13. The effective height of the overhead ground cable shall be maintained between the low point of the sag and the protected facility.

MIL-HDBK 1004/6



FORMULAE:

$$D = \sqrt{\left(\frac{L + 2C}{B-2}\right)^2 + \left(\frac{W + 2C + B}{2}\right)^2}$$

$$M = S + 0.293\sqrt{2D^2 + P}$$

CHECK:

- P = 2 FOR VALUES OF D FROM 0 TO 20 FT.
 P = 3 FOR VALUES OF D FROM 20 TO 30 FT.
 P = 4 FOR VALUES OF D FROM 30 TO 100 FT.

DIMENSIONAL LIMITS:

- D < 100
 $6' \leq C \leq 25'$
 $L < 1.5 W$

DEFINITION OF TERMS:

- M - HEIGHT OF MAST ABOVE FIN. FIRST FL.
 S - SALIENT PLANE (HIGHEST POINT OF BLDG.)
 D - DISTANCE FROM CENTER OF MAST TO CENTERLINE OF COMPLEX AS MEASURED ALONG DIAGONAL AXIS
 L - LENGTH OF BUILDING
 W - WIDTH OF BUILDING
 N - NUMBER OF MASTS
 C - CLEARANCE DISTANCE BETWEEN CENTER OF MAST AND BUILDING OR BOX CAR ON RR TRACK (R/2 SEE TEXT)
 B - 2 TIMES DISTANCE FROM EDGE OF LOADING PLATFORM TO CENTERLINE OF RR TRACK PLUS WIDTH OF LOADING PLATFORM
 K - DISTANCE BETWEEN MASTS
 Y - DISTANCE FROM CENTERLINE OF COMPLEX TO ROW OF MASTS (SEE EXAMPLE (1))
 R - STRIKING DISTANCE RADIUS

A-1
 PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6

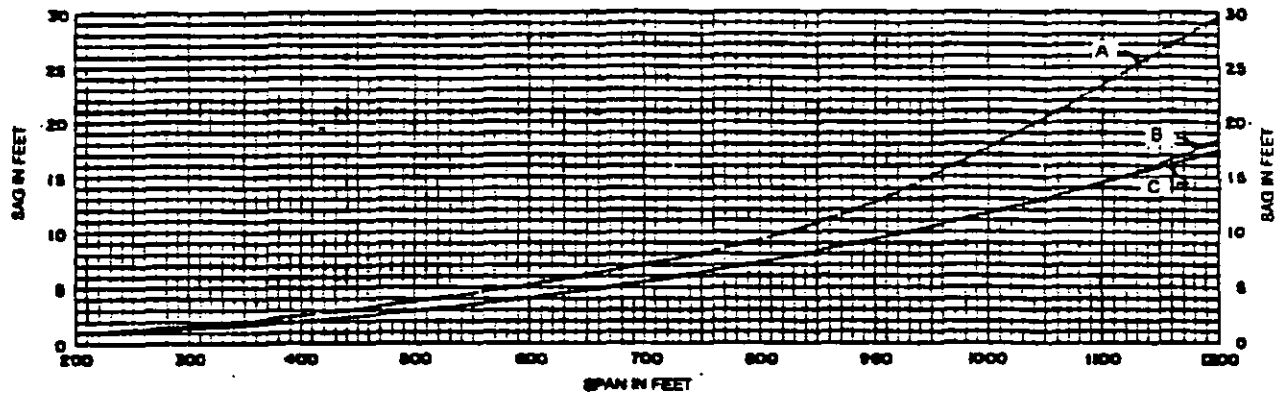


CHART NO. 1

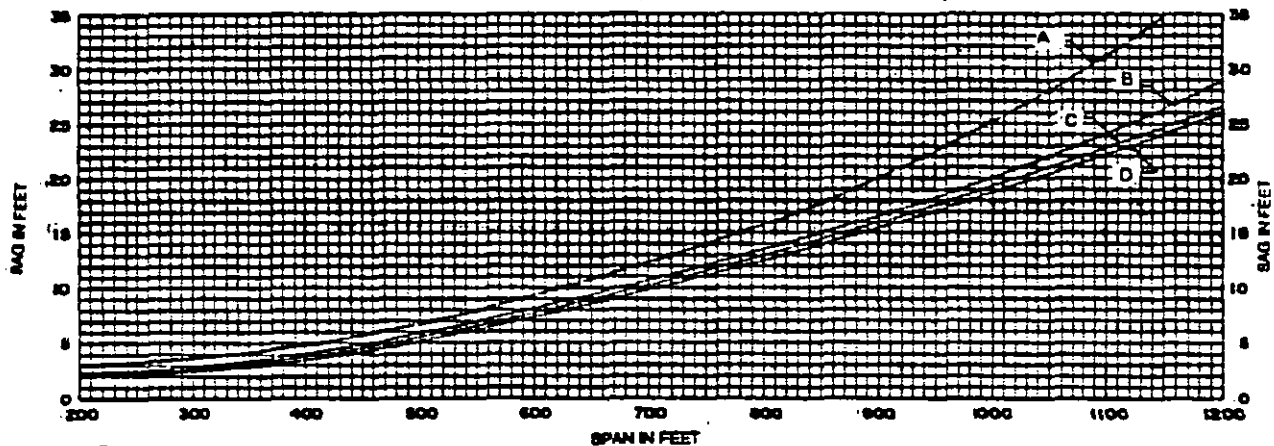


CHART NO. 2

OVERHEAD GROUND WIRE BAG ESTIMATING CHARTS: COPPER COATED STEEL STRANDED CABLE, 30% CONDUCTIVITY, MAXIMUM TENSION NOT EXCEEDING 50% OF RATED BREAKING STRENGTH, FINAL NORMAL TENSION AT 60°F LIMITED TO 25% OF RATED BREAKING STRENGTH.

CHART NO. 1: 60°F FINAL NORMAL BAGS FOR DEAD-END SPANS.

CURVE A: 3/8" DIA. HIGH STRENGTH

B: 3/8" DIA. EXTRA HIGH STRENGTH

C: 7/16" AND 1/2" DIA. EXTRA HIGH STRENGTH

CHART NO. 2: MAXIMUM VERTICAL BAGS AT 32°F WITH 1/2" INCH OF ICE AND NO WIND FOR DEAD-END SPANS.

CURVE A: 3/8" DIA. HIGH STRENGTH

B: 3/8" DIA. EXTRA HIGH STRENGTH

C: 7/16" DIA. EXTRA HIGH STRENGTH

D: 1/2" DIA. EXTRA HIGH STRENGTH

A-2
PRIMARY LIGHTNING PROTECTION DESIGN
FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6

DATA:

L = 110'
 W = 75'
 S = 50'
 B = 18'
 N = 6
 C = SEE TEXT

COMPUTATION:

$$D = \sqrt{\left(\frac{110 + 2(40)}{6-2}\right)^2 + \left(\frac{75 + 2(40) + 18}{2}\right)^2}$$

$$D = 98.5'$$

FROM CURVES CHART 1:

