February 26, 2020

ADDENDUM NO. 3

FOR

RUNWAY 9R-27L EXTENSION – EAST

SPECIFICATION NO. 1190708

For which Bids are due in the office of the Chief Procurement Officer, Department of Procurement Services, Bid & Bond Room 103, City Hall, 121 N. LaSalle Street, Chicago, IL 60602 at **11:00 a.m., Central Time on February 28, 2020.**

The following additions, changes and revisions are incorporated into the above-referenced Specification (the "Contract Documents") as noted. All other provisions and requirements as originally set forth, except as amended by previous addenda, remain in full force and are binding. Any additional work required by this Addendum shall conform to the applicable provisions of the original Contract Documents.

BIDDER MUST ACKNOWLEDGE RECEIPT OF THIS ADDENDUM IN THE SPACE PROVIDED ON THE PROPOSAL EXECUTION PAGE

NOTICE OF REVISIONS/CHANGES/CLARIFICATIONS

1	***Bid Opening Date has been extended to March 10, 2020.***

PART 1 OF 3 INSTRUCTION AND EXECUTION DOCUMENTS

See attached Schedule of Prices which has been amended. Specifically, the following Line Items have been amended:

Item Number	Pay Item Number	Change
193C	L-110-24	Added New Pay Item - 1 WAY, 2-INCH PVC CONDUIT SAW KERF IN BITUMINOUS BASE COURSE UNDER FULL STRENGTH PAVEMENT, 22,200 LF
193D	L-110-25	Added New Pay Item - 2 WAY, 2-INCH PVC CONDUIT SAW KERF IN BITUMINOUS BASE COURSE UNDER FULL STRENGTH PAVEMENT, 1,400 LF
246B	JT132634	Allowance amount $10,000 added for CCTV System Commissioning

PART 3 OF 3 TECHNICAL SPECIFICATIONS

Section Number	Change
L-108	• Replaced Section L-108 with new Section L-108 issued as part of this Addendum.
L-110	• Replaced Section L-110 with new Section L-110 issued as part of this Addendum.
P-501	• Replaced Section P-501 with new Section P-501 issued as part of this Addendum.
Attachment B	• Replaced FAA-STD-019e with FAA-STD-019f.

DRAWINGS

Drawing Sheet Number	Change
EN-125	• Ductbank tags revised
EN-126	• Ductbank tags revised
EN-127	• Ductbank tags revised
EN-130	• Cable legend revised
EP-300	• New Sheet – RCC #6 Single Line Diagram

RESPONSES TO QUESTIONS/REQUESTS FOR CLARIFICATIONS

The following questions and requests for clarification were submitted in accordance with the instructions provided in the Contract Documents. The City's response (shown in ***bold italics***) follows each question or request for clarification in the table below:

Question 1:	We received Addendum 2 for the above referenced project yesterday. Please refer to Questions 64 and 77. These questions state that Sheets EN-125 thru EN-127, EN-670, and EN-210 were revised. This sheets were not included in the addendum and are not part of the Addendum's revised list of Drawings. (Sheet EN-670 was never part of the original bid documents.) Please provide new/revised drawings.
Response:	***See revised drawings EN-125 thru EN-127 and EN-130.***
Question 2:	Section: P-501 Page: P-501-3 Issue: Inconsistent Specific Gravity test medium requirement for Chert Suggestion: Accept historical P-501 test medium gravity of 2.40, list under ASTM column
Response:	***The ASTM test method should be performed per the table in the P-501. The medium solution utilized for the test method should have a specific gravity of 2.0.***
Question 3:	Section: P-406 Page: P-406-4 Issue: Requirement to test F and E every 10,000 tons of shipment Suggestion: Unless aggregate source changes the initial flat and elongated tests submitted for material acceptance are valid through life of project.
Response:	***Refer to revised P-406 specification issued in Addendum No. 2. This mix will not contain any coarse aggregate which will negate the need for Flat and Elongated testing.***
Question 4:	Section: P-501 Page: P-501-48 Issue: Requirement of where to take samples fro Suggestion: Continue with current OMP accepted practice of taking representative sample from incoming loads using the Illinois Department of Transportation field sampling procedures for aggregates.
Response:	***Aggregate samples shall be taken from the onsite/plant stockpiles in accordance with ASTM D75, see revised Specification P-501 issued in this Addendum No. 3.***
Question 5:	Please reference TN-501 of the contract drawings. Detail E is called out but no Detail E is provided. Please clarify.

Response:	***Refer to revised TN series drawings issued in Addendum No. 2.***
Question 6:	Can we please receive the colored copy of drawings TN – 502 to TN – 511 as provided on TN -500 with the colored legend.
Response:	***No. The legend provides line types to differentiate between New/Demo/Remain items.***
Question 7:	On TN – 502, Keynote 3 is called out in an area tagged for remove/abandoned FOTS LOOP. Please clarify. See the south end of the site by HH2.
Response:	***Refer to revised TN series drawings issued in Addendum No. 2.***
Question 8:	Please reference TN-804, can you define what the "1" with the diamond tag is in the "Comm section Existing Duct"? It does not appear on the legend. The same question applies to TN-805.
Response:	***Refer to revised TN series drawings issued in Addendum No. 2.***
Question 9:	What pay items is the work shown on TN-XX to be paid under. For example these items appear to be missing pay items: a. Install (1) Yellow, 12-Strand, Single Mode Fiber Optic cable b. Install (1) #14 yellow insulated solid copper tracer wire in interstice of the innerduct. c. Install (3) yellow 1" HDPE innerducts. Install plugs in end of each. See L-110-2.05
Response:	***Refer to revised TN series drawings issued in Addendum No. 2. Refer to revised pay items issued in Addendum No. 2. All fiber optic cable shall be 24-strand and paid for under Pay Item 16125-01. Tracer wire shall be considered incidental to the installation of the innerduct. Innerduct will be paid for under Pay Item L-110-23.***
Question 10:	Please define what detail A on TN-819 is calling out or showing? There is no proposed work shown where the cut section is called out.
Response:	***Refer to revised TN series drawings issued in Addendum No. 2.***
Question 11:	Please provide pay items for FAA manholes and handholes. There are numerous pay items missing.
Response:	***The FAA manholes and handholes are included in the L-115 CED manhole and handhole pay items.***
Question 12:	Bid Item # 246B-CCTV System Commissioning Allowance does not have an Allowance amount in the Unit Price Field in the Schedule of Prices. Please clarify.
Response:	***Refer to revised Schedule of Prices.***

In accordance with Section 1 of the "Requirements for Bidding and Instructions for Bidders" in Part One of Three: Interpretation of Contract Documents, the deadline for questions has passed. No additional questions will be answered prior to bid opening except as the Chief Procurement Officer, in her sole discretion, deems to be in the best interest of the City.

END OF ADDENDUM NO. 3

CITY OF CHICAGO
DEPARTMENT OF PROCUREMENT SERVICES

SHANNON E. ANDREWS
CHIEF PROCUREMENT OFFICER

CITY OF CHICAGO
DEPARTMENT OF AVIATION
CHICAGO-O'HARE INTERNATIONAL AIRPORT
RUNWAY 9R-27L EXTENSION - EAST

PRINT AND SUBMIT THIS DOCUMENT

PART ONE OF THREE
INSTRUCTIONS AND EXECUTION DOCUMENTS

SPECIFICATION NUMBER: 1190708
PROJECT NUMBER: OH.6144.200.422

CITY OF CHICAGO
Lori E. Lightfoot
Mayor

O'HARE INTERNATIONAL AIRPORT
Jamie L. Rhee
Commissioner
Chicago Department of Aviation

Issued by:

DEPARTMENT OF PROCUREMENT SERVICES
Shannon E. Andrews
Chief Procurement Officer

ISSUED FOR ADDENDUM No. 3
FEBUARY 26, 2020

SECTION 3
BID FORM
CONTRACT BASE BID

BIDDER: ____

The Bidder agrees to submit its bid without limitations or exceptions, except as permitted by the Contract Documents.

The Bidder represents and warrants that this bid is all-inclusive for completion of the Runway 9R-27L Extension - East Project, including all labor, materials and incidentals necessary thereto. The Bidder further represents that the Work shall be performed in a diligent, workmanlike manner and the Runway 9R-27L Extension – East Project will, upon substantial completion or phase substantial completion, be ready for the use and occupancy for its intended purpose.

Contract Base Bid shall include entire scope of work and requirements of Part One, Part Two, Part Three and the Contract Drawings or the Contract Documents.

The Bidder further agrees that if awarded the Contract, the Bidder shall perform the Contract with no limitations or exceptions.

The Contract will be awarded to the lowest responsive and responsible Bidder offering the lowest Contract Base Bid, as determined by the Chief Procurement Officer.

CONTRACT BASE BID

____
(Words)

Dollars ($____________________________________)
(Figures)

NOTE: TAKE THE CONTRACT BASE BID FIGURE FROM THE SCHEDULE OF PRICES.

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ________________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
1	M-101-01	MOBILIZATION (TOTAL PRICE FOR MOBILIZATION MUST NOT EXCEED 6% OF THE TOTAL BASE BID)	1	LS		
2	M-101-02	CLOSEOUT DOCUMENTATION	1	LS	$ 500,000.00	$ 500,000.00
3	M-103-01	ALLOWANCE FOR SECURITY STAFFING, MAINTENANCE AND INFRASTRUCTURES	1	ALLOW	$ 300,000.00	$ 300,000.00
4	M-103-02	ALLOWANCE FOR SUPPLEMENTAL SAFETY MEASURES	1	ALLOW	$ 250,000.00	$ 250,000.00
5	M-103-03	ALLOWANCE FOR UTILITY AND DRAINAGE CONFLICTS	1	ALLOW	$ 500,000.00	$ 500,000.00
6	M-103-04	ALLOWANCE FOR CDA/FAA COORDINATION	1	ALLOW	$ 750,000.00	$ 750,000.00
7	M-103-05	ALLOWANCE FOR AIRLINE COORDINATION	1	ALLOW	$ 500,000.00	$ 500,000.00
8	M-107-01	PORTABLE CLOSED RUNWAY MARKER	4	EACH		
9	N-110-01	ALLOWANCE FOR STANDBY TIME	1	ALLOW	$ 150,000.00	$ 150,000.00
10	01010-01	ALLOWANCE FOR OWNER REQUESTED TESTING AND INVESTIGATION	1	ALLOW	$ 150,000.00	$ 150,000.00
11	01010-02	ALLOWANCE FOR WORKFORCE DEVELOPMENT	1	ALLOW	$ 150,000.00	$ 150,000.00
12	01010-03	ALLOWANCE FOR RUNWAY AND TAXIWAY COMMISSIONING AND DECOMMISSIONING	1	ALLOW	$ 4,500,000.00	$ 4,500,000.00
12A	01010-04	ALLOWANCE FOR FAA SUPPORT	1	ALLOW	$ 250,000.00	$ 250,000.00
13	01502-01	TRAFFIC CONTROL AND PROTECTION	1	LS		
14	01510-01	ALLOWANCE FOR UNFORESEEN UTILITY CROSSING	1	ALLOW	$ 50,000.00	$ 50,000.00
15	02221-01	DEMOLISH 9R MALSR SHELTER	1	LS		
16	02221-02	DEMOLISH 9R GLIDE SLOPE SHELTER	1	LS		
17	02221-03	DEMOLISH 27L ALSF SHELTER	1	LS		
18	02221-04	DEMOLISH 27L GLIDE SLOPE SHELTER	1	LS		
19	02241-01	CONTROL OF WATER	1	LS		

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ______________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
20	02245-01	MOBILIZATION, DE-MOBILIZATION, AND SITE RESTORATION	1	LS		
21	02245-02	CRUSHED AGGREGATE, RCB	300,850	TON		
22	02245-03	CRUSHED AGGREGATE, CA-6	164,128	TON		
23	02260-01	MECHANICALLY STABILIZED EARTH RETAINING WALL	1,800	SF		
23A	02455-01	FURNISHING METAL SHELL PILES	7,200	LF		
23B	02455-02	DRIVING PILES	7,200	LF		
23C	02455-03	PILE SHOES	144	EACH		
23D	02455-04	TEST PILES	8	EACH		
23E	02495-01	SURFACE SETTLEMENT MARKER	10	EACH		
24	02713-01	ALLOWANCE FOR HAUL ROAD MAINTENANCE	1	ALLOW	$ 250,000.00	$ 250,000.00
25	02783-01	THERMOPLASTIC PAVEMENT MARKING LINE, 4"	5,870	LF		
26	02783-02	THERMOPLASTIC PAVEMENT MARKING LINE, 12"	25	LF		
27	02783-03	THERMOPLASTIC PAVEMENT MARKING LETTERS AND SYMBOLS	351	SF		
28	02783-04	ALLOWANCE FOR SIGNAGE AND MARKING	1	ALLOW	$ 100,000.00	$ 100,000.00
29	02822-01	ORNAMENTAL STEEL FENCE	84	LF		
30	02839-01	TRAFFIC SIGN, 24-30, COMPLETE	10	EACH		
31	02839-02	TRAFFIC SIGN, 30-30, COMPLETE	10	EACH		
32	02839-03	TRAFFIC SIGN, 30-30-30, COMPLETE	10	EACH		
33	02845-01	FLEXIBLE DELINEATORS	260	EACH		
34	02845-02	FAA NAVIAD PROTECTION BOLLARD	247	EACH		

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

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ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
35	02845-03	COMED VEHICULAR BARRIER	17	EACH		
36	02845-04	STEEL PLATE BEAM GUARDRAIL, TYPE A, 6 FOOT STEEL POSTS	1,090	LF		
37	13280-01	ALLOWANCE FOR HAZARDOUS MATERIAL REMEDIATION	1	ALLOW	$ 300,000.00	$ 300,000.00
38	16125-01	1-24 STRAND, TYPE B, SINGLE-MODE FIBER OPTIC CABLE	29,000	LF		
39	16125-02	SINGLE-MODE FIBER OPTIC PATCH PANEL, 72 PORT	2	EACH		
40	16125-03	FIBER OPTIC CABLE AND TRACER WIRE REMOVAL	11,330	LF		
41	16125-04	ALLOWANCE FOR FOTS COORDINATION	1	ALLOW	$ 500,000.00	$ 500,000.00
42	16210-01	COMED TRANSFORMER PAD	2	EACH		
43	16210-02	COMED SECTIONALIZER PAD	1	EACH		
44	16210-03	METERING CABINET, 480V, 3 PHASE, 4 WIRE, 400A	1	EACH		
45	16420-01	CONSTANT CURRENT REGULATOR, 15KV	4	EACH		
46	P-150-01	PAVEMENT REMOVAL - C.R.C.P. RUNWAY/ TAXIWAY (FULL DEPTH)	53,915	SY		
47	P-150-02	PAVEMENT REMOVAL - PCC RUNWAY/TAXIWAY (FULL DEPTH)	119,460	SY		
48	P-150-03	PAVEMENT REMOVAL - BITUMINOUS RUNWAY/TAXIWAY (FULL DEPTH)	9,540	SY		
49	P-150-04	PAVEMENT REMOVAL - BITUMINOUS RUNWAY/TAXIWAY SHOULDER (FULL DEPTH)	92,215	SY		
50	P-150-05	PAVEMENT REMOVAL - ACCESS ROAD	24,275	SY		
51	P-150-06	PAVEMENT REMOVAL - ASPHALT PARKING LOT	6,000	SY		
52	P-150-07	PAVEMENT REMOVAL - FOUNDATION/ CONCRETE PAD	2,305	SY		

SCHEDULE OF PRICES

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ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
53	P-151-01	CLEARING AND GRUBBING	2	ACRE		
54	P-152-01	UNCLASSIFIED EXCAVATION	629,920	CY		
55	P-152-02	UNCLASSIFIED EXCAVATION UNDERCUT AND BACKFILL	132,542	CY		
56	P-152-03	ALLOWANCE FOR UNCLASSIFIED CONTAMINATED MATERIAL	1	ALLOW	$ 500,000.00	$ 500,000.00
57	P-152-04	DISPOSAL OF EXCESS SOIL OFFSITE	194,082	TON		
57A	P-152-05	DISPOSAL OF EXCESS ASPHALT GRINDINGS OFFSITE	70,921	TON		
58	P-154-01	PAVING - FROST PROTECTION COURSE, RCB	119,750	CY		
59	P-154-02	PAVING - FROST PROTECTION COURSE, CA-5	1,000	CY		
60	P-154-03	PAVING - FROST PROTECTION COURSE, CA-6 CRUSHED RECYCLED CONCRETE	6,730	CY		
61	P-154-04	PAVING – FROST PROTECTIION COURSE, RECYCLED ASPHALT GRINDINGS	51,090	CY		
62	P-156-01	SILT FENCE	21,464	LF		
63	P-156-02	DROP INLET INSERT BASKET PROTECTION	149	EACH		
64	P-156-03	SEDIMENT LOG AND/OR GEOSYNTHETIC CHECK STRUCTURE	19	EACH		
65	P-156-04	INLET AND PIPE (CULVERT) PROTECTION	4	EACH		
66	P-156-05	EROSION CONTROL BLANKET - SINGLE NET	478,656	SY		
67	P-156-06	EROSION CONTROL BLANKET - DOUBLE NET	10,821	SY		
68	P-156-07	ALLOWANCE FOR SUPPLEMENTAL EROSION CONTROL MEASURES	1	ALLOW	$ 50,000.00	$ 50,000.00
69	P-158-01	STABILIZED FPC, IDOT, 12"-DEPTH	245,840	SY		
70	P-158-02	LIME, IDOT	5,550	TON		

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ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
70A	P-158-03	CEMENT, TYPE I	2,000	TON		
71	P-159-01	LIME MODIFICATION	3,500	TON		
71A	P-159-02	CEMENT MODIFICATION	2,000	TON		
72	P-401-01	BITUMINOUS CONCRETE SURFACE COURSE	40,800	TON		
73	P-401-02	BITUMINOUS CONCRETE TESTING - TEST STRIP	1	LS		
74	P-404-01	ASPHALT TREATED PERMEABLE BASE COURSE	64,610	TON		
75	P-404-02	ATPB TESTING - TEST STRIP	1	LS		
76	P-405-01	BITUMINOUS CONCRETE BASE COURSE, (IDOT BINDER IL-19.0, N50)	131,690	TON		
77	P-405-02	BITUMINOUS CONCRETE BASE COURSE, (IDOT BINDER IL-19.0, N70)	8,630	TON		
78	P-405-03	BITUMINOUS CONCRETE SURFACE COURSE, (IDOT SURFACE IL-9.5, N70)	37,960	TON		
79	P-405-04	BITUMINOUS CONCRETE TESTING - TEST STRIP	1	LS		
80	P-406-01	BITUMINOUS CONCRETE SURFACE COURSE - TORSION RESISTANT FOR CRACK REPAIRS	2,500	SY		
81	P-501-01	PAVING - PORTLAND CEMENT CONCRETE, 19"	167,400	SY		
82	P-602-01	BITUMINOUS PRIME COAT	62,910	GAL		
83	P-603-01	BITUMINOUS TACK COAT	94,320	GAL		
84	P-617-01	BITUMINOUS PAVEMENT SCARIFICATION - 3" DEPTH	184,800	SY		
85	P-617-02	BITUMINOUS PAVEMENT SCARIFICATION - >3"-6" DEPTH	8,100	SY		
86	P-620-01	PAVEMENT MARKING - YELLOW	187,000	SF		
87	P-620-02	PAVEMENT MARKING - WHITE	182,830	SF		

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ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
88	P-620-03	PAVEMENT MARKING - RED	18,630	SF		
89	P-620-04	PAVEMENT MARKING - TEMPORARY	89,042	SF		
90	P-620-05	PAVEMENT MARKING - REMOVAL	17,144	SF		
91	P-620-06	ALLOWANCE FOR SUPPLEMENTAL PAVEMENT MARKING	1	ALLOW	$ 100,000.00	$ 100,000.00
92	P-623-01	SAWCUT AND SEAL - 2"	22,652	LF		
93	P-623-02	CLEAN AND SEAL EXISTING PCC JOINTS	2,700	LF		
94	S-802-01	PAVEMENT GROOVING - PORTLAND CEMENT CONCRETE	397,345	SF		
95	S-802-02	PAVEMENT GROOVING - BITUMINOUS	1,112,258	SF		
96	D-701-01	REINFORCED CONCRETE PIPE - 18" DIA, CLASS V	115	LF		
97	D-701-02	REINFORCED CONCRETE PIPE - 24" DIA, CLASS V	6,309	LF		
98	D-701-03	REINFORCED CONCRETE PIPE - 30" DIA, CLASS V	2,039	LF		
99	D-701-04	REINFORCED CONCRETE PIPE - 36" DIA, CLASS V	2,412	LF		
100	D-701-05	REINFORCED CONCRETE PIPE - 42" DIA, CLASS V	1,106	LF		
101	D-701-06	REINFORCED CONCRETE PIPE - 48" DIA, CLASS V	695	LF		
102	D-701-07	REINFORCED CONCRETE PIPE - 54" DIA, CLASS V	905	LF		
103	D-701-08	REINFORCED CONCRETE PIPE - 60" DIA, CLASS V	584	LF		
104	D-701-09	REINFORCED CONCRETE PIPE - 72" DIA, CLASS V	335	LF		
105	D-701-10	REINFORCED CONCRETE PIPE – 108” DIA, CLASS IV	329	LF		
105A	D-701-11	REINFORCED CONCRETE PIPE - 72” DIA., CLASS V, JACKED IN PLACE	615	LF		

SCHEDULE OF PRICES

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ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
107	D-705-01	SMOOTH WALL PVC PIPE, 8 INCH, SCH. 40, PERFORATED	40,341	LF		
108	D-751-01	CATCH BASIN - STANDARD	57	EACH		
109	D-751-02	CATCH BASIN - AIRCRAFT RATED	2	EACH		
110	D-751-03	MANHOLE - IDOT STANDARD 5' DIA	8	EACH		
111	D-751-04	MANHOLE - IDOT STANDARD 6' DIA	10	EACH		
112	D-751-05	MANHOLE - IDOT STANDARD 7' DIA	6	EACH		
113	D-751-06	MANHOLE - IDOT STANDARD 8' DIA	3	EACH		
114	D-751-07	MANHOLE - IDOT STANDARD 9' DIA	6	EACH		
115	D-751-08	MANHOLE - AIRCRAFT RATED 6’ DIA	2	EACH		
115A	D-751-08A	MANHOLE - AIRCRAFT RATED 7' DIA	1	EACH		
115B	D-751-08B	MANHOLE - AIRCRAFT RATED 8' DIA	1	EACH		
115C	D-751-08C	MANHOLE - AIRCRAFT RATED 9' DIA	1	EACH		
116	D-751-09	JUNCTION CHAMBER - JC-OH6144.200.422-201	1	EACH		
117	D-751-10	UNDERDRAIN INSPECTION HOLE	135	EACH		
118	D-751-11	DRAINAGE STRUCTURE ADJUSTMENT (NON-AIRCRAFT LOADING) (12" OR LESS)	6	EACH		
119	D-751-12	DRAINAGE STRUCTURE ADJUSTMENT (NON-AIRCRAFT LOADING) (GREATER THAN 12")	1	EACH		
120	D-751-13	SANITARY STRUCTURE ADJUSTMENT (12" OR LESS)	1	EACH		
121	D-751-14	CONCRETE DITCH PAVING - 6"	25	SY		

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

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Name of Bidder: ________________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
121A	D-751-15	DRAINAGE STRUCTURE ADJUSTMENT (AIRCRAFT LOADING)	1	EACH		
121B	D-752-01	10'X4' PRECAST CONCRETE BOX CULVERT	400	LF		
121C	D-752-02	CONCRETE FOR CULVERT WINGWALLS	120	CY		
121D	D-752-03	STEEL REINFORCEMENT FOR CULVERT WINGWALLS	10,000	LB		
122	F-162-01	FENCE - TYPE A, 10'	185	LF		
123	F-162-02	FENCE - TYPE A, 10' GATE	1	EACH		
124	F-162-03	FENCE - TYPE D, 10'	116	LF		
125	T-901-01	SEEDING, PERMANENT	101	ACRE		
126	T-901-02	LIME, pH ADJUSTMENT	202	TON		
127	T-905-01	TOPSOILING - PULVERIZING AND PLACEMENT, 6"MINIMUM THICKNESS	479,402	SY		
128	T-906-01	RIPRAP PLACEMENT, RR4	60	SY		
129	L-100-01	LIGHTING – TAXIWAY, TYPE 1 MARKER LIGHT BASE WITH L-861T LED (L) ELEVATED EDGE LIGHT, COMPLETE	629	EACH		
130	L-100-02	LIGHTING – TAXIWAY, AMBER LED (L) ELEVATED EDGE LIGHT-SPECIAL, COMPLETE	48	EACH		
131	L-100-03	LIGHTING – RUNWAY, TYPE 1 MARKER LIGHT BASE, WITH L-862 LED (L) ELEVATED EDGE LIGHT, COMPLETE	43	EACH		
132	L-100-04	LIGHTING – RUNWAY EDGE IN-PAVEMENT LIGHT BASE WITH L-850C LED (L) LIGHT, COMPLETE	19	EACH		
133	L-100-05	LIGHTING – RUNWAY CENTERLINE IN-PAVEMENT LIGHT BASE WITH L-850A LED LIGHT, COMPLETE	58	EACH		
134	L-100-06	LIGHTING – RUNWAY TOUCHDOWN ZONE IN-PAVEMENT LIGHT BASE WITH L-850B LED LIGHT, COMPLETE	180	EACH		

Name of Bidder: ________________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
135	L-100-07	LIGHTING – RUNWAY TOUCHDOWN ZONE IN-PAVEMENT LIGHT BASE WITH L-850B LED LIGHT, COMPLETE, CORE DRILLED	18	EACH		
136	L-100-08	LIGHTING – RWSL REL IN-PAVEMENT LIGHT BASE WITH L-850T LED (L) LIGHT, COMPLETE	73	EACH		
137	L-100-09	LIGHTING – RWSL REL IN-PAVEMENT LIGHT BASE WITH L-850T LED (L) LIGHT, COMPLETE, CORE DRILLED	10	EACH		
138	L-100-10	LIGHTING – INSTALL FAA FURNISHED RWSL REL L-850T LED (L) LIGHT ON EXISTING BASE	18	EACH		
139	L-100-11	LIGHTING – RWSL THL IN-PAVEMENT LIGHT BASE WITH L-850T LED (L) LIGHT, COMPLETE	54	EACH		
140	L-100-12	LIGHTING – RWSL THL IN-PAVEMENT LIGHT BASE WITH L-850T LED (L) LIGHT, COMPLETE, CORE DRILLED	32	EACH		
141	L-100-13	LIGHTING – INSTALL FAA FURNISHED RWSL THL L-850T LED (L) LIGHT ON EXISTING BASE	4	EACH		
142	L-100-14	LIGHTING – RUNWAY GUARD LIGHT IN-PAVEMENT LIGHT BASE WITH L-852G LED LIGHT, COMPLETE	159	EACH		
143	L-100-15	LIGHTING – RUNWAY GUARD LIGHT IN-PAVEMENT LIGHT BASE WITH L-852G LED LIGHT, COMPLETE, CORE DRILLED	22	EACH		
144	L-100-16	LIGHTING – RUNWAY GUARD LIGHT ELEVATED TYPE 1 MARKER LIGHT BASE WITH L-804 ELEVATED LIGHT, COMPLETE	39	EACH		
145	L-100-17	LIGHTING - RUNWAY THRESHOLD LIGHT TYPE 1 MARKER LIGHT BASE WITH L-862E ELEVATED EDGE LIGHT, COMPLETE	8	EACH		
146	L-100-18	LIGHTING SYSTEMS – NEW L-858 GUIDANCE SIGN BASE, WITH 1 MODULE LED SIGN, SIZE 4, COMPLETE	8	EACH		
147	L-100-19	LIGHTING SYSTEMS – NEW L-858 GUIDANCE SIGN BASE, WITH 1 MODULE LED SIGN, SIZE 3, COMPLETE	4	EACH		

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ________________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
148	L-100-20	LIGHTING SYSTEMS – NEW L-858 GUIDANCE SIGN BASE, WITH 2 MODULE LED SIGN, SIZE 3, COMPLETE	17	EACH		
149	L-100-21	LIGHTING SYSTEMS – NEW L-858 GUIDANCE SIGN BASE, 3 MODULE(S), SIZE 3, COMPLETE	31	EACH		
150	L-100-22	LIGHTING SYSTEMS – NEW L-858 GUIDANCE SIGN BASE, 4 MODULE(S), SIZE 3, COMPLETE	30	EACH		
151	L-100-23	LIGHTING SYSTEMS – NEW L-858 GUIDANCE SIGN BASE, WITH 6 MODULE LED SIGN, SIZE 3, COMPLETE	2	EACH		
152	L-100-24	LIGHTING - INSTALL AIRPORT FURNISHED ELEVATED TAXIWAY EDGE LIGHT	141	EACH		
153	L-100-25	LIGHTING - INSTALL AIRPORT FURNISHED IN-PAVEMENT RUNWAY END LIGHT	8	EACH		
154	L-100-26	LIGHTING - RE-INSTALL EXISTING RUNWAY LIGHT ON EXISTING BASE	27	EACH		
155	L-100-27	LIGHTING – TAXIWAY EDGE LIGHT IN-PAVEMENT LIGHT BASE WITH L-852T LED LIGHT, COMPLETE	2	EACH		
156	L-100-28	LIGHTING - INSTALL AIRPORT FURNISHED IN-PAVEMENT RUNWAY TOUCHDOWN ZONE LIGHT	198	EACH		
157	L-100-29	LIGHTING - NSTALL AIRPORT FURNISHED ELEVATED RUNWAY EDGE LIGHT ON EXISTING TYPE 1 MARKER BASE	40	EACH		
158	L-100-30	LIGHTING - INSTALL AIRPORT FURNISHED IN-PAVEMENT RUNWAY CENTERLINE LIGHT	166	EACH		
159	L-100-31	LIGHTING - INSTALL AIRPORT FURNISHED ELEVATED RUNWAY GUARD LIGHT	21	EACH		
160	L-100-32	LIGHTING - INSTALL AIRPORT FURNISHED IN-PAVEMENT RUNWAY GUARD LIGHT	108	EACH		
161	L-100-33	LIGHTING - INSTALL AIRPORT FURNISHED 1-MODULE SIGN	2	EACH		
162	L-100-34	LIGHTING - INSTALL AIRPORT FURNISHED 2-MODULE SIGN	10	EACH		

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ________________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
163	L-100-35	LIGHTING - INSTALL AIRPORT FURNISHED 3-MODULE SIGN	16	EACH		
164	L-100-36	LIGHTING - INSTALL AIRPORT FURNISHED 4-MODULE SIGN	11	EACH		
165	L-100-37	LIGHTING - INSTALL AIRPORT FURNISHED L-862 LED (L) ELEVATED RUNWAY EDGE LIGHT ON EXISTING TYPE 1 MARKER LIGHT BASE	37	EACH		
166	L-100-38	LIGHTING - INSTALL AIRPORT FURNISHED L-850C LED (L) IN-PAVEMENT RUNWAY LIGHT ON EXISTING LIGHT BASE	7	EACH		
167	L-100-39	LIGHTING - INSTALL NEW IN-PAVEMENT BASE CAN EXTENSION RING ON EXISTING BASE CAN	394	EACH		
168	L-100-40	LIGHTING - RUNWAY LAND AND HOLD SHORT IN-PAVEMENT LIGHT BASE WITH L-850F LIGHT, COMPLETE	6	EACH		
169	L-100-41	LIGHTING - RUNWAY LAND AND HOLD SHORT IN-PAVEMENT LIGHT BASE WITH L-850F LIGHT, COMPLETE, CORE DRILL	6	EACH		
169A	L-100-42	LIGHTING - TEMPORARY L-867 SHALLOW SURFACE MOUNTED BASE CAN WITH CDA FURNISHED L-861T LED EDGE LIGHT WITH ARCTIC KIT	384	EACH		
170	L-107-01	INSTALL L-806 WIND CONE (10 FEET OVERALL HEIGHT)	1	EACH		
171	L-108-01	POWER CABLE - L-824, TYPE C 5KV, 1/C, SIZE 6 AWG	488,993	LF		
172	L-108-02	COUNTERPOISE WIRE - 1/C, SIZE 6 AWG, 600 V, BARE COPPER	125,757	LF		
172A	L-108-03	2-1/C #10 XHHW-2 CABLE, 1/C #6 GND, IN RMC SURFACE MOUNTED CONDUIT	48,800	LF		
173	L-110-01	CONCRETE ENCASED DUCTS, 1 WAY, 2" PVC	34,253	LF		
174	L-110-02	CONCRETE ENCASED DUCTS, 2 WAY, 3" PVC	47,402	LF		
175	L-110-03	SAWKERFED 1-WAY, 2" PVC	2,513	LF		

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ______________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
176	L-110-04	COMMON ELECTRIC DUCTBANK, 2-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	2,170	LF		
177	L-110-05	COMMON ELECTRIC DUCTBANK, 2-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	651	LF		
178	L-110-06	COMMON ELECTRIC DUCTBANK, 4-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	2,133	LF		
179	L-110-07	COMMON ELECTRIC DUCTBANK, 4-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	2,111	LF		
180	L-110-08	COMMON ELECTRIC DUCTBANK, 8-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	5,741	LF		
181	L-110-09	COMMON ELECTRIC DUCTBANK, 8-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	1,807	LF		
182	L-110-10	COMMON ELECTRIC DUCTBANK, 12-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	379	LF		
183	L-110-11	COMMON ELECTRIC DUCTBANK, 12-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	268	LF		
184	L-110-12	COMMON ELECTRIC DUCTBANK, 16-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	2,307	LF		
185	L-110-13	COMMON ELECTRIC DUCTBANK, 20-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	771	LF		
186	L-110-14	FAA DUCTBANK, 2-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	209	LF		
187	L-110-15	FAA DUCTBANK, 4-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	2,683	LF		
188	L-110-16	FAA DUCTBANK, 4-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	460	LF		
189	L-110-17	FAA DUCTBANK, 8-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	1,726	LF		
190	L-110-18	FAA DUCTBANK, 10-WAY, 2" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	110	LF		

Name of Bidder: ________________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
191	L-110-19	FAA DUCTBANK, 10-WAY, 2" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	285	LF		
192	L-110-20	FAA DUCTBANK, 14-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	467	LF		
193	L-110-21	CECO DUCTBANK, 8-WAY, 5" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	963	LF		
193A	L-110-22	SURFACE MOUNTED DUCTS, 1-WAY, 1" RMC CONDUIT	22,181	LF		
193B	L-110-23	INNERDUCT	77,800	LF		
193C	L-110-24	1 WAY, 2-INCH PVC CONDUIT SAW KERF IN BITUMINOUS BASE COURSE UNDER FULL STRENGTH PAVEMENT	22,200	LF		
193D	L-110-25	2 WAY, 2-INCH PVC CONDUIT SAW KERF IN BITUMINOUS BASE COURSE UNDER FULL STRENGTH PAVEMENT	1,400	LF		
194	L-111-01	10.75" STEEL CASING FOR CED ELECTRICAL DUCTBANK JACKED IN PLACE	620	LF		
195	L-111-02	16" STEEL CASING FOR CED ELECTRICAL DUCTBANK JACKED IN PLACE	310	LF		
196	L-111-03	18" STEEL CASING FOR CED ELECTRICAL DUCTBANK JACKED IN PLACE	1,365	LF		
197	L-111-04	24" STEEL CASING FOR CED ELECTRICAL DUCTBANK JACKED IN PLACE	342	LF		
198	L-111-05	48" STEEL CASING FOR CED ELECTRICAL DUCTBANK JACKED IN PLACE	880	LF		
199	L-115-01	CED MANHOLE NON-AIRCRAFT RATED	19	EACH		
199A	L-115-01A	CED MANHOLE AIRCRAFT RATED	1	EACH		
200	L-115-02	CED MANHOLE CLUSTER, 2-STRUCTURE, NON-AIRCRAFT RATED	12	EACH		
201	L-115-03	CED MANHOLE CLUSTER, 2-STRUCTURE, AIRCRAFT RATED	13	EACH		

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ________________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
202	L-115-04	CED MANHOLE CLUSTER, 3-STRUCTURE, NON-AIRCRAFT RATED	3	EACH		
203	L-115-05	CED MANHOLE CLUSTER, 3-STRUCTURE, AIRCRAFT RATED	1	EACH		
204	L-115-06	CED MANHOLE CLUSTER, 4-STRUCTURE, NON-AIRCRAFT RATED	6	EACH		
205	L-115-07	CED MANHOLE CLUSTER, 5-STRUCTURE, NON-AIRCRAFT RATED	2	EACH		
206	L-115-08	CED HANDHOLE, NON-AIRCRAFT RATED	3	EACH		
207	L-115-09	CED HANDHOLE, AIRCRAFT RATED	8	EACH		
208	L-115-10	CED HANDHOLE CLUSTER, 2-STRUCTURE, NON-AIRCRAFT RATED	5	EACH		
209	L-115-11	CED HANDHOLE CLUSTER, 2-STRUCTURE, AIRCRAFT RATED	3	EACH		
210	L-115-12	CED HANDHOLE CLUSTER, 3-STRUCTURE, NON-AIRCRAFT RATED	5	EACH		
211	L-115-13	CED HANDHOLE CLUSTER, 3-STRUCTURE, AIRCRAFT RATED	3	EACH		
212	L-115-14	CED HANDHOLE CLUSTER, 5-STRUCTURE, NON-AIRCRAFT RATED	1	EACH		
213	L-115-15	COMED MANHOLE, NON-AIRCRAFT RATED, PRECAST	1	EACH		
214	L-115-16	CED-AIRFIELD ELECTRIC MANHOLE CLUSTER STRUCTURE ADJUSTMENT (12" OR LESS)	1	EACH		
215	L-115-17	CED-AIRFIELD ELECTRIC HANDHOLE CLUSTER STRUCTURE ADJUSTMENT (12" OR LESS)	1	EACH		
216	L-115-18	CED-AIRFIELD ELECTRIC HANDHOLE CLUSTER STRUCTURE ADJUSTMENT (GREATER THAN 12")	1	EACH		
217	L-125-01	ALLOWANCE FOR MODIFICATIONS TO EXISTING AIRFIELD LIGHTING CONTROL SYSTEM (ALCS)	1	ALLOW	$ 500,000.00	$ 500,000.00

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ________________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
218	L-140-01	RUNWAY PAVEMENT WEATHER SENSOR REMOTE PROCESSING UNIT	1	EACH		
219	L-140-02	RUNWAY PAVEMENT WEATHER SENSOR ASSEMBLY	1	EACH		
220	L-891-01	RUNWAY 9R ALSF-2 APPROACH LIGHTING SYSTEM, COMPLETE	1	LS		
221	L-891-02	RUNWAY 27L ALSF-2 APPROACH LIGHTING SYSTEM, COMPLETE	1	LS		
222	L-891-03	RUNWAY 9R ALSF-2 TOLLWAY BRIDGE STRUCTURE, COMPLETE	1	LS		
223	L-891-04	RUNWAY 27L ALSF-2 SPECIAL CANTILEVERED STRUCTURE, COMPLETE	1	LS		
224	L-895-01	RUNWAY 27L FAR FIELD MONITOR INFRASTRUCTURE	1	LS		
225	L-895-02	RUNWAY 27L INNER MARKER INFRASTRUCTURE	1	LS		
226	L-895-03	RUNWAY 9R LOCALIZER INFRASTRUCTURE	1	LS		
227	L-895-04	RUNWAY 9R PAPI INFRASTRUCTURE	1	LS		
228	L-895-05	RUNWAY 9R TOUCHDOWN RVR INFRASTRUCTURE	1	LS		
229	L-895-06	RUNWAY 9R-27L MID RVR INFRASTRUCTURE	1	LS		
230	X-100-01	SITE DEMOLITION	1	LS		
231	X-100-02	FAA NAVAID REMOVAL	1	LS		
232	X-100-03	ALLOWANCE FOR UNFORESEEN CONDITIONS	1	ALLOW	$ 750,000.00	$ 750,000.00
233	X-200-01	ARTIFICIAL TURF OVER PAVEMENT	1,069	SY		
234	20200100	EARTH EXCAVATION	3,083	CY		
236	21101625	TOPSOIL FURNISH AND PLACE, 6"	2,148	SY		

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ______________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
237	25100127	MULCH, METHOD 3A	2.00	ACRE		
237A	28100105	STONE RIPRAP, CLASS A3	107	SY		
237B	28200200	FILTER FABRIC	123	SY		
239	40200900	AGGREGATE SURFACE COURSE, TYPE B	991	CY		
239A	50102400	CONCRETE REMOVAL	23	CY		
239B	66400205	CHAIN LINK FENCE, 5'	24	LF		
240A	X0323265	REMOVE EXISTING RIPRAP	82	SY		
240B	X0327758	RELOCATE EXISTING CONDUIT AND CABLES	176	LF		
240C	X0900075	COFFERDAM (TYPE 1) (IN-STREAM/WETLAND WORK)	1	EACH		
240D	X2200003	FENCE (SPECIAL)	182	LF		
241	X4200408	PORTLAND CEMENT CONCRETE PAVEMENT 8", SPECIAL	567	SY		
241A	X5011100	FOUNDATION REMOVAL	1	EACH		
241B	X5012502	CONCRETE REMOVAL (SPECIAL)	63	CY		
241C	X6640300	CHAIN LINK FENCE REMOVAL	24	LF		
241D	X8440110	RELOCATE EXISTING LIGHT POLE WITH LUMINAIRE	1	EACH		
241E	X8950215	RELOCATE EXISTING HANDHOLE	2	EACH		
241F	Z0005305	BOX CULVERTS TO BE CLEANED	15	LF		
241G	Z0022800	FENCE REMOVAL	639	LF		
242	JI251010	EROSION CONTROL BLANKET, BIODEGRADABLE NETTING	16,458	SY		

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ______________________________

ITEM NO.	PAY ITEM NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
242A	JI501031	REMOVAL OF MOVEABLE GATE SYSTEM	1	EACH		
242B	JI606010	GUTTER, TYPE G-2	20	LF		
242C	JI836009	LIGHT POLE FOUNDATION (SPECIAL)	1	EACH		
243	JS280020	MANAGEMENT OF EROSION AND SEDIMENT CONTROL	6	CAL. MO.		
243A	JS280080	FLOTATION BOOM	79	LF		
243B	JS280100	SUPER SILT FENCE	240	LF		
245	JS280151	SAME-DAY STABILIZATION	8,229	SY		
245A	JS810220	CONDUIT ENCASED IN CONCRETE, 3" DIA., PVC	176	LF		
246	JS810883	UNDERGROUND CONDUIT, COILABLE NONMETALLIC CONDUIT, 8" DIA.	1,087	LF		
246A	JT131430	CONDUIT REMOVAL	172	LF		
246B	JT132634	CCTV SYSTEM COMMISSIONING ALLOWANCE	1	ALLOW	$ 10,000.00	$ 10,000.00
247	JT154015	ALLOWANCE FOR UNFORESEEN DRAINAGE WORK	1	ALLOW	$ 10,000.00	$ 10,000.00
248	JT250446	SEEDING, GRASS-FORB MIX 2 (SPECIAL)	3.00	ACRE		
249	JT570P21	PERFORMANCE BASED RETAINING WALL, NO. 1	738	SF		
249A	JT570P22	PERFORMANCE BASED RETAINING WALL, NO. 2	92	SF		
		CONTRACT BASE BID:				

SCHEDULE OF PRICES

Runway 9R-27L Extension - East

Specification No. 1190708

Name of Bidder: ________________________________

NOTES TO BIDDER:

1) **Total price for mobilization must not exceed 6% of the Contract Base Bid.**
2) **Bidders should round all quoted prices to the nearest two decimal points.**
3) **In the event of discrepancy between the "Unit Price" and the "Total Price", the Unit Price will prevail.**
4) **The Chief Procurement Officer reserves the right to make corrections, after receiving the bids, to any clerical error apparent on the above Line Items, including but not limited to obviously incorrect units or misplaced decimal points, or arithmetic error. The Bidder must bid all line items set forth on the Schedule of Prices, except to the extent that the Specifications expressly allow otherwise. In the event that comparison of the Bidder's "Unit Price" and "Total Price" submitted for any line item reveals a calculation error, the Unit Price will prevail.**
5) **Bidder must not assign a greater DBE participation amount to any allowance greater than the Contract DBE Participation Goal.**
6) **The Commissioner has determined per Part Two, General Conditions that the safety representative for this project is not permitted to have other responsibilities.**

CITY OF CHICAGO
DEPARTMENT OF AVIATION
O'HARE INTERNATIONAL AIRPORT
RUNWAY 9R-27L EXTENSION – EAST

PART THREE OF THREE
TECHNICAL SPECIFICATIONS

SPECIFICATION NUMBER: 1190708
PROJECT NUMBER: OH.6144.200.422

CITY OF CHICAGO
Lori E. Lightfoot
Mayor

O'HARE INTERNATIONAL AIRPORT
Jamie L. Rhee
Commissioner
Chicago Department of Aviation

Issued by:

DEPARTMENT OF PROCUREMENT SERVICES
Shannon E. Andrews
Chief Procurement Officer

ISSUED FOR ADDENDUM NO. 3
FEBRUARY 26, 2020

INSTALLATION OF UNDERGROUND CABLE FOR AIRPORTS SECTION L-108

PART 1 DESCRIPTION

1.01 GENERAL

A. The work consists of furnishing and installing underground cable in accordance with these Specifications at the locations shown in the Drawings. This item includes the installation of airfield lighting and power cables. It includes cable connections, splicing, tagging, cable marking, and testing of the installation and all work necessary to place the cable in operating condition as a completed unit to the satisfaction of the Commissioner. The work under this Section is subject to the requirements of the Contract Documents.

PART 2 EQUIPMENT AND MATERIALS

2.01 GENERAL

A. Airport underground cables covered by Federal Aviation Administration (FAA) Specifications must have the prior approval of the FAA, and are described in Advisory Circular (AC) 150/5345-7 (latest revision), "Specification for L-824 Underground Electrical Cable for Airport Lighting Circuits” and must be listed in the latest issue of FAA Advisory Circular (AC) 150/5345-53 “Airport Lighting Equipment Certification Program”, Appendix 3 and 4 Addendum.

B. All other equipment and materials covered by other referenced Specifications will be subject to acceptance through manufacturer's certification of compliance with the applicable Specification, when requested by the Commissioner.

C. All materials and equipment used to construct this item must be submitted to the Commissioner for approval prior to ordering the materials and equipment. Submittals consisting of marked catalog sheets or shop drawings must be provided. Submittal data must be presented in a clear, precise, and thorough manner. Manufacturer’s certifications will not relieve the Contractor of his responsibility to provide materials in accordance with these Specifications and acceptable to the Commissioner. Materials supplied and/or installed that do not materially comply with these Specifications must be removed, when directed by the Commissioner, and replaced with materials that comply with these Specifications, at the sole cost of the Contractor.

D. All equipment and materials furnished and installed under this Section must be guaranteed against defects in materials and workmanship for a period of at least 12 months from final acceptance by the Commissioner. The defective materials and/or equipment must be repaired or replaced, at the Commissioner's discretion at the sole cost of the Contractor. The Contractor must be responsible to maintain the required insulation resistance with isolation transformers connected in new circuits and new segments of existing circuits through the end of the Contract warranty period.

2.02 SERIES AIRFIELD LIGHTING CABLE, COUNTERPOISE, GUARD WIREAND GROUNDING CONDUCTORS

A. Runway and taxiway series lighting cables must be 5,000 volt (5KV) MV-90 cross-linked polyethylene (XLPE) insulated and must conform to the requirements of AC 150/5345-7 (latest revision), L-824 Type C, 5KV , size 6 AWG copper, 7 strand, single conductor cable and as indicated in the Contract Drawings. Cables must have a conductor stress relief shield, in accordance with Section 3 of the Insulated Cable Engineers Association Inc, ICEA S-96-659/NEMA WC71 as referenced in AC 150/5345-7 (latest revision). Acceptable manufacturer of this type of cable are Draka Cableteq USA; Prysmian Power Cables and Systems USA, LLC; South Wire Company; and Coleman Cable, Inc.; or other manufacturers approved by FAA and listed in the current AC150/5345-53 Appendix 3 Addendum.

B. All CED electrical ductbanks must be provided with lightning protection, either with counterpoise conductor or FAA guard wire conductor, depending on the cables installed in the ductbank. Ductbanks containing FAA copper cables must be provided with FAA guard wire, all other ductbanks must be provided with counterpoise only.

C. Airfield lighting counterpoise conductors installed underground must be soft drawn bare copper, size 6 AWG, solid, and must conform to the requirements of AC 150/5340-30 (latest revision), Chapter 12, Equipment and Material. Acceptable manufacturers of this type of wire are Draka Cableteq USA; Prysmian Power Cables and Systems USA, LLC; South Wire Company; and Coleman Cable, Inc.

D. FAA airfield guard wire conductors installed underground must be soft drawn bare copper, 1/0 AWG, stranded, and must conform to the requirements of ~~FAA standard 019e, Section 4.2.1.5 Equipment and Material~~FAA Standard 019f. Acceptable manufacturers of this type of wire are Draka Cableteq USA; Prysmian Power Cables and Systems USA, LLC; South Wire Company; and Coleman Cable, Inc

E. Equipment grounding conductors installed within airfield lighting bases/ fixtures, grounding conductors installed underground in conduit or ductbank must be soft drawn copper, size 6 AWG, 7 strand, with a 45 mil minimum coating of Type XHHW green insulation for airfield lighting and shall conform to the requirements of AC 150/5340-30 (latest revision), Chapter 12, Equipment and Material. Acceptable manufacturers of this type of wire are Draka Cableteq USA; Prysmian Power Cables and Systems USA, LLC; South Wire Company; and Coleman Cable, Inc..

F. Equipment grounding conductors installed within manholes must be soft drawn copper, utilizing a grounding bus of 4/0 AWG bare stranded copper and size 2 AWG pigtails bare copper to bond all metal hardware within the structure. The equipment grounding conductor must be bonded to ¾" diameter, 10'-0" long stainless steel ground rod installed in each manhole. The Equipment Grounding System must conform to the requirements of AC 150/5370-10 (latest revision). Acceptable manufacturers of this type of wire are Draka Cableteq USA; Prysmian Power Cables and Systems USA, LLC; South Wire Company; and Coleman Cable, Inc. Ground bus, ground pigtails, and ground rods are included in the unit price of the L-115 electrical manhole pay items.

G. Equipment grounding conductors installed within handholes must be soft drawn copper, utilizing a ground bus of 4/0 AWG stranded copper with 45 mil minimum coating of Type XHHW green insulation and size 2 AWG pigtails with a 45 mil minimum coating of Type XHHW green insulation to bond all metal hardware within the structure. The equipment grounding conductor must be bonded to ¾" diameter, 10'-0" long stainless steel ground rod installed in each handhole. The Equipment Grounding System must conform to the requirements of AC 150/5370-10 (latest revision). Acceptable manufacturers of this type of wire are Draka Cableteq USA; Prysmian Power Cables and Systems USA, LLC; South Wire Company; and Coleman Cable, Inc. Ground bus, ground pigtails, and ground rods are included in the unit price of the L-115 electrical handhole pay items.

H. Samples and reports on the results of shop tests for all wire and cables and descriptive literature for cable connectors, splices and terminations must be submitted for review by the Commissioner prior to installation.

I. The following wires and cables must be tested after installation but before final connections are made up: Service feeders, distribution feeders, branch circuit wiring and control wiring.

2.03 GROUND RODS

A. Ground rods must be Type 304 solid stainless steel, ¾” diameter x 10’-0” long.

2.04 CABLE CONNECTIONS

A. Cable connectors for series airfield lighting cables must be factory-molded or field attached plug-in connectors in accordance with the following. When the Plans or the proposal permit a choice of connection, the Contractor must indicate in the bid the type of connection that will be furnished.

1. The Field-Attached Plug-in Splice: Figure 3 of AC 150/5345-26 (latest revision), "Specification for L-823 Plug and Receptacle, Cable Connectors," employing connector kits, is approved for field attachment to single conductor cables.

2. The Factory-Molded Plug-in Splice: Specification for L-823 Connectors, Factory-Molded to individual conductors, is approved.

B. Series circuit cable connectors for the connection of two single conductor wires to the secondary connector on the airfield lighting isolation transformer leads must be in accordance with FAA Specification L-823, Figure 2, of AC 150/5345-26 (latest revision).

C. For CDA power circuit (non-airfield lighting 5 KV) cables at 600V – 7500V, splices and terminations must be made with compression type connectors and lugs that are U.L. listed and per the NEC. All lugs and connectors must be of the smooth conformable compression type suitable for use on 5 KV. Lugs must be two-hole, color-keyed for medium voltage requirements. Lug equipment and tools must be per the lug manufacturer’s recommendations. All airfield splices must conform to appropriate FAA Advisory Circulars.

D. For CDA power circuit cables at 0 - 600V, splices and terminations must be made with compression type connectors and lugs. Lugs must be 2 hole, color keyed. Lug bolting must include a flat washer, a Belleville washer, and a locknut. The lug manufacturer's recommended tools must be used. Indenter type compression fittings are not acceptable. All airfield splices must conform to appropriate FAA Advisory Circulars.

E. Provide FAA approved electrical tape (Scotch Electrical Tape No. 88, 1 ½” wide; and Scotch 130C, 2” wide, as manufactured by Minnesota Mining and Company, or approved equivalent) and 16” of approved heat shrink tubing over all primary cable splices in manholes, handholes and all light bases.

F. Acceptable manufacturers of cable connectors are Amerace Ltd., Crouse-Hinds Molded products and Integro, LCC, and other manufacturers approved by FAA and listed in the current revision of FAA AC 150/5345-53C, Appendix 3.

2.05 SHRINKABLE CABLE CONNECTOR KITS

A. Heat shrink tubing is to be designated for FAA Type L-823 plug and receptacle cable connectors. The heat shrink tubing is to be thick wall polyolefin, 16” full length, with a minimum shrink ratio of 3:1, designed for use with a heat gun or propane torch, and suitable for indoor or outdoor applications. Taping of connectors will not be permitted in lieu of heat shrink tubing. Connectors must be taped with a few turns of FAA approved vinyl tape prior to the installation of heat shrink tubing. Heat shrink tubing kits are to be installed in manholes, handholes and light bases. The secondary L-823 connectors from isolation transformers to airfield lighting/signage matching connectors must not have heat shrink tubing applied. These connectors are designed to be secured to the fixture and sign cover plates to provide an electrical disconnect at the frangible connector location, by break away action of the L-823 connectors.

PART 3 CONSTRUCTION METHODS

3.01 GENERAL

A. The Contractor must install the specified cable at the approximate locations indicated in the Drawings.

B. The work performed under this Section of these Specifications must conform to the requirements of the Chicago Electrical Code and the National Electric Code. The electrical systems must be complete with all necessary accessories to make them fully operational with the greatest assurance of protection to life and property.

C. The Plans indicate the extent and general arrangement of the electrical work. If any departures from the Plans are deemed necessary by the Contractor, details of such departures and the reasons therefore must be submitted in writing as soon as practicable to the Commissioner for approval. No such departures must be made without the prior written approval of the Commissioner.

D. Cable connections between lights will be permitted only at the light locations for connecting the underground cable to the primary leads of the individual isolation transformers. The Contractor must be responsible for providing cable in continuous lengths for home runs or other long cable runs without connections, unless otherwise authorized in writing by the Commissioner or shown in the Drawings.

E. In addition to connectors being installed at individual isolation transformers, L-823 cable connectors for maintenance and test points must be installed at locations shown on the Drawings. Cable circuit identification markers must be installed on both sides of the L-823 connectors installed or at least once in each access point where L-823 connectors are not installed.

F. Provide not less three feet of cable slack on each side of all connections, isolation transformers, light units, and at points where cable is connected to field equipment. Where provisions must be made for testing or for future above grade connections, provide enough slack to allow the cable to be extended at least one foot vertically above the top of the access structure. This requirement also applies where primary cable passes through empty base cans, junction and access structures to allow for future connections, or as designated by the Commissioner.

3.02 INSTALLATION IN CONDUIT

A. This item includes the installation of the cable in duct or conduit as described below. The maximum number and voltage ratings of cables installed in each single duct or conduit, and the current-carrying capacity of each cable must be in accordance with the Chicago Electric Code.

B. The Contractor must make no connections or joints of any kind in cables installed in conduits or ducts.

C. The conduit must be installed as a separate item in accordance with Section L-110, Installation of Airport Underground Electrical Duct. The Contractor must run a mandrel through duct banks or conduit prior to installation of cable to insure that the conduit is open, continuous, and clear of debris. The Contractor must swab out all conduits/ducts and clean base can, manhole, etc., interiors immediately prior to pulling cable. Once cleaned and swabbed, the base cans and all accessible points of entry to the duct/conduit system must be kept closed except when installing cables. Cleaning of ducts, base cans, manholes, etc. is incidental to the pay item being cleaned. All raceway systems left open, after initial cleaning, for any reason, must be recleaned at the

Contractor’s expense. All accessible points must be kept closed when not installing cable. The Contractor must verify existing ducts proposed for use in this project as clear and open. The Contractor must notify the Commissioner of any blockage in the existing ducts. The cable must be installed in a manner to prevent harmful stretching of the conductor, injury to the insulation, or damage to the outer protective covering. The ends of all cables must be sealed with moisture-seal tape before pulling into the conduit, and it must be left sealed until connections are made. Where more than one cable is to be installed in a conduit or duct under the same Contract, all cable must be pulled in the conduit or duct at the same time. The pulling of a cable through ducts or conduits may be accomplished by hand winch or power winch with the use of cable grips or pulling eyes. Installation of cable in ducts must be carried out by the use of nylon or polypropylene pull lines. Flat steel tapes or steel cables must not be used. Pulling tensions must be governed by recommended standard practices for straight pulls or bends and must not exceed manufacturer's recommendation. The Contractor must submit pulling tension values to the Commissioner prior to any cable installation. If required by the Commissioner, pulling tension values for cable pulls must be monitored by a dynamometer in the presence of the Commissioner. Cable pull tensions must be recorded by the Contractor and reviewed by the Commissioner. Cables exceeding the maximum allowable pulling tension values must be removed and replaced by the Contractor at Contractor’s expense. A lubricant recommended for the type of cable being installed must be used where pulling lubricant is required. All cable must be installed directly from reels. Dragging the cable over the ground and across base can or manhole edges is not permitted. When cable must be coiled, lay cable out on a canvas tarp or utilize other appropriate means to prevent abrasion to the cable jacket.

D. Cable installation, handling, and storage must be per manufacturer’s recommendations. During cold weather, particular attention must be paid to the manufacturer’s minimum installation temperature. At the Contractor’s option, the Contractor may submit a plan, for review by the Commissioner, for heated storage of the cable and maintenance of an acceptable cable temperature during installation when temperatures are below the manufacturer’s minimum cable installation temperature.

3.03 SPLICING

A. For 5KV series circuit airfield lighting, the connections of the type required in the Plans must be made by experienced personnel regularly engaged in this type of work and must be completed in accordance with the following:

1. Field-attached or Plug-in Splices. (5KV Splices) These must be assembled in accordance with the National Electrical Code and manufacturer's recommendations. These splices must be made with compression type connectors or lugs plugging directly into mating connectors. In all cases the joint where the connectors come together must be cleaned, taped and encased with heat shrink tubing. Indenter type compression fittings are not acceptable. Provide tape and heat shrink tubing over all cable splices in manholes, handholes, and light bases.
2. For splicing cables with L-823 plug and receptacle cable connectors, see Paragraphs 2.04A, 2.04B, and 2.05 above.
3. Every splice must be housed in a light base, handhole, or manhole. In a light base, leave at least 6 feet of slack cable on each side of the splice. In a handhole or manhole, the cable must make one loop around the handhole or manhole and the splice must be located near the center of the loop.

B. For power cable splicing above 600 Volt, splices and terminations will not be permitted except in junction boxes, manholes and handholes. These must be assembled in accordance with the National Electrical Code and manufacturer's recommendations. Splices and terminations must be made with compression type connectors and lugs for medium voltage use. Splices must only be made where necessary when pulling tensions exceed manufacturer's recommendations. Lugs will only be allowed in above ground enclosures or junction boxes. Lugs must be 2-hole, color keyed only and installed with tools as required by the lug manufacturer. Lug bolting and solderless lug terminations must be per manufacturer's recommendation for medium voltage.

C. For 600 Volt and lower cables, splices and terminations will not be permitted except in junction boxes, pad-mounted transformers, manholes, and handholes. These must be assembled in accordance with the National Electrical Code and manufacturer's recommendations. Splices and terminations must be made with compression type connectors and lugs. Splices must only be made where necessary at branches or where pulling tensions exceed manufacturer's' recommendations. The lug manufacturer's recommended tools must be used. Indenter type compression fittings are not acceptable. Lugs must be 2 hole, color keyed. Lug bolting must include a flat washer, a Belleville washer and a locknut. All stranded wire must be terminated with solderless lugs.

D. The Contractor must splice underground signal (control, telephone) cables as follows:

1. Kit and Resin: The splices must consist of a rigid polypropylene mold body with a built-in spacer web to provide cable centering and proper compound coverage. The mold body must be filled with a flexible polyurethane electrical compound capable of continuous operation at 90 degrees C, with an emergency overload temperature rating of 130 degrees C. Splices must have provisions for inline splicing of shielded or non-shielded plastic or rubber-jacketed control (telephone) cables. The splices must be rated for direct burial applications. For control cables with outside diameters between 0.25 inches and 3.25 inches, 3M Scotchcast Signal and Control Cable In-line Splicing kits of the 72N series meet these Specifications, and are acceptable.

2. Connectors: Control cable splice connectors must be in-line type, in which two conductors are spliced by laying one conductor in each end of the connector and crimping the connector with a special tool selected to match the connector type and size. Before crimping, the connector is open on one side of its length. After crimping, the connector is closed all around its length. The connector bodies must be made with a tin-plated phosphor bronze piece on the inside, to contact the cable conductors, and bonded polyester insulation on the outside to insulate the connection. The insulation must be color coded to denote wire size range. The cable splice connectors and tools must incorporate the insulation displacement termination technique which uses a slotted, tin-plated contact to displace the conductor insulation, thus providing four redundant electrical contact points. Connectors which require prestripping the conductor must not be used.

3.04 COUNTERPOISE OR FAA GUARD WIRE INSTALLATION FOR LIGHTNING PROTECTION

A. Counterpoise or FAA guard wire must be installed for lightning protection of the underground cables. Counterpoise or FAA guard wire must be installed in the same trench for the entire length of buried cable, conduits and duct banks that are installed to contain airfield lighting cables and/or FAA copper conductors. In trenches counterpoise or FAA guard wire must be installed continuously a minimum of 10 inches above the cable, conduit or duct bank, or as shown on the Drawings if greater. Additionally, counterpoise or FAA guard wire must be installed at least 8 inches below the top of subgrade in paved areas or 10 inches below finished grade in un-paved areas. This dimension may be less than 4 inches where conduit is to be embedded in existing pavement. Counterpoise or FAA guard wire must not be installed in conduit. Refer to paragraph 2.02B as to where counterpoise wire or FAA guard wire is required. The counterpoise wire must be exothermically welded to ground rods spaced a maximum of 500 feet apart around the entire circuit. The FAA guard wire must be exothermically welded to ground rods spaced a maximum of 90 feet apart around the entire circuit. Refer to paragraphs 2.02C and 2.02D for airfield lighting counterpoise size and FAA guard wire size, respectively.

B. The counterpoise or FAA guard wire must be routed around each edge light fixture base, handhole and manhole. Connection is not made to light fixture base can (edge light), handhold or manhole. The requirements for counterpoise must conform to the FAA Advisory Circular AC 150/5340-30 (latest revision), Chapter 12, paragraph 12.5 “Counterpoise” (Lightning Protection). The counterpoise or FAA guard wire must also be exothermically welded to ground rods installed as per these Specifications.

C. For in-pavement runway touchdown zone lights, runway centerline lights and taxiway centerline lights installed in rigid pavement the counterpoise connections are made to the exterior ground lug on fixture bases and bonded to the rebar cage around the fixture base. The counterpoise wire must also be exothermically welded to ground rods installed as shown on the Drawings, but not more than 500 feet (150 m) apart around the entire circuit.

3.05 SAFETY (EQUIPMENT) GROUND

A. A separate safety (equipment) ground system must be provided in addition to the counterpoise wire. The requirements for safety ground must conform to the FAA Advisory Circular AC 150/5340-30 (latest revision), Chapter 12, Paragraph 12.6 “Light base Ground” and as shown in the Drawings. The equipment ground must not run in conduit between fixture bases.

1. A ground rod must be installed at and securely attached with a size 6 AWG bare jumper to each airfield in-pavement light fixture base can.
2. For each electrical manhole, bond all metal surfaces to the 4/0 AWG bare stranded copper ground bus utilizing size 2 AWG pigtail bare copper cables.
3. For each electrical handhole, bond all metal surfaces to the 4/0 AWG stranded copper insulated ground bus utilizing size 2 AWG pigtail insulated cables. Insulation must be green, Type XHHW.

4. For each Type 1 marker base handhole, bond all metal surfaces to the ground rod in the handhole using size 6 AWG green insulated wire.

3.06 COUNTERPOISE OR FAA GUARD WIRE INSTALLATION ABOVE MULTIPLE CONDUITS AND DUCT BANKS

A. Counterpoise or FAA guard wires must be installed above multiple conduits/duct banks for airfield lighting or FAA copper cables, to provide a complete cone of protection over the cables. When multiple conduits and/or duct banks are installed in the same trench, the number and location of counterpoise or FAA guard wires above the conduits must be adequate to provide a complete cone of protection measured 22 ½ degrees each side of vertical. For ductbank of extra width, multiple counterpoise or FAA guard wires may be required.

B. Where duct banks pass under pavement to be constructed in the Project, the counterpoise or FAA guard wire must be placed above the duct bank.

3.07 COUNTERPOISE OR FAA GUARD WIRE INSTALLATION AT EXISTING DUCT BANKS

A. Where new ductbank is to connect to an existing ductbank and counterpoise/guard wire system, the new counterpoise or FAA guard wiring must be terminated at ground rods at the end of the existing duct bank. The new counterpoise or FAA guard wire must be bonded to the existing counterpoise or FAA guard wire system in accordance with these Specifications.

3.08 EXOTHERMIC BONDING FOR COUNTERPOISE, FAA GUARD WIRE, AND GROUNDING CONDUCTORS

A. Bonding of counterpoise or FAA guard wire must be by the exothermic welding process. Only personnel experienced in and regularly engaged in this type of work must make these connections.

B. Contractor must demonstrate to the satisfaction of the Commissioner, the welding kits, materials and procedures to be used for welded connections prior to any installations in the field. The installations must comply with the manufacturer's recommendations and the following:

1. All slag must be removed from welds.
2. For welds at light fixture base cans, all coated surface areas and "melt" areas, both inside and outside of base cans, damaged by exothermic bond process must be restored by

coating with a compound conforming to the base can manufacturer's recommendations.

3. All buried stainless steel, copper, and weld materials at weld connections must be thoroughly coated with 6 mil of 3M “Scotchkote”, or approved equivalent, or coated with coal tar bitumastic material to prevent surface exposure to corrosive soil or moisture.

3.09 INTERFERENCE WITH AIRPORT OPERATION

A. The normal operating functions of the Drawings will be continued and the work in some areas will be permitted only at specified times and during suitable weather conditions. The installation of equipment and the opening of vital circuits must be done only for minimum intervals at such times and with such restrictions as approved and agreed upon by the Commissioner and may be required during non-regular working hours. The installation of temporary wiring may also be required to permit operations and work in certain areas and will be required to maintain operation of all lighting.