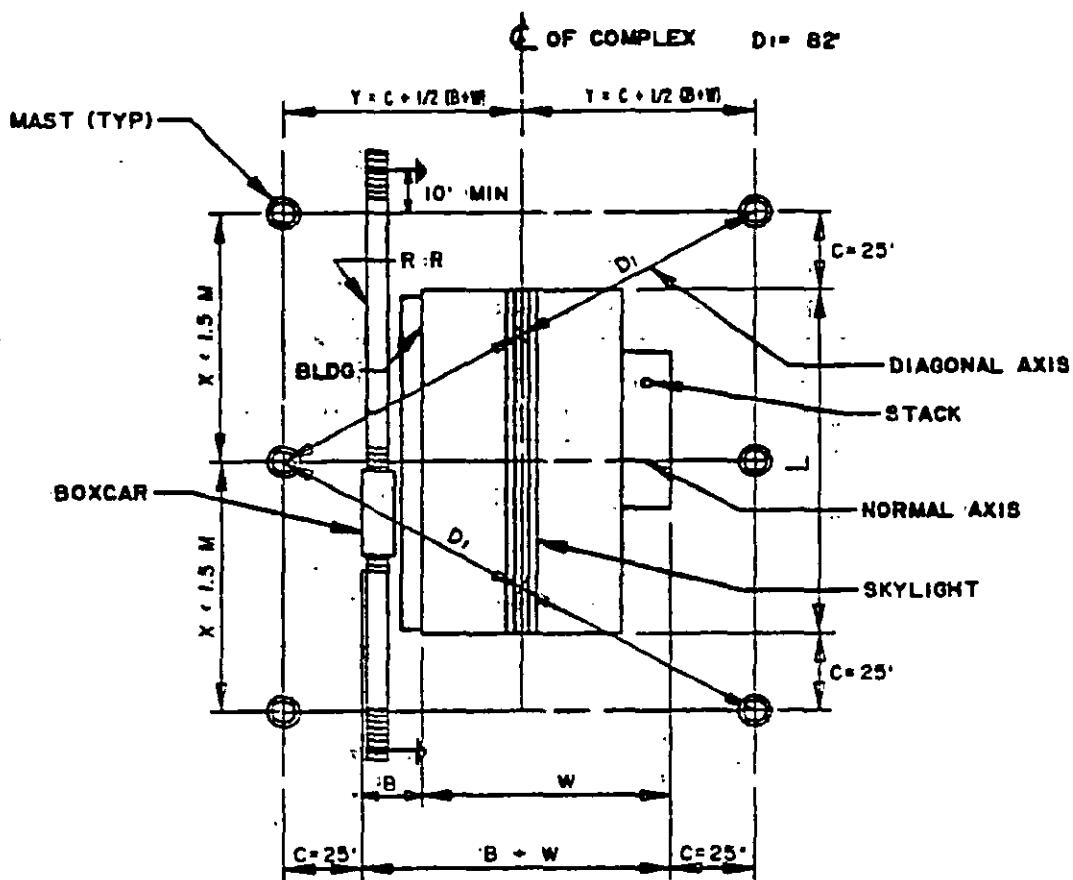
$$M = 95.5'$$

ACTUAL DISTANCE ON
DIAGONAL AXIS:

$$D_1 = \sqrt{\left(\frac{110 + 2(25)}{6-2}\right)^2 + \left(\frac{75 + 2(25) + 18}{2}\right)^2}$$