3.10 TESTING REQUIREMENTS

A. The Contractor must furnish all necessary equipment and appliances for testing the underground cable circuits after installation. The Contractor must test and demonstrate in the presence of and to the satisfaction of the Commissioner the following:

1. That all lighting power and control circuits are continuous and free from short circuits. This task includes a megger test at the respective Airfield Lighting Vault.
2. That all circuits are free from unspecified grounds.
3. That the insulation resistance to ground of all nongrounded series circuits and all nongrounded conductors of multiple circuits is not less than 100 megohms at the Airfield Lighting Vault.
4. That all circuits are properly connected in accordance with applicable wiring diagrams.
5. That all circuits are operable. Tests must be conducted that include operating each control not less than 10 times and the continuous operation of each lighting and power circuit for not less than 1/2 hour at each intensity.
6. That for airfield ground testing other than FAA installations, the impedance to ground of each ground rod does not exceed 25 ohms prior to establishing connections to other ground

electrodes. The fall-of-potential ground impedance test must be utilized, as described by ANSI/IEEE Standard 81, to verify this requirement.

7. That for all FAA guard wire/FAA ground electrodes, the impedance to ground for each ground rod or connected system for ground electrodes must meet the requirement of FAA-STD-~~019e~~019f, *"Lightning and Surge Protection, Grounding, Bonding and Shielding Requirements for Facilities and Electronic Equipment"* and FAA-GL-918 (latest revision) *"FAA Great Lakes Region Specification for Construction of Terminal Navigational Aid Facilities"*. Ground resistance requirements related to FAA-ALSF-2 systems is outlined in FAA Specification Number FAA-C-2722, *"Construction of a High Intensity Approach Lighting System With Sequenced Flashing Lights for Category II (ALSF-2) Runways"*.

8. All tests and measurements must be documented in writing for future reference. A log must be maintained for all tests. This log must be certified before completion of the work both as to test value and date of test. The log and all test results must be submitted to the Commissioner.

9. All cables must be factory-tested and certified before shipping. The test reports must be submitted and approved by the Commissioner before shipping.

10. Tests must be coordinated with the field schedule and field conditions.

11. Before testing, all necessary precautions must be taken to ensure the safety of personnel and equipment. All enclosures for conductors and equipment must be properly grounded.

12. Any faults in the work performed by this Contractor or in materials furnished by this Contractor must be corrected or replaced promptly by this Contractor at his own expense. Any faults in materials furnished by the Contractor which are the result of careless, incompetent or improper workmanship must be repaired and the work retested.

3.11 TESTING PROCEDURES

A. After home-run cable installation operations have been completed, including splices and terminations, the individual conductors of all cables must have all test requirements listed in Section 3.10.

B. On all new airfield lighting circuits comprised of all new size 6 AWG-5 KV series circuit conductors, megger testing between fixtures will not be required provided that the 100 megohms requirement is met at the appropriate North or South Airfield Lighting Control Vault per 3.10.A.1, 2, 3.

With reference to new portions or extensions of size 6 AWG-5 KV cable that have been added to existing 5 KV cabling circuit, the megger testing must conform to Paragraph 3.11.G of this Specification and the 100 megohms requirement at the vault per Paragraph 3.10.A.1, 2, 3. Megger testing between fixtures will be required to check for improper grounds if the vault testing with adjusted values for testing based on Paragraph 3.11.G cannot be met.

C. Any cable which fails to meet any specified tests must be removed and replaced by the Contractor, without added expense to the Contract. Any splice or termination which fails must be repaired or replaced as determined by the Commissioner.

D. All new cables provided due to failures during the warranty or the above specified tests must be tested in the same manner and at the same times as the original new cables provided by this Contract.

E. The Contractor must maintain a readily available supply of replacement cables so that in the case of a cable failure no delays shall occur in the prompt replacement or repair of the faulty cable.

F. Tests must be performed in accordance with ICEA and AEIC recommended procedures. The Contractor must notify the Commissioner two weeks prior to each test that these tests can be witnessed by the Commissioner. Certified copies of all tests must be delivered to the Commissioner upon completion of all tests.

G. Whenever the new 5KV cables are spliced or otherwise connected to existing cables which are older, have a lower insulation level or have a different construction, the test voltage and time duration applied to this combination must not exceed the lower of the specified values for the different types of cable. It must be the Contractor's sole responsibility to check the conditions and to establish these test values before setting up the tests.

H. Tests must be coordinated with the field schedule and field conditions. Before testing, all necessary precautions must be taken to ensure the safety of personnel and equipment. All enclosures for conductors and equipment must be properly grounded.

3.12 IDENTIFICATION OF CONDUCTORS

A. Where conductors pass through handholes, manholes and at each side of an L-823 Connector they must be identified with phenolic engraved tags. Each conductor must be tagged at each end of each handhole, manhole, and light base. For the North Airfield (supplied from the North Airfield Lighting Control Vault) the tags must be yellow with black one-quarter inch high lettering and attached with nylon locking ties at each end of the tag. For the South Airfield (supplied from the South Airfield Lighting Control Vault) the tags must be white with black one-quarter inch high lettering and attached with nylon locking ties at each end of the tag. The cable must be thoroughly cleaned before applying the tags. At splices, conductors on each side of the splice shall be tagged. The circuit identification must be as shown on the Contract Drawings and in accordance with Airfield Circuit Identification System.

PART 4 METHOD OF MEASUREMENT

4.01 MEASUREMENT

A. Cable and counterpoise wire installed must be measured by the number of lineal feet measured in place, completed, ready for operation, and accepted as satisfactory.

B. Separate measurement must be made for each cable or counterpoise wire installed. The footage of wire or cable will be lineal measurement plus two percent for slack of wire or cable. Measurement will be from center to center of manholes, handholes and bases. Additional length for connection of isolation transformers, in handholes, etc. will be included in the appropriate items of this Contract. Connector kits, cable tagging, and electrical testing will not be paid for separately; but, will be included in the unit price for the pay item for wire and/or cable installed. Ground rods and exothermic welding for counterpoise wire and guard wire will not be measured and paid for separately, but are included in the unit price of the pay items in this Specification requiring their installation.

C. FAA guard wire will not be measured and paid for separately but shall be included in the unit prices of the items requiring its installation.

PART 5 BASIS OF PAYMENT

5.01 PAYMENT

A. Payment will be made at the Contract unit price for wire and cable installed by the Contractor and accepted by the Commissioner. This price includes full compensation for furnishing all materials and for all preparation and installation of these materials, and for all labor, equipment, tools, and all work necessary to complete this item.

B. Payment will be made under the following items:

ITEM NO.	DESCRIPTION	UOM
L-108-01	POWER CABLE – L-824, TYPE C 5KV, 1/C, SIZE 6 AWG	LF
L-108-02	COUNTERPOISE WIRE – 1/C, SIZE 6 AWG, 600 V, BARE COPPER	LF
L-108-03	2-1/C #10 XHHW-2 CABLE, 1/C #6 GND, IN RMC SURFACE MOUNTED CONDUIT	LF

END OF SECTION L-108

INSTALLATION OF AIRPORT UNDERGROUND ELECTRICAL DUCT
SECTION L-110

PART 1 DESCRIPTION

1.01 GENERAL

A. The work consists of underground electrical conduit and ducts installed in accordance with this Specification at the locations and in accordance with the dimensions, designs, and details shown in the Drawings. The work includes the installation of all underground electrical ducts or underground conduits. It includes the connection of the ducts and conduit into the existing underground electrical system, including all trenching, jacking steel casing where shown on the Plans, backfilling, removal, restoration of any paved areas, connection to new or existing manholes and handholes, concrete encasement, installation of innerducts, mandreling and installation of nylon or polypropylene rope, capping and the testing of the installation as a completed duct system ready for installation of cables, to the satisfaction of the Commissioner. The work under this Section is subject to the requirements of the Contract Documents.

B. Special Requirements for ComEd Utility Ductbanks – Unless otherwise indicated on the Contract Plans, all ComEd ductbank materials, installation, ductbank run formations, curve layouts, transposition and connection to ComEd manholes must be in accordance with the ComEd Standards. Refer to CE-100, *Commentary on ComEd Standards for Utility Manholes, Ductbanks, and Equipment Foundations at the CDA/OMP*.

1.02 RELATED WORK

A. Section P-157 – Trench Backfilling

B. Section P-610 – Structural Portland Cement Concrete

PART 2 EQUIPMENT AND MATERIALS

2.01 GENERAL

A. Equipment and materials covered by referenced Specifications must be subject to acceptance through manufacturer's certification of compliance with the applicable Specification when so requested by the Commissioner.

2.02 POLYVINYLCHLORIDE (PVC) CONDUIT

A. Non-metallic conduit must be PVC Schedule 40 or Schedule 80 concrete encased as indicated on the Drawings.

B. PVC conduit, including elbows and couplings, must meet the requirements of NEMA standards TC2 (latest edition), UL Standard 651, Federal Specifications WC-1094A, and must be UL rated and listed for use with 90 degrees C-rated conductors in compliance with Article 352 of the NEC.

C. The conduit must be manufactured from PVC compound that meets the applicable requirements of ASTM No. D 1784.

D. PVC conduit fittings must meet with the requirements of NEMA Standard TC3 (latest edition), UL Standard 514 supplement, and Federal Specifications WC-1094A.

E. All PVC conduit and fittings for communication conduits that will carry fiber optic cables must utilize sweeping bends. The bend must allow for the minimum bending (radius) requirements of the innerduct manufacturer and installer.

F. Standard PVC fittings and PVC cement adhesive must be compatible with the conduits and must be obtained from the same conduit manufacturers.

G. Acceptable PVC conduit manufacturers are National Pipe, Carlon (Lamson and Sessions), Cantex, and IPEX.

H. Industry produced short radius PVC bends will not be allowed.

2.03 PVC-COATED GALVANIZED RIGID STEEL (GRS) CONDUIT

A. A Polyvinyl Chloride (PVC) coating nominal thickness 0.04 inches (40 mil), will be bonded to the exterior of the conduit. The bond between the coating and the conduit must be greater than the tensile strength of the plastic.

B. Fittings must be coated in the same manner as the conduit. Fittings must have a PVC sealing sleeve extending from the ends. The sleeve length must be approximately equal to the outside diameter of the conduit or 1-1/2 inches, whichever is smaller.

C. The PVC coated galvanized rigid conduit must be U.L. listed /labeled. The Manufacturer must submit certified test results from a recognized independent testing company validating that their product meets or exceeds the requirements of ASTM D870-02 Testing Water Resistance of PVC Coating Using Water Immersion and ASTM D2247-02 Testing Water Resistance of PVC Coating in 100% Relative Humidity, to signify compliance to the adhesion performance standards.

D. A urethane chemical coating must be uniformly and consistently applied to the interior of the conduit and fittings. The internal coating must be applied at a minimum thickness of 2 mils.

E. Provide solvent cement and patching compound as recommended by the manufacturer for sealing joints and repairing gouges and cuts.

F. Provide PVC coating cement and patching compound as recommended by the PVC coated conduit and fitting manufacturer.

G. PVC coated conduit and fittings must be 1 inch trade size or larger.

H. Galvanized rigid steel conduit heavy wall must be milled steel, hot-dip galvanized conduit, complying with ANSI C80.1 and Federal Specification WWC-581 and must be U.L. listed.

I. Elbows, bends, and fittings must be made of full weight materials and must comply with the above and threaded the same as conduit.

J. Threads for conduit, couplings and fittings must be full depth and clean cut. Field cut threads must be coated with Coppercoat or in accordance with manufacturer’s instruction.

2.04 CONCRETE

A. Concrete used to form duct banks with conduit must be as specified in Section P-610 Structural Portland Cement Concrete. Reinforcing bars where required will be as shown on the Drawings and in accordance with P-610.

2.05 INNERDUCT

A. Materials for innerducts for airfield communication cables will be subject to acceptance through manufacturer’s certification of compliance with applicable Specifications.

1. All innerduct must be provided with a pull rope.
2. Footage label must be sequentially marked on the innerduct.

B. Outdoor Installations

1. Innerduct that is to be installed outside, as indicated in the Contract Drawings, must meet the following requirements:

   a. The innerduct must meet or exceed the minimum standards of PE334470E/C as defined in ASTM D3350.
   b. The innerduct must conform to ASTM F2160.
   c. As indicated on the Contract Drawings, provide 1.00-inch for FAA or 1.25-inch for CDA innerduct for outdoor applications. The innerduct must meet the following Specifications.

(1)	Type	Solidwall
(2)	Wall Construction	SDR 11
(3)	Material	High Density Polyethylene
(4)	Color	Yellow for FAA single mode fiber; grey for FAA copper control cable; orange for all other applications.

   d. All solid wall innerduct, after final length trimming in manholes or building entrances, and prior to any cable installations within the innterduct must be reamed at the inside diameter edge at both ends of the innerduct to provide a smooth, rounded edge for protection to all copper and fiber optic cables and cable jacketing.

C. Indoor Installations

1. Innerduct that is installed indoors, as indicated in the Contract Drawings, must meet the following requirements.

   a. The plenum rated innerduct must be recognized per NEC Articles, 770 and 800 for Plenum, Riser and General Purpose Raceway for optical fiber and telecommunications cables.
   b. The riser rated innerduct must be recognized per NEC Articles, 770 and 800 for Riser and General Purpose Raceway for optical fiber and telecommunications cables.
   c. The innerduct must conform to UL 2024.
   d. As indicated on the Contract Drawings, provide 1.00-inch plenum or riser rated innerduct for FAA indoor applications. The innerduct for indoor applications must meet the following Specifications.

(1)	Type	Corrugated
(2)	Material	PVC (Riser Rated) PVDF Resin (Plenum Rated)
(3)	Inner Diameter	1.05 inches (+0.010 inch, -0.020 inch)
(4)	Outside Diameter	1.31 inches (+0.010 inch,

-0.020 inch

e. As indicated on the Contract Drawings, provide 1.25-inch plenum or riser rated innerduct for CDA indoor applications. The innerduct for indoor applications must meet the following Specifications.

(1)	Type	Corrugated
(2)	Material	PVC (Riser Rated) PVDF Resin (Plenum Rated)
(3)	Inner Diameter	1.38 inches (+0.010 inch, -0.020 inch)
(4)	Outside Diameter	1.65 inches (+0.010 inch, -0.020 inch

f. Innerduct color must be yellow for FAA single mode fiber, grey for FAA copper control cable, and must be orange for all other applications.

D. Pull Rope

1. Provide pull rope in all innerduct with minimum pull strength of 1250 pounds for outdoor applications and 900 pounds for indoor applications. The pull rope must extend 6 feet beyond the termination at each end.

E. Duct Plugs and Conduit Seals

1. Duct plugs and conduit/innerduct seals must be constructed of high impact plastic and fully corrosion resistant. Where fasteners are required they must be stainless steel. The duct plugs and conduit/innerduct seals must provide a water tight and gas tight installation. The devices must be easily installed or removed. The design must be of a split type configuration for retrofitting without any disassembly of existing conduits, innerducts, or cables. The compressible gaskets must be elastic, expandable, and durable for a permanent or temporary installation. Where conduits or innerducts contain pull ropes or cords the plug devices must have internal fastening loops to secure the rope or cord with slack within the conduit or innerduct for access at a later date during cable installations.

a. Blank Duct Plugs – Compression type mechanical plugs must be installed to seal spare conduits and spare innerducts of various sizes at all building/facility entrances and at the first manhole or handhole outside of the building/facility entrance. Plugs are to be sized per conduit inside diameters as required.

b. Innerduct Seals – Compression type mechanical seals must be provided to seal annular space around innerducts within conduits at all building entrances and at the first manhole or handhole outside of the building/facility entrance. Seals must be split type that can be installed around existing innerducts that are in place with or without cable.

c. Cable Seals – Compression type mechanical seals must be provided to seal all cable entrances in conduits and all cable entrances in innerduct at all building entrances and at the first manhole or handhole outside of the building/facility entrance. Fiber optic cable are installed individually, one cable of various diameter within one innerduct. 5KV or 600 volt power cables must have seals selected per total number of cables, diameter of cables, and conduit sizes as required.

F. Pulling Lubricant

1. A water based propylene glycol solution must be used when placing innerduct into duct banks as well as placing cable into innerduct.

2. The lubricant must have characteristics intended for the pulling of MDPE and HDPE fiber sheaths through PVC innerduct.

G. Provide all fittings, terminations, connectors, etc. for a complete integrated raceway system.

H. Acceptable innerduct manufacturers are Carlon, EW&C and Innerduct.

PART 3 CONSTRUCTION METHODS

3.01 GENERAL

A. The Contractor must install underground duct banks at the locations and grades as indicated in the Drawings. Conduits must be of the size, material, and type indicated in the Plans or Specifications. Where no size is indicated in the Drawings or Specifications, the conduits must not be less than 3 inches inside diameter. All duct banks must be laid to pitch toward structures for drainage as shown on the Drawings. Pockets or traps where moisture may accumulate are not acceptable unless pre-existing underground field conditions prohibit ductbank pitch to structure.

B. The Contractor must mandrel each conduit. After completion of construction, each conduit must first be thoroughly cleaned before being mandrelled. Cleaning can be accomplished by drawing a wire duct brush, a flexible mandrel or power water rodding/jetting through each conduit to make sure that no foreign materials are left in the conduits after construction. When cleaning is completed, each conduit must be mandrelled with a non-flexible, durable, wood or metal conduit mandrel made specifically for this purpose. The diameter of the mandrel must not be more than ¼ inch smaller in diameter of the bore of the conduit and the length of the mandrel must be at least 1 inch longer than the diameter of the bore.

C. Conduit installed must be provided with a nylon or polypropylene rope for pulling the permanent wiring. Sufficient length must be left in handholes and secured to prevent it from slipping back into the conduit.

D. Conduit must be securely fastened in place during construction and progress of the work and must be plugged to prevent seepage or grout, water, or dirt. Conduits must be placed on supports/spacers designed and manufactured for this specific purpose. When not being worked, conduits must be capped using metal or plastic caps designed for this purpose. The use of materials such as rags, paper, plastic bags or tape is forbidden. Any duct bank having a defective joint must not be installed.

E. Conduit must be encased in concrete, with a 3 inch minimum concrete envelope poured around all conduit.

F. Where turf is well established and the sod can be removed, it must be carefully stripped and properly stored and replaced after backfilling in accordance with Section 3.06, as directed by the Commissioner.

G. Trenches for conduit and ducts may be excavated manually or with mechanical trenching equipment. Walls of trenches must be essentially vertical so that a minimum of base material or soil is disturbed.

H. Dozers, wheel loaders, or motor graders must not be used to excavate the trench. The Contractor must ascertain the type of soil or rock to be excavated before bidding. All excavation material will be unclassified. Work shall be performed in accordance with Section 3.08-Unclassified Excavation.

I. Conduit must be provided with slip couplings where it crosses through or under transverse construction joints in Portland cement concrete pavement.

J. Conduit must be provided with approved expansion and deflection couplings where it crosses through expansion joints.

K. PVC-Coated Galvanized Rigid Steel Conduit must be provided with grounding bushings to insure continuity of ground for the underground electrical system. The grounding bushings must be threaded onto the conduit.

L. The Contractor must connect into the electrical duct bank system at the location indicated on the Plans by core drilling into structures, by connecting to existing conduit or ducts, or as directed by the Commissioner.

3.02 CONDUIT ENCASED IN CONCRETE

A. Unless otherwise shown in the Plans, concrete-encased conduit must be installed so that the top of the concrete envelope is not less than 30 inches below the finished subgrade where installed under runways, taxiways, aprons, or roads, and not less than 30 inches below finished grade where installed in unpaved areas. Ducts under paved areas must extend at least 5 feet beyond the edges of the pavement or 5 feet beyond any underdrains which may be installed alongside the paved area. Trenches for concrete encased conduit must be opened the complete length before concrete is laid, so that if any obstructions are encountered, proper provisions can be made to avoid them. Concrete for the duct must be placed to form a single unit, not incrementally. The concrete cover thickness must be a minimum of three inches on all sides. Where two or more conduits are encased in concrete, the Contractor must space them not less than 2 inches apart (measured from outside wall to outside wall) using spacers applicable to the type of conduit. End bells or end couplings must be installed flush with the end of the concrete encasement where required.

B. Tracing FAA and Common Electric Ductbank (CED) Containing FAA Fiber

Tracer wire is required by the FAA to trace and locate concrete encased ductbank containing FAA fiber optic cable. Tracer wire will allow traceability of a fiber optic cable segment into and out of all facilities along the path of the specific fiber optic cable FOTS loop for every facility with FAA fiber optic equipment connected to the cable being traced.

Because the routing of FAA fiber optic cable for Communication FOTS loops and NAVAID (ILS) FOTS loops often follow the same ductbank route, the number of tracer wires in a given ductbank will vary as required to achieve traceability of each segment on a whole fiber optic loop. Most ductbanks will require only a single tracer wire, however other short facility branch ductbanks from the main would require multiple tracer wires when fiber optic cable segments overlap. When in the case of a NAVAID fiber optic cable loop which can double back on itself, at a facility that uses a single ductbank branch to access both of the cable segments serving it by ductbank with multiple segment entrances, 2 or 3 tracer wires would be required within that short ductbank branch to the FAA site/shelter. Where tracer wires converge at the lower level, Concourse “E” and “G” entrances of the main terminal, and the south entrance to the SATCT three (3) tracer wires within a common ductbank would be needed.

All new fiber installations and tracer wire routings for design packages must be coordinated with the CDA/OMP/FAA to conform with the overall or master Airport FAA fiber routing plan developed by FAA.

1. Provide and install 6” wide red plastic warning tape above all ductbanks and #14 AWG insulated copper tracer wire within all FAA dedicated ductbanks, handholes and manholes; all Common Electrical Ductbanks (CED), handholes and manholes containing FAA fiber optical cable; and existing ductbanks, handholes and manholes when used to route FAA fiber. (These requirements apply to both single-mode FAA fiber and multi-mode FAA fiber installations).
2. Tracer wire must be placed by the contractor installing FAA fiber optic cable to follow the entire fiber segment route between FAA buildings and facilities through new infrastructure and existing infrastructure. It is the contractor’s responsibility to coordinate all fiber tracer wire requirements with the OMP/FAA for all new FAA fiber work or expansion of existing fiber/tracer wire work.
3. The tracer wire must be #14 AWG insulated solid copper wire. The insulation color must be orange for multi-mode fiber or yellow for single-mode fiber. The tracer wire must be placed with the installation of innerduct within a conduit in conjunction with the later installation of FAA fiber cable in that contract. The tracer wire should optimally be pulled in with the innerduct, in the conduit void between innerducts or in a FAA spare innerduct with the FAA’s approval and is run continuously from FAA facility/shelter to FAA facility/shelter without splices. Within manholes or handholes the tracer wire must be fastened to the cable racks and tagged “FAA Fiber Optic Tracer Wire”.
4. The tracer wire must follow the entire run of FAA fiber optic cable segments from Airport Traffic Control Tower or Concourse lower level duct entrances into and out of each of the respective FAA NAVAID and Communication / Radar facility to accommodate the tracing of each fiber segment. Tracer wire is

not required beyond the Concourse ductbank entrances, in the lower level Concourse tunnels or to the ATCT. A separate tracer run in general follows each fiber segment from building to building and will not be shared nor spliced / tied together.

5. When the tracer wire is brought into a facility it will not be terminated. The tracer wire must be coiled in an interior mounted fiber optic junction box. The contractor must provide ten (10) feet of cable, coiled and tagged “FAA Fiber Optic Tracer Wire”. The junction box must also be tagged “FAA Fiber Optic Tracer Wire”.
6. Tracer wire continuity between facilities along each fiber optic cable segment must be demonstrated by the contractor to the FAA for acceptance.
7. When a field manhole tracer wire splice is required due only to the cable spool limitations the splice must be made with approved mechanical type connectors, Pro-Trace TW Connector, as directed by the Director and the FAA. The connection must also be wrapped with an overlapping layer of 3M Super 88 Electrical tape and an overlapping layer of 3M Super 33+ Electrical tape
8. In the event tracer wire is damaged or rendered inoperable during the course of construction activities, the contractor will be responsible to re-establish or install new tracer wire between facilities.

C. ComEd Ductbank, Common Electrical Ductbank (CED) Warning Tape

1. Unless the ComEd Ductbank or Common Electrical Ductbank is being jacked in place, or the Plans indicated otherwise, a 6 inch wide red plastic warning tape must be placed 12 inches below grade directly over the entire length of a proposed ComEd Ductbank or Common Electrical Ductbank. The CED ductbanks contain as part of the CDA/OMP both electrical power and communications assigned cells.
2. The plastic warning must be colorfast and chemically inert. Clips for bonding tears and completing end-of-roll splices must be provided and installed per manufacturers’ recommendations.

3.03 INNERDUCT INSTALLATION

A. Equipment

1. Cable tuggers, tension metering equipment, break-away swivels, sheaves, quadrant blocks, hooked hanger sheaves, cable feeding sheaves, corner cable guides, reel trailers, reel

trucks and continuous lubricating equipment are the most suitable types of equipment for this Project; however, the Contractor must make its own determination and selection of the equipment to use to install the innerduct.

2. Use pulling means, including fish tape, cable rope and basket weave innerduct grips that will not damage the innerduct media or raceway. Pull innerducts simultaneously in the same raceway as shown on the Drawings with equipment to equalize pulling tensions on each innerduct. A reliable non-freezing type of swivel must be inserted between the pulling line and the innerduct grips to prevent twisting under strain. The swivel must be equipped with shear to tension pins with a breaking strength recommended by the innerduct manufacturer. Pulling equipment must be equipped with a hydraulic bypass which must be set so that a maximum tension (recommended by the innerduct manufacturer) is not exceeded.

3. Prior to being installed, multiple innerducts must be bundled and secured with lashing ties per the manufacturers recommendations. The lashing ties must be installed every two (2) meters.

B. Joints and Breaks

C. Innerducts must be installed continuous in the ductbank. No joints or breaks of any kind will be allowed in any of the innerduct segments. Innerduct breaks are allowed only in manholes/handholes/pullboxes and at Panel locations.Placing Innerduct In Segments

1. Contractor must utilize secured sheaves and quadrant blocks to guide the innerduct from reels above the manhole or from buildings into the manhole chamber and into the 4 inch conduit. Contractor must maintain tension on the innerduct from the supply reel to the 4 inch conduit.

2. Contractor must lubricate the innerduct at the point that it enters the conduit. Use pulling compound or lubricant as recommended by the innerduct manufacturer. Contractor must use a lubricant application system to minimize lubricant loss and spillage in the manhole and/or immediate work surface area. All spilled lubricant must be cleaned completely from the surfaces of the manhole and work surface area.

D. Manhole Terminations

1. The innerduct must enter the manholes through conduit fittings cast into the side of the manholes.

2. To compensate for innerduct elongation due to installation pulling stress and installation temperature, the Contractor must pull the multiple innerducts past the conduit system and/or manholes to allow the innerduct to recover to its original length. The amount of innerduct left after the initial cutting in manholes must be coordinated with the innerduct manufacturer. This coordination must take into account allowable pulling tension, pulling techniques/equipment, conduit conditions, length of innerduct pulls, size/quantity of innerducts per conduit, and installation temperature. The time needed for innerduct recovery must be per innerduct manufacturer's requirements prior to the final innerduct trimming to 6 inches extending out of the interior side of the manhole wall. Any innerduct improperly trimmed or compensated for elongation, that contracts into the conduit after relaxation must be removed and replaced at the Contractor's expense.

E. Building Terminations

1. The innerduct must enter the buildings through 4 inch conduit fittings. Mechanical compression type seals are to be installed based on quantity and size of innerducts to provide a water and gas tight seal.

2. After installation of innerduct seals, Contractor must cut all HDPE innerduct per manufacturer's requirements as described in Paragraph 3.03.G. If the Contract Drawings call for the innerduct to continue from the building wall, an innerduct transition piece must be installed and plenum rated innerduct is to be connected to it and extended into the building.

3. Contractor must provide an innerduct connector on all innerduct that is to be terminated onto an enclosure. The connector is to be securely fastened on the innerduct and enclosure. The 4 inch openings in buildings that are not used for innerduct entry must be plugged with a 4 inch blank compression type conduit plug.

F. Innerduct Support

1. Exposed innerduct must be supported in an approved manner. Innerducts must not be fastened to or come in contact with any mechanical system pipes, ducts or equipment of other trades, except as approved by the Commissioner. In all innerduct work

including vertical runs, acceptable electrical support devices including hangers, racks, ties or a combination thereof must be used as supports.

G. Innerduct and Conduit Mechanical Seals

1. The conduit and innerduct must be sealed with compression type mechanical seals at building penetrations and at the first manhole/handhole to building only.
2. Corrosion resistant compression type mechanical cable seals must be used to terminate the various cables at building entrance conduits and innerducts at buildings.
3. Duct tape must be used to temporarily seal all innerduct segments during the course of construction.
4. Immediately upon installation of an innerduct segment, the Contractor must place duct tape temporarily at both ends of each innerduct in the segment. Contractor must attach the pulling rope to the exterior of the innerduct with duct tape temporarily.
5. At the close of each workday, all innerduct installed as of the end of the workday is to be taped with duct tape to ensure that innerducts remain free of liquids and particles.

H. Prior to installing new innerducts inside existing underground ductbanks, the existing ducts must be cleared and cleaned. Clearing and cleaning by mandrelling, power rodding, power washing or other means necessary for the installation of the new innerducts will be included in the unit price for the Innerduct Pay Item.

3.04 DUCTBANK END DELINEATION

A. In locations where ductbank ends; but, will be extended at a later date, the ductbank ends will be bulkheaded or stubbed and capped below grade. The ends of these ductbanks must be surveyed by the Contractor for their exact locations based on O'Hare Survey Control Monuments (easting and northing of each corner referred to the IL State Plane Coordinates NAD 1983 and the vertical elevation of the top of each corner referred to NAVD 1988). This survey information must be provided and indicted by the Contractor on the As-built Drawings for reference.

3.05 BACKFILLING

A. After concrete-encased conduits have been properly installed and the concrete has set, the trench must be backfilled in accordance with Specification P-157, Trench Backfilling.

B. Trenches must not be excessively wet and must not contain pools of water during backfilling operations.

C. Excess excavated material must be removed and disposed of in accordance with instructions issued by the Commissioner.

D. Material to be used in backfilling under and adjacent to the paved areas must conform to the requirements of Trench Backfill, but the cost of furnishing and placing such backfill must be included in the Contract unit price for the items listed under installation of underground electrical duct.

3.06 RESTORATION

A. After the backfill is completed, the Contractor must dispose of all surplus material and rubbish off site. Excess dirt and excavated material must be embanked within the project embankment limits in accordance with section P-152 Excavation and Embankment, and will be considered incidental to the work. The Contractor must restore all disturbed areas to their original condition. Where the original condition is grass, topsoil and sod or permanent seeding must be used for restorations, as shown on the drawings. All costs for restoration will be included in the Contract unit price. Any future settlement of trenches must be restored at the Contractor's expense.

3.07 UNCLASSIFIED EXCAVATION

A. Provide all excavation for ductbank to the lines and grades for elevations, shown on the Drawings or as stated by the Commissioner. The excavation is to be of sufficient size to permit the placing of the full width and length of the ductbank shown. Excavated material is to be stockpiled where directed by the Commissioner. The elevations, as shown on the Drawings, are to be considered as approximate only; and the Commissioner may order, in writing, changes in dimensions or elevations necessary to secure a satisfactory installation.

B. Boulders, logs, or other objectionable materials encountered in excavation are to be removed. All rock or other hard foundation material is to be cleaned of all loose material and cut to a firm surface either level, stepped or serrated, as directed by the Commissioner. All seams or crevices are to be cleaned out and grouted. Remove all loose and disintegrated rock and thin strata. When concrete is to rest on a surface other than rock, special care is to be taken not to disturb the bottom of the excavation, and excavation to final grade is not to be made until just before the concrete or reinforcing is to be placed.

C. Provide all bracing, sheathing or shoring necessary to implement and protect the excavation and the ductbank, as well as protect existing adjacent structures located above or below grade as required, as required for safety or conformance to governing laws. The cost of bracing, sheathing or shoring is to be included in the unit price for the ductbank.

D. Unless otherwise provided, bracing, sheathing, or shoring involved in the construction of this item is to be removed by the Contractor after the completion of the structure. Removal is to be effected in a manner which will not disturb or mar finish masonry. The cost of removal is to be included in the unit price bid for the structure. The Contractor is to notify the Commissioner to the effect; and concrete or reinforcing steel is to be placed after the Commissioner has approved the depth of the excavation and the character of the foundation material.

PART 4 METHOD OF MEASUREMENT

4.01 MEASUREMENT

A. Underground duct bank, including innerduct for fiber optic cables where shown on the plans, and surface mounted ducts will be measured by the lineal feet of duct bank installed, measured in place, completed, and accepted. Measurement will be made from the centroid of manhole and handhole clusters or connecting structures.

B. No separate measurement will be made for the various types and sizes, or the individual ductbank fingers that enter into each manhole, handhole, or connecting structure. No separate measurement will be made for ductbank warning and fiber optic tracer wires, innerduct and conduit mechanical seals, excavation, backfilling, miscellaneous materials or connections to the existing underground ductbank system including removal of standard duct banks and appurtenances within limits of the ductbank trench and layout, and clearing of existing underground ductbank necessary for the installation of new innerducts.

C. When conduits contain multiple innerducts, the innerducts are to be measured individually.

1. Tracer wires and pull ropes that are to be installed within innerducts are to be considered incidental to the installation of the innerduct and will not be measured separately.

2. Innerduct plugs, duct seal, associated devices that are to be installed as described within this section will not be measured separately.

PART 5 BASIS OF PAYMENT

5.01 PAYMENT

A. Payment will be made at the Contract unit price for each type and size of duct bank, including innerduct for fiber optic cable where shown on the plans, completed by the Contractor and accepted by the Commissioner. This price includes full compensation for furnishing all materials; for all preparation, assembly, and installation of these materials; for all trenching and backfilling necessary; for all restoration of disturbed areas; for clearing existing underground ductbank for new innerduct installations, ductbank warning and fiber optic tracer wires, innerduct and conduit mechanical seals; for removal of surface mounted ducts when no longer required; and for all labor, equipment, tools, and all work necessary to complete this item as required by these Specifications and as detailed on the Contract Drawings

B. Payment will be made under the following items:

ITEM NO.	DESCRIPTION	UOM
L-110-01	CONCRETE ENCASED DUCTS, 1 WAY, 2" PVC	LF
L-110-02	CONCRETE ENCASED DUCTS, 2 WAY, 3" PVC	LF
L-110-03	SAWKERFED, 1 WAY, 2" PVC	LF
L-110-04	COMMON ELECTRIC DUCTBANK, 2-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-05	COMMON ELECTRIC DUCTBANK, 2-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	LF
L-110-06	COMMON ELECTRIC DUCTBANK, 4-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-07	COMMON ELECTRIC DUCTBANK, 4-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	LF

L-110-08	COMMON ELECTRIC DUCTBANK, 8-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-09	COMMON ELECTRIC DUCTBANK, 8-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	LF
L-110-10	COMMON ELECTRIC DUCTBANK, 12-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-11	COMMON ELECTRIC DUCTBANK, 12-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	LF
L-110-12	COMMON ELECTRIC DUCTBANK, 16-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-13	COMMON ELECTRIC DUCTBANK, 20-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-14	FAA DUCTBANK, 2-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-15	FAA DUCTBANK, 4-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-16	FAA DUCTBANK, 4-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	LF
L-110-17	FAA DUCTBANK, 8-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-18	FAA DUCTBANK, 10-WAY, 2" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-19	FAA DUCTBANK, 10-WAY, 2" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	LF
L-110-20	FAA DUCTBANK, 14-WAY, 4" PVC CONDUIT, CONCRETE ENCASED, REINFORCED	LF
L-110-21	CECO DUCTBANK, 8-WAY, 5" PVC CONDUIT, CONCRETE ENCASED, NON-REINFORCED	LF
L-110-22	SURFACE MOUNTED DUCTS, 1-WAY, 1" RMC CONDUIT	LF
L-110-23	INNERDUCT	LF
L-110-24	1 WAY, 2-INCH PVC CONDUIT SAW KERF IN BITUMINOUS BASE COURSE UNDER FULL STRENGTH PAVEMENT	LF
L-110-25	2 WAY, 2-INCH PVC CONDUIT SAW KERF IN BITUMINOUS BASE COURSE UNDER FULL STRENGTH PAVEMENT	LF

END OF SECTION L-110

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PORTLAND CEMENT CONCRETE (PCC) PAVEMENT ITEM P-501

PART 1 DESCRIPTION

1.01 GENERAL

A. This work must consist of pavement composed of Portland cement concrete (PCC), with reinforcement or without reinforcement, constructed on a prepared underlying surface in accordance with these specifications and must conform to the lines, grades, thickness, and typical cross-sections shown on the plans.

PART 2 MATERIALS

2.01 AGGREGATES

A. Reactivity. Fine and Coarse aggregates to be used in all concrete must be evaluated and tested by the Contractor for alkali-aggregate reactivity in accordance with both ASTM C1260 and ASTM C1567. Aggregate and mix proportion reactivity tests must be performed for each project.

1. Coarse and fine aggregate must be tested separately in accordance with ASTM C1260. The aggregate must be considered innocuous if the expansion of test specimens, tested in accordance with ASTM C1260, does not exceed 0.10% at 28 days (30 days from casting).

2. Combined coarse and fine aggregate must be tested in accordance with ASTM C1567, modified for combined aggregates, using the proposed mixture design proportions of aggregates, cementitious materials, and/or specific reactivity reducing chemicals. If lithium nitrate is proposed for use with or without supplementary cementitious materials, the aggregates must be tested in accordance with Corps of Commissioners (COE) Concrete Research Division (CRD) C662. If lithium nitrate admixture is used, it must be nominal 30% ±0.5% weight lithium nitrate in water.

3. If the expansion of the proposed combined materials test specimens, tested in accordance with ASTM C1567, modified for combined aggregates, or COE CRD C662, does not exceed 0.10% at 28 days, the proposed combined materials will be accepted. If the expansion of the proposed combined materials

test specimens is greater than 0.10% at 28 days, the aggregates will not be accepted unless adjustments to the combined materials mixture can reduce the expansion to less than 0.10% at 28 days, or new aggregates must be evaluated and tested.

B. Fine aggregate. Fine aggregate must conform to the requirements of ASTM C33. Grading of the fine aggregate, as delivered to the mixer, must conform to the requirements of ASTM C33 and must have a fineness modulus of not less than 2.50 nor more than 3.40. The soundness loss must not exceed 10% when sodium sulfate is used or 15% when magnesium sulfate is used, after five cycles, when tested per ASTM C88.

The amount of deleterious material in the fine aggregate must not exceed the following limits:

Limits for Deleterious Substances in Fine Aggregate for Concrete

Deleterious material	**ASTM**	**Percentage by Mass**
Clay Lumps and friable particles	ASTM C142	1.0
Material finer than 0.075mm (No. 200 sieve)	ASTM C117	3.0
Lightweight particles	ASTM C123 using a medium with a density of Sp. Gr. of 2.0	0.5
Total of all deleterious Material		3.0

C. Coarse aggregate. Gradation, within the separated size groups, must meet the coarse aggregate grading requirements of ASTM C33 when tested in accordance with ASTM C136. When the nominal maximum size of the aggregate is greater than one inch (25 mm), the aggregates must be furnished in two size groups.

Aggregates delivered to the mixer must consist of crushed stone, crushed or uncrushed gravel, air-cooled iron blast furnace slag, crushed recycled concrete pavement, or a combination. The aggregates should be free of ferrous sulfides, such as pyrite, that would cause “rust” staining that can bleed through pavement markings. Steel blast furnace slag must not be permitted. The aggregate must be composed of clean, hard, uncoated particles. Dust and other coating must be removed from the aggregates by washing.

The percentage of wear must be no more than **40 percent** when tested in accordance with ASTM C131.

The quantity of flat, elongated, and flat and elongated particles in any size group coarser than 3/8 sieve (9 mm) must not exceed 8% by weight when tested in accordance with ASTM D4791. A flat particle is defined as one having a ratio of width to thickness greater than 5. An elongated particle is one having a ratio of length to width greater than 5.

The soundness loss must not exceed 12% when sodium sulfate is used or 18% when magnesium sulfate is used, after five cycles, when tested per ASTM C88.

The amount of deleterious material in the coarse aggregate must not exceed the following limits:

Limits for Deleterious Substances in Coarse Aggregate for Concrete

Deleterious material	**ASTM**	**Percentage by Mass**
Clay Lumps and friable particles	ASTM C142	1.0
Material finer than No. 200 sieve (0.075mm)	ASTM C117	1.0
Lightweight particles	ASTM C123 using a medium with a density of Sp. Gr. of 2.0	0.5
Chert (less than 2.40 Sp Gr.)	ASTM C123 using a medium with a density of Sp. Gr. of 2.0)	1.0
Total of all deleterious Material		3.0

Table 1. Gradation For Coarse Aggregate

(ASTM C33)

Sieve Designations (square openings)		**Percentage by Weight Passing Sieves**	
		From 1-½ inch to No. 4 (38mm – 4.75mm)	
		#4 **1-½ inch – ¾ inch**	**#67** **¾ inch – No. 4**
inch	**mm**		
2-1/2	60	---	---
2	50	100	---
1-1/2	38	90-100	---
1	25	20-55	100
3/4	19	0-15	90-100
1/2	13	---	---
3/8	9	0-5	20-55
No. 4	4.75	---	0-10

Sieve Designations (square openings)		Percentage by Weight Passing Sieves	
		From 1-½ inch to No. 4 (38mm – 4.75mm)	
		#4 1-½ inch – ¾ inch	#67 ¾ inch – No. 4
inch	**mm**		
No. 8	2.36	---	0-5

1. Aggregate susceptibility to durability (D) cracking. Aggregates that have a history of D-cracking must not be used.

Coarse aggregate may be accepted from sources that have a 20 year service history for the same gradation to be supplied with no durability issues. Aggregates that do not have a record of 20 years of service without major repairs (less than 5% of slabs replaced) in similar conditions without D-cracking must not be used unless it meets the following:

a. Material currently being produced must have a durability factor ≥ 95 using ASTM C666 procedure B. Coarse aggregates that are crushed granite, calcite cemented sandstone, quartzite, basalt, diabase, rhyolite or trap rock are considered to meet the D-cracking test but must meet all other quality tests. Aggregates meeting State Highway Department material specifications may be acceptable.

b. The Contractor must submit a current certification that the aggregate does not have a history of D-cracking and that the aggregate meets the state specifications for use in PCC pavement for use on interstate highways. Certifications, tests and any history reports must be for the same gradation as being proposed for use on the project. Certifications which are not dated or which are over one (1) year old or which are for different gradations will not be accepted. Test results will only be accepted when tests were performed by a State Department of Transportation (DOT) materials laboratory or an accredited laboratory.

2. Combined aggregate gradation. If substituted for the grading requirements specified for coarse aggregate and for fine aggregate and when approved by the Commissioner, the combined aggregate grading must meet the following requirements:

a. The materials selected and the proportions used must be such that when the Coarseness Factor (CF) and the Workability Factor (WF) are plotted on a diagram as described in d. below, the point thus determined must fall within the parallelogram described therein.

b. The CF must be determined from the following equation:

CF = (cumulative percent retained on the 3/8 in. sieve)(100) / (cumulative percent retained on the No. 8 sieve)

c. The Workability Factor WF is defined as the percent passing the No. 8 (2.36 mm) sieve based on the combined gradation. However, WF must be adjusted, upwards only, by 2.5 percentage points for each 94 pounds (42 kg) of cementitious material per cubic meter yard greater than 564 pounds per cubic yard (335 kg per cubic meter).

d. A diagram must be plotted using a rectangular scale with WF on the Y-axis with units from 20 (bottom) to 45 (top), and with CF on the X-axis with units from 80 (left side) to 30 (right side). On this diagram a parallelogram must be plotted with corners at the following coordinates (CF-75, WF-28), (CF-75, WF-40), (CF-45, WF-32.5), and (CF-45, WF-44.5). If the point determined by the intersection of the computed CF and WF does not fall within the above parallelogram, the grading of each size of aggregate used and the proportions selected must be changed as necessary.

2.02 CEMENT

A. Cement must conform to the requirements of ASTM C150 Type I.

B. If aggregates are deemed innocuous when tested in accordance with paragraph 2.01.a.1 and accepted in accordance with paragraph 2.01.a.2, higher equivalent alkali content in the cement may be allowed if approved by the Commissioner and FAA. If cement becomes partially set or contains lumps of caked cement, it must be rejected. Cement salvaged from discarded or used bags must not be used.

2.03 CEMENTITIOUS MATERIALS

A. **Fly ash.** Fly ash must meet the requirements of ASTM C618, with the exception of loss of ignition, where the maximum must be less than 6%. Fly ash for use in mitigating alkali-silica reactivity must have a Calcium Oxide (CaO) content of less than 13% and a total available alkali content less than 3% per ASTM C311. Fly ash produced in furnace operations using liming materials or soda ash (sodium carbonate) as an additive must not be acceptable. The Contractor must furnish the previous three most recent, consecutive ASTM C618 reports for each source of fly ash proposed in the mix design, and must furnish each additional report as they become available during the project. The reports can be used for acceptance or the material may be tested independently by the Commissioner.

B. **Slag cement (ground granulated blast furnace (GGBF).** Slag cement must conform to ASTM C989, Grade 100 or Grade 120. Slag cement must be used only at a rate between 25% and 55% of the total cementitious material by mass.

C. **Raw or calcined natural pozzolan.** Natural pozzolan must be raw or calcined and conform to ASTM C618, Class N, including the optional requirements for uniformity and effectiveness in controlling Alkali-Silica reaction and must have a loss on ignition not exceeding 6%. Class N pozzolan for use in mitigating Alkali-Silica Reactivity must have a total available alkali content less than 3%.

D. **Ultrafine fly ash and ultrafine pozzolan.** UltraFine Fly Ash (UFFA) and UltraFine Pozzolan (UFP) must conform to ASTM C618, Class F or N, and the following additional requirements:

1. The strength activity index at 28 days of age must be at least 95% of the control specimens.
2. The average particle size must not exceed 6 microns.

2.04 JOINT SEAL

A. The joint seal for the joints in the concrete pavement must meet the requirements of Item P-605 and must be of the type specified in the plans.

2.05 ISOLATION JOINT FILLER

A. Premolded joint filler for isolation joints must conform to the requirements of ASTM D1752, Type II or III and must be where shown on the plans. The filler for each joint must be furnished in a single piece for the full depth and width required for the joint, unless otherwise specified by the Commissioner. When the use of more than one piece is required for a joint, the abutting ends must be fastened securely and held accurately to shape by stapling or other positive fastening means satisfactory to the Commissioner.

2.06 STEEL REINFORCEMENT

A. Reinforcing must consist of welded steel wire fabric conforming to the requirements of ASTM 185. Welded wire fabric must be furnished in flat sheets only.

2.07 DOWEL AND TIE BARS

A. Dowel bars must be plain steel bars conforming to ASTM A615 and must be free from burring or other deformation restricting slippage in the concrete. Before delivery to the construction site each dowel bar must be epoxy coated per ASTM A1078. The dowels must be coated with a bond-breaker recommended by the manufacturer. Dowel sleeves or inserts are not permitted. Grout retention rings must be fully circular metal or plastic devices capable of supporting the dowel until the grout hardens.

B. Tie bars must be deformed steel bars and conform to the requirements of ASTM A615. Tie bars designated as Grade 60 in ASTM A615 or ASTM A706 must be used for construction requiring bent bars.

2.08 WATER

A. Water used in mixing or curing must be potable, clean, free of oil, salt, acid, alkali, sugar, vegetable, or other substances injurious to the finished product, except that non-potable water, or water from concrete production operations, may be used if it meets the requirements of ASTM C1602.

2.09 MATERIAL FOR CURING CONCRETE

A. Curing materials must conform to one of the following specifications:

1. Liquid membrane-forming compounds for curing concrete must conform to the requirements of ASTM C309, Type 2, Class B, or Class A if wax base only.
2. White polyethylene film for curing concrete must conform to the requirements of ASTM C171.
3. White burlap-polyethylene sheeting for curing concrete must conform to the requirements of ASTM C171.
4. Waterproof paper for curing concrete must conform to the requirements of ASTM C171.

2.10 ADMIXTURES

A. The Contractor must submit certificates indicating that the material to be furnished meets all of the requirements indicated below. In addition, the Commissioner may require the Contractor to submit complete test data from an approved laboratory showing that the material to be furnished meets all of the requirements of the cited specifications. Subsequent tests may be made of samples taken by the Commissioner from the supply of the material being furnished or proposed for use on the work to determine whether the admixture is uniform in quality with that approved.

1. **Air-entraining admixtures.** Air-entraining admixtures must meet the requirements of ASTM C260 and must consistently entrain the air content in the specified ranges under field conditions. The air-entrainment agent and any water reducer admixture must be compatible.

2. **Water-reducing admixtures.** Water-reducing admixture must meet the requirements of ASTM C494, Type A, B, or D. ASTM C494, Type F and G high range water reducing admixtures and ASTM C1017 flowable admixtures must not be used.

3. **Other admixtures.** The use of set retarding, and set-accelerating admixtures must be approved by the Commissioner. Retarding must meet the requirements of ASTM C494, Type A, B, or D and set-accelerating must meet the requirements of ASTM C494, Type C. Calcium chloride and admixtures containing calcium chloride must not be used.

4. **Lithium Nitrate.** The lithium admixture must be a nominal 30% aqueous solution of Lithium Nitrate, with a density of 10 pounds/gallon (1.2 kg/L), and must have the approximate chemical form as shown below:

Constituent	Limit (Percent by Mass)
LiNO3 (Lithium Nitrate)	30 ±0.5
SO4 (Sulfate Ion)	0.1 (max)
Cl (Chloride Ion)	0.2 (max)
Na (Sodium Ion)	0.1 (max)
K (Potassium Ion)	0.1 (max)

Provide a trained manufacturer’s representative to supervise the lithium nitrate admixture dispensing and mixing operations.

2.11 EPOXY-RESIN

A. All epoxy-resin materials must be two-component materials conforming to the requirements of ASTM C881, Class as appropriate for each application temperature to be encountered, except that in addition, the materials must meet the following requirements:

1. Material for use for embedding dowels and anchor bolts must be Type IV, Grade 3.
2. Material for use as patching materials for complete filling of spalls and other voids and for use in preparing epoxy resin mortar must be Type III, Grade as approved.
3. Material for use for injecting cracks must be Type IV, Grade 1.
4. Material for bonding freshly mixed Portland cement concrete or mortar or freshly mixed epoxy resin concrete or mortar to hardened concrete must be Type V, Grade as approved.

2.12 MATERIAL ACCEPTANCE

A. Prior to use of materials, the Contractor must submit certified test reports to the Commissioner for those materials proposed for use during construction. The certification must show the appropriate ASTM test for each material, the test results, and a statement that the material passed or failed.

B. The Commissioner may request samples for testing, prior to and during production, to verify the quality of the materials and to ensure conformance with the applicable specifications.

PART 3 MIX DESIGN

3.01 GENERAL.

A. No concrete must be placed until the mix design has been submitted to the Commissioner for review and the Commissioner has taken appropriate action. The Commissioner's review must not relieve the Contractor of the responsibility to select and proportion the materials to comply with this section.

3.02 PROPORTIONS

A. The laboratory preparing the mix design must be accredited in accordance with ASTM C1077. The mix design for all Portland cement concrete placed under P-501 must be stamped or sealed by the responsible professional Engineer of the laboratory. Concrete must be proportioned to achieve a 28-day flexural strength that meets or exceeds the acceptance criteria contained in paragraph 5.02 for a flexural strength of 625 psi per ASTM C78. The mix must be developed using the procedures contained in the Portland Cement Association's (PCA) publication, "Design and Control of Concrete Mixtures".

B. The minimum cementitious material must be adequate to ensure a workable, durable mix. The minimum cementitious material (cement plus fly ash, or slag cement) must be 517 pounds per cubic yard. The ratio of water to cementitious material, including free surface moisture on the aggregates but not including moisture absorbed by the aggregates must not be more than 0.45 by weight.

C. Flexural strength test specimens must be prepared in accordance with ASTM C192 and tested in accordance with ASTM C78. The mix determined must be workable concrete having a maximum allowable slump between one and two inches as determined by ASTM C 143. For slip-form concrete, the slump must be between ½ inch and 1- ½ inch. At the start of the project, the Contractor must determine a maximum allowable slump for slip-form pavement which will produce in-place pavement to control the edge slump. The selected slump must be applicable to both pilot and fill-in lanes.

D. Before the start of paving operations and after approval of all material to be used in the concrete, the Contractor must submit a mix design showing the proportions and flexural strength obtained from the concrete at seven (7) and 28 days. The mix design must include copies of test reports, including test dates, and a complete list of materials including type, brand, source, and amount of cement, fly ash, ground slag, coarse aggregate, fine aggregate, water, and admixtures. The mix design must be submitted to the Commissioner at least 30 days prior to the start of operations. The submitted mix design must not be more than 90 days old. Production must not begin until the mix design is approved in writing by the Commissioner.

E. If a change in sources is made, or admixtures added or deleted from the mix, a new mix design must be submitted to the Commissioner for approval.

F. The results of the mix design must include a statement giving the maximum nominal coarse aggregate size and the weights and volumes of each ingredient proportioned on a one cubic yard (meter) basis. Aggregate quantities must be based on the mass in a saturated surface dry condition. The recommended mixture proportions must be accompanied by test results demonstrating that the proportions selected will produce concrete of the qualities indicated. Trial mixtures having proportions, slumps, and air content suitable for the work must be based on methodology described in PCA's publication, Design and Control of Concrete Mixtures, modified as necessary to accommodate flexural strength.

G. The submitted mix design must be stamped or sealed by the responsible professional Engineer of the laboratory and must include the following items as a minimum:

   1. Coarse, fine, and combined aggregate gradations and plots including fineness modulus of the fine aggregate.
   2. Reactivity Test Results.
   3. Coarse aggregate quality test results, including deleterious materials.
   4. Fine aggregate quality test results, including deleterious materials.
   5. Mill certificates for cement and supplemental cementitious materials.

6. Certified test results for all admixtures, including Lithium Nitrate if applicable.
7. Specified flexural strength, slump, and air content.
8. Recommended proportions/volumes for proposed mixture and trial water-cementitious materials ratio, including actual slump and air content.
9. Flexural and compressive strength summaries and plots, including all individual beam and cylinder breaks.
10. Correlation ratios for acceptance testing and Contractor Quality Control testing, when applicable.
11. Historical record of test results documenting production standard deviation, when applicable.

3.03 CEMENTITIOUS MATERIALS.

A. **Fly ash.** When fly ash is used as a partial replacement for cement, the replacement rate must be determined from laboratory trial mixes, and must be between 20 and 30% by weight of the total cementitious material. If fly ash is used in conjunction with slag cement the maximum replacement rate must not exceed 10% by weight of total cementitious material.

B. **Slag cement (ground granulated blast furnace (GGBF)).** Slag cement may be used. The slag cement, or slag cement plus fly ash if both are used, may constitute between 25 to 55% of the total cementitious material by weight. If the concrete is to be used for slipforming operations and the air temperature is expected to be lower than 55°F (13°C) the percent slag cement must not exceed 30% by weight.

C. **Raw or calcined natural pozzolan.** Natural pozzolan may be used in the mix design. When pozzolan is used as a partial replacement for cement, the replacement rate must be determined from laboratory trial mixes, and must be between 20 and 30% by weight of the total cementitious material. If pozzolan is used in conjunction with slag cement the maximum replacement rate must not exceed 10% by weight of total cementitious material.

D. **Ultrafine fly ash (UFFA) and ultrafine pozzolan (UFP).** UFFA and UFP may be used in the mix design with the Commissioner’s approval. When UFFA and UFP is used as a partial replacement for cement, the replacement rate must be determined from laboratory trial mixes, and must be between seven (7) and 16% by weight of the total cementitious material.

3.04 ADMIXTURES

A. **Air-entraining admixtures.** Air-entraining admixture are to be added in such a manner that will ensure uniform distribution of the agent throughout the batch. The air content of freshly mixed air-entrained concrete must be based upon trial mixes with the materials to be used in the work adjusted to produce concrete of the required plasticity and workability. The percentage of air in the mix must be 6.0 percent. Air content must be determined by testing in accordance with ASTM C231 for gravel and stone coarse aggregate and ASTM C173 for slag and other highly porous coarse aggregate.

B. **Water-reducing admixtures.** Water-reducing admixtures must be added to the mix in the manner recommended by the manufacturer and in the amount necessary to comply with the specification requirements. Tests must be conducted on trial mixes, with the materials to be used in the work, in accordance with ASTM C494.

C. **Other admixtures.** Set controlling, and other approved admixtures must be added to the mix in the manner recommended by the manufacturer and in the amount necessary to comply with the specification requirements. Tests must be conducted on trial mixes, with the materials to be used in the work, in accordance with ASTM C 494.

D. **Lithium nitrate.** Lithium nitrate must be added to the mix in the manner recommended by the manufacturer and in the amount necessary to comply with the specification requirements in accordance with paragraph 501-2.10A4.

3.05 CONCRETE MIX DESIGN LABORATORY

A. The Contractor's laboratory used to develop the concrete mix design must be accredited in accordance with ASTM C1077. The laboratory accreditation must be current and listed on the accrediting authority's website. All test methods required for developing the concrete mix design must be listed on the lab accreditation. A copy of the laboratory's current accreditation and accredited test methods must be submitted to the Commissioner prior to start of construction

PART 4 CONSTRUCTION METHODS

4.01 EQUIPMENT

A. Equipment necessary for handling materials and performing all parts of the work must be approved by the Commissioner, but does not relieve the Contractor of the responsibility for the proper operation of equipment and maintaining the equipment in good working condition. The equipment must be at the jobsite sufficiently ahead of the start of paving operations to be examined thoroughly and approved.

B. The batch plant and equipment must conform to the requirements of ASTM C94.

C. Mixers and transportation equipment**.**

1. General. Concrete may be mixed at a central plant, or wholly or in part in truck mixers. Each mixer must have attached in a prominent place a manufacturer's nameplate showing the capacity of the drum in terms of volume of mixed concrete and the speed of rotation of the mixing drum or blades.
2. Central plant mixer. Central plant mixers must conform to the requirements of ASTM C94. The mixer must be examined daily for changes in condition due to accumulation of hard concrete or mortar or wear of blades. The pickup and throwover blades must be replaced when they have worn down 3/4 inch (19 mm) or more. The Contractor must have a copy of the manufacturer's design on hand showing dimensions and arrangement of blades in reference to original height and depth.
3. Truck mixers and truck agitators. Truck mixers used for mixing and hauling concrete and truck agitators used for hauling central-mixed concrete must conform to the requirements of ASTM C94.
4. Nonagitator trucks. Nonagitating hauling equipment must conform to the requirements of ASTM C94.
5. Transfer and spreading equipment. Equipment for transferring concrete from the transporting equipment to the paving lane in front of the paver must be specially manufactured, self-propelled transfer equipment which will accept the concrete outside the paving lane and will transfer and spread it evenly across the paving lane in front of the paver and strike off the surface evenly to a depth which permits the paver to operate efficiently.

D. Finishing equipment. The standard method of constructing concrete pavements must be with an approved slip-form paving equipment designed and operated to spread, consolidate, screed, and float-finish the freshly placed concrete in one complete pass of the machine so that the end result is a dense and homogeneous pavement which is achieved with a minimum of hand finishing. The paver-finisher must be a heavy duty, self-propelled machine designed specifically for paving and finishing high quality concrete pavements. It must weigh at least 2,200 lbs per foot (3274 kg/m) of paving lane width and powered by an engine having at least 6.0 horsepower per foot of lane width.

On projects requiring less than 500 square yard (418 sq m) of cement concrete pavement or requiring individual placement areas of less than 500 square yard (418 sq m), or irregular areas at locations inaccessible to slip-form paving equipment, concrete pavement may be placed with approved placement and finishing equipment using stationary side forms. Hand screeding and float finishing may only be used on small irregular areas as allowed by the Commissioner.

E. Vibrators. Vibrator must be the internal type. Operating frequency for internal vibrators must be between 8,000 and 12,000 vibrations per minute. Average amplitude for internal vibrators must be 0.025-0.05 inch (0.06 - 0.13 cm).

The number, spacing, and frequency must be as necessary to provide a dense and homogeneous pavement and meet the recommendations of American Concrete Institute (ACI) 309, Guide for Consolidation of Concrete. Adequate power to operate all vibrators must be available on the paver. The vibrators must be automatically controlled so that they must be stopped as forward motion ceases. The Contractor must provide an electronic or mechanical means to monitor vibrator status. The checks on vibrator status must occur a minimum of two times per day or when requested by the Commissioner.

Hand held vibrators may be used in irregular areas only, but must meet the recommendations of ACI 309R, Guide for Consolidation of Concrete.

F. Concrete saws. The Contractor must provide sawing equipment adequate in number of units and power to complete the sawing to the required dimensions. The Contractor must provide at least one standby saw in good working order and a supply of saw blades at the site of the work at all times during sawing operations. Early-entry saws may be used, subject to demonstration and approval of the Commissioner.

G. Side forms. Straight side forms must be made of steel and must be furnished in sections not less than 10 feet (3 m) in length. Forms must have a depth equal to the pavement thickness at the edge, and a base width equal to or greater than the depth. Flexible or curved forms of proper radius must be used for curves of 100-foot (31 m) radius or less. Forms must be provided with adequate devices for secure settings so that when in place they will withstand, without visible spring or settlement, the impact and vibration of the consolidating and finishing equipment. Forms with battered top surfaces and bent, twisted or broken forms must not be used. Built-up forms must not be used, except as approved by the Commissioner. The top face of the form must not vary from a true plane more than 1/8 inch (3 mm) in 10 feet (3 m), and the upstanding leg must not vary more than 1/4 inch (6 mm). The forms must contain provisions for locking the ends of abutting sections together tightly for secure setting. Wood forms may be used under special conditions, when approved by the Commissioner.

H. Pavers. The paver must be fully energized, self-propelled, and designed for the specific purpose of placing, consolidating, and finishing the concrete pavement, true to grade, tolerances, and cross-section. It must be of sufficient weight and power to construct the maximum specified concrete paving lane width as shown in the plans, at adequate forward speed, without transverse, longitudinal or vertical instability or without displacement. The paver must be equipped with electronic or hydraulic horizontal and vertical control devices.

4.02 FORM SETTING

A. Forms must be set sufficiently in advance of the concrete placement to ensure continuous paving operation. After the forms have been set to correct grade, the underlying surface must be thoroughly tamped, either mechanically or by hand, at both the inside and outside edges of the base of the forms. Forms must be staked into place sufficiently to maintain the form in position for the method of placement.

B. Form sections must be tightly locked and must be free from play or movement in any direction. The forms must not deviate from true line by more than 1/8 inch (3 mm) at any joint. Forms must be so set that they will withstand, without visible spring or settlement, the impact and vibration of the consolidating and finishing equipment. Forms must be cleaned and oiled prior to the placing of concrete.

C. The alignment and grade elevations of the forms must be checked and corrections made by the Contractor immediately before placing the concrete.

4.03 CONDITIONING OF UNDERLYING SURFACE

A. The compacted underlying surface on which the pavement will be placed must be widened approximately 3 feet (1 m) to extend beyond the paving machine track to support the paver without any noticeable displacement. After the underlying surface has been placed and compacted to the required density, the areas that will support the paving machine and the area to be paved must be trimmed or graded to the plan grade elevation and profile by means of a properly designed machine. The grade of the underlying surface must be controlled by a positive grade control system using lasers, stringlines, or guide wires. If the density of the underlying surface is disturbed by the trimming operations, it must be corrected by additional compaction and retested at the option of the Commissioner before the concrete is placed except when stabilized subbases are being constructed. If damage occurs on a stabilized subbase, it must be corrected full depth by the Contractor. If traffic is allowed to use the prepared grade, the grade must be checked and corrected immediately before the placement of concrete. The prepared grade must be moistened with water, without saturating, immediately ahead of concrete placement to prevent rapid loss of moisture from concrete. The underlying surface must be protected so that it will be entirely free of frost when concrete is placed.

4.04 CONDITIONING OF UNDERLYING SURFACE, SIDE-FORM AND FILL-IN LANE CONSTRUCTION.

A. The prepared underlying surface must be moistened with water, without saturating, immediately ahead of concrete placement to prevent rapid loss of moisture from the concrete. Damage caused by hauling or usage of other equipment must be corrected and retested at the option of the Commissioner. If damage occurs to a stabilized subbase, it must be corrected full depth by the Contractor. A template must be provided and operated on the forms immediately in advance of the placing of all concrete. The template must be propelled only by hand and not attached to a tractor or other power unit. Templates must be adjustable so that they may be set and maintained at the correct contour of the underlying surface. The adjustment and operation of the templates must be such as will provide an accurate retest of the grade before placing the concrete thereon. All excess material must be removed and wasted. Low areas must be filled and compacted to a condition similar to that of the surrounding grade. The underlying surface must be protected so that it will be entirely free from frost when the concrete is placed. The use of chemicals to eliminate frost in the underlying surface must not be permitted.

B. The template must be maintained in accurate adjustment, at all times by the Contractor, and must be checked daily.

4.05 HANDLING, MEASURING, AND BATCHING MATERIAL

A. The batch plant site, layout, equipment, and provisions for transporting material must assure a continuous supply of material to the work. Stockpiles must be constructed in such a manner that prevents segregation and intermixing of deleterious materials. Aggregates from different sources must be stockpiled, weighed and batched separately at the concrete batch plant.

B. Aggregates that have become segregated or mixed with earth or foreign material must not be used. All aggregates produced or handled by hydraulic methods, and washed aggregates, must be stockpiled or binned for draining at least 12 hours before being batched. Rail shipments requiring more than 12 hours will be accepted as adequate binning only if the car bodies permit free drainage.

C. Batching plants must be equipped to proportion aggregates and bulk cement, by weight, automatically using interlocked proportioning devices of an approved type. When bulk cement is used, the Contractor must use a suitable method of handling the cement from weighing hopper to transporting container or into the batch itself for transportation to the mixer, such as a chute, boot, or other approved device, to prevent loss of cement. The device must be arranged to provide positive assurance that the cement content specified is present in each batch.

4.06 MIXING CONCRETE

A. The concrete may be mixed at the work site, in a central mix plant or in truck mixers. The mixer must be of an approved type and capacity. Mixing time must be measured from the time all materials, except water, are emptied into the drum. All concrete must be mixed and delivered to the site in accordance with the requirements of ASTM C94.

B. Mixed concrete from the central mixing plant must be transported in truck mixers, truck agitators, or non-agitating trucks. The elapsed time from the addition of cementitious material to the mix until the concrete is deposited in place at the work site must not exceed 30 minutes when the concrete is hauled in non-agitating trucks, nor 90 minutes when the concrete is hauled in truck mixers or truck agitators. Retempering concrete by adding water or by other means will not be permitted. With transit mixers additional water may be added to the batch materials and additional mixing performed to increase the slump to meet the specified requirements provided the addition of water is performed within 45 minutes after the initial mixing operations and provided the water/cementitious ratio specified in the approved mix design is not exceeded, and approved by the Commissioner.

4.07 LIMITATIONS ON MIXING AND PLACING

A. No concrete must be mixed, placed, or finished when the natural light is insufficient, unless an adequate and approved artificial lighting system is operated.

1. Cold weather**.** Unless authorized in writing by the Commissioner, mixing and concreting operations must be discontinued when a descending air temperature in the shade and away from artificial heat reaches 40°F (4°C) and must not be resumed until an

ascending air temperature in the shade and away from artificial heat reaches 35°F (2°C).

The aggregate must be free of ice, snow, and frozen lumps before entering the mixer. The temperature of the mixed concrete must not be less than 50°F (10°C) at the time of placement. Concrete must not be placed on frozen material nor must frozen aggregates be used in the concrete.

When concreting is authorized during cold weather, water and/or the aggregates may be heated to not more than 150°F (66°C). The apparatus used must heat the mass uniformly and must be arranged to preclude the possible occurrence of overheated areas which might be detrimental to the materials.