$$D_1 = \sqrt{1600 + 5112}$$

$$D_1 = 82'$$

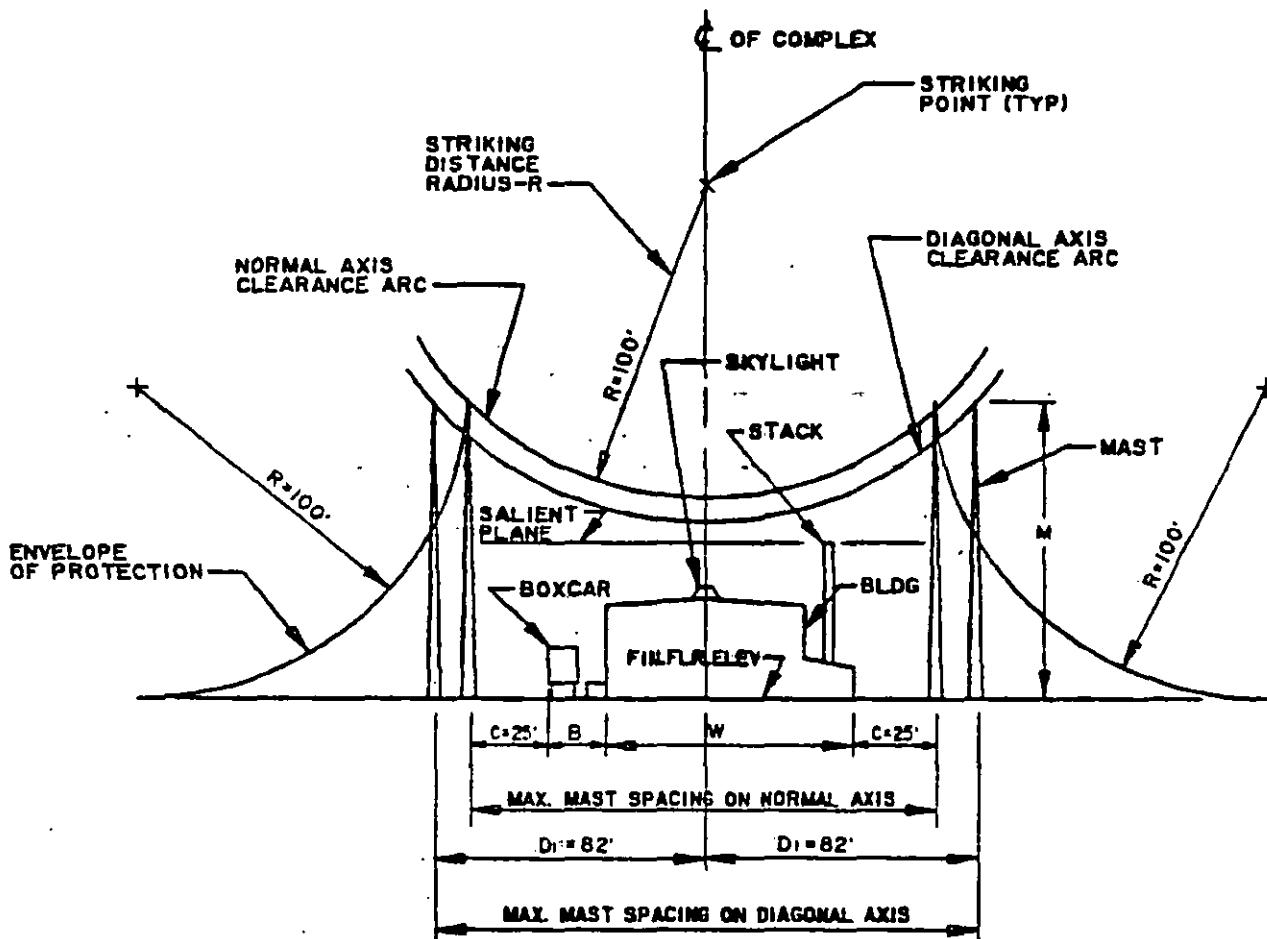
NOTES

1. BOXCAR ON RR TRACK AND LOADING PLATFORM ARE IMPORTANT FACTORS TO BE INCLUDED AS PART OF COMPLEX.

A-3

PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES

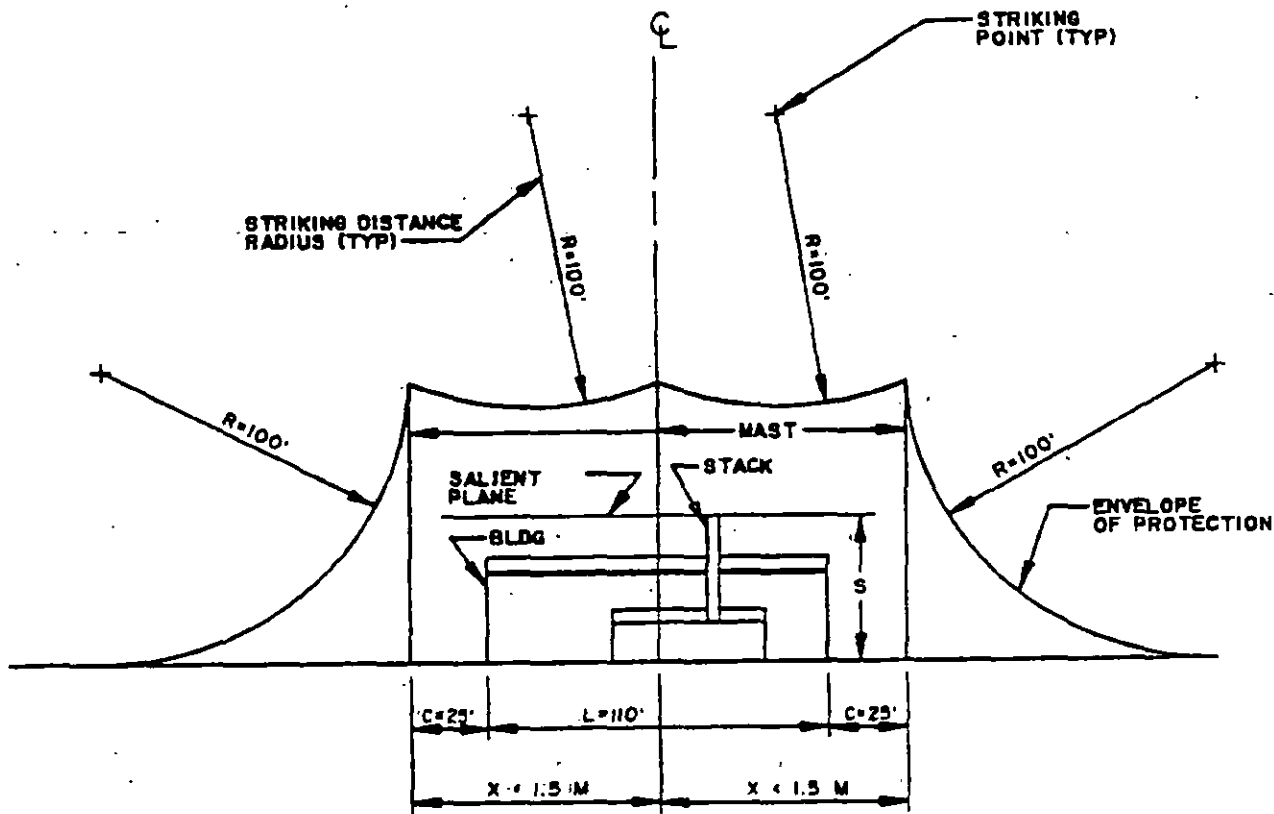
MIL-HDBK 1004/6



CLEARANCE ARC DIAGRAM

A-4
 PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES

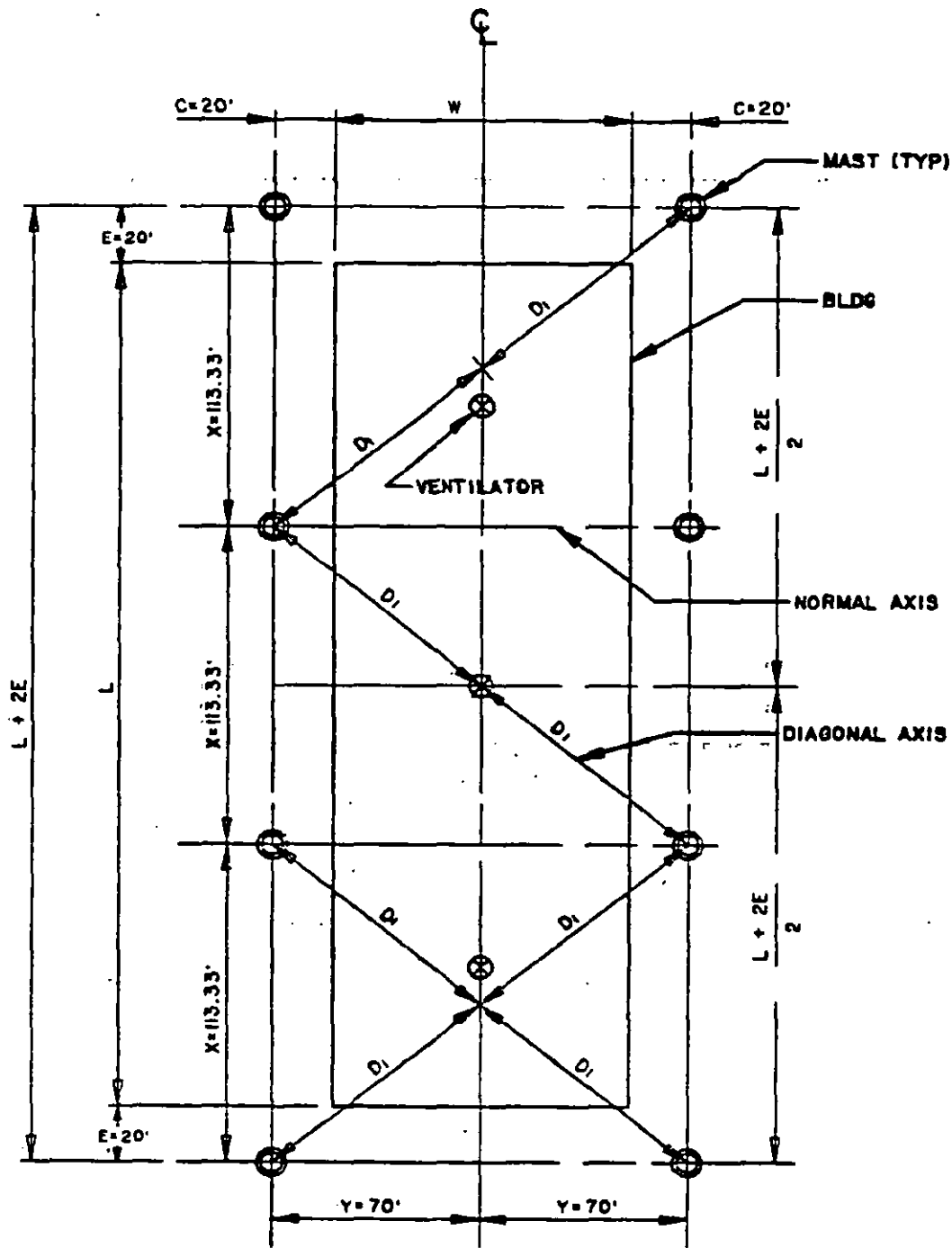
MIL-HDBK 1004/6



ELEV. SIDE VIEW

A-5
PRIMARY LIGHTNING PROTECTION DESIGN
FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6



PLAN

NOTES

1. FOR DATA & COMPUTATIONS SEE DWG A-7

A-6
 PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6

DATA:

L = 300'
 W = 100'
 S = 40'
 B = 0'
 N = 8
 C = SEE TEXT

COMPUTATION:

$$D = \sqrt{\left(\frac{300 + 2(40)}{8-2}\right)^2 + \left(\frac{100 + 2(40) + 0}{2}\right)^2}$$