2. Hot weather**.** During periods of hot weather when the maximum daily air temperature exceeds 85°F (30°C), the following precautions must be taken.

   The forms and/or the underlying surface must be sprinkled with water immediately before placing the concrete. The concrete must be placed at the coolest temperature practicable, and in no case must the temperature of the concrete when placed exceed 90°F (32°C). The aggregates and/or mixing water must be cooled as necessary to maintain the concrete temperature at or not more than the specified maximum.

   The finished surfaces of the newly laid pavement must be kept damp by applying a water-fog or mist with approved spraying equipment until the pavement is covered by the curing medium. When necessary, wind screens must be provided to protect the concrete from an evaporation rate in excess of 0.2 psf (0.98 kg/m^2 per hour) per hour. When conditions are such that problems with plastic cracking can be expected, and particularly if any plastic cracking begins to occur, the Contractor must immediately take such additional measures as necessary to protect the concrete surface. Such measures must consist of wind screens, more effective fog sprays, and similar measures commencing immediately behind the paver. If these measures are not effective in preventing plastic cracking, paving operations must be immediately stopped.

3. Temperature management program. Prior to the start of paving operation for each day of paving, the Contractor must provide the Commissioner with a Temperature Management Program for the concrete to be placed to assure that uncontrolled cracking is avoided. As a minimum the program must address the following items:

a. Anticipated tensile strains in the fresh concrete as related to heating and cooling of the concrete material.

b. Anticipated weather conditions such as ambient temperatures, wind velocity, and relative humidity; and anticipated evaporation rate using Figure 11-8, PCA, Design and Control of Concrete Mixtures.

c. Anticipated timing of initial sawing of joint.

d. Anticipated number and type of saws to be used.

4.08 PLACING CONCRETE

A. At any point in concrete conveyance, the free vertical drop of the concrete from one point to another or to the underlying surface must not exceed 3 feet. The finished concrete product must be dense and homogeneous, without segregation and conforming to the standards in this specification. Backhoes and grading equipment must not be used to distribute the concrete in front of the paver. Front end loaders will not be used. All concrete must be consolidated without voids or segregation, including under and around all load-transfer devices, joint assembly units, and other features embedded in the pavement. Hauling equipment or other mechanical equipment can be permitted on adjoining previously constructed pavement when the concrete strength reaches a flexural strength of 550 psi, based on the average of four field cured specimens per 2,000 cubic yards of concrete placed. Also, subgrade and sub-base planers, concrete pavers, and concrete finishing equipment may be permitted to ride upon the edges of previously constructed pavement when the concrete has attained a minimum flexural strength of 400 psi.

B. The Contractor must have available materials for the protection of the concrete during inclement weather. Such protective materials must consist of rolled polyethylene sheeting at least 4 mils thick of sufficient length and width to cover the plastic concrete slab and any edges. The sheeting may be mounted on either the paver or a separate movable bridge from which it can be unrolled without dragging over the plastic concrete surface. When rain appears imminent, all paving operations must stop and all available personnel must begin covering the surface of the unhardened concrete with the protective covering.

C. Slip-form construction:

1. The concrete must be distributed uniformly into final position by a self-propelled slip-form paver without delay. The alignment and elevation of the paver must be regulated from outside reference lines established for this purpose. The paver must

vibrate the concrete for the full width and depth of the strip of pavement being placed and the vibration must be adequate to provide a consistency of concrete that will stand normal to the surface with sharp well defined edges. The sliding forms must be rigidly held together laterally to prevent spreading of the forms. The plastic concrete must be effectively consolidated by internal vibration with transverse vibrating units for the full width of the pavement and/or a series of equally placed longitudinal vibrating units. The space from the outer edge of the pavement to longitudinal unit must not exceed 9 inches (23 cm) for slipform and at the end of the dowels for the fill-in lanes The spacing of internal units must be uniform and must not exceed 18 inches (0.5 m).

2. The term internal vibration means vibrating units located within the specified thickness of pavement section.

3. The rate of vibration of each vibrating unit must be within 8000 to 12000 cycles per minute and the amplitude of vibration must be sufficient to be perceptible on the surface of the concrete along the entire length of the vibrating unit and for a distance of at least one foot (30 cm). The frequency of vibration or amplitude must vary proportionately with the rate of travel to result in a uniform density and air content. The paving machine must be equipped with a tachometer or other suitable device for measuring and indicating the actual frequency of vibrations.

4. The concrete must be held at a uniform consistency. The slip-form paver must be operated with as nearly a continuous forward movement as possible and all operations of mixing, delivering, and spreading concrete must be coordinated to provide uniform progress with stopping and starting of the paver held to a minimum. If for any reason, it is necessary to stop the forward movement of the paver, the vibratory and tamping elements must also be stopped immediately. No tractive force must be applied to the machine, except that which is controlled from the machine.

5. When concrete is being placed adjacent to an existing pavement, that part of the equipment which is supported on the existing pavement must be equipped with protective pads on crawler tracks or rubber-tired wheels on which the bearing surface is offset to run a sufficient distance from the edge of the pavement to avoid breaking the pavement edge.

6. Not more than 15% of the total free edge of each 500 foot (150 m) segment of pavement, or fraction thereof, must have an edge slump exceeding 1/4 inch (6 mm), and none of the free

edge of the pavement must have an edge slump exceeding 3/8 inch (9 mm). (The total free edge of 500 feet (150 m) of pavement will be considered the cumulative total linear measurement of pavement edge originally constructed as nonadjacent to any existing pavement; that is, 500 feet (150 m) of paving lane originally constructed as a separate lane will have 1,000 feet (300 m) of free edge, 500 feet (150 m) of fill-in lane will have no free edge, etc.). The area affected by the downward movement of the concrete along the pavement edge must be limited to not more than 18 inches (0.5 m) from the edge. When excessive edge slump cannot be corrected before the concrete has hardened, the area with excessive edge slump must be removed and replaced at the expense of the Contractor as directed by the Commissioner.

D. Side-form construction:

1. Side form sections must be straight, free from warps, bends, indentations, or other defects. Defective forms must be removed from the work. Metal side forms must be used except at end closures and transverse construction joints where straight forms of other suitable material may be used.

2. Side forms may be built up by rigidly attaching a section to either top or bottom of forms. If such build-up is attached to the top of metal forms, the build-up must also be metal.

3. Width of the base of all forms must be equal to or greater than the specified pavement thickness.

4. Side forms must be of sufficient rigidity, both in the form and in the interlocking connection with adjoining forms, that springing will not occur under the weight of subgrading and paving equipment or from the pressure of the concrete. The Contractor must provide sufficient forms so that there will be no delay in placing concrete due to lack of forms.

5. Before placing side forms, the underlying material must be at the proper grade. Side forms must have full bearing upon the foundation throughout their length and width of base and must be placed to the required grade and alignment of the finished pavement. They must be firmly supported during the entire operation of placing, compacting, and finishing the pavement.

6. Forms must be drilled in advance of being placed to line and grade to accommodate tie bars where these are specified.

7. Immediately in advance of placing concrete and after all subbase operations are completed, side forms must be trued

and maintained to the required line and grade for a distance sufficient to prevent delay in placing.

8. Side forms must remain in place at least 12 hours after the concrete has been placed, and in all cases until the edge of the pavement no longer requires the protection of the forms. Curing compound must be applied to the concrete immediately after the forms have been removed.

9. Side forms must be thoroughly cleaned and oiled each time they are used and before concrete is placed against them.

10. Concrete must be spread, screeded, shaped and consolidated by one or more self-propelled machines. These machines must uniformly distribute and consolidate concrete without segregation so that the completed pavement will conform to the required cross-section with a minimum of handwork.

11. The number and capacity of machines furnished must be adequate to perform the work required at a rate equal to that of concrete delivery.

12. Concrete for the full paving width must be effectively consolidated by internal vibrators without causing segregation. Internal type vibrators' rate of vibration must be not less than 7,000 cycles per minute. Amplitude of vibration must be sufficient to be perceptible on the surface of the concrete more than one foot (30 cm) from the vibrating element. The Contractor must furnish a tachometer or other suitable device for measuring and indicating frequency of vibration.

13. Power to vibrators must be connected so that vibration ceases when forward or backward motion of the machine is stopped.

14. The provisions relating to the frequency and amplitude of internal vibration must be considered the minimum requirements and are intended to ensure adequate density in the hardened concrete.

E. Consolidation:

1. Concrete must be consolidated with the specified type of lane-spanning, gang-mounted, mechanical, immersion type vibrating equipment mounted in front of the paver, supplemented, in rare instances as specified, by hand-operated vibrators. The vibrators must be inserted into the concrete to a depth that will provide the best full-depth consolidation but not closer to the underlying material than inches (50 mm). Excessive vibration must not be permitted. If the vibrators cause visible tracking in the paving lane, the paving operation must be stopped and

equipment and operations modified to prevent it. Concrete in small, odd-shaped slabs or in isolated locations inaccessible to the gang-mounted vibration equipment must be vibrated with an approved hand-operated immersion vibrator operated from a bridge spanning the area. Vibrators must not be used to transport or spread the concrete. Hand-operated vibrators must not be operated in the concrete at one location for more than 20 seconds. Insertion locations for hand-operated vibrators must be between 6 to 15 inches (150 to 400 mm) on centers. For each paving train, at least one additional vibrator spud, or sufficient parts for rapid replacement and repair of vibrators must be maintained at the paving site at all times. Any evidence of inadequate consolidation (honeycomb along the edges, large air pockets, or any other evidence) must require the immediate stopping of the paving operation and adjustment of the equipment or procedures as approved by the Commissioner.

2. If a lack of consolidation of the concrete is suspected by the Commissioner, referee testing may be required. Referee testing of hardened concrete will be performed by the Commissioner by cutting cores from the finished pavement after a minimum of 24 hours curing. Density determinations will be made by the Commissioner based on the water content of the core as taken. ASTM C642 must be used for the determination of core density in the saturated-surface dry condition. When required, referee cores will be taken at the minimum rate of one for each 500 cubic yards (382 m^2) of pavement, or fraction. The Contractor must be responsible for all referee testing cost if they fail to meet the required density.

3. The average density of the cores must be at least 97% of the original mix design density, with no cores having a density of less than 96% of the original mix design density. Failure to meet the referee tests will be considered evidence that the minimum requirements for vibration are inadequate for the job conditions. Additional vibrating units or other means of increasing the effect of vibration must be employed so that the density of the hardened concrete conforms to the above requirements.

4.09 STRIKE-OFF OF CONCRETE AND PLACEMENT OF REINFORCEMENT

A. Following the placing of the concrete, it must be struck off to conform to the cross-section shown on the plans and to an elevation that when the concrete is properly consolidated and finished, the surface of the pavement must be at the elevation shown on the plans. When reinforced concrete pavement is placed in two layers, the bottom layer must be struck off to such length and depth that the sheet of reinforcing steel fabric or bar mat may be laid full length on the concrete in its final position without further manipulation. The reinforcement must then be placed directly upon the concrete, after which the top layer of the concrete must be placed, struck off, and screeded. If any portion of the bottom layer of concrete has been placed more than 30 minutes without being covered with the top layer or if initial set has taken place, it must be removed and replaced with freshly mixed concrete at the Contractor's expense. When reinforced concrete is placed in one layer, the reinforcement may be positioned in advance of concrete placement or it may be placed in plastic concrete by mechanical or vibratory means after spreading.

B. Reinforcing steel, at the time concrete is placed, must be free of mud, oil, or other organic matter that may adversely affect or reduce bond. Reinforcing steel with rust, mill scale or a combination of both will be considered satisfactory, provided the minimum dimensions, weight, and tensile properties of a hand wire-brushed test specimen are not less than the applicable ASTM specification requirements.

4.10 JOINTS

A. Joints must be constructed as shown on the plans and in accordance with these requirements. All joints must be constructed with their faces perpendicular to the surface of the pavement and finished or edged as shown on the plans. Joints must not vary more than 1/2 inch (12 mm) from their designated position and must be true to line with not more than 1/4 inch (6 mm) variation in 10 feet (3 m). The surface across the joints must be tested with a 12 feet (3 m) straightedge as the joints are finished and any irregularities in excess of 1/4 inch (6 mm) must be corrected before the concrete has hardened. All joints must be so prepared, finished, or cut to provide a groove of uniform width and depth as shown on the plans.

B. Construction. Longitudinal construction joints must be slip-formed or formed against side forms as shown in the plans.

Transverse construction joints must be installed at the end of each day's placing operations and at any other points within a paving lane when concrete placement is interrupted for more than 30 minutes or it appears that the concrete will obtain its initial set before fresh concrete arrives. The installation of the joint must be located at a planned contraction or expansion joint. If placing of the concrete is stopped, the Contractor must remove the excess concrete back to the previous planned joint.

C. Contraction. Contraction joints must be installed at the locations and spacing as shown on the plans. Contraction joints must be installed to the dimensions required by forming a groove or cleft in the top of the slab while the concrete is still plastic or by sawing a groove into the concrete surface after the concrete has hardened. When the groove is formed in plastic concrete the sides of the grooves must be finished even and smooth with an edging tool. If an insert material is used, the installation and edge finish must be according to the manufacturer's instructions. The groove must be finished or cut clean so that spalling will be avoided at intersections with other joints. Grooving or sawing must produce a slot at least 1/8 inch (3 mm) wide and to the depth shown on the plans.

D. Isolation (expansion). Isolation joints must be installed as shown on the plans. The premolded filler of the thickness as shown on the plans, must extend for the full depth and width of the slab at the joint, except for space for sealant at the top of the slab. The filler must be securely staked or fastened into position perpendicular to the proposed finished surface. A cap must be provided to protect the top edge of the filler and to permit the concrete to be placed and finished. After the concrete has been placed and struck off, the cap must be carefully withdrawn leaving the space over the premolded filler. The edges of the joint must be finished and tooled while the concrete is still plastic. Any concrete bridging the joint space must be removed for the full width and depth of the joint.

E. Tie bars. Tie bars must consist of deformed bars installed in joints as shown on the plans. Tie bars must be placed at right angles to the centerline of the concrete slab and must be spaced at intervals shown on the plans. They must be held in position parallel to the pavement surface and in the middle of the slab depth. When tie bars extend into an unpaved lane, they may be bent against the form at longitudinal construction joints, unless threaded bolt or other assembled tie bars are specified. Tie bars must not be painted, greased, or enclosed in sleeves. When slip-form operations call for tie bars, two-piece hook bolts can be installed.

F. Dowel bars. Dowel bars or other load-transfer units of an approved type must be placed across joints as shown on the plans. They must be of the dimensions and spacings as shown and held rigidly in the middle of the slab depth in the proper horizontal and vertical alignment by an approved assembly device to be left permanently in place. The dowel or load-transfer and joint devices must be rigid enough to permit complete assembly as a unit ready to be lifted and placed into position. The dowels must be coated with a bond-breaker or other lubricant recommended by the manufacturer and approved by the Commissioner.

Dowels bars at longitudinal construction joints must be bonded in drilled holes.

G. Placing dowels and tie bars. The method used in installing and holding dowels in position must ensure that the error in alignment of any dowel from its required horizontal and vertical alignment after the pavement has been completed will not be greater than 1/8 inch per feet. Except as otherwise specified below, horizontal spacing of dowels must be within a tolerance of ±5/8 inch. The vertical location on the face of the slab must be within a tolerance of ±1/2 inch. The vertical alignment of the dowels must be measured parallel to the designated top surface of the pavement, except for those across the crown or other grade change joints. Dowels across crowns and other joints at grade changes must be measured to a level surface. Horizontal alignment must be checked perpendicular to the joint edge. The horizontal alignment must be checked with a framing square. Dowels must not be placed closer than 0.6 times the dowel bar length to the planned joint line. If the last regularly spaced longitudinal dowel is closer than that dimension, it must be moved away from the joint to a location 0.6 times the dowel bar length, but not closer than 6 inches to its nearest neighbor. The portion of each dowel intended to move within the concrete or expansion cap must be wiped clean and coated with a thin, even film of lubricating oil or light grease before the concrete is placed. Dowels must be installed as specified in the following subparagraphs.

1. Contraction joints. Dowels and tie bars in longitudinal and transverse contraction joints within the paving lane must be held securely in place, as indicated, by means of rigid metal frames or basket assemblies of an approved type. The basket assemblies must be held securely in the proper location by means of suitable pins or anchors. Do not cut or crimp the dowel basket tie wires. At the Contractor's option, in lieu of the above, dowels and tie bars in contraction joints must be installed near the front of the paver by insertion into the plastic concrete using approved equipment and procedures. Approval will be based on the results of a preconstruction demonstration, showing that the dowels and tie bars are installed within specified tolerances.

2. Construction joints. Install dowels and tie bars by the cast-in-place or the drill-and-dowel method. Installation by removing and replacing in preformed holes will not be permitted. Dowels and tie bars must be prepared and placed across joints where indicated, correctly aligned, and securely held in the proper horizontal and vertical position during placing and finishing operations, by means of devices fastened to the forms. The spacing of dowels and tie bars in construction joints must be as indicated.

3. Dowels installed in isolation joints and other hardened concrete. Install dowels for isolation joints and in other hardened concrete by bonding the dowels into holes drilled into the hardened concrete. The concrete must have cured for seven (7) days or reached a minimum flexural strength of 450 psi before drilling commences. Holes 1/8 inch greater in diameter than the dowels must be drilled into the hardened concrete using rotary-core drills. Rotary-percussion drills may be used, provided that excessive spalling does not occur to the concrete joint face. Modification of the equipment and operation must be required if, in the Commissioner’s opinion, the equipment and/or operation is causing excessive damage. Depth of dowel hole must be within a tolerance of ±1/2 inch of the dimension shown on the drawings. On completion of the drilling operation, the dowel hole must be blown out with oil-free, compressed air. Dowels must be bonded in the drilled holes using epoxy resin. Epoxy resin must be injected at the back of the hole before installing the dowel and extruded to the collar during insertion of the dowel so as to completely fill the void around the dowel. Application by buttering the dowel will not be permitted. The dowels must be held in alignment at the collar of the hole, after insertion and before the grout hardens, by means of a suitable metal or plastic grout retention ring fitted around the dowel. Dowels required to be installed in any joints between new and existing concrete must be grouted in holes drilled in the existing concrete, all as specified above.

H. Sawing of joints. Joints must be cut as shown on the plans. Equipment must be as described in paragraph 501-4.1. The circular cutter must be capable of cutting a groove in a straight line and must produce a slot at least 1/8 inch (3 mm) wide and to the depth shown on the plans. The top of the slot must be widened by sawing to provide adequate space for joint sealers as shown on the plans. Sawing must commence, without regard to day or night, as soon as the concrete has hardened sufficiently to permit cutting without chipping, spalling, or tearing and before uncontrolled shrinkage cracking of the pavement occurs and must continue without interruption until all joints have been sawn. The joints must be sawn at the required spacing. All slurry and debris produced in the sawing of joints must be removed by vacuuming and washing. Curing compound or system must be reapplied in the initial sawcut and maintained for the remaining cure period.

4.11 FINISHING

A. Finishing operations must be a continuing part of placing operations starting immediately behind the strike-off of the paver. Initial finishing must be provided by the transverse screed or extrusion plate. The sequence of operations must be transverse finishing, longitudinal machine floating if used, straightedge finishing, texturing, and then edging of joints. Finishing must be by the machine method. The hand method must be used only on isolated areas of odd slab widths or shapes and in the event of a breakdown of the mechanical finishing equipment. Supplemental hand finishing for machine finished pavement must be kept to an absolute minimum. Any machine finishing operation which requires appreciable hand finishing, other than a moderate amount of straightedge finishing, must be immediately stopped and proper adjustments made or the equipment replaced. Any operations which produce more than 1/8 inch (3 mm) of mortar-rich surface (defined as deficient in plus U.S. No. 4 (4.75 mm) sieve size aggregate) must be halted immediately and the equipment, mixture, or procedures modified as necessary. Compensation must be made for surging behind the screeds or extrusion plate and settlement during hardening and care must be taken to ensure that paving and finishing machines are properly adjusted so that the finished surface of the concrete (not just the cutting edges of the screeds) will be at the required line and grade. Finishing equipment and tools must be maintained clean and in an approved condition. At no time must water be added to the surface of the slab with the finishing equipment or tools, or in any other way, except for fog (mist) sprays specified to prevent plastic shrinkage cracking.

1. Machine finishing with slipform pavers. The slipform paver must be operated so that only a very minimum of additional finishing work is required to produce pavement surfaces and edges meeting the specified tolerances. Any equipment or procedure that fails to meet these specified requirements must immediately be replaced or modified as necessary. A self-propelled non-rotating pipe float may be used while the concrete is still plastic, to remove minor irregularities and score marks. Only one pass of the pipe float must be allowed. If there is concrete slurry or fluid paste on the surface that runs over the edge of the pavement, the paving operation must be immediately stopped and the equipment, mixture, or operation modified to prevent formation of such slurry. Any slurry which does run down the vertical edges must be immediately removed by hand, using stiff brushes or scrapers. No slurry, concrete or concrete mortar must be used to build up along the edges of the pavement to compensate for excessive edge slump, either while the concrete is plastic or after it hardens.
2. Machine finishing with fixed forms. The machine must be designed to straddle the forms and must be operated to screed and consolidate the concrete. Machines that cause

displacement of the forms must be replaced. The machine must make only one pass over each area of pavement. If the equipment and procedures do not produce a surface of uniform texture, true to grade, in one pass, the operation must be immediately stopped and the equipment, mixture, and procedures adjusted as necessary.

3. Other types of finishing equipment. Clary screeds, other rotating tube floats, or bridge deck finishers are not allowed on mainline paving, but may be allowed on irregular or odd-shaped slabs, and near buildings or trench drains, subject to the Commissioner's approval.

   Bridge deck finishers must have a minimum operating weight of 7500 pounds (3400 kg) and must have a transversely operating carriage containing a knock-down auger and a minimum of two immersion vibrators. Vibrating screeds or pans must be used only for isolated slabs where hand finishing is permitted as specified, and only where specifically approved.

4. Hand finishing. Hand finishing methods will not be permitted, except under the following conditions: (1) in the event of breakdown of the mechanical equipment, hand methods may be used to finish the concrete already deposited on the grade and (2) in areas of narrow widths or of irregular dimensions where operation of the mechanical equipment is impractical. Use hand finishing operations only as specified below.

   a. Equipment and screed. In addition to approved mechanical internal vibrators for consolidating the concrete, provide a strike-off and tamping screed and a longitudinal float for hand finishing. The screed must be at least one foot (30 cm) longer than the width of pavement being finished, of an approved design, and sufficiently rigid to retain its shape, and must be constructed of metal or other suitable material shod with metal. The longitudinal float must be at least 10 feet (3 m) long, of approved design, and rigid and substantially braced, and must maintain a plane surface on the bottom. Grate tampers (jitterbugs) must not be used.

   b. Finishing and floating. As soon as placed and vibrated, the concrete must be struck off and screeded to the crown and cross-section and to such elevation above grade that when consolidated and finished, the surface of the pavement will be at the required elevation. In addition to previously specified complete coverage with handheld immersion vibrators, the entire surface must be tamped with the strike-off and tamping template, and the tamping operation continued until the required compaction and reduction of internal and surface voids are accomplished. Immediately following the final tamping of the surface, the pavement must be floated longitudinally from bridges resting on the side forms and spanning but not touching the concrete. If necessary, additional concrete must be placed, consolidated and screeded, and the float operated until a satisfactory surface has been produced. The floating operation must be advanced not more than half the length of the float and then continued over the new and previously floated surfaces.

5. Straightedge testing and surface correction**.** After the pavement has been struck off and while the concrete is still plastic, it must be tested for trueness with a Contractor furnished 12-foot (3.7-m) straightedge swung from handles 3 feet (1 m) longer than one-half the width of the slab. The straightedge must be held in contact with the surface in successive positions parallel to the centerline and the whole area gone over from one side of the slab to the other, as necessary. Advancing must be in successive stages of not more than one-half the length of the straightedge. Any excess water and laitance in excess of 1/8 inch (3 mm) thick must be removed from the surface of the pavement and wasted. Any depressions must be immediately filled with freshly mixed concrete, struck off, consolidated, and refinished. High areas must be cut down and refinished. Special attention must be given to assure that the surface across joints meets the smoothness requirements of paragraph 501-5.2e(3). Straightedge testing and surface corrections must continue until the entire surface is found to be free from observable departures from the straightedge and until the slab conforms to the required grade and cross-section. The use of long-handled wood floats must be confined to a minimum; they may be used only in emergencies and in areas not accessible to finishing equipment. This straight-edging is not a replacement for the straightedge testing of paragraph 501-5.2e(3), Smoothness.

4.12 SURFACE TEXTURE

A. The surface of the pavement must be finished with either a brush or broom, burlap drag, or artificial turf finish for all newly constructed concrete pavements. It is important that the texturing equipment not tear or unduly roughen the pavement surface during the operation. Any imperfections resulting from the texturing operation must be corrected to the satisfaction of the Commissioner.

B. Brush. If the pavement surface texture is to be a type of brush, it must be applied when the water sheen has practically disappeared. The equipment must operate transversely across the pavement surface, providing corrugations that are uniform in appearance and approximately 1/16 inch (2 mm) in depth.

4.13 CURING

A. Immediately after finishing operations are completed and marring of the concrete will not occur, the entire surface of the newly placed concrete must be cured for a 7-day cure period in accordance with one of the methods below. Failure to provide sufficient cover material of whatever kind the Contractor may elect to use, or lack of water to adequately take care of both curing and other requirements, must be cause for immediate suspension of concreting operations. The concrete must not be left exposed for more than 1/2 hour during the curing period.

B. When a two-sawcut method is used to construct the contraction joint, the curing compound must be applied to the sawcut immediately after the initial cut has been made. The sealant reservoir must not be sawed until after the curing period has been completed. When the one cut method is used to construct the contraction joint, the joint must be cured with wet rope, wet rags, or wet blankets. The rags, ropes, or blankets must be kept moist for the duration of the curing period.

C. Impervious membrane method. The entire surface of the pavement must be sprayed uniformly with white pigmented curing compound immediately after the finishing of the surface and before the set of the concrete has taken place. The curing compound must not be applied during rainfall. Curing compound must be applied by mechanical sprayers under pressure at the rate of one gallon (4 liters) to not more than 150 sq ft (14 sq m). The spraying equipment must be of the fully atomizing type equipped with a tank agitator. At the time of use, the compound must be in a thoroughly mixed condition with the pigment uniformly dispersed throughout the vehicle. During application the compound must be stirred continuously by mechanical means. Hand spraying of odd widths or shapes and concrete surfaces exposed by the removal of forms will be permitted. When hand spraying is approved by the Commissioner, a double application rate must be used to ensure coverage. The curing compound must be of such character that the film will harden within 30 minutes after application. Should the film become damaged from any cause, including sawing operations, within the required curing period, the damaged portions must be repaired immediately with additional compound or other approved means. Upon removal of side forms, the sides of the exposed slabs must be protected immediately to provide a curing treatment equal to that provided for the surface. Curing must be applied immediately after the bleed water is gone from the surface.

D. White burlap-polyethylene sheets. The surface of the pavement shall be entirely covered with the sheeting. The sheeting used shall be such length (or width) that it will extend at least twice the thickness of the pavement beyond the edges of the slab. The sheeting shall be placed so that the entire surface and both edges of the slab are completely covered. The sheeting shall be placed and weighted to remain in contact with the surface covered, and the covering shall be maintained fully saturated and in position for seven (7) days after the concrete has been placed.

E. Water method. The entire area shall be covered with burlap or other water absorbing material. The material shall be of sufficient thickness to retain water for adequate curing without excessive runoff. The material shall be kept wet at all times and maintained for seven (7) days. When the forms are stripped, the vertical walls shall also be kept moist. It shall be the responsibility of the Contractor to prevent ponding of the curing water on the subbase.

F. Concrete protection for cold weather. The concrete must be maintained at an ambient temperature of at least 50°F (10°C) for a period of 72 hours after placing and at a temperature above freezing for the remainder of the curing time. The Contractor must be responsible for the quality and strength of the concrete placed during cold weather; and any concrete damaged must be removed and replaced at the Contractor’s expense.

G. Concrete protection for hot weather. Concrete should be continuous moisture cured for the entire curing period and must commence as soon as the surfaces are finished and continue for at least 24 hours. However, if moisture curing is not practical beyond 24 hours, the concrete surface must be protected from drying with application of a liquid membrane-forming curing compound while the surfaces are still damp. Other curing methods may be approved by the Commissioner.

4.14 REMOVING FORMS

A. Unless otherwise specified, forms must not be removed from freshly placed concrete until it has hardened sufficiently to permit removal without chipping, spalling, or tearing. After the forms have been removed, the sides of the slab must be cured as per the methods indicated in paragraph 501-4.13. Major honeycombed areas must be considered as defective work and must be removed and replaced in accordance with paragraph 501-5.2(f).

4.15 SAW-CUT GROOVING

A. If shown on the plans, grooved surfaces must be provided in accordance with the requirements of Item S-802.

4.16 SEALING JOINTS

A. The joints in the pavement must be sealed in accordance with Item P-605.

4.17 PROTECTION OF PAVEMENT

A. The Contractor must protect the pavement and its appurtenances against both public traffic and traffic caused by the Contractor's employees and agents until accepted by the Commissioner. This must include watchmen to direct traffic and the erection and maintenance of warning signs, lights, pavement bridges, crossovers, and protection of unsealed joints from intrusion of foreign material, etc. Any damage to the pavement occurring prior to final acceptance must be repaired or the pavement replaced at the Contractor's expense.

Aggregates, rubble, or other similar construction materials must not be placed on airfield pavements. Traffic must be excluded from the new pavement by erecting and maintaining barricades and signs until the concrete is at least seven (7) days old, or for a longer period if directed by the Commissioner.

In paving intermediate lanes between newly paved pilot lanes, operation of the hauling and paving equipment will be permitted on the new pavement after the pavement has been cured for seven (7) days and the joints have been sealed or otherwise protected, and the concrete has attained a minimum field cured flexural strength of 550 psi and approved means are furnished to prevent damage to the slab edge.

All new and existing pavement carrying construction traffic or equipment must be continuously kept completely clean, and spillage of concrete or other materials must be cleaned up immediately upon occurrence.

Damaged pavements must be removed and replaced at the Contractor's expense. Slabs must be removed to the full depth, width, and length of the slab.

4.18 OPENING TO CONSTRUCTION TRAFFIC

A. The pavement must not be opened to traffic until test specimens molded and cured in accordance with ASTM C31 have attained a flexural strength of 550 lb / square inch when tested in accordance with ASTM C78. If such tests are not conducted, the pavement must not be opened to traffic until 14 days after the concrete was placed. Prior to opening the pavement to construction traffic, all joints must either be sealed or protected from damage to the joint edge and intrusion of foreign materials into the joint. As a minimum, backer rod or tape may be used to protect the joints from foreign matter intrusion.

4.19 REPAIR, REMOVAL, OR REPLACEMENT OF SLABS

A. General. New pavement slabs that are broken or contain cracks or are otherwise defective or unacceptable must be removed and replaced or repaired, as directed by the Commissioner and as specified hereinafter at no cost to the Owner. Spalls along joints must be repaired as specified. Removal of partial slabs is not permitted. Removal and replacement must be full depth, must be full width of the slab, and the limit of removal must be normal to the paving lane and to each original transverse joint. The Commissioner will determine whether cracks extend full depth of the pavement and may require cores to be drilled on the crack to determine depth of cracking. Such cores must be 4 inch (100 mm) diameter, must be drilled by the Contractor and must be filled by the Contractor with a well consolidated concrete mixture bonded to the walls of the hole with epoxy resin, using approved procedures. Drilling of cores and refilling holes must be at no expense to the Owner. All epoxy resin used in this work must conform to ASTM C881, Type V. Repair of cracks as described in this section must not be allowed if in the opinion of the Commissioner the overall condition of the pavement indicates that such repair is unlikely to achieve an acceptable and durable finished pavement. No repair of cracks must be allowed in any panel that demonstrates segregated aggregate with an absence of coarse aggregate in the upper 1/8 inch (3 mm) of the pavement surface.

B. Shrinkage cracks. Shrinkage cracks, which do not exceed 4 inches (100 mm) in depth, must be cleaned and then pressure injected with epoxy resin, Type IV, Grade 1, using procedures as approved by the Commissioner. Care must be taken to assure that the crack is not widened during epoxy resin injection. All epoxy resin injection must take place in the presence of the Commissioner. Shrinkage cracks, which exceed 4 inches (100 mm) in depth, must be treated as full depth cracks in accordance with paragraphs 4.19b and 4.19c.

C. Slabs with cracks through interior areas. Interior area is defined as that area more than 6 inches (150 mm) from either adjacent original transverse joint. The full slab must be removed and replaced at no cost to the Owner, when there are any full depth cracks, or cracks greater than 4 inches (100 mm) in depth, that extend into the interior area.

D. Cracks close to and parallel to joints. All cracks essentially parallel to original joints, extending full depth of the slab, and lying wholly within 6 inches (150 mm) either side of the joint must be treated as specified here. Any crack extending more than 6 inches (150 mm) from the joint must be treated as specified above in subparagraph c.

1. Full depth cracks present, original joint not opened. When the original un-cracked joint has not opened, the crack must be sawed and sealed, and the original joint filled with epoxy resin as specified below. The crack must be sawed with equipment specially designed to follow random cracks. The reservoir for joint sealant in the crack must be formed by sawing to a depth of 3/4 inches (19 mm), ±1/16 inch (2 mm), and to a width of 5/8 inch (16 mm), ±1/8 inch (3 mm). Any equipment or procedure which causes raveling or spalling along the crack must be modified or replaced to prevent such raveling or spalling. The joint sealant must be a liquid sealant as specified. Installation of joint seal must be as specified for sealing joints or as directed. If the joint sealant reservoir has been sawed out, the reservoir and as much of the lower saw cut as possible must be filled with epoxy resin, Type IV, Grade 2, thoroughly tooled into the void using approved procedures.

   If only the original narrow saw cut has been made, it must be cleaned and pressure injected with epoxy resin, Type IV, Grade 1, using approved procedures. If filler type material has been used to form a weakened plane in the transverse joint, it must be completely sawed out and the saw cut pressure injected with epoxy resin, Type IV, Grade 1, using approved procedures. Where a parallel crack goes part way across paving lane and then intersects and follows the original joint which is cracked only for the remained of the width, it must be treated as specified above for a parallel crack, and the cracked original joint must be prepared and sealed as originally designed.

2. Full depth cracks present, original joint also cracked. At a joint, if there is any place in the lane width where a parallel crack and a cracked portion of the original joint overlap, the entire slab containing the crack must be removed and replaced for the full lane width and length.

E. Removal and replacement of full slabs. Where it is necessary to remove full slabs, unless there are dowels present, all edges of the slab must be cut full depth with a concrete saw. All saw cuts must be perpendicular to the slab surface. If dowels, or tie bars are present along any edges, these edges must be sawed full depth just beyond the end of the dowels or tie bars. These joints must then be carefully sawed on the joint line to within one inch (25 mm) of the depth of the dowel or tie bar.

   The main slab must be further divided by sawing full depth, at appropriate locations, and each piece lifted out and removed. Suitable equipment must be used to provide a truly vertical lift, and approved safe lifting devices used for attachment to the slabs. The narrow strips along doweled edges must be carefully broken up and removed using light, hand-held jackhammers, 30 lb (14 kg) or less, or other approved similar equipment.

Care must be taken to prevent damage to the dowels, tie bars, or to concrete to remain in place. The joint face below dowels must be suitably trimmed so that there is not abrupt offset in any direction greater than 1/2 inch (12 mm) and no gradual offset greater than one inch (25 mm) when tested in a horizontal direction with a 12-foot (3.7-m) straightedge.

No mechanical impact breakers, other than the above hand-held equipment must be used for any removal of slabs. If underbreak between 1-1/2 and 4 inches (38 and 100 mm) deep occurs at any point along any edge, the area must be repaired as directed before replacing the removed slab. Procedures directed will be similar to those specified for surface spalls, modified as necessary.

If underbreak over 4 inches (100 mm) deep occurs, the entire slab containing the underbreak must be removed and replaced. Where there are no dowels or tie bars, or where they have been damaged, dowels or tie bars of the size and spacing as specified for other joints in similar pavement must be installed by epoxy grouting them into holes drilled into the existing concrete using procedures as specified. Original damaged dowels or tie bars must be cut off flush with the joint face. Protruding portions of dowels must be painted and lightly oiled. All four (4) edges of the new slab must contain dowels or original tie bars.

Placement of concrete must be as specified for original construction. Prior to placement of new concrete, the underlying material (unless it is stabilized) must be re-compacted and shaped as specified in the appropriate section of these specifications. The surfaces of all four joint faces must be cleaned of all loose material and contaminants and coated with a double application of membrane forming curing compound as bond breaker. Care must be taken to prevent any curing compound from contacting dowels or tie bars. The resulting joints around the new slab must be prepared and sealed as specified for original construction.

F. Repairing spalls along joints. Where directed, spalls along joints of new slabs, and along parallel cracks used as replacement joints, must be repaired by first making a vertical saw cut at least one inch (25 mm) outside the spalled area and to a depth of at least 2 inch (50 mm). Saw cuts must be straight lines forming rectangular areas. The concrete between the saw cut and the joint, or crack, must be chipped out to remove all unsound concrete and at least 1/2 inch (12 mm) of visually sound concrete. The cavity thus formed must be thoroughly cleaned with high-pressure water jets supplemented with compressed air to remove all loose material. Immediately before filling the cavity, a prime coat of epoxy resin, Type III, Grade I, must be applied to the dry cleaned surface of all sides and bottom of the cavity, except any joint face. The prime coat must be applied in a thin coating and scrubbed into the surface with a stiff-bristle brush. Pooling of epoxy resin must be avoided. The cavity must be filled with low slump Portland cement concrete or mortar or with epoxy resin concrete or mortar. Concrete must be used for larger spalls, generally those more than 1/2 cu. ft. (0.014 m^3) in size, and mortar must be used for the smaller ones. Any spall less than 0.1 cu. ft. (0.003 m^3) must be repaired only with epoxy resin mortar or a Grade III epoxy resin. Portland cement concrete and mortar mixtures must be proportioned as directed and must be mixed, placed, consolidated, and cured as directed. Epoxy resin mortars must be made with Type III, Grade 1, epoxy resin, using proportions and mixing and placing procedures as recommended by the manufacturer and approved by the Commissioner. The epoxy resin materials must be placed in the cavity in layers not over 2 inches (50 mm) thick. The time interval between placement of additional layers must be such that the temperature of the epoxy resin material does not exceed 140°F (60°C) at any time during hardening. Mechanical vibrators and hand tampers must be used to consolidate the concrete or mortar. Any repair material on the surrounding surfaces of the existing concrete must be removed before it hardens. Where the spalled area abuts a joint, an insert or other bond-breaking medium must be used to prevent bond at the joint face. A reservoir for the joint sealant must be sawed to the dimensions required for other joints, or as required to be routed for cracks. The reservoir must be thoroughly cleaned and sealed with the sealer specified for the joints. If any spall penetrates half the depth of the slab or more, the entire slab must be removed and replaced as previously specified. If any spall would require over 25% of the length of any single joint to be repaired, the entire slab must be removed and replaced. Repair of spalls as described in this section must not be allowed if in the opinion of the Commissioner the overall condition of the pavement indicates that such repair is unlikely to achieve an acceptable and durable finished pavement. No repair of spalls must be allowed in any panel that demonstrates segregated aggregate with a significant absence of coarse aggregate in the upper one-eight (1/8th) inch of the pavement surface.

G. Diamond grinding of PCC surfaces. Diamond grinding of the hardened concrete with an approved diamond grinding machine should not be performed until the concrete is 14 days or more old and concrete has reached full minimum strength. When required, diamond grinding must be accomplished by sawing with saw blades impregnated with industrial diamond abrasive. The saw blades must be assembled in a cutting head mounted on a machine designed specifically for diamond grinding that will produce the required texture and smoothness level without damage to the pavement. The saw blades must be 1/8-inch (3-mm) wide and there must be a minimum of 55 to 60 blades per 12 inches (300 mm) of cutting head width; the actual number of blades will be determined by the Contractor and depend on the hardness of the aggregate. Each machine must be capable of cutting a path at least 3 feet (0.9 m) wide. Equipment that causes ravels, aggregate fractures, spalls or disturbance to the joints will not be permitted. The area corrected by diamond grinding the surface of the hardened concrete should not exceed 10% of the total area of any sublot. The depth of diamond grinding must not exceed 1/2 inch (13 mm) and all areas in which diamond grinding has been performed will be subject to the final pavement thickness tolerances specified. Grinding will be tapered in all directions to provide smooth transitions to areas not requiring grinding. All pavement areas requiring plan grade or surface smoothness corrections in excess of the limits specified above, may require removing and replacing in conformance with paragraph 501-4.19.

4.20 EXISTING CONCRETE PAVEMENT REMOVAL AND REPAIR

A. All operations must be carefully controlled to prevent damage to the concrete pavement and to the underlying material to remain in place. All saw cuts must be made perpendicular to the slab surface.

B. Removal of existing pavement slab. When it is necessary to remove existing concrete pavement and leave adjacent concrete in place, the joint between the removal area and adjoining pavement to stay in place, including dowels or tie bars, must first be cut full depth with a standard diamond-type concrete saw. If dowels are present at this joint, the saw cut must be made full depth just beyond the end of dowels. The edge must then be carefully sawed on the joint line to within one inch of the top of the dowel. Next, a full depth saw cut must be made parallel to the joint at least 24 inches from the joint and at least 12 inches from the end of any dowels. All pavement between this last saw cut and the joint line must be carefully broken up and removed using hand-held jackhammers, 30 lb or less, or the approved light-duty equipment which will not cause stress to propagate across the joint saw cut and cause distress in the pavement which is to remain in place. Where dowels are present, care must be taken to produce an even, vertical joint face below the dowels. If the Contractor is unable to produce such a joint face, or if underbreak or other distress occurs, the Contractor must saw the dowels flush with the joint. The Contractor must then install new dowels, of the size and spacing used for other similar joints, by epoxy resin bonding them in holes drilled in the joint face as specified in paragraph 501-4.10G. All this must be at no additional cost to the Owner. Dowels of the size and spacing indicated must be installed as shown on the drawings by epoxy resin bonding them in holes drilled in the joint face as specified in paragraph 501-4.10 G. The joint face must be sawed or otherwise trimmed so that there is no abrupt offset in any direction greater than 1/2 inches and no gradual offset greater than one inch when tested in a horizontal direction with a 12-foot straightedge.

C. Edge repair. The edge of existing concrete pavement against which new pavement abuts must be protected from damage at all times. Areas that are damaged during construction must be repaired at no cost to the Owner.

1. Spall repair. Spalls must be repaired where indicated and where directed by the Commissioner. Repair materials and procedures must be as previously specified in subparagraph 501-4.19f.

2. Underbreak repair. All underbreak must be repaired. First, all delaminated and loose material must be carefully removed. Next, the underlying material must be recompacted, without addition of any new material. Finally, the void must be completely filled with paving concrete, thoroughly consolidated. Care must be taken to produce an even joint face from top to bottom. Prior to placing concrete, the underlying material must be thoroughly moistened. After placement, the exposed surface must be heavily coated with curing compound.

3. Underlying material. The underlying material adjacent to the edge and under the existing pavement which is to remain in place must be protected from damage or disturbance during removal operations and until placement of new concrete, and must be shaped as shown on the drawings or as directed. Sufficient material must be kept in place outside the joint line to prevent disturbance (or sloughing) of material under the pavement that is to remain in place. Any material under the portion of the concrete pavement to remain in place, which is disturbed or loses its compaction must be carefully removed and replaced with concrete as specified in paragraph 501-4.20b(2). The underlying material outside the joint line must be thoroughly compacted and moist when new concrete is placed.

PART 5 MATERIAL ACCEPTANCE

5.01 ACCEPTANCE SAMPLING AND TESTING

A. All acceptance sampling and testing necessary to determine conformance with the requirements specified in this section, with the exception of coring for thickness determination, will be performed by the Commissioner at no cost to the Contractor. The Contractor must bear the cost of providing curing facilities for the strength specimens, per paragraph 501-5.1a(3), and coring and filling operations, per paragraph 501-5.1b(1). Testing organizations performing these tests must be accredited in accordance with ASTM C1077. The laboratory accreditation must be current and listed on the accrediting authority's website. All test methods required for acceptance sampling and testing must be listed on the lab accreditation. A copy of the laboratory's current accreditation and accredited test methods must be submitted to the Commissioner prior to start of construction.

Concrete must be accepted for strength and thickness on a lot basis.

B. A lot must consist of a day's production not to exceed 4,000 square yards.

C. Flexural strength.

1. Sampling. Each lot must be divided into four equal sublots. One sample must be taken for each sublot from the plastic concrete delivered to the job site. Sampling locations must be determined by the Commissioner in accordance with random sampling procedures contained in ASTM D3665. The concrete must be sampled in accordance with ASTM C172.

2. Testing. Two (2) specimens must be made from each sample. Specimens must be made in accordance with ASTM C31 and the flexural strength of each specimen must be determined in accordance with ASTM C78. The flexural strength for each sublot must be computed by averaging the results of the two test specimens representing that sublot.

   Immediately prior to testing for flexural strength, the beam must be weighed and measured for determination of a sample unit weight. Measurements must be made for each dimension; height, depth, and length, at the mid-point of the specimen and reported to the nearest 1/10 inch (3 mm). The weight of the specimen must be reported to the nearest 0.1 pound (45 gm). The sample unit weight must be calculated by dividing the sample weight by the calculated volume of the sample. This information must be reported as companion information to the measured flexural strength for each specimen.

   The samples will be transported while in the molds. The curing, except for the initial cure period, will be accomplished using the immersion in saturated lime water method.

   Slump, air content, and temperature tests will also be conducted by the quality assurance laboratory for each set of strength test samples, per ASTM C31.

3. Curing. The Contractor must provide adequate facilities for the initial curing of beams. During the 24 hours after molding, the temperature immediately adjacent to the specimens must be maintained in the range of 60° to 80°F (16° to 27°C), and loss of moisture from the specimens must be prevented. The specimens may be stored in tightly constructed wooden boxes, damp sand pits, temporary buildings at construction sites, under wet burlap in favorable weather, or in heavyweight closed plastic bags, or using other suitable methods, provided the temperature and moisture loss requirements are met.

4. Acceptance. Acceptance of pavement for flexural strength will be determined by the Commissioner in accordance with paragraph 5.02B.

D. Pavement thickness.

1. Sampling. Each lot must be divided into four equal sublots and one core must be taken by the Contractor for each sublot. Sampling locations must be determined by the Commissioner in accordance with random sampling procedures contained in ASTM D3665. Areas, such as thickened edges, with planned variable thickness, must be excluded from sample locations.

   Cores must be neatly cut with a core drill. The Contractor must furnish all tools, labor, and materials for cutting samples and filling the cored hole. Core holes must be filled by the Contractor with a non-shrink grout approved by the Commissioner within one day after sampling.

2. Testing. The thickness of the cores must be determined by the Commissioner by the average caliper measurement in accordance with ASTM C174.

3. Acceptance. Acceptance of pavement for thickness must be determined by the Commissioner in accordance with paragraph 5.02C.

E. Partial lots. When operational conditions cause a lot to be terminated before the specified number of tests have been made for the lot, or when the Contractor and Commissioner agree in writing to allow overages or minor placements to be considered as partial lots, the following procedure will be used to adjust the lot size and the number of tests for the lot.

   Where three sublots have been produced, they must constitute a lot. Where one or two sublots have been produced, they must be incorporated into the next lot or the previous lot and the total number of sublots must be used in the acceptance criteria calculation, that is, n=5 or n=6.

F. Outliers. All individual flexural strength tests within a lot must be checked for an outlier (test criterion) in accordance with ASTM E178, at a significance level of 5%. Outliers must be discarded, and the percentage of material within specification limits (PWL) must be determined using the remaining test values.

5.02 ACCEPTANCE CRITERIA

A. General. Acceptance will be based on the following characteristics of the completed pavement discussed in paragraph 501-5.2e:

a. Flexural strength

b. Thickness

c. Smoothness

d. Grade

e. Edge slump

Flexural strength and thickness must be evaluated for acceptance on a lot basis using the method of estimating PWL. Acceptance using PWL considers the variability (standard deviation) of the material and the testing procedures, as well as the average (mean) value of the test results to calculate the percentage of material that is above the lower specification tolerance limit (L).

Acceptance for flexural strength will be based on the criteria contained in accordance with paragraph 5.02 E 1. Acceptance for thickness will be based on the criteria contained in paragraph 5.02 E 2. Acceptance for smoothness will be based on the criteria contained in paragraph 5.02 E 3. Acceptance for grade will be based on the criteria contained in paragraph 5.02 E 4.

The Commissioner may at any time, notwithstanding previous plant acceptance, reject and require the Contractor to dispose of any batch of concrete mixture which is rendered unfit for use due to contamination, segregation, or improper slump. Such rejection may be based on only visual inspection. In the event of such rejection, the Contractor may take a representative sample of the rejected material in the presence of the Commissioner, and if it can be demonstrated in the laboratory, in the presence of the Commissioner, that such material was erroneously rejected, payment will be made for the material at the contract unit price.

B. Flexural strength. Acceptance of each lot of in-place pavement for flexural strength must be based on PWL. The Contractor must target production quality to achieve 90 PWL or higher.

C. Pavement thickness. Acceptance of each lot of in-place pavement must be based on PWL. The Contractor must target production quality to achieve 90 PWL or higher.

D. Percentage of material within limits (PWL). The PWL must be determined in accordance with procedures specified in Section 110 of Part Three of Three, Technical Specifications.

The lower specification tolerance limit (L) for flexural strength and thickness must be:

Lower Specification Tolerance Limit (L)

Flexural Strength	0.93 × strength specified in paragraph 501-3.1
Thickness	Lot Plan Thickness in inches, - 0.50 in

E. Acceptance criteria.

1. Flexural Strength. If the PWL of the lot equals or exceeds 90%, the lot must be acceptable. Acceptance and payment for the lot must be determined in accordance with paragraph 501-8.01.

2. Thickness. If the PWL of the lot equals or exceeds 90%, the lot must be acceptable. Acceptance and payment for the lot must be determined in accordance with paragraph 501-8.01.

3. Smoothness. As soon as the concrete has hardened sufficiently, but not later than 48 hours after placement, the surface of each lot must be tested in both longitudinal and transverse directions for smoothness to reveal all surface irregularities exceeding the tolerances specified. The Contractor must furnish paving equipment and employ methods that produce a surface for each section of pavement having an average profile index meeting the requirements of paragraph 501-8.01 C when evaluated with a profilograph; and the finished surface of the pavement must not vary more than 1/4 inch (6mm) when evaluated with a 12-foot straightedge. When the surface smoothness exceeds specification tolerances which cannot be corrected by diamond grinding of the pavement, full depth removal and replacement of pavement must be to the limit of the longitudinal placement. Corrections involving diamond grinding will be subject to the final pavement thickness tolerances specified.

   a. Transverse measurements. Transverse measurements will be taken for each lot placed. Transverse measurements will be taken perpendicular to the pavement centerline each 50 feet or more often as determined by the Commissioner.

(1) Testing must be continuous across all joints, starting with one-half the length of the straight edge at the edge of pavement section being tested and then moved ahead one-half the length of the straight edge for each successive measurement. Smoothness readings will not be made across grade changes or cross slope transitions; at these transition areas, the straightedge position must be adjusted to measure surface smoothness and not design grade or cross slope transitions. The amount of surface irregularity must be determined by placing the freestanding (unleveled) straightedge on the pavement surface and allowing it to rest upon the two highest spots covered by its length, and measuring the maximum gap between the straightedge and the pavement surface in the area between these two high points. Deviations on final pavement > 1/4 inch (6mm) in transverse direction must be corrected with diamond grinding per paragraph 501-4.19G or by removing and replacing full depth of pavement. Grinding will be tapered in all directions to provide smooth transitions to areas not requiring grinding. The area corrected by grinding should not exceed 10% of the total area and these areas must be retested after grinding.

(2) The joint between lots must be tested separately to facilitate smoothness between lots. The amount of surface irregularity must be determined by placing the freestanding (unleveled) straightedge on the pavement surface, with half the straightedge on one side of the joint and the other half of the straightedge on the other side of the joint. Measure the maximum gap between the straightedge and the pavement surface in the area between these two high points. One measurement must be taken at the joint every 50 feet or more often if directed by the Commissioner. Maximum gap on final pavement surface > 1/4 inch in transverse direction must be corrected with diamond grinding per paragraph 501-4.19G or by removing and replacing full depth of surface. Each measurement must be recorded and a copy of the data must be furnished to the Commissioner at the end of each days testing.

b. Longitudinal measurements. Longitudinal measurements will be taken for each lot placed. Longitudinal tests will be parallel to the centerline of paving; at the center of paving lanes when widths of paving lanes are less than 20 feet; and at the one third points of paving lanes when widths of paving lanes are 20 ft or greater.

(1) Longitudinal Short Sections. Longitudinal Short Sections are when the longitudinal lot length is less than 200 feet and areas not requiring a profilograph. When approved by the Commissioner, the first and last 15 feet of the lot can also be considered as short sections for smoothness. The finished surface must not vary more than 1/4 inch when evaluated with a 12-foot straightedge. Smoothness readings will not be made across grade changes or cross slope transitions, at these transition areas, the straightedge position must be adjusted to measure surface smoothness and not design grade or cross slope transitions. Testing must be continuous across all joints, starting with one-half the length of the straight edge at the edge of pavement section being tested and then moved ahead one-half the length of the straight edge for each successive measurement. The amount of surface irregularity must be determined by placing the freestanding (unleveled) straightedge on the pavement surface and allowing it to rest upon the two highest spots covered by its length, and measuring the maximum gap between the straightedge and the pavement surface in the area between these two high points. Deviations on final pavement surface > 1/4 inch in longitudinal direction will be corrected with diamond grinding per paragraph 501-4.19 G or by removing and replacing full depth of surface. Grinding will be tapered in all directions to provide smooth transitions to areas not requiring grinding. The area corrected by grinding should not exceed 10% of the total area and these areas must be retested after grinding.

(2) Profilograph Testing. Profilograph testing must be performed by the contractor using approved equipment and procedures as described as ASTM E1274. The equipment must utilize electronic

recording and automatic computerized reduction of data to indicate “must grind” bumps and the Profile Index for the pavement using a 0.2 inch blanking band. The bump template must span one inch with an offset of 0.4 inches. The profilograph must be calibrated prior to use and operated by a factory or State DOT approved operator. Profilograms must be recorded on a longitudinal scale of one inch equals 25 feet and a vertical scale of one inch equals one inch. A copy of the reduced tapes must be furnished to the Commissioner at the end of each days testing.

The pavement must have an average profile index meeting the requirements of paragraph 501-8.1c. Deviations on final surface in longitudinal direction must be corrected with diamond grinding per paragraph 501-4.19G or by removing and replacing full depth of pavement. Grinding will be tapered in all directions to provide smooth transitions to areas not requiring grinding. The area corrected by grinding should not exceed 10% of the total area and these areas must be retested after grinding.

Where corrections are necessary, second profilograph runs must be performed to verify that the corrections produced an average profile index of 15 inches per mile or less. If the initial average profile index was less than 15 inches, only those areas representing greater than 0.4 inch deviation will be re-profiled for correction verification.

4. Grade**.** An evaluation of the surface grade must be made by the Commissioner for compliance to the tolerances contained below. The finish grade will be determined by running levels at intervals of 50 feet or less longitudinally and all breaks in grade transversely (not to exceed 50 feet to determine the elevation of the completed pavement. The Contractor must pay the costs of surveying the level runs, and this work must be performed by a licensed surveyor. The documentation, stamped and signed by a licensed surveyor, must be provided by the Contractor to the Commissioner.

a. Lateral deviation. Lateral deviation from established alignment of the pavement edge must not exceed ±0.10 feet in any lane.

b. Vertical deviation. Vertical deviation from established grade must not exceed ±0.04 feet at any point.

5. Edge slump. When excessive edge slump cannot be corrected before the concrete has hardened, the area with excessive edge slump must be removed and replaced at the expense of the Contractor as directed by the Commissioner in accordance with paragraph 501-4.08A.

F. Removal and replacement of concrete. Any area or section of concrete that is removed and replaced must be removed and replaced back to planned joints. The Contractor must replace damaged dowels and the requirements for doweled longitudinal construction joints in paragraph 501-4.10 must apply to all contraction joints exposed by concrete removal. Removal and replacement must be in accordance with paragraph 501-4.20.

PART 6 CONTRACTOR QUALITY CONTROL

6.01 QUALITY CONTROL PROGRAM.

The Contractor must develop a Quality Control Program in accordance with Section 100 of the General Provisions. The program must address all elements that affect the quality of the pavement including but not limited to:

1. Mix Design
2. Aggregate Gradation
3. Quality of Materials
4. Stockpile Management
5. Proportioning
6. Mixing and Transportation
7. Placing and Consolidation
8. Joints
9. Dowel Placement and Alignment
10. Flexural or Compressive Strength
11. Finishing and Curing
12. Surface Smoothness

6.02 QUALITY CONTROL TESTING

A. The Contractor must perform all quality control tests necessary to control the production and construction processes applicable to this specification and as set forth in the Quality Control Program. The testing program must include, but not necessarily be limited to, tests for aggregate gradation, aggregate moisture content, slump, and air content.

A Quality Control Testing Plan must be developed as part of the Quality Control Program.

B. Fine aggregate.

1. Gradation. A sieve analysis must be made at least twice daily in accordance with ASTM C136 from randomly sampled material taken from the discharge gate of storage bins or from the conveyor belt. Sampling of aggregate will be in accordance with ASTM D75.

2. Moisture content. If an electric moisture meter is used, at least two direct measurements of moisture content must be made per week to check the calibration. If direct measurements are made in lieu of using an electric meter, two tests must be made per day. Tests must be made in accordance with ASTM C70 or ASTM C566.

C. Coarse Aggregate.

1. Gradation. A sieve analysis must be made at least twice daily for each size of aggregate. Tests must be made in accordance with ASTM C136 from randomly sampled material taken from the discharge gate of storage bins or from the conveyor belt. Sampling of aggregate will be in accordance with ASTM D75.

2. Moisture content. If an electric moisture meter is used, at least two direct measurements of moisture content must be made per week to check the calibration. If direct measurements are made in lieu of using an electric meter, two tests must be made per day. Tests must be made in accordance with ASTM C566.

D. Slump. Four slump tests must be performed for each lot of material produced in accordance with the lot size defined in paragraph 501-5.1. One test must be made for each sublot. Slump tests must be performed in accordance with ASTM C143 from material randomly sampled from material discharged from trucks at the paving site. Material samples must be taken in accordance with ASTM C172.

E. Air content. Four air content tests, must be performed for each lot of material produced in accordance with the lot size defined in paragraph 501-5.1. One test must be made for each sublot. Air content tests must be performed in accordance with ASTM C231 for gravel and stone coarse aggregate and ASTM C173 for slag or other porous coarse aggregate, from material randomly sampled from trucks at the paving site. Material samples must be taken in accordance with ASTM C172.

F. Four unit weight and yield tests must be made in accordance with ASTM C138. The samples must be taken in accordance with ASTM C172 and at the same time as the air content tests.

6.03 CONTROL CHARTS

A. The Contractor must maintain linear control charts for fine and coarse aggregate gradation, slump, moisture content and air content.

Control charts must be posted in a location satisfactory to the Commissioner and must be kept up to date at all times. As a minimum, the control charts must identify the project number, the contract item number, the test number, each test parameter, the Action and suspension Limits, or Specification limits, applicable to each test parameter, and the Contractor’s test results. The Contractor must use the control charts as part of a process control system for identifying potential problems and assignable causes before they occur. If the Contractor’s projected data during production indicates a potential problem and the Contractor is not taking satisfactory corrective action, the Commissioner may halt production or acceptance of the material.

B. Fine and coarse aggregate gradation. The Contractor must record the running average of the last five gradation tests for each control sieve on linear control charts. Specification limits contained in the Lower Specification Tolerance Limit (L) table above and the Control Chart Limits table below must be superimposed on the Control Chart for job control.

C. Slump and air content. The Contractor must maintain linear control charts both for individual measurements and range (that is, difference between highest and lowest measurements) for slump and air content in accordance with the following Action and Suspension Limits.

Control Chart Limits

Control Parameter	Individual Measurements		Range Suspension Limit
	Action Limit	**Suspension Limit**	
Slip Form:			
Slump	+0 to -1 inch (0-25 mm)	+0.5 to -1.5 inch (13-38 mm)	±1.5 inch (38 mm)
Air Content	±1.2%	±1.8%	±2.5%
Side Form:			
Slump	+0.5 to -1 inch (13-25 mm)	+1 to -1.5 inch (25-38 mm)	±1.5 inch (38 mm)
Air Content	±1.2%	±1.8%	±2.5%

The individual measurement control charts must use the mix design target values as indicators of central tendency.

6.04 CORRECTIVE ACTION

A. The Contractor Quality Control Program must indicate that appropriate action must be taken when the process is believed to be out of control. The Contractor Quality Control Program must detail what action will be taken to bring the process into control and must contain sets of rules to gauge when a process is out of control. As a minimum, a process must be deemed out of control and corrective action taken if any one of the following conditions exists.

B. Fine and coarse aggregate gradation. When two consecutive averages of five tests are outside of the specification limits in paragraph 501-2.1, immediate steps, including a halt to production, must be taken to correct the grading.

C. Fine and coarse aggregate moisture content. Whenever the moisture content of the fine or coarse aggregate changes by more than 0.5%, the scale settings for the aggregate batcher and water batcher must be adjusted.

D. Slump. The Contractor must halt production and make appropriate adjustments whenever:

1. one point falls outside the Suspension Limit line for individual measurements or range

OR

2. two points in a row fall outside the Action Limit line for individual measurements.

E. Air content. The Contractor must halt production and adjust the amount of air-entraining admixture whenever:

1. one point falls outside the Suspension Limit line for individual measurements or range

OR

2. two points in a row fall outside the Action Limit line for individual measurements.

Whenever a point falls outside the Action Limits line, the air-entraining admixture dispenser must be calibrated to ensure that it is operating correctly and with good reproducibility.

PART 7 METHOD OF MEASUREMENT

7.01 MEASUREMENT

A. Portland cement concrete pavement must be measured by the number of square yards of either plain or reinforced pavement as specified in-place, completed and accepted.

B. Measurement for Thickened Edge PCC pavement will be measures as the number of square yards of either plain or reinforced pavement of the thicker pavement in place, completed and accepted.

PART 8 BASIS OF PAYMENT

8.01 PAYMENT

A. Payment for concrete pavement meeting all acceptance criteria as specified in paragraph 5.02 Acceptance Criteria must be based on results of smoothness, strength and thickness tests. Payment for acceptable lots of concrete pavement must be adjusted in accordance with paragraph 8.01B for strength and thickness and 8.01D for smoothness, subject to the limitation that:

The total project payment for concrete pavement must not exceed 100 percent of the product of the contract unit price and the total number of square yards of concrete pavement used in the accepted work (See Note 1 under the Price Adjustment Schedule table below).

Payment must be full compensation for all labor, materials, tools, equipment, and incidentals required to complete the work as specified herein and on the drawings.

B. Basis of adjusted payment. The pay factor for each individual lot must be calculated in accordance with the Price Adjustment Schedule table below. A pay factor must be calculated for both flexural strength and thickness. The lot pay factor must be the higher of the two values when calculations for both flexural strength and thickness are 100% or higher. The lot pay factor must be the product of the two values when only one of the calculations for either flexural strength or thickness is 100% or higher. The lot pay factor must be the lower of the two values when calculations for both flexural strength and thickness are less than 100%.

Price Adjustment Schedule[1]

Percentage of Materials Within Specification Limits (PWL)	Lot Pay Factor (Percent of Contract Unit Price)
96 – 100	106
90 – 95	PWL + 10
75 – 90	0.5 PWL + 55
55 – 74	1.4 PWL – 12
Below 55	Reject[2]

[1] Although it is theoretically possible to achieve a pay factor of 106% for each lot, actual payment in excess of 100% must be subject to the total project payment limitation specified in paragraph 501-8.01.

[2] The lot must be removed and replaced. However, the Commissioner may decide to allow the rejected lot to remain. In that case, if the Commissioner and Contractor agree in writing that the lot must not be removed, it must be paid for at 50% of the contract unit price and the total project payment limitation must be reduced by the amount withheld for the rejected lot.

For each lot accepted, the adjusted contract unit price must be the product of the lot pay factor for the lot and the contract unit price. Payment must be subject to the total project payment limitation specified in paragraph 501-8.01. Payment in excess of 100% for accepted lots of concrete pavement must be used to offset payment for accepted lots of concrete pavement that achieve a lot pay factor less than 100%.

C. Payment will be made under the following items:

ITEM NO.	DESCRIPTION	UOM
P-501-01	PAVING - PORTLAND CEMENT CONCRETE, 19”	SY

D. Basis of adjusted payment for smoothness. Price adjustment for pavement smoothness will apply to the total area of concrete within a section of pavement and must be applied in accordance the following equation and schedule:

(Square yard in section) × (original unit price per square yard) × PFm = reduction in payment for area within section

Average Profile Index (Inches Per Mile) Pavement Strength Rating			Contract Unit Price Adjustment (PFm)
Over 30,000 lb	**30,000 lb or Less**	**Short Sections**	
0 – 7	0 - 10	0 - 15	0.00
7.1 – 9	10.1 - 11	15.1 - 16	0.02
9.1 – 11	11.1 - 12	16.1 - 17	0.04
11.1 – 13	12.1 - 13	17.1 - 18	0.06
13.1 – 14	13.1 - 14	18.1 - 20	0.08
14.1 – 15	14.1 - 15	20.1 - 22	0.10
15.1 and up	15.1 and up	22.1 and up	Corrective work required

TESTING REQUIREMENTS

ASTM C31	Standard Practice for Making and Curing Concrete Test Specimens in the Field
ASTM C39	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C70	Standard Test Method for Surface Moisture in Fine Aggregate
ASTM C78	Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C88	Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate
ASTM C117	Standard Test Method for Materials Finer Than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing
ASTM C131	Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
ASTM C136	Standard Test Method for Sieve or Screen Analysis of Fine and Coarse Aggregates
ASTM C138	Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
ASTM C142	Standard Test Method for Clay Lumps and Friable Particles in Aggregates
ASTM C143	Standard Test Method for Slump of Hydraulic-Cement Concrete
ASTM C172	Standard Practice for Sampling Freshly Mixed Concrete
ASTM C173	Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

ASTM C174	Standard Test Method for Measuring Thickness of Concrete Elements Using Drilled Concrete Cores
ASTM C227	Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
ASTM C231	Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
ASTM C289	Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)
ASTM C295	Standard Guide for Petrographic Examination of Aggregates for Concrete
ASTM C114	Standard Test Methods for Chemical Analysis of Hydraulic Cement
ASTM C311	Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland Cement Concrete
ASTM C566	Standard Test Method for Total Evaporable Moisture Content of Aggregates by Drying
ASTM C642	Standard Test Method for Density, Absorption, and Voids in Hardened Concrete
ASTM C666	Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing
ASTM C1077	Standard Practice for Agencies Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Testing Agency Evaluation
ASTM C1260	Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
ASTM C1567	Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)
ASTM C1602	Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete
ASTM D75	Standard Practice for Sampling Aggregates
ASTM D3665	Standard Practice for Random Sampling of Construction Materials
ASTM D4791	Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate
ASTM E178	Standard Practice for Dealing With Outlying Observations

ASTM E1274	Standard Test Method for Measuring Pavement Roughness Using a Profilograph

U.S. Army Corps of Commissioners (USACE) Concrete Research Division (CRD) C662
Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials, Lithium Nitrate Admixture and Aggregate (Accelerated Mortar-Bar Method)

MATERIAL REQUIREMENTS

ASTM A184	Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement
ASTM A615	Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
ASTM A704	Standard Specification for Welded Steel Plain Bar or Rod Mats for Concrete Reinforcement
ASTM A706	Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
ASTM A714	Standard Specification for High-Strength Low-Alloy Welded and Seamless Steel Pipe
ASTM A775	Standard Specification for Epoxy-Coated Steel Reinforcing Bars
ASTM A934	Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars
ASTM A996	Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement
ASTM A1064	Standard Specification for Carbon-Steel Wire and Welded Wire Reinforcement, Plain and Deformed, for Concrete
ASTM A1078	Standard Specification for Epoxy-Coated Steel Dowels for Concrete Pavement
ASTM C33	Standard Specification for Concrete Aggregates
ASTM C94	Standard Specification for Ready-Mixed Concrete
ASTM C150	Standard Specification for Portland Cement
ASTM C171	Standard Specification for Sheet Materials for Curing Concrete
ASTM C260	Standard Specification for Air-Entraining Admixtures for Concrete
ASTM C309	Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
ASTM C494	Standard Specification for Chemical Admixtures for Concrete

ASTM C595	Standard Specification for Blended Hydraulic Cements
ASTM C618	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
ASTM C881	Standard Specification for Epoxy-Resin-Base Bonding Systems for Concrete
ASTM C989	Standard Specification for Slag Cement for Use in Concrete and Mortars
ASTM D1751	Standard Specification for Preformed Expansion Joint Filler for Concrete Paving and Structural Construction (Nonextruding and Resilient Bituminous Types)
ASTM D1752	Standard Specification for Preformed Sponge Rubber and Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving And Structural Construction
ACI 211.1	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
ACI 305R	Guide to Hot Weather Concreting
ACI 306R	Guide to Cold Weather Concreting
ACI 309R	Guide for Consolidation of Concrete
AC 150/5320-6	Airport Pavement Design and Evaluation
PCA	Design and Control of Concrete Mixtures

END OF SECTION P-501

FAA-STD-019f
October 18, 2017

DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

STANDARD

LIGHTNING AND SURGE PROTECTION, GROUNDING, BONDING, AND SHIELDING REQUIREMENTS FOR FACILITIES AND ELECTRONIC EQUIPMENT

FOREWORD

1. Construction of Federal Aviation Administration (FAA) operational facilities and the electronic equipment installed therein shall conform to this standard. This standard defines minimum requirements for FAA facilities. When specific needs of a facility exceed these minimum requirements, the facility design and construction shall meet the specific needs. The equipment type, configuration, and location along with the configuration of site structures and environmental/weather conditions influence these needs.