$$D = 110'$$

FROM CURVES CHART II

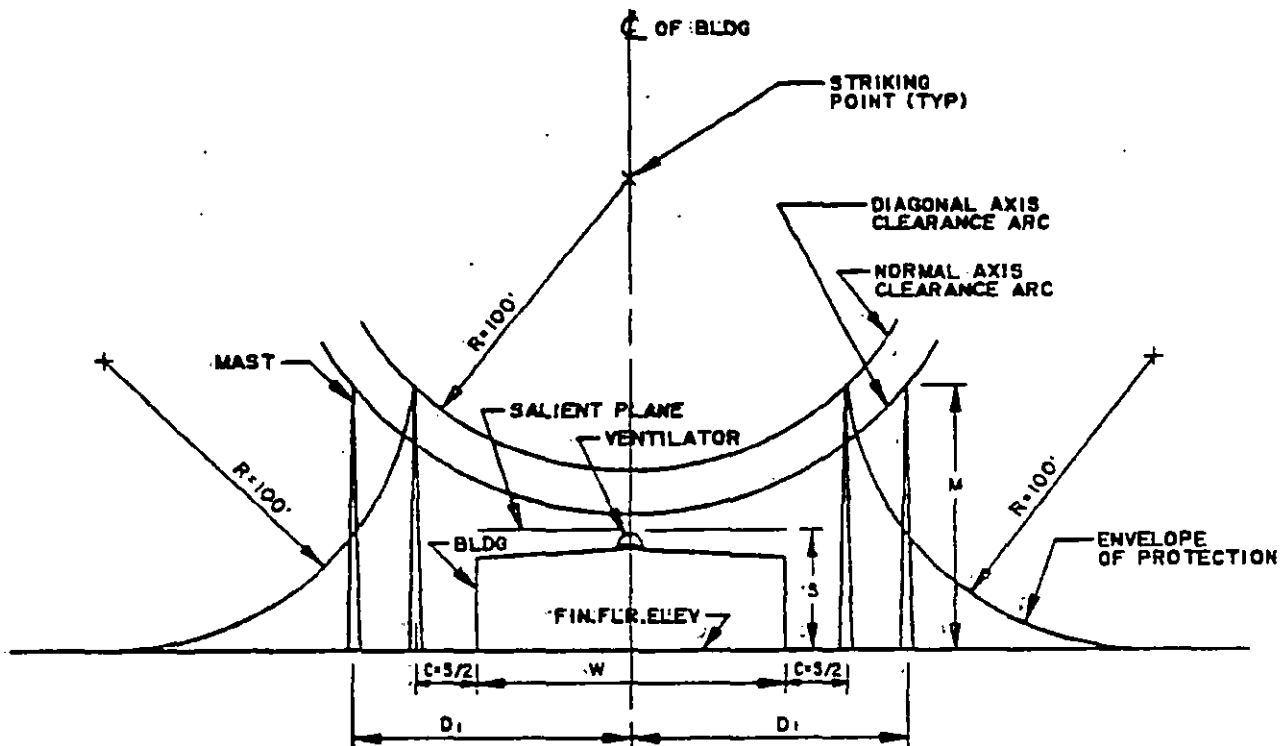
$$M = 90.5'$$

ACTUAL DISTANCE ON
DIAGONAL AXIS:

$$D_1 = \sqrt{\left(\frac{300 + 2(20)}{8-2}\right)^2 + \left(\frac{100 + 2(20)}{2}\right)^2}$$

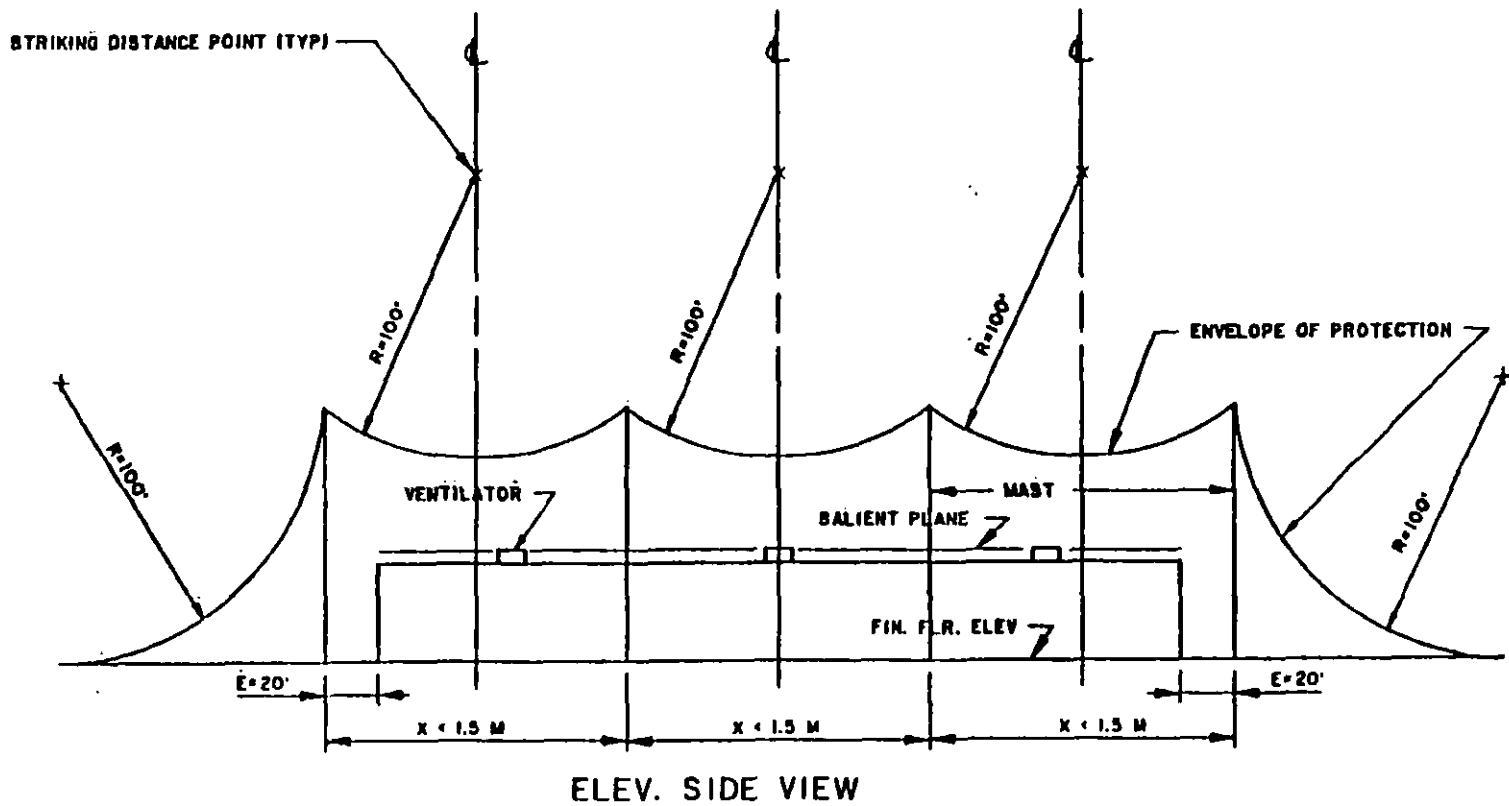
$$D_1 = \sqrt{321 + 4900}$$

$$D_1 = 90'$$



CLEARANCE ARC DIAGRAM
 EXAMPLE NO. 2

A-7
 PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES



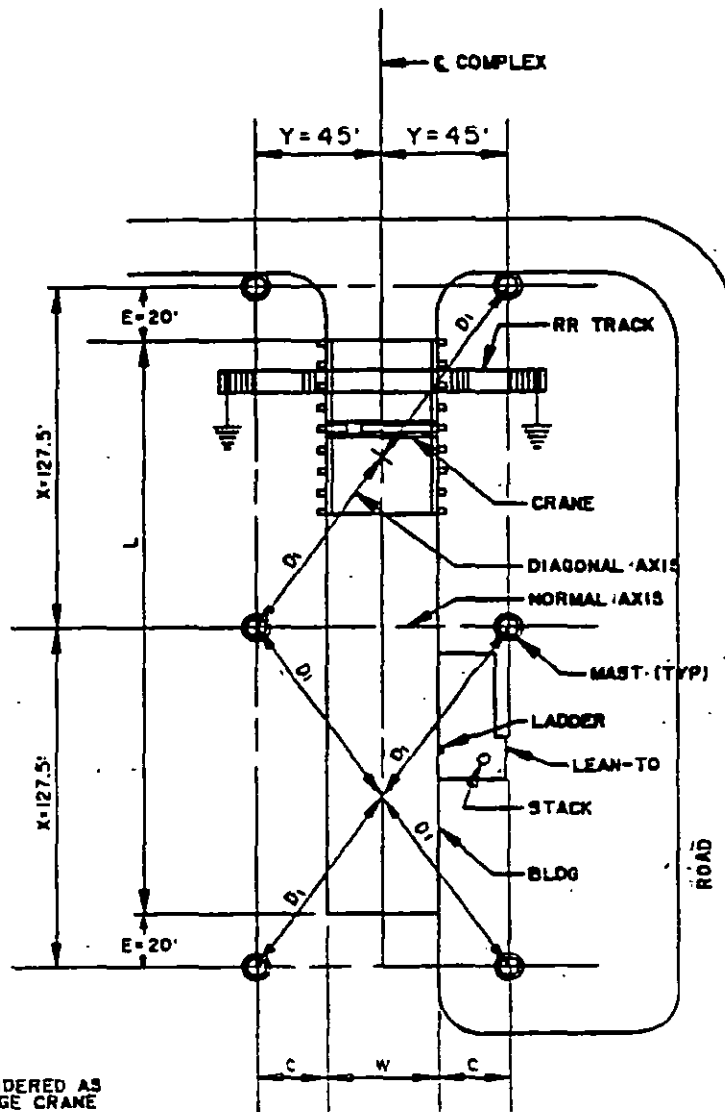
EXAMPLE NO. 2

A-8
PRIMARY LIGHTNING PROTECTION DESIGN
FOR ORDNANCE HANDLING FACILITIES

MIL-EDSK 1004/6

DATA:

L = 215'
 W = 40'
 SB = 48'
 SB = 0'
 C = 6'
 C = SEE TEXT

**CONDITIONS:**

1. RR TRACK NOT CONSIDERED AS IT RUNS UNDER BRIDGE CRANE STRUCTURE.
2. BRIDGE CRANE STRUCTURE BEING LARGE IS CONSIDERED EXTENSION OF BUILDING.
3. LEAN-TO BEING LOW COMPARED TO BUILDING IS NOT CONSIDERED.