2. The requirements herein reflect lessons learned from investigation and resolution of malfunctions and failures experienced at field locations. The FAA thus considers these requirements the minimum necessary to harden sites sufficiently for the FAA missions – to prevent delay or loss of service, to minimize or preclude outages, and to enhance personnel safety. Further, the requirements herein are coordinated with industry standards, and in some cases exceed industry standards where necessary to meet the FAA missions.

3. The use of "shall" or verbs such as "provide," "construct," "weld," or "connect" indicates mandatory compliance. Deviations are permissible in cases when implementation of certain requirements is not technically feasible, and in such cases, the FAA shall submit a National Airspace System (NAS) Change Proposal (NCP) with justification and technical documentation, and receive approval by the NAS Configuration Control Board (CCB).

4. The format and content requirements of this standard are in accordance with FAA-STD-068, and the grammar and style are in accordance with the Government Printing Office (GPO) Style Manual.

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List of Figures

<u>Note.</u> *Colors in figure illustrations distinguish the fundamental elements of the grounding system concept and do not represent color-coding or labeling requirements of this standard.*

List of Tables

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1 SCOPE

This standard establishes design, procurement, installation, construction, and evaluation standards for lightning protection, transient surge protection, grounding, bonding, shielding configurations and procedures, and control of electrostatic discharge (ESD).

1.1 Applications

The requirements of this standard are mandatory for both new facilities and modifications and upgrades to existing facilities, new equipment installations, and new electronic equipment procurement used in the National Airspace System (NAS) facilities.

The use of the term "facilities" herein can differ from the manner in which it is frequently used in other Federal Aviation Administration (FAA) documents. In this standard, facilities may refer to an entire building, tower, interior or exterior system(s), or portions thereof which support the NAS and its operation. The physical proximity of the system(s) or equipment typically defines a single facility, while significant physical separation of the system or equipment defines separate facilities.

This standard covers government owned or leased property and "facilities."

a. Contractor-Owned Equipment Interface. The interface between contractor-owned equipment or electronic equipment not used for operational purposes, such as administrative local area network (LAN), administrative telephone, and the operational NAS facilities shall be in accordance with this standard.

1.2 Tailoring of Mandatory Requirements

The FAA recommends that the Office of Primary Responsibility (OPR) is contacted to obtain technical guidance on the applicability of requirements herein for modifications, upgrades, and new equipment installations in existing facilities.

a. Application for Previously Funded Programs. This standard is not mandatory for programs funded prior to the issue date of this standard, nor is it mandatory for construction contracts associated with programs funded prior to the issue of the standard. Application of this standard is at the discretion of the user for programs funded prior to the issue of the standard.

b. Mandatory Applications. The OPR can mandate the use of this standard for programs started before the issue date of this standard, if funding is provided.

1.3 Purpose

The requirements of this standard provide a systematic approach to minimize electrical hazards to personnel, and minimize electromagnetic interference (EMI) that can cause damage to facilities and electronic equipment from lightning, transients, ESD, and power faults.

1.4 Content Organization

The standard is organized in accordance with FAA-STD-068.

FAA-STD-019F Content Arrangement		
FOREWORD	⇨	Normative Process Information
1 SCOPE	⇨	This chapter contains: a. Scope Statement b. Applicability Statement for mandatory compliance with requirements c. Procedure for Tailoring of Mandatory Requirements
2 APPLICABLE DOCUMENTS	⇨	This chapter includes technical documents used in this standard.
3 DEFINITIONS	⇨	This chapter contains definitions essential to the understanding and application of this standard. It is not intended to include commonly defined general or technical terms from building codes or industry standards.
4 GENERAL REQUIREMENTS	⇨	This chapter addresses the general grounding system requirements commonly included in building codes and industry standards, and covers the general common requirements and standard practice for the overall design, installation, construction, and evaluation for FAA installations. The general requirements of industry codes and standards are often too general for many FAA applications. This chapter is organized to define and build upon the requirements of general industry standards and building codes as they relate to FAA applications. This chapter includes the following parts: a. Bonding Requirements b. Lightning Protection System Requirements c. Earth Electrode System Requirements d. National Electrical Code Power Distribution System Grounding Compliance e. Surge Protective Device Requirements f. Grounding and Bonding Requirements for NAS Electronic Equipment Areas g. Shielding Requirements h. Electrostatic Discharge Requirements

FAA-STD-019F Content Arrangement (continued)		
5 DETAILED REQUIREMENTS	⇨	This chapter describes detailed performance requirements, which are specific to FAA facility applications, organized by facility special conditions and equipment as follows: a. Airport Traffic Control Tower Facilities b. Lightning Protection System – Special Conditions c. Facility Transient Protection – Special Conditions d. Single Point Ground System (SPG) – Special Conditions e. NAS Electronic Equipment – Interface and Procurement Requirements f. Surge Protective Device (SPD) – Procurement Requirements g. Electrostatic Discharge Equipment – Interface and Specification Requirements h. Electromagnetic Compatibility Requirements
6 NOTES	⇨	This chapter includes: a. Acronyms and Abbreviations b. Guidelines and References Notes c. Version Cross-Reference d. Bibliography Document conventions: Designations indicated with brackets, e.g., " [A1] " preceding a section or paragraph title denote that explanatory material is provided in section 6.2. Designations indicated with brackets, e.g., " [B1] " preceding a section or paragraph title indicates that bibliography reference material is provided in section 6.4.

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2 APPLICABLE DOCUMENTS

2.1 General

Documents listed in this chapter are government and non-government reference documents that form a part of this standard and are applicable to the extent specified herein. While every effort has been made to ensure the completeness of this list, document users are cautioned that they shall meet all specified requirements of documents cited in Chapters 3, 4, and 5 of this standard, and national safety standards, whether or not they are listed.

a. In the event of a conflict between the text of this standard and the references cited herein, the text of this standard takes precedence. Nothing in this standard shall supersede applicable laws and regulations unless a specific exemption has been obtained.
b. Bibliography and reference source material is included in Chapter 6.

2.2 Government Documents

Due to periodic updating of government documents, the Contracting Officer and/or the Implementation Engineer shall specify the current version for project design or at contract award.

2.2.1 FAA Specifications

FAA-C-1217	Electrical Work, Interior
FAA-G-2100	Electronic Equipment, General Requirements
FAA-STD-012	Paint Systems for Equipment

2.2.2 FAA Orders and Handbooks

FAA-HDBK-010	Recommended Practices and Procedures for Lightning and Surge Protection, Grounding, Bonding, and Shielding Implementation
FAA-HDBK-011	Fundamental Considerations of Lightning Protection and Surge Protection, Grounding, Bonding, and Shielding

Copies of FAA specifications, standards, orders, and other applicable documents may be obtained from the Contracting Officer issuing the invitation-for-bid or request-for-proposal. Requests for this material should identify the material desired, for example, the specifications, standards, amendments, drawing numbers and dates. Requests should cite the use for the material, invitation-for-bid, request-for-proposal, the contract number, or other intended use.

2.2.3 Military Documents

MIL-HDBK-232	Revision A Red/Black Engineering-Installation Guidelines
MIL-HDBK-237	Electromagnetic Compatibility Management Guide for Platforms, Systems and Equipment
DOD/MIL-HDBK-263	Electrostatic Discharge Control Handbook
DOD-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
MIL-HDBK-419	Grounding, Bonding, and Shielding for Electronic Equipment and Facilities

MIL-PRF-87893	Performance Specification, Workstation, Electrostatic Discharge Control
MIL-W-87893	Military Specification Workstation, Electrostatic Discharge (ESD) Control
MIL-STD-461	The Control of Electromagnetic Interference Emissions and Susceptibility
MIL-STD-889	Dissimilar Metals
MIL-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices)
NACSIM 5203	Guidelines for Facility Design and Red/Black Installation (Confidential Document)
Single copies of Military specifications, standards, and handbooks are available by mail or telephone from Document Automation and Production Service Customer Service, Standardization Documents Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094. http://quicksearch.dla.mil/ Not more than five items may be ordered on a single request and all requests must contain the document number. Only the latest revisions (complete with latest amendments) are available. Slash sheets must be individually requested. The Invitation for Bid or Contract Number should be cited where applicable.	

2.3 Non-Government Documents

Due to periodic updating of non-government documents, the Contracting Officer and/or the Implementation Engineer must specify the current version for project design or at contract award unless a specific version is identified in this standard. These documents form a part of this standard and are applicable to the extent specified herein. While this standard may exceed the requirements of the following documents, building codes and industry standards always shall be followed as a minimum.

2.3.1 Electronic Industries Alliance (EIA)

JEDEC Standard JESD625	Requirements for Handling Electrostatic-Discharge-Sensitive (ESDS) Devices
Copies of EIA Standards are available from JEDEC Solid State Technology Association, Mailing Address: 3103 North 10th Street, Suite 240-S, Arlington, VA 22201-2107. https://www.jedec.org/	

2.3.2 National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code (NEC)
NFPA 77	Recommended Practice on Static Electricity
NFPA 780	Standard for the Installation of Lightning Protection Systems
Copies of NFPA documents are available from the National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269. www.nfpa.org	

2.3.3 Underwriters Laboratories (UL)

UL 96	Lightning Protection Components
UL 96A	Installation Requirements for Lightning Protection Systems
UL 779 (ANSI-A148.1)	Electrically Conductive Floorings
UL 1449	Standard for Surge Protective Devices
Copies of UL documents are available from Global Engineering Documents, 1500 Inverness Way, East Englewood, CO 80112. Telephone 303-397-7945, 800-854-7179. www.ul.com	

2.3.4 Institute of Electrical and Electronic Engineers (IEEE)

ANSI/IEEE C62.41.2	Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits
ANSI/IEEE C62.45	Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V and Less) AC Power Circuits
ANSI/IEEE 1100	Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (Emerald Book)
Copies of IEEE documents are available from Institute of Electrical and Electronic Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-9916. www.ieee.org	

2.3.5 Electrostatic Discharge (ESD) Association Documents

ESD ADV1.0	Electrostatic Discharge Terminology - Glossary
ESD ADV53.1	ESD Protective Workstations
ESD S4.1	Worksurfaces Resistance Measurements
ANSI/ESD S8.1	Symbols - ESD Awareness
ANSI/ESD S20.20	Development of an Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment
ANSI/ESD STM 7.1	Floor Materials - Resistive Characterization of Materials
ANSI/ESD STM 11.11	Surface Resistance Measurement of Static Dissipative Planar Materials
ANSI/ESD STM 12.1	Seating - Resistive Measurement
ESD TR20.20	Handbook for the Development of an Electrostatic Discharge Control Program for the Protection of Electronic Parts, Assemblies and Equipment
ANSI/ESDA/JEDECD JS-001	ESDA/JEDEC Joint Standard for Electrostatic Discharge Sensitivity Testing - Human Body Model (HBM) - Component Level
Copies of ESD Association documents are available from the EOS/ESD Association, Inc. 7900 Turin Road, Building 3, Rome, NY 13440-2069. Telephone 315-339-6937. www.esda.org	

2.3.6 Telecommunication Industry Association (TIA) Documents

TIA-222	Structural Standard for Antenna Supporting Structures and Antennas
Copies of TIA documents are available from the Telecommunications Industry Association, 1320 North Courthouse Road, Suite 200, Arlington, VA 22201. Telephone 703-907-7700. www.tiaonline.org/standards/	

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3 DEFINITIONS

A	
Access Well	A covered opening in the earth using concrete or other cementitious material to provide access to an EES connection.
Armored Cable	Power, signal, control, or data cable having an overall armor or covering constructed of ferrous (steel) material that provides both structural protection and electromagnetic shielding for direct buried cables.
Arrester	Components, devices, and circuits used to attenuate, suppress, limit, or divert adverse electrical surge and transient energy. The terms arrester, suppressor, and protector are used interchangeably, except the term "arrester" is used herein for components, devices, and circuits installed on the primary side of FAA-owned distribution transformers.
B	
Bond	The electrical connection between two metallic surfaces used to provide a low-resistance path between them.
Bond, Direct	An electrical connection utilizing continuous metal-to-metal contact between the members being joined.
Bond, Indirect	An electrical connection employing an intermediate electrical conductor between the bonded members.
Bonding	The joining of metallic parts to form an electrically conductive path to ensure electrical continuity and the capacity to conduct current imposed between the metallic parts.
Bonding Jumper	A conductor installed to ensure electrical conductivity between metal parts required to be electrically connected.
Bonding Jumper, for NEC Compliance	See NEC definitions for power distribution wiring terms such as "Equipment", "Main", or "System" bonding jumper.
Branch Circuit	The circuit conductors between the final overcurrent protective device and the load.
Building "*Structural*" Steel	The main building structural steel members consisting of columns and beams or girders. Concrete-encased reinforcing steel rebars may be considered structural steel, depending on location.
Bulkhead Ground Plate	A metallic plate located where conduits, conductors, cables, waveguides, etc, enter the facility from the exterior. The bulkhead plate provides a central point for the grounding of these services to minimize external transients from entering the facility or structure.
Bushing	An insulated device that allows an electrical conductor to pass safely through a grounded conducting barrier such as the case of a panel, transformer, etc. The primary purpose is to prevent chafing of the conductors.
Bushing, Grounding or Bonding	An insulated device that allows for a grounding method at the end of the conduit. Also known as grounding-type bonding bushing or bonding bushing.
C	
Cabinet	An enclosure designed either for surface mounting or flush mounting that is provided with a frame, mat, or trim in which a swinging door or doors are, or can be, supported.
Cable	A fabricated assembly of one or more conductors in a single outer insulation. Types include axial, armored, and shielded.

Cable, AC	A fabricated assembly of insulated conductors in a flexible metallic enclosure. Type armored-cable (AC) cable is not the same as DEB cable.
Cable, Axial	Cable where all conductors are oriented on a single axis, such as coaxial, biaxial, and tri-axial cables.
Cable, Direct Buried	Cable with construction suitable for use in direct buried, underground installations without any form of conduit. Type direct buried cable is not the same as DEB cable.
Cable, Direct Earth Burial (DEB)	Cable with a ferrous shield designed to provide both physical and electromagnetic protection to the conductors.
Cable, MC	Metal-Clad Cable, Type MC. A factory assembly of one or more insulated circuit conductors with or without optical fiber members enclosed in an armor of interlocking metal tape, or a smooth or corrugated metallic sheath. See NEC. Note: For the purpose of this standard, MC cable is only permitted when installed in accordance with FAA-C-1217.
Cable, Shielded	Cable with a metalized or braid shield to improve resistance to electromagnetic interference (EMI).
Case	A protective housing for a unit or piece of electrical or electronic equipment.
Chassis	The metal structure that supports the electrical or electronic components which make up the unit or system.
Conductor, Bare	An electrical conductor that has no covering or electrical insulation.
Conductor, Insulated	An electrical conductor encased within material of composition and thickness recognized by the NEC as electrical insulation.
Conductor, Lightning Bonding (Secondary)	An electrical conductor used to bond a metal object, within the zone of protection and subject to currents induced by lightning strikes, to the lightning protection system.
Conductor, Lightning Down	The down conductor serves as the path to the EES from the roof system of air terminals and roof conductors or from an overhead ground wire.
Conductor, Lightning Main	Conductors intended to carry lightning currents between air terminals and the EES. These can be conductors interconnecting air terminals on the roof, conductors connecting a metal object on or above the roof level that is subject to a direct lightning strike to the lightning protection system, or the down conductor.
Conductor, Lightning Roof	Roof conductors interconnecting all air terminals to form a two-way path to the EES from the base of each air terminal.
E	
Earth Electrode System (EES)	A network of electrically interconnected grounding systems such as ground rods, ground plates, ground mats, incidental electrodes including metallic piping and tanks, or ground grids installed below grade to establish a low resistance contact with earth.
Electromagnetic Interference (EMI)	Any emitted, radiated, conducted, or induced voltage that degrades, obstructs, or interrupts the required performance of electronic equipment.

Electronic Multipoint Ground System (MPG)	An electrically continuous network consisting of interconnected ground plates, equipment racks, cabinets, conduit junction boxes, raceways, duct work, pipes, copper grid system, building framing steel, and other non-current-carrying metal elements. It includes conductors, jumpers, and straps that connect individual electronic equipment components to the signal reference structure (SRS).
Electronic Single Point Ground System (SPG)	A discreet signal reference network that provides a single point of reference in the facility for electronic equipment which require single point grounding. It consists of conductors, plates, and equipment terminals, all of which are isolated from any other grounding system except at the main ground plate.
Enclosed Cable Tray	A cable tray with steel/aluminum sides and bottom with a steel/aluminum cover or lid.
Equipment	A general term including materials such as fittings, devices, appliances, fixtures, apparatus, and machines, used in conjunction with an electrical installation.
Equipment Areas	Areas that house electronic equipment used to support NAS operations, such as electronic equipment rooms, telephone company (TELCO) rooms, Very High Frequency Omni Directional Range (VORs), and Radars.
Equipment Grounding Conductor (EGC)	The conductive path installed to connect normally non-current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both. For FAA purposes, the EGC is to be green-insulated, solid or stranded, copper wire.
F	
Ferrous Conduit	Conduits composed of or containing iron, which are used to provide magnetic shielding, such as Rigid Galvanized Steel Conduit (RGS) or thick walled threaded conduit (NEC Rigid Metal Conduit-RMC). Note: For the purpose of this standard, Electrical Metallic Tubing (EMT), Intermediate Metal Conduit (IMC), and conduits made from silicon bronze and stainless steel are not adequate for magnetic shielding protection.
Fitting, High Compression	See "Pressure Connector Terminations."
G	
Ground	A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to a conducting body that serves in place of the earth.
Ground Dissipation Plate Design	Ground plate, refer to Figure 6.
Grounded	Connected to earth via a path of sufficiently low impedance and having sufficient current carrying capacity, such that fault current cannot build up voltage potentials that are hazardous to personnel.
Grounded Conductor	A system or circuit conductor that is intentionally grounded at the SDM or at the source of a separately derived system. This grounded conductor is the neutral conductor for the power system.
Grounding Conductor	A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes.

Grounding Electrode	Copper rod, plate, or wire embedded in the ground for the specific purpose of dissipating electric energy to the earth. Also referred to as the Grounding Electrode System.
Grounding Electrode Conductor (GEC)	A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system.
H	
High Frequency	All electrical signals at frequencies greater than 100 kHz, and pulse and digital signals with rise and fall times of less than 10 µs.
High Transient Ground Plate	Entry or termination ground plate for connection of axial cable surge protection equipment and termination of cable shields, waveguides, conduits, and cable jackets. See Bulkhead Ground Plate.
Horizontal Transitions	Architectural term used to describe horizontal elements in a vertical structure, such as floor levels and stair landings.
Hydraulically Crimped Termination	Conductor termination using a hydraulic crimping tool that applies a 12-ton minimum compression force, using concentrically or circumferentially matching dies to form the connection.
I	
Inaccessible Location	A condition where gaining access to a system or part thereof requires significant effort, cost, or risk to personnel safety. Examples of such locations include below grade, behind walls and obstructions, or enclosed or concealed spaces that impede visual inspection.
L	
Landline	Any conductor, line, or cable installed externally above or below grade to interconnect electronic equipment in different facility structures or to interconnect externally mounted electronic equipment.
Low Frequency	Voltages and currents, whether signal, control, or power, up to and including 100 kHz. Pulse and digital signals with rise and fall times of 10 µs or greater are considered to be low-frequency signals.
M	
Main Service Disconnect	A switch, fused switch, or circuit breaker that disconnects the main ac power service, generally utility power source, from a facility, located at the service disconnecting means (SDM).
O	
Office of Primary Responsibility (OPR)	The authority assigned to maintain and interpret this standard.
Operational Areas	Areas used to provide NAS support such as Instrument Flight Rules (IFR) rooms, Air Route Traffic Control Center (ARTCC) control rooms, ATCT tower cabs, operations control centers, and TRACON control rooms.
P	
Pressure Connector Terminations	Conductor termination using a mechanically bolted pressure connection.

R	
Rack	A metal frame in which one or more electronic equipment units are mounted.
Rigid Metal Conduit (RMC), Rigid Galvanized Steel Conduit (RGS)	A threaded raceway of circular cross-section designed for the physical protection, routing, and shielding of conductors and cables.
S	
Service Disconnecting Means (SDM)	Refer to the NEC definition for Service Point location.
Shield	A housing, shield, or cover that substantially reduces the coupling of electric and magnetic fields into or out of circuits or prevents accidental contact of objects or persons with parts or components operating at hazardous voltage levels.
Signal	Any electromagnetic transmission of information or control function. A signal can be analog, digital data, or a control function such as a relay closure.
Signal Reference Structure (SRS) System	The conductive terminal, wire, bus, plane, or network that serves as the relative zero potential for all associated electronic signals. Signal Reference Structures are required at locations or areas containing NAS electronic equipment.
Structure	Any fixed or transportable building, shelter, tower, mast, or other load-bearing system that is intended to house electrical or electronic equipment or otherwise support or function as an integral element of the air traffic control system.
Surface Resistivity	Surface Resistivity can be described as follows: For electric current flowing across a surface, the ratio of DC voltage drop per unit length to the surface current per unit width. In effect, the surface resistivity is the resistance between two opposite sides of a square and is independent of the size of the square or its dimensional units. Surface resistivity is expressed in ohms/square. See ESD ADV1.0 Glossary of Terms.
Surge	A short-term disturbance characterized by a sharp, brief discontinuity of a waveform. May be of either polarity and may be additive to, or subtractive from, the normal waveform.
Surge Protective Device (SPD)	A device intended to limit surge voltages on equipment by diverting or limiting surge current and is capable of repeating these functions as specified. SPDs are also commonly referred to as Transient Voltage Surge Suppressors (TVSS) or secondary surge arresters.
Susceptibility Level	The transient level on signal, control, or data lines that causes damage, degradation, or upset to electronic circuitry connected to the line.
T	
Transient	See Surge.
Transient Suppressor	Components, devices, or circuits designed for the purpose of attenuating, absorbing, and suppressing conducted transient and surge energy to protect facility equipment.
Z	
Zone of Protection	The space adjacent to a lightning protection system that has a reduced probability of receiving a direct lightning strike.

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4 GENERAL REQUIREMENTS

4.1 Introduction

This chapter covers the common requirements and standard practice for the overall design, installation, construction, and evaluation of the following grounding systems in FAA facilities:

a. Bonding Requirements
b. Lightning Protection System Requirements
c. Earth Electrode System (EES) Requirements
d. National Electrical Code (NEC) Power Distribution System Grounding Compliance
e. Surge Protective Device (SPD) Requirements
f. Grounding and Bonding Requirements for NAS Electronic Equipment Areas
g. Shielding Requirements
h. Electrostatic Discharge (ESD) Requirements

4.2 Bonding Requirements

The method of bonding, for the purpose of achieving electrical continuity, shall be in accordance with 4.2.1 through 4.2.5.

4.2.1 General

This section covers the following topics:

a. Dissimilar Metals Compatibility Requirements
b. Methods of Bonding
c. Bonding Connection Installation Requirements
d. Hardware for Bonding Jumpers and Straps

4.2.1.1 [A1] Resistance of Bonds

Unless otherwise specified in this standard, bonds shall have a maximum direct current (dc) resistance of 1 mΩ when measured between the bonded components with a four-terminal milliohmmeter.

4.2.2 Dissimilar Metals

Bonding connections and associated fastener hardware for grounding system conductors shall comply with Table 1**.**

Table 1. Mechanical Bonds Between Dissimilar Metals

METAL	Copper, solid or plate	Brass and bronze	Stainless Steel	Tin-plate; tin-lead solder	Aluminum, wrought alloys of the 2000 Series	Iron, wrought, gray or malleable, plain carbon and low alloy steels	Aluminum, wrought alloys other than 2000 Series aluminum, cast alloys of the silicon type	Aluminum, cast alloys other than silicon type, plated and chromate	Galvanized steel	Zinc, wrought; zinc-base die-casting alloys; zinc plated
Copper, solid or plate	●●●	●●●	●●	●	●	●	No	No	No	No
Brass and bronze	●●●	●●●	●●	●●	●	●	●	No	No	No
Stainless Steel	●●	●●	●●●	●●●	●●●	●●	●	●	No	No
Tin-plate; tin-lead solder	●	●●	●●●	●●●	●●●	●●	●●	●	No	No
Aluminum, wrought alloys of the 2000 Series	●	●	●●●	●●●	●●●	●●●	●●●	●●	●	●
Iron, wrought, gray or malleable, plain carbon and low alloy steels	●	●	●●	●●	●●●	●●●	●●●	●●●	●	●
Aluminum, wrought alloys other than 2000 Series aluminum, cast alloys of the silicon type	No	●	●	●●	●●●	●●●	●●●	●●●	●	●
Aluminum, cast alloys other than silicon type, plated and chromate	No	No	●	●	●●	●●●	●●●	●●●	●●	●
Galvanized steel	No	No	No	No	●	●	●	●●	●●●	●●●
Zinc, wrought; zinc-based die-casting alloys; zinc plated	No	No	No	No	●	●	●	●	●●●	●●●

LEGEND: Four Basic Categories of Possible Metal Interfaces	
No	Not suitable. This interface is highly likely to result in significant corrosion.
●	Suitable for indoor environments where temperature and humidity are controlled (non-condensing environment).
●●	Suitable for all indoor environment.
●●●	Suitable for all environments.

4.2.3 Methods of Bonding

Direct bonding techniques include:

a. Exothermic Welds. Exothermic welds are permitted for any type of bond connection specified herein.

b. Hydraulically Crimped Terminations. Crimped terminations are permitted as an alternative technique to facilitate installation of connections in permanently concealed or inaccessible locations.

c. Welded Assemblies. Metal fabrication assembly process constructed by welding the joints between the individual components.

d. Mechanical Connections. Electrical bond connections constructed with bolted assemblies.

e. Brazing and Soldering. Metal-joining process formed by brazing or soldering a filler alloy metal is not permitted for bond connections.

f. Silver Soldering - Only Applicable for NAS Electronic Equipment. To improve conductivity, silver soft soldering material may be applied for the bonding of enclosure shielding joints already secured with mechanical fasteners. Mechanical fasteners shall be attached prior to application of solder to prevent cold solder joints. Soft soldering techniques are not permitted as a method for providing mechanical restraint.

4.2.3.1 Exothermic Welds

Exothermic welded connections shall be provided for the following applications:

a. Permanent Bonding. Permanent bonding of copper conductors to metal assemblies or building steel.

b. Underground or Buried Locations.

c. Exposed Exterior Locations. Any exposed location where an exothermic weld connection is possible.

d. Permanently Concealed Locations. Locations where the connection will be permanently concealed after completion of fabrication or building construction process.

e. Inaccessible Locations. Locations rendered inaccessible due to a building feature or other physical constraint that restricts routine access necessary to perform maintenance and visual inspection.

Exception. *Where exothermic welds are not possible due to dissimilar materials, incompatible shapes, voiding of a manufactured finish warranty, or in hazardous locations, such as near fuel tanks or other combustible material, provide UL listed hydraulically crimped or mechanical connections.*

4.2.3.1.1 Exothermic Welds – Installation within Existing Facilities

The following measures shall be taken in the installation of exothermic welds within existing facilities:

a. Where combustion from the use of a standard exothermic weld process would result in problems within the facility, a smokeless type exothermic weld process shall be provided.

b. After completing the welding process, to prevent corrosion, remove or neutralize residual fluxes between components.

4.2.3.2 Hydraulically Crimped Terminations

A UL 467 and UL 96 listed irreversible compression type bonding connection is permitted for use within concealed and inaccessible locations.

a. Bonding Conductors. Bonding conductors shall be wire size 6 AWG or larger.

b. Hydraulic Compression Tool System. Hydraulic compression tool system shall be capable of producing a 12-ton minimum force applied with a tool using matching dies.

4.2.3.3 Welded Assemblies

Individual components of a welded assembly shall not require additional bonds between components if the dc resistance between individual components is less than 1 mΩ.

4.2.3.4 Mechanical Bolted Bond Connections

Mechanical bolted bond connections shall be prepared and completed in accordance with the installation conditions and requirements provided herein.

4.2.3.4.1 [A2] Coupling of Dissimilar Metals

Compression bonding with bolts and clamps shall comply with Table 1. When dissimilar base metals form couples that are not permitted per Table 1, the metals shall be coated, plated, or otherwise protected with a conductive finish.

4.2.3.4.2 Bolted Connections

Bonding bolts shall be used primarily as mechanical fasteners to hold electrical bonding components in place. Tighten bolts sufficiently to achieve adequate contact pressures for effective bonding, but do not overtighten them to the extent that deformation of bond members occurs. To prevent loosening of the connection, provide disc springs for connections using bolts 1/4-in. diameter and greater.

a. Torque Requirements. Bolted connections 1/4-in. diameter and greater shall conform to the torque requirements in Table 2.

b. Bolts, Nuts and Washers. Bolted connections in corrosive, damp, or wet locations, 1/4-in. diameter and greater, shall utilize stainless steel type 18-8 bolts, nuts, and load distribution washers. All other locations shall use corrosion-inhibited SAE Standard J429 Grade 5 nuts and bolts. Load distribution washers shall comply with ANSI B18.22.1 for stainless steel washers, Wide Series, Type B.

c. Assembly. Bolted connections 1/4-in. diameter and greater shall be assembled in the order shown in Figure 1. Additional load distribution washers, if used, shall be positioned directly beneath the bolt head. Disc springs shall be between the nut and the load distribution washer. Washers shall not be placed between bonded members. Load distribution washers shall be Wide Series, Type B.

d. Termination Lugs. Provide 2-hole termination lugs for connections to ground plates. Provide 2-hole termination lug connections to equipment metal members for conductors size 6 AWG and larger. If the equipment metal members do not allow modification for installation of 2-hole lug terminations, then 1-hole termination lug are permitted.

4.2.3.4.2.1 Sheet Metal Screws

Sheet metal screws shall not be used to provide an electrical bond.

4.2.3.4.2.2 Self-drilling and Self-tapping Screw Fasteners

Self-drilling and self-tapping metal screws are permitted to make a physical connection between metal back panels within equipment cabinet/enclosures when access to the opposite side of the bond is not available using other bonding methods.

4.2.3.4.3 Riveting

Rivets shall be employed solely as mechanical fasteners to hold multiple smooth, clean metal surfaces together or to provide a mechanical load-bearing capability to a soldered bond.