PLAN

NOTES

1. LOCATION OF END MASTS ADJUSTED TO CLEAR ROAD.
2. FOR COMPUTATIONS SEE DWG A-10.

EXAMPLE NO. 3

A-9

PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6

COMPUTATION:

$$D = \sqrt{\left(\frac{215 + 2(40)}{8-2}\right)^2 + \left(\frac{40 + 2(40) + 0}{2}\right)^2}$$

$$D = 95.2'$$

FROM CURVES CHART 1:

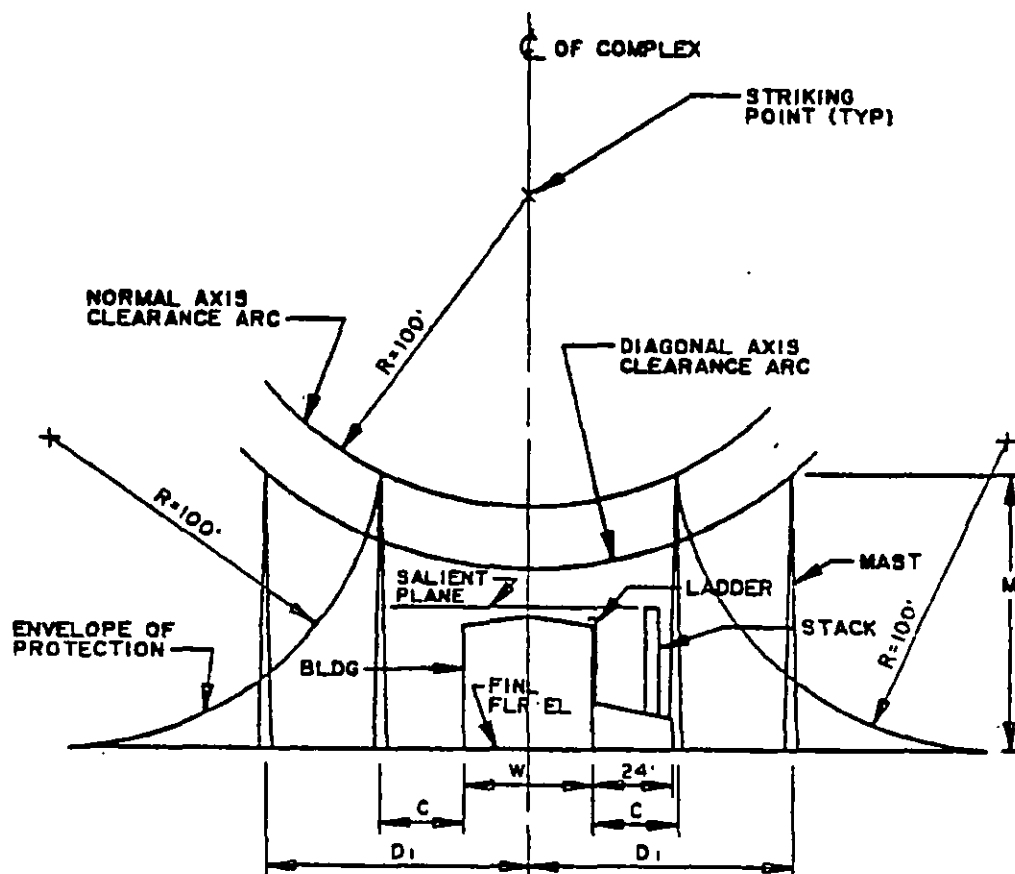
$$M = 89'$$

ACTUAL DISTANCE ON
DIAGONAL AXIS:

$$D_1 = \sqrt{\left(\frac{215 + 2(25)}{8-2}\right)^2 + \left(\frac{40 + 2(25)}{2}\right)^2}$$

$$D_1 = \sqrt{4389 + 2025}$$

$$D_1 = 80'$$



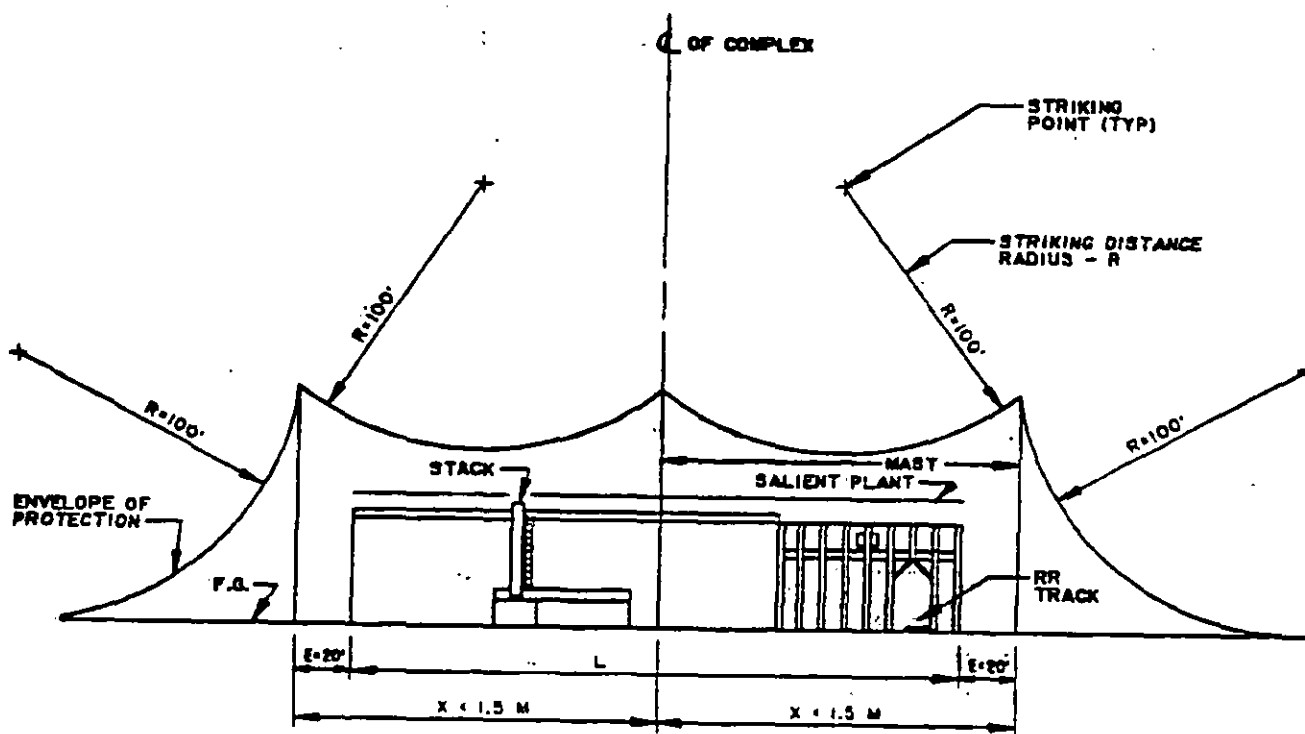
CLEARANCE ARC DIAGRAM

EXAMPLE NO. 3

A-10

PRIMARY LIGHTNING PROTECTION DESIGN
FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6



ELEV. SIDE VIEW

EXAMPLE NO. 3

A-11

PRIMARY LIGHTNING PROTECTION DESIGN
FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK-1004/6



RAILROAD MARSHALLING YARD

LEGEND

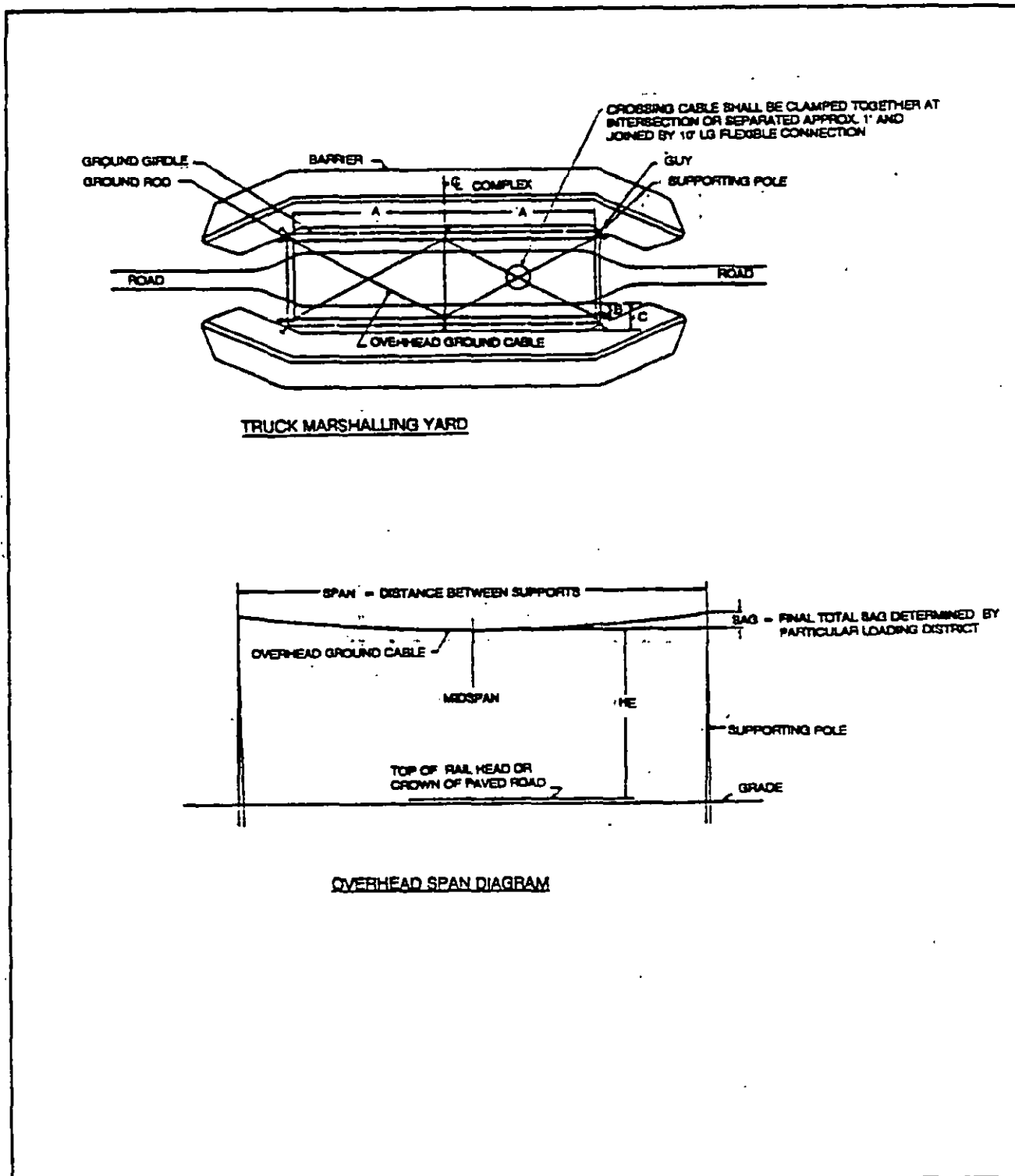
- | | |
|----|--|
| A | DISTANCE BETWEEN POLES (SHOULD BE 100'-150') |
| B | " " CENTERLINE OF RR TRACK OR EDGE OF ROW OF POLES (15' MIN) |
| C | " " CENTERLINE OF RR TRACK OR EDGE OF ROAD TO FOOT OF BARRIER (25' MIN) |
| D | " " END OF BARRIER AND END POLE (25' MAX., APPLIES TO RR YARD ONLY) |
| E | " " END OF BARRIER AND TRACK GROUND (10' MIN) |
| ME | EFFECTIVE HEIGHT OF OVERHEAD GROUND CABLE ABOVE RAIL HEAD OR CROWN OF PAVED ROAD AT MIDSPAN (SEE NOTE 2) |

NOTES

1. FOR DESIGN OF OVERHEAD SPANS USE STANDARD PRACTICE FOR MECHANICAL DESIGN OF OVERHEAD SPANS (REF. A.E. KNOWLTON'S STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS).
2. THE DIMENSION ME SHALL BE THE MINIMUM HEIGHT OBTAINED BY THE MAXIMUM TOTAL SAG COMPUTED FOR THE PARTICULAR LOADING DISTRICT IN WHICH THE FACILITY IS LOCATED. FOR RR YARDS ME = 35'; FOR TRUCK YARDS ME = 30'.
3. IN THE LAYOUT OF RR YARD, MEASUREMENT OF POLE SPACING BEGINS WITH POLE A AND POLE B WHICH ARE SPOTTED AT THE INTERSECTION OF THE POLE ROW CENTERLINES DETERMINED BY DIM. B ALONG OUTSIDE TRACKS.

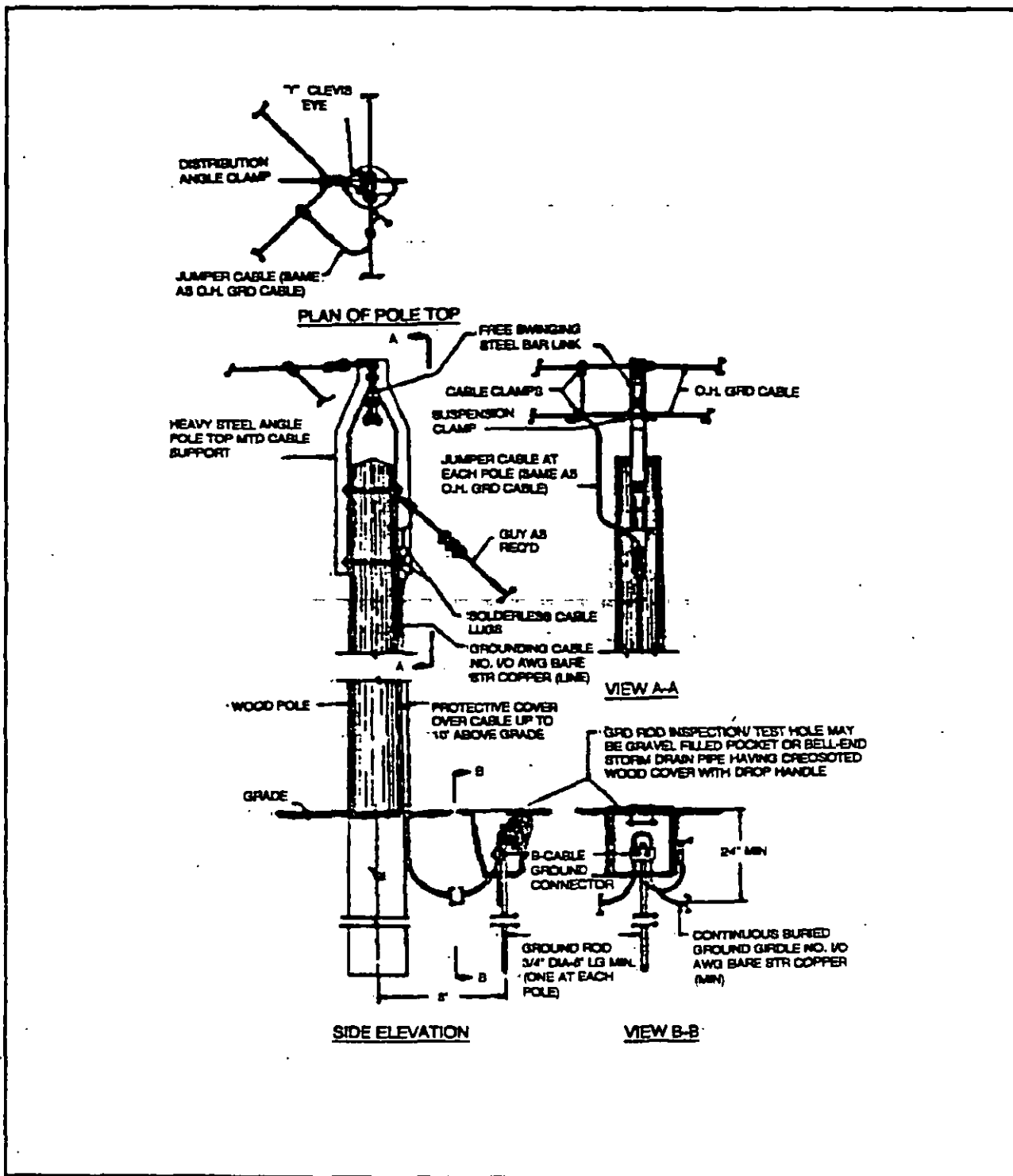
A-12 (PAGE 1 of 3) PRIMARY LIGHTNING PROTECTION DESIGN FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6