Table 2. Connection Torque Requirements for Bolted Bonds

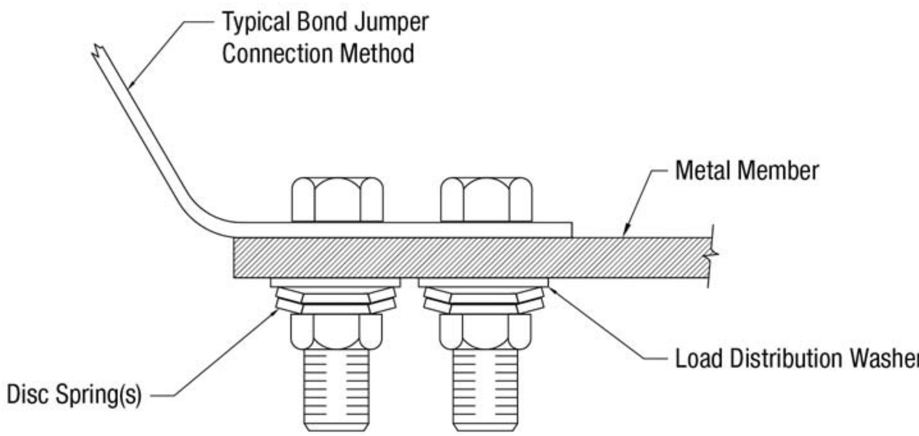
Bolt Specification for Stainless Steel 301 Type SS 18-8						
Bolt diam. (in.)	**Threads per inch**	**Torque (ft-lbs) SS 18-8**	**Bolt Clamp Load (lbs.)**	**Flat Load (lbs.)**	**Washers Required** (see note 2)	**Solon Part Number** (see note 1)
1/4	20	6	1,510	600	3	4-L-42-301
5/16	18	11	2,120	1,000	3	5-L-52-301
3/8	16	19	3,150	2,100	2	6-M-80-301
7/16	14	31	4,300	N/A	N/A	N/A
1/2	13	43	5,170	3,300	2	8-L-90-301
9/16	12	56	6,070	2,800	3	9-L-89-301
5/8	11	92	8,880	5,500	2	10-20-125-301
3/4	10	127	10,200	13,800	1	12-EH-168-177
7/8	9	194	13,310	14,400	1	14-H-168-177
1	8	286	17,200	14,200	2	16-H-187-177
Bolt Specification for SAE J429 Type Grade 5						
Bolt diam. (in.)	**Threads per inch**	**Torque (ft-lbs) Grade 5**	**Bolt Clamp Load (lbs.)**	**Flat Load (lbs.)**	**Washers Required** (see note 2)	**Rolex-Fastenal Part Number** (see note 1)
1/4	20	10	2,500	1,390	2	0124030
5/16	18	21	4,000	5,345	1	0124033
3/8	16	34	5,500	8,000	1	0124035
7/16	14	55	7,500	N/A	N/A	N/A
1/2	13	83	10,000	9,900	2	0124037
9/16	12	117	12,500	12,000	2	0124039
5/8	11	167	16,000	13,000	2	0124041
3/4	10	288	23,000	31,000	1	0124043
7/8	9	452	31,000	40,276	1	0124044
1	8	567	40,000	46,000	1	0124046

Notes:

1. Other manufacturers of disc spring washers of equal or better performance are permissible. Use bolt assembly manufacturer's recommended torque values.
2. The sum of the individual disc washer flat load ratings shall exceed the listed bolt clamp load. The number of washers required is calculated by the following formula:

$$B_{\text{Bolt Clamp Load}} < W_{\text{Number of Washers}} \times F_{\text{Washer Flat Load}}$$

For example, a 1/4-in. stainless steel bolted connection requires minimum 1,510 lbs clamp load, therefore, 3 disc washers will be needed.



Notes:

1. Remove all paint on the entire bonding area of the metal member.
2. Stack disc spring washers to obtain required amount per Table 2.
3. Provide 2-hole termination lugs for connections to ground plates.

Figure 1. Order of Assembly for Bolted Connections

4.2.4 Bonding Connections – Installation Requirements

Bonding connections shall be prepared and completed in accordance with the installation conditions and requirements provided herein.

4.2.4.1 Surface Preparation

Bonding surfaces shall be cleaned thoroughly and free of dirt, dust, grease, oxides, nonconductive films, and foreign material. Paint and other coatings at the location shall be removed to expose the base metal.

a. Surface Area To Be Cleaned. Clean mating surfaces at least 1/4-in. beyond each side of the smaller bonded area.

b. Clad Metals. Clean clad metal to a bright, shiny, smooth surface without penetrating the cladding. Wipe the cleaned area with solvent and allow the surface to air dry before completing the bond.

c. Aluminum Alloys. To create a bright finish after cleaning, apply a conductive coating with paint or resin finish to aluminum mating surfaces.

4.2.4.2 Completion of Bonding Connection

Clean surfaces with a solvent suitable for electrical work immediately prior to assembly. Mating surfaces shall be joined within 2 hours after cleaning if an intentional protective coating has been removed from the metal surface. If delays beyond 2 hours are necessary in corrosive environments, then the cleaned surfaces shall be protected with an appropriate coating that shall be removed prior to completion of the bond connection.

a. Refinishing of Bond. Areas around the bond connection shall be restored to match the original finish, unless not feasible.

b. Surface Plating or Treatments. Surface plating or treatments may be applied to the connection to improve abrasion resistance and corrosion protection, provided the treatment material enhances bond conductivity. Silver and other easily tarnished metals shall not be used to plate bonded surfaces, except where use of other metals may result in an unacceptable increase in surface contact resistance. In such cases, protect plating material by sealing exposed surfaces of the completed connection from the atmosphere.

4.2.4.3 Sealing and Finish Treatments for Bonding Connections

All bonds shall be protected against weather, corrosive atmospheres, vibration, and mechanical damage. Under dry conditions, apply a compatible corrosion preventive or sealant within 24 hours of assembly of the bond materials. Under conditions exceeding 60 percent humidity, seal the bond with a compatible corrosion preventive or sealant within 1 hour of joining.

Exterior bonds shall be protected against corrosion. Interior bonds exposed to moisture or high humidity shall be protected against corrosion.

a. Sealing Treatment for Corrosion Protection. Corrosion protection shall be provided by sealing the bond connection with a moistureproof paint conforming to FAA-STD-012 or with a silicone or petroleum based sealant to prevent moisture from reaching the bonding area. Bonds protected by conductive finishes such as alodine and iridite shall not require painting to meet the requirements of this standard.

b. Compression Bonds in Climatically Protected Areas. Sealing is not required for compression bonds between copper conductors or compatible aluminum alloys that are located in readily accessible areas that are not exposed to moisture, corrosive fumes, or excessive dust.

c. Painted Finishes. If a paint finish treatment is required on the final assembly, then the bond shall be sealed in accordance with the manufacturer's recommendation. To ensure the bond is completely sealed against moisture, a waterproof type of paint or primer shall be used if the recommended finish treatment is not waterproof.

4.2.5 Bonding Connections – Hardware for Bonding Jumpers and Straps

Bonding jumpers and straps shall be installed in accordance with the requirements provided herein.

4.2.5.1 Installation of Bonding Jumpers

Bonding jumpers shall be insulated conductors, except as noted herein.

Bare conductors shall be used for the following applications:

a. Raised access floor installations.

b. Jumpers for structural steel or rebar connected to the EES, lightning protection systems, and plenums or environmental air spaces.

c. Jumpers too short to be insulated or where required by NEC.

4.2.5.2 Installation of Bonding Straps

Bonding straps for bonding of electronic equipment shall be as short as possible. Herein, bonding straps are expected to be bare.

Bonding straps shall conform to the following:

a. Bonding straps shall be attached to the integral structural frame portion of the cabinet/enclosure rather than through adjacent parts to achieve optimal electrical connection.

b. Bonding straps shall be installed so that the electrical bond is not affected by motion or vibration.

c. Bonding straps shall be installed wherever possible in areas accessible for maintenance and inspection.

d. Bonding straps shall be installed to allow movement of the components being bonded or other adjacent components intended to move as part of normal functional operation.

e. Two or more bonding straps shall not be connected in series to provide a single bonding path.

f. The method of installation and point of attachment of bonding straps shall not weaken the components to which they are attached.

g. Bonding straps shall not be compression fastened through nonmetallic material.

h. Bonding installed across shock mounts or other suspension/support devices shall not restrict the performance of the mounting device. Bonding connections shall be capable of withstanding anticipated motion and vibration of supports without suffering metal fatigue, loosening of ground connections, or other degradation.

4.2.5.3 Fastener Hardware

Fastener materials for attachment of bonding straps and jumpers to structures shall conform to materials listed in Table 1.

4.2.5.4 Temporary Bonding Connections

Alligator clips or spring-loaded clamping products are permitted only for the purpose of establishing a temporary bond connection while performing repair work on equipment or facility wiring.

4.3 Lightning Protection System Requirements

4.3.1 General

The purpose of the lightning protection system is to provide preferred paths for lightning discharges to enter or leave the earth without causing damage to facility or equipment or injury to personnel. The essential components of a lightning protection system are air terminals and roof and down conductors connecting to the EES, the EES, and SPDs. These components act together as a system to dissipate lightning energy. The lightning protection system shall meet or exceed the requirements of FAA standards and orders as specified herein and the following:

a. Standard for the Installation of Lightning Protection Systems (NFPA 780)

b. Installation Requirements for Lightning Protection Systems (UL 96A)

The risk assessment guide in NFPA 780 indicates that many NAS facilities have a high risk index. Accordingly, lightning protection requirements that exceed the minimum requirements of NFPA 780 are specified herein. Inclusion of a UL Master label is not sufficient to indicate compliance with this standard.

a. <u>ATCT Special Requirements</u>. See section 5.2 for Airport Traffic Control Tower (ATCT) special requirements.

b. <u>Other Special Conditions</u>. See section 5.3 for other lightning protection system special conditions.

4.3.2 Lightning Protection System – Components

Products shall be UL listed and labeled with the UL certification mark in accordance with UL requirements. All equipment shall be new and of adequate design and construction to suit the application in accordance with UL 96A requirements. Provide copper or tinned copper cable materials. Aluminum cables shall only be used on aluminum and galvanized surfaces. Bimetallic connectors shall be used for interconnecting copper and aluminum conductors. Dissimilar materials shall conform to the bonding requirements of paragraph 4.2.2.

4.3.3 Lightning Protection System – Material Class Requirements

The FAA has opted to exceed minimum NFPA 780 cable sizing requirements. Provide Class II or larger rated materials, as specified in NFPA 780, for the following:

a. Air Terminals

b. Main and Down Conductors

c. Bonding Conductors

4.3.4 Lightning Protection for NAS Facilities Buildings and Structures

Lightning protection shall be provided for buildings and structures, or parts thereof that are not within the zone of protection provided by another building, higher part of a building, an antenna, or a tower. The zone of protection scheme for all structures shall be as defined in NFPA 780.

4.3.4.1 Number of External Down Conductors for Buildings

The number of down conductors shall be based on both the building height and perimeter.

a. Buildings and Structures Less Than 60 ft High Above Grade. These buildings and structures measured to the highest point of the building or structure shall have at least two down conductors.

b. Buildings and Structures More Than 60 ft High. See section 5.2.2.

c. Buildings and Structures with Perimeters in Excess of 250 ft. These buildings and structures shall have one additional down conductor for each 100 ft of perimeter distance or part thereof. Down conductors shall be as widely separated as possible, e.g., at diagonally opposite corners on square or rectangular buildings.

4.3.4.2 Metal Parts of Buildings

Building steel, metal roofing, metal supporting structures, concrete reinforcing steel, siding, eave troughs, down spouts, ladders, duct, and similar metal parts shall not be used as substitutes for roof or down conductors. A lightning protection system shall be applied to the metal roof and metal siding of a metal clad building in the same manner as on a building without metal covering. Building metal parts shall be bonded in accordance with paragraph 4.3.8.

Exception. *See paragraph 5.2.2.3*b *for ATCT lightning protection system design requirements.*

4.3.4.3 Roof-Mounted Antenna Masts

Unless it is a radiating or receiving part of the antenna, the metallic mast of a roof-mounted antenna shall be bonded to the nearest main roof conductor or down conductor.

a. If a main roof conductor or down conductor is not available where an antenna is installed on top of an ATCT, then bond the antenna mast to building steel in lieu of the EES. Reinforcing bars shall not be used in lieu of building steel.

b. If an antenna is installed on top of a building or base building, and the path is longer than a tenth of the difference between building steel and the EES (i.e. building steel is 5 feet away and the EES is more than 50 feet away), then bond the antenna mast to building steel. Reinforcing bars shall not be used in lieu of building steel.

4.3.5 Lightning Protection System - Conductor Routing

Down conductors shall follow the most direct downward path to earth. Main and bonding conductors shall maintain a downward or horizontal course, and are permitted to rise at no greater than a 1 to 4 slope.

a. Conductor Bends. Down conductors shall be installed without any sharp bends or kinks. No bend in a main and bonding conductor shall form an included angle of less than 90 degrees, nor shall it have a bend sweep radius of less than 8 in.

b. Conductor Connections. T-style and cross-over cable-to-cable connections between main conductors shall be in accordance with Figure 2.

c. Conductor Routing. Conductors shall be routed outside of structures and not penetrate structural cladding except as indicated in 5.2.2.3b. Conductors shall be routed 6 ft or more from power or signal conductors. If this clearance cannot be met, the power and signal conductors shall be routed in ferrous RGS conduit or enclosed ferrous cable tray.

d. Main Conductors. Main conductors shall be permitted to pass through elements of the building structure, e.g., parapets, eaves, walkways, walls, where necessary to maintain horizontal or downward course. Provide a 2-in., Schedule 80 rigid PVC conduit sleeve, or UL listed through-connector fitting at penetrations. When the conductor penetrates a metallic structure of any thickness, the conductor shall be bonded to the metallic structure. Conductors are permitted to pass through metal gratings or plates without a conduit sleeve; however, the conductor shall be bonded to the metallic structure.

4.3.5.1 Main and Down Conductor Terminations to EES

Conductor terminations to the EES shall be exothermically welded to a 4/0 AWG copper conductor prior to entering the ground at not less than 18 in. above grade. The 4/0 AWG copper conductor shall be bonded directly to a ground rod or electrode conductor in the EES. Exothermic weld connections to the EES shall be in accordance with Figure 3.

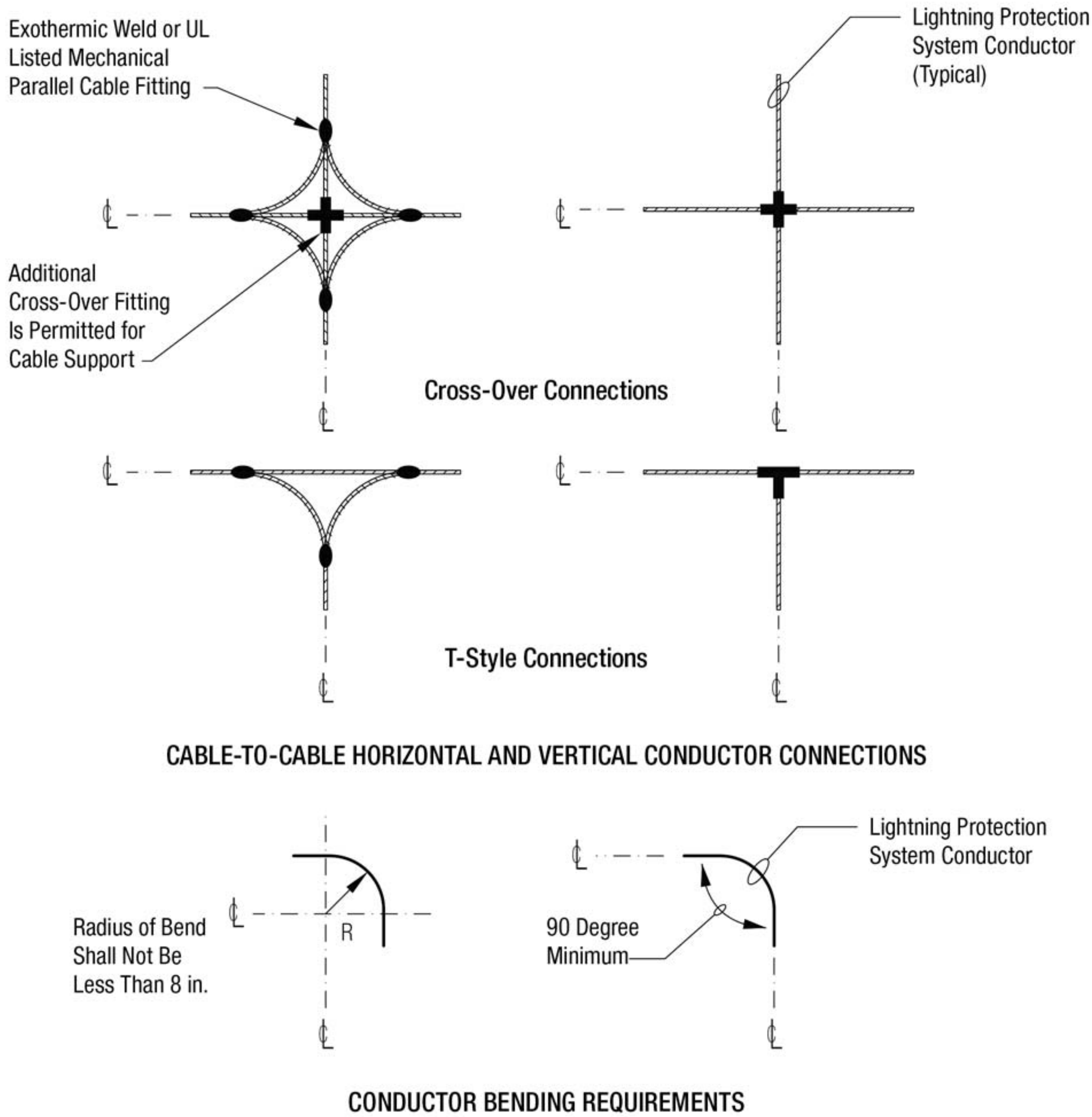
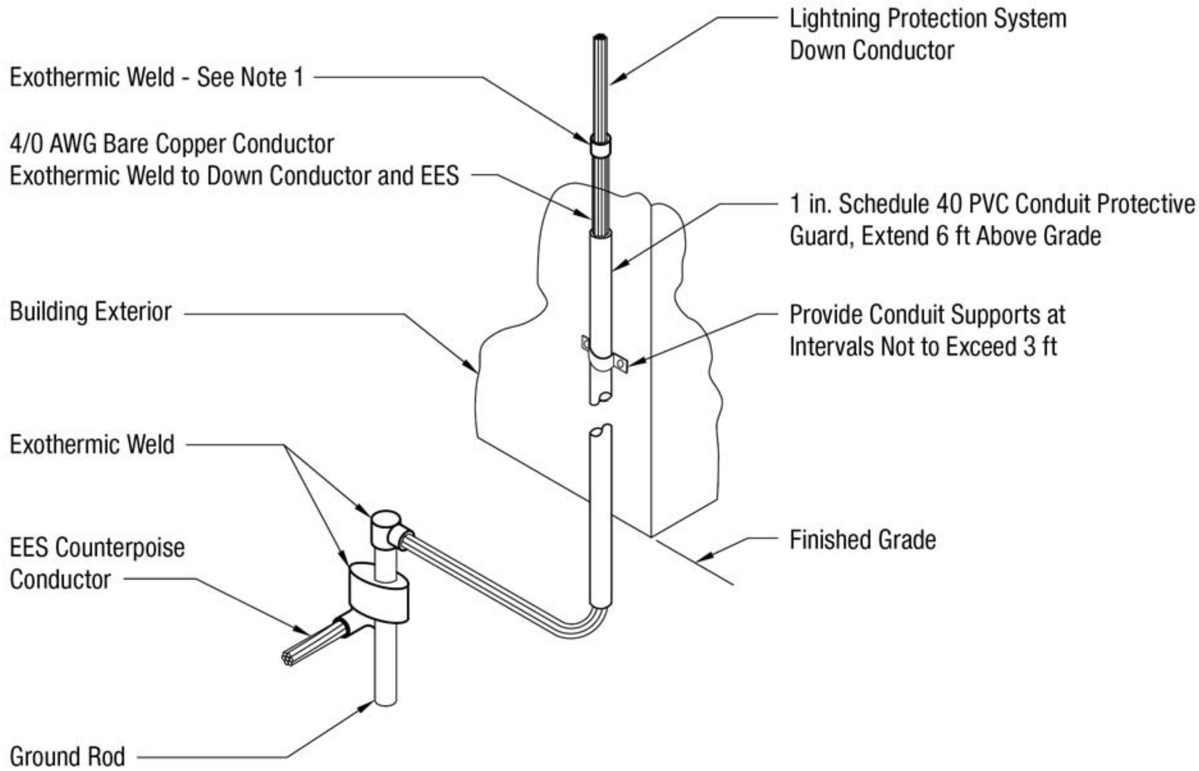


Figure 2. Lightning Protection System Main Conductor Connections – Illustrative Example



Note:

1. Locate exothermic weld above the conduit guard to ensure connection is available for visual inspection. When installation of the connection is not possible at top of conduit guard, locate the exothermic weld at least 18 in. above finished grade and provide guard system with pull box and removable cover that will permit visual inspection of the weld connection.

Figure 3. Main and Down Conductor Termination to EES – Illustrative Example

4.3.6 Lightning Protection System - Air Terminals

Air terminals shall be solid copper, bronze, or aluminum. Air terminals shall be stainless steel in areas of high potential for corrosion. Copper air terminals shall be allowed to have nickel plating. Air terminals shall be 12-in. high minimum, with a diameter of at least 1/2-in. for copper and 5/8-in. for aluminum, and have sharp, blunt or approved protective style tip. Air terminals shall be located and installed in accordance with NFPA 780 and UL 96A, and as required herein. Closer spacing is permitted for unique geometries. Air terminals shall extend at least 10-in. above the object or area it is to protect.

Air terminals located near working or walking surfaces may present an impalement hazard to personnel. The impalement protection design may be accomplished through use of air terminal selection, air terminal mounting type, mounting height, or a combination thereof. If mounting height is selected to mitigate the impalement hazard, the top of the air terminal shall not be less than 5-ft above the adjacent walking surface. If it is not feasible to install the air terminal on the object, locate air terminals next to the object to achieve this requirement, and bond the metallic object to the lightning protection system.

4.3.6.1 Mast Poles Used For Air Terminal Installation

Air terminals installed on mast poles shall be at least 2 ft tall and extend a minimum of 10 in. above the top of the mast pole. Provide a down conductor installed on the exterior of the mast pole. Air terminal and down conductor shall be fastened to the pole in accordance with NFPA 780. Connect air terminal to the nearest main roof conductor or down conductor. If a roof or down conductor is not available, bond directly to the EES.

4.3.7 Lightning Protection System - Hardware

Lightning protection system hardware and installation shall be prepared and completed in accordance with the installation conditions and requirements provided herein.

4.3.7.1 Fastener Hardware

Provide conductor fasteners at intervals in accordance with NFPA 780. Provide fastener material using the same base material as the system conductor, or a material equally resistant to corrosion as the system conductor.

a. Plastic, Galvanized, or Plated Materials. Not permitted.

b. Fasteners. Where fasteners are part of a bonding connection component, the bonding surface shall be prepared and protected in accordance with paragraph 4.2.4. Cable holders that do not have mechanical support such as products with fold-over or break-away tabs shall not be used.

4.3.7.2 Terminations and Fittings

The preferred method for conductor connections and terminations is by exothermic welding. Where mechanical bolted pressure termination fittings are used the bonding devices, conductor splices, conductor terminations, and connectors shall be compatible with the installed conductor. Provide stainless steel, copper, bronze, or aluminum termination materials in accordance with the following:

a. Materials. Fitting material shall be suitable for use with the system conductor.

b. Straight and 90 Degree Through-Connectors. UL listed straight and 90 degree through-connectors are permitted to facilitate horizontal and vertical routing of system conductors.

4.3.7.3 Conductor Protective Guards

Provide protective guards for system down conductors located in or next to driveways, walkways, or other areas where they are subject to damage or displacement.

a. Nonmetallic Guards. Provide nonmetallic conductor guards, schedule 40 polyvinyl chloride (PVC) conduit or equivalent.

b. Guard Installation. Install guard from 1 ft below grade level extending to 6 ft above grade. When the roof or roof soffit construction is within 2 ft of the guard, the protective guard may be lowered to facilitate termination of the down conductor.

***Exception*.** *Metal guards are permitted in lieu of nonmetallic material; however, metal guards shall be bonded to the down conductors at both ends of the guard. Provide bonding conductor size equal to the down conductor size.*

4.3.8 Lightning Protection System – Bonding Connections

Bonding connections shall be prepared and completed in accordance with the installation conditions and requirements provided herein. Provide exothermic welds for conductor connections to the EES.

4.3.8.1 Metallic Bodies Subject to Direct Lightning Strikes

Metallic bodies and assemblies that protrude beyond the zone of protection provided by the installed air terminals are subject to direct lightning strikes. This includes but is not limited to roof drains, gutters, vents, canopies, electrical raceway and fixtures, pipes, exhaust fans, metal cooling towers, HVAC units, ladders, railings, antennas, structures with metal louvers, etc.

Provide lightning protection for metallic bodies and assemblies for the following conditions:

a. Electrically Continuous Assemblies.

   1. Where metal thickness is 3/16 in. or greater, bond the assembly to the nearest lightning protection system main conductor. Provide fitting with bonding surface of at least 3 in.^{2}
   2. Where metal thickness is less than 3/16 in., install air terminals, main conductors, and fittings to provide at least two paths to ground from each air terminal device.

b. Not Electrically Continuous Assemblies. If the assembly consists of segmented parts and is not electrically continuous, then provide an additional main conductor interconnected to the nearest lightning protection system. Bond the individual metal parts. Provide at least two paths to ground.

4.3.8.2 Metallic Bodies Subject to Induced Charges

Metallic bodies that are subject to induced charges from lightning, including those in a zone of protection, shall be bonded to the lightning protection system in accordance with NFPA 780. This includes, but is not limited to, roof drains, vents, coping, flashing, gutters, downspouts, doors, door and window frames, balcony railing, conduits, and pipes, etc.

4.3.8.3 Metallic Bodies – Special Conditions

Metallic bodies located at grade or outside the lightning protection system's zone of protection may be bonded by direct connections to the EES.

4.3.8.3.1 Exhaust Stack Grounding

Fossil fuel exhaust stacks shall be bonded to the nearest lightning protection system main conductor or directly to the EES, using a bonding conductor of greater than or equal size as the main conductor. Provide exothermic weld or mechanical connection at exhaust stack, and exothermic weld at EES.

When the exhaust stack is located farther than 6 ft from a main conductor and, the exhaust stack shall be bonded directly to the EES.

4.3.8.3.2 Fuel and Oil Storage Tanks

Provide exothermic welds to bond tank vent piping and assemblies to the EES. Mechanical bonds may be used where required for dissimilar metals or component compatibility at the tank assembly. Bond tank vent piping and assemblies in accordance with following:

a. Above-Ground Nonpressurized Fuel and Oil Tank Vent Piping. Bond above-ground tank vent piping directly to the EES using a bonding conductor of greater than or equal size as the lightning protection system main conductor.

b. Above-Ground Tank Assemblies. Provide at least two easily accessible and widely separated grounding points for the tank assembly. Bond each grounding point directly to the EES using a 2/0 AWG conductor. Bond other metallic components, e.g., stairs, ladders, or skids, with a 2/0 AWG copper conductor.

c. Above Ground Pressurized Fuel Tanks. For pressurized fuel tanks, e.g., propane and compressed natural gas, provide at least one bond connection from tank mounting supports connected directly to the EES using a 2/0 AWG copper conductor.

d. Indoor Fuel and Oil Tank Vent Piping. Bond indoor mounted engine-generator day tank or other metallic fuel storage system vent piping mounted on the building exterior in accordance with NFPA 780.

e. Secondary Containment Systems. Secondary containment for fuel piping shall be bonded directly to the EES.

4.4 Earth Electrode System (EES)

4.4.1 General

An EES shall be installed at each facility to provide a common point of reference for all grounded systems at the facility. The EES establishes a low resistance to earth for lightning discharges, electrical and electronic equipment grounding, and surge/transient protection. The EES shall be capable of dissipating within the earth the energy of direct lightning strikes with no ensuing degradation to the system itself. The EES shall dissipate dc, ac, and radio frequency currents from equipment and facility grounding conductors.

4.4.2 [A3] Site Survey and Geotechnical Investigation

A subsurface geotechnical investigation shall be required to establish the design approach and parameters for new building construction to determine soil composition and resistivity characteristics. Information to be collected shall include location of rock formations, gravel deposits, soil types and classifications, and moisture content. The survey data shall be noted on a scaled drawing or sketch of the site, and documented in the Facility Reference Data File (FRDF). Soil resistivity testing shall be in accordance with FAA-HDBK-010.

4.4.3 EES – Design

The EES normally consists of driven ground rods, buried interconnecting conductors, and connections to underground metallic pipes, excluding gas lines and fuel tanks. The site survey and geotechnical investigation shall be used as the basis for the design of new buildings. The design objective for the EES resistance to earth shall be as low as possible, but shall not be greater than 10 **Ω**. Where "poor soil" conditions are encountered such as surface rock, shallow soils, permafrost, soils with low moisture, or high mineral content, then grounding enhancement methods listed in paragraph 4.4.5 shall be considered.

4.4.4 EES - Configuration

The EES shall consist of a continuous buried counterpoise conductor loop that extends around the entire perimeter of the facility or building structures. Provide ground rods interconnected along the counterpoise loop, spaced at least one ground rod length apart. Refer to FAA-HDBK-010 for design considerations.

For sites comprising multiple building structures, such as a building and antenna tower, configure the EES based on the following facility separations:

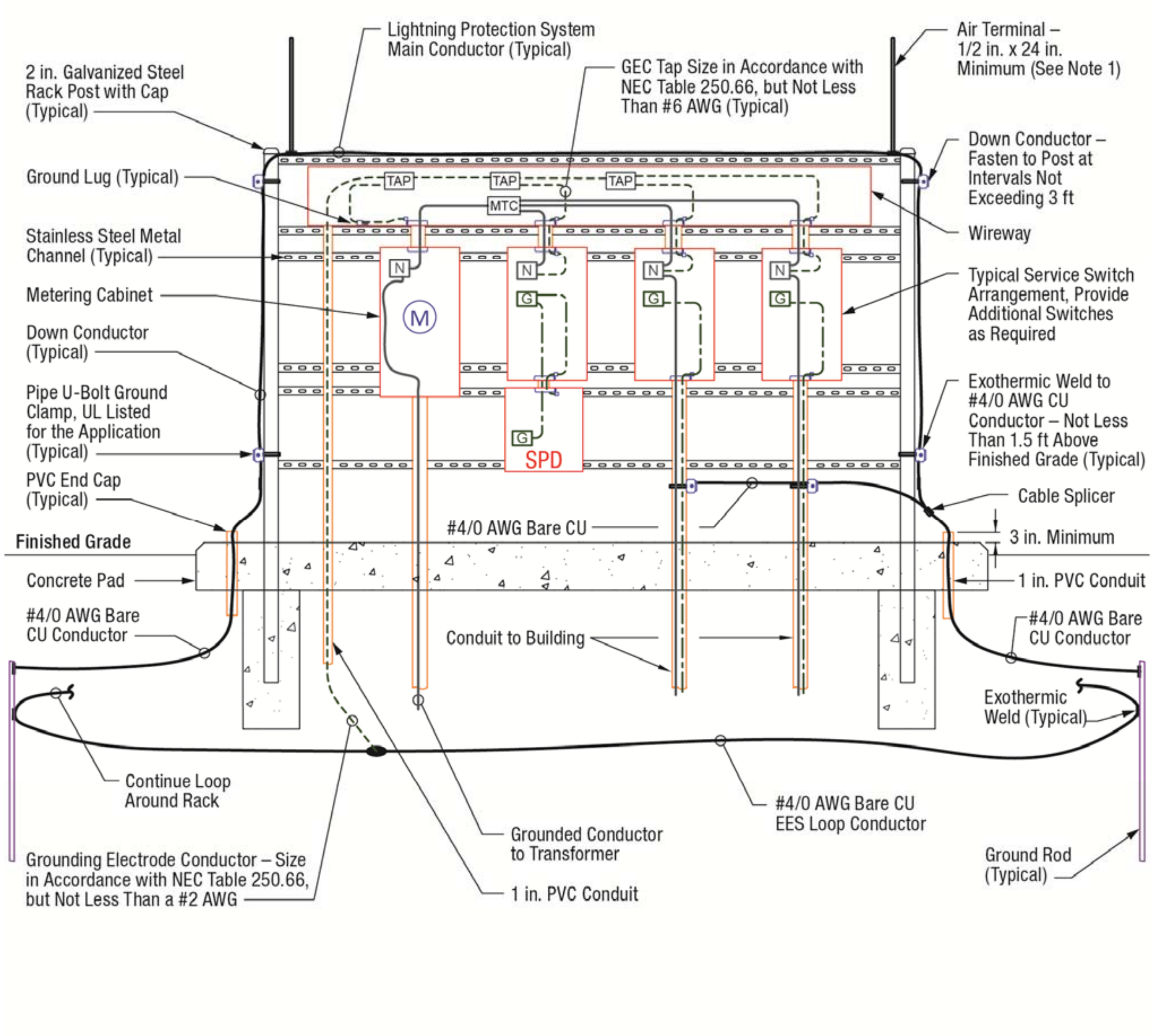
a. Less than 15 ft. A single EES loop designed to encircle the adjacent facilities is permitted.

b. Greater than 15 ft but Less than 30 ft. Design a separate EES for each facility, where adjacent EES loops may share a common side.

c. Greater than 30 ft but Less than 100 ft. Design a separate EES loop for each facility. Interconnect all EES loops by a minimum of two buried conductors, separated as widely as possible.

d. Greater than 100 ft. Design a separate EES for each facility. Interconnection of the separate EES is not required.

For small facilities, such as airfield navigation aids (NAVAIDS) or outdoor equipment service racks illustrated in Figure 4, an alternative EES design consisting of a minimum of two ground rods with a 4/0 AWG interconnecting ground wire is permitted.



Notes:

1. Only one air terminal, mounted at the center of the rack, is required for racks less than 6 ft in width.
2. Drawing is diagrammatic, phase conductors are not shown for illustrative purposes.

Figure 4. Typical Service Rack EES Installation – For Illustrative Purposes Only

4.4.4.1 Ground rods

Installation of ground rods shall meet the following requirements:

a. Material and Size. Ground rods shall be copper or copper clad steel, a minimum of 10 ft long and 3/4 in. diameter. Rod cladding shall not be less than 1/100 in. thick.

b. Spacing. Ground rods shall be as widely spaced as possible, and in no case spaced less than one rod length. Nominal spacing between ground rods is between two and three times the rod length.

c. Depth of Rods. Install top of ground rods at least 1 ft below grade level, or 1 ft below frost depth if required to suit climatic conditions.

d. Location. Rods shall be located 2 to 6 feet beyond the foundation or exterior footing of the structure, except at locations where abutting sidewalks, equipment, or other obstructions warrant locating rods farther away from the foundation. On buildings with overhangs or sidewalks in close proximity, then the ground rods are permitted to be placed at locations further out.

e. Orientation. Ground rods shall