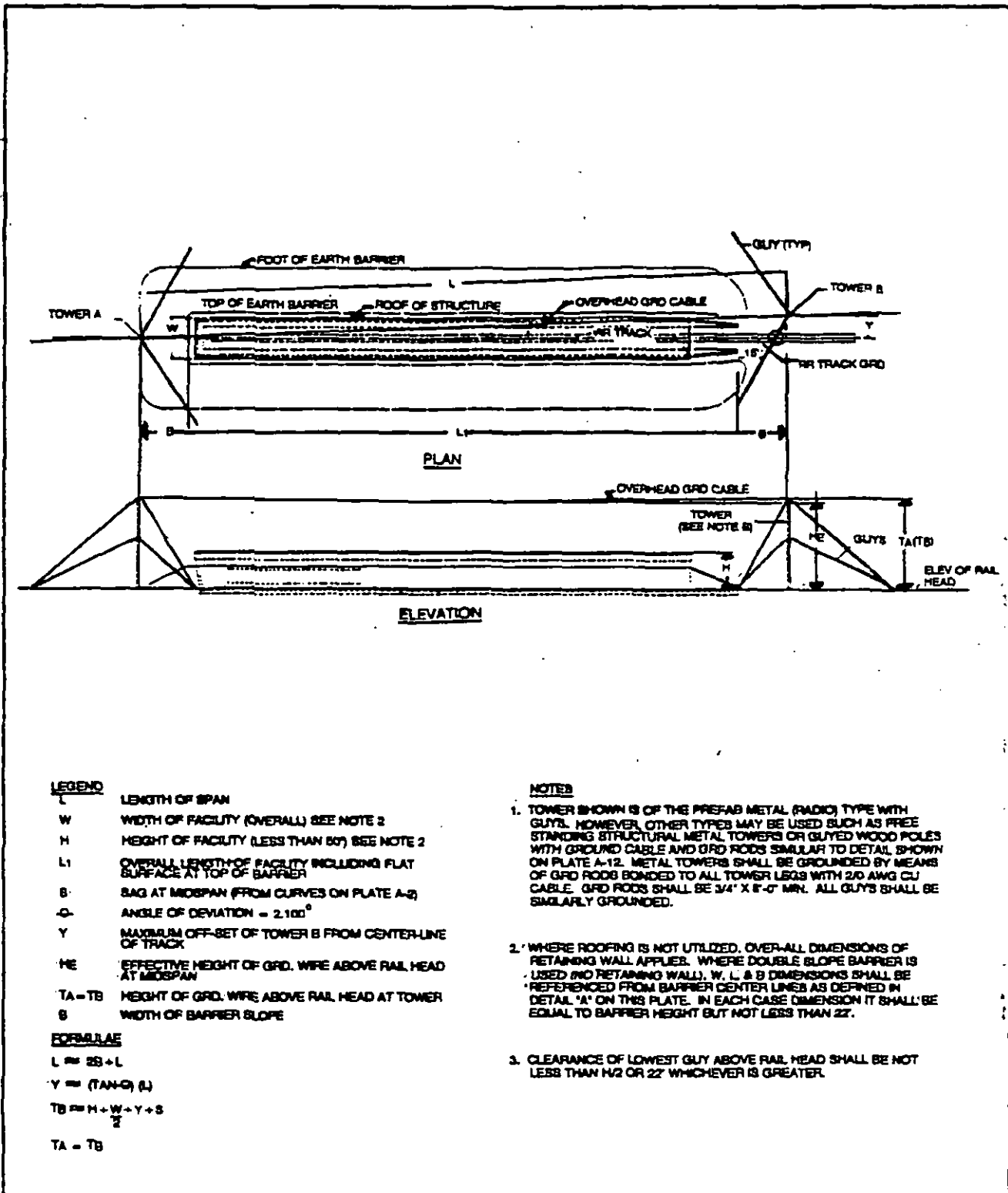
A-12 (PAGE 2 of 3)
 PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6



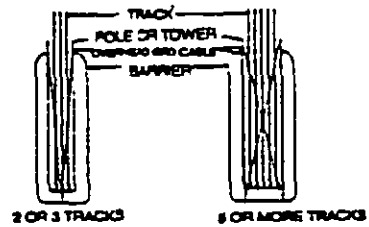
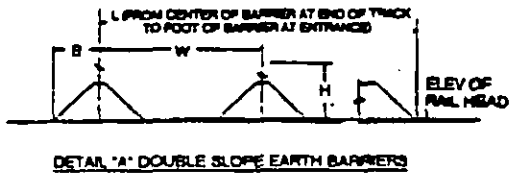
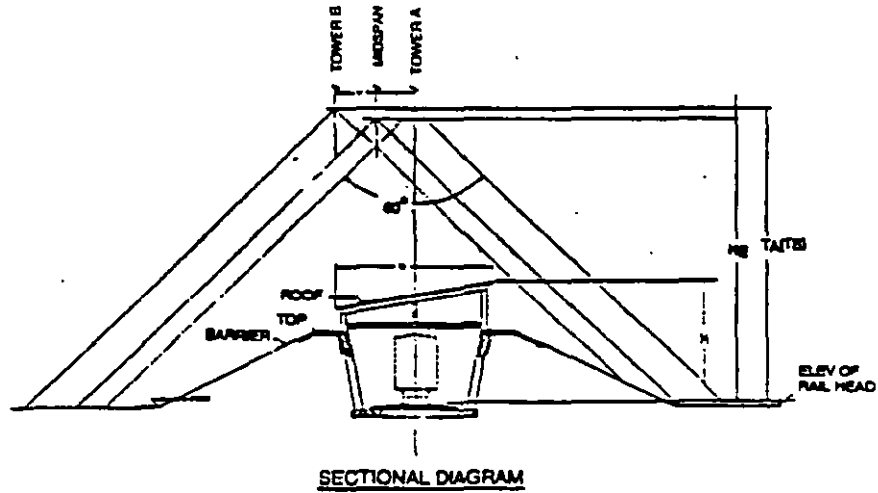
A-12 (PAGE 3 of 3)
 PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES

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A-13 (PAGE 1 of 2)
 PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6



APPLICABLE SCHEMES FOR MULTITRACK INSTALLATIONS

A-13 (PAGE 2 of 2)
 PRIMARY LIGHTNING PROTECTION DESIGN
 FOR ORDNANCE HANDLING FACILITIES

MIL-HDBK 1004/6

APPENDIX B

INTERNATIONAL SYSTEM OF UNITS (SI) CONVERSION FACTORS

<u>QUANTITY</u>	<u>U.S. CUSTOMARY UNIT</u>	<u>INTERNATIONAL (SI) UNIT</u>	<u>APPROXIMATE CONVERSION</u>
<u>LENGTH</u>	foot(ft)	meter(m)	1 ft = 0.3048 m
	foot(ft)	millimeter(mm)	1 ft = 304.8 mm
	inch(in)	millimeter(mm)	1 in = 25.4 mm
<u>AREA</u>	square yard(yd ²)	square meter(m ²)	1 yd ² = 0.836 127 m ²
	square foot(ft ²)	square meter(m ²)	1 ft ² = 0.092 903 m ²
	square inch(in ²)	square millimeter(mm ²)	1 in ² = 645.16 mm ²
<u>VOLUME</u>	cubic yard(yd ³)	cubic meter(m ³)	1 yd ³ = 0.764 555 m ³
	cubic foot(ft ³)	cubic meter(m ³)	1 ft ³ = 0.028 317 m ³
	cubic inch(in ³)	cubic millimeter(mm ³)	1 in ³ = 16,387.1 mm ³
<u>CAPACITY</u>	gallon(gal)	liter(L)	1 gal = 3.785 41 L
	fluid ounce(fl oz)	milliliter(mL)	1 fl oz = 29.5735 mL
<u>VELOCITY, SPEED</u>	foot per second (ft/s or f.p.s.)	meter per second(m/s)	1 ft/s = 0.3048 m/s
	mile per hour (mile/h or m.p.h.)	kilometer per hour (km/h)	1 mile/h = 1.609 344 km/h
<u>ACCELERATION</u>	foot per second squared(ft/s ²)	meter per second squared(m/s ²)	1 ft/s ² = 0.3048 m/s ²
<u>MASS</u>	short ton(2000lb)	metric ton(t) (1000 kg)	1 ton = 0.907 185 t
	pound(lb)	kilogram(kg)	1 lb = 0.453 592 kg
	ounce(oz)	gram(g)	1 oz = 28.3495 g
<u>DENSITY</u> t/m ³	ton per cubic yard(ton/yd ³)	metric ton per cubic meter(t/m ³)	1 ton/yd ³ = 1.186 55
	pound per cubic foot(lb/ft ³)	kilogram per cubic meter(kg/m ³)	1 lb/ft ³ = 16.0185 kg/m ³
<u>FORCE</u>	ton-force(tonf)	kilonewton(kN)	1 tonf = 8.896 44 kN
	kip(1000 lbf)	kilonewton(kN)	1 kip = 4.448 22 kN
	pound-force(lbf)	newton(N)	1 lbf = 4.448 22 N
<u>MOMENT OF FORCE TORQUE</u>	ton-force foot (tonf.ft)	kilonewton meter(kN.m)	1 tonf.ft = 2.711 64 kN.m
	pound-force inch(lbf.in)	newton meter(N.m)	1 lbf.in = 0.112 985 N.m

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APPENDIX B

INTERNATIONAL SYSTEM OF UNITS (Continued)

<u>QUANTITY</u>	<u>U.S. CUSTOMARY UNIT</u>	<u>INTERNATIONAL (SI) UNIT</u>	<u>APPROXIMATE CONVERSION</u>
<u>PRESSURE, STRESS</u>	ton-force per square inch (tonf/in ²)	megapascal(MPa)	1 tonf/in ² = 13.7895 MPa
	ton-force per square foot (tonf/ft ²)	kilopascal(kPa)	1 tonf/ft ² = 95.7605 kPa
	pound-force per square inch (lbf/in ²)	kilopascal(kPa)	1 lbf/in ² = 6.894 76 kPa
	pound-force per square foot (lbf/ft ²)	pascal(Pa)	1 lbf/ft ² = 47.8803 Pa
<u>WORK, ENERGY, QUANTITY OF HEAT</u>	kilowatthour(kWh)	megajoule(MJ)	1 kWh = 3.6 MJ
	British thermal unit(Btu)	kilojoule(kJ)	1 Btu = 1.055 06 kJ
	foot-pound-force (ft.lbf)	joule(J)	1 ft.lbf = 1.355 82 J
<u>POWER, HEAT FLOW RATE</u>	horsepower(hp)	kilowatt(kW)	1 hp = 0.745 700 kW
	British thermal unit per hour (Btu/h)	watt(W)	1 Btu/h = 0.293 071 W
	foot pound-force per second (ft.lbf/s)	watt(W)	1 ft.lbf/s = 1.355 82 W
<u>COEFFICIENT OF HEAT TRANSFER (U-value)</u>	Btu per square foot hour degree Fahrenheit(Btu/ft ² .hr.°F)	watt per square meter kelvin (W/m ² .K)	1 Btu/ft ² .h.°F = 5.678 26 W/m ² .K
<u>THERMAL CONDUCTIVITY (K-value)</u>	Btu per foot hour Degree Fahrenheit (Btu/ft.hr. °F)	watt per meter kelvin (W/m.K)	1 Btu/ft.h.°F = 1.730 73 W/m.K

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APPENDIX B (Continued)

AMERICAN WIRE GAGE (AWG) CONVERSION

AWG	RCM	mm ²
20	1.02	0.517
18	1.62	0.823
16	2.58	1.31
14	4.11	2.08
12	6.53	3.31
10	10.4	5.26
8	16.5	8.37
6	26.2	13.3
4	41.7	21.2
2	66.4	33.6
1	83.6	42.4
1/0	105.6	53.5
2/0	133.1	67.4
3/0	167.8	85.0
4/0	211.6	107.0

MIL-HDBK 1004/6

BIBLIOGRAPHY

Military Handbooks Government agencies may obtain copies of military handbooks from the United States Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120, TWX: 710-670-1685, TELEX: 834295, AUTOVON telephone 422-3321. Nongovernment organizations may obtain copies of military handbooks from the same source.

MIL-HDBK-1008A Fire Protection for Facilities Engineering,
Design, and Construction

MIL-HDBK 1004/6

REFERENCES

American National Standard Institute (ANSI), 1430 Broadway, New York, NY 10017.

C2 National Electric Safety Code

Institute of Electrical and Electronics Engineers, Inc., IEEE Publications,
345 East 47th Street, New York, NY 10017.

80 Guide for Safety in Substation Grounding

81 Guide for Measuring Earth Resistivity, Ground
Impedance, and Earth Surface Potentials of a Ground
System

142 Recommended Practice for Grounding Industrial and
Commercial Power Systems

Military Standards and Handbooks, Government agencies may obtain copies of
military standards and handbooks from the United States Naval Publications and
Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120, TWX: 710-670-1685,
TELEX: 834295, AUTOVON telephone 422-3321. Nongovernment organizations may
obtain copies from the Superintendent of Documents, United States Government
Printing Office, Washington, DC 20402.

MIL-HDBK-419 Grounding, Bonding, and Shielding for Electronic
Equipments and Facilities.

DOD-6055.9-STD Ammunition and Explosives Safety Standards

National Fire Protection Association (NFPA), Batterymarch Park,
Quincy, MA 02269.

70 National Electrical Code

70B Electrical Equipment Maintenance

78 Lightning Protection Code

MIL-HDBK 1004/6

Naval Facilities Engineering Command (NAVFACENGCOM). Government agencies may obtain copies of Design Manuals (DM), Naval Facilities Guide Specifications (NFGS) and Ordnance Pamphlets (OP), from the United States Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120, TWX: 710-670-1685, TELEX: 834295, AUTOVON telephone 422-3321. Nongovernment organizations may obtain copies from the Superintendent of Documents, United States Government Printing Office, Washington, DC 20402.

DM-2 Series	Structural Engineering
DM-4.2	Power Distribution Systems
DM-7 Series	Soil Mechanics, Foundations and Earth Structures
DM-21.1	Airfield Geometric Design
DM-21.9	Skid Resistant Runway Surface
NFGS-16302	Overhead Electrical Work

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NAVSEA OP-5 Vol. I	Ammunition and Explosives Ashore
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UL Standards, Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, IL 60062.

UL 96	Lightning Protection Components
UL 96A	Installation Requirements for Lightning Protection Systems
UL 467	Grounding and Bonding Equipment

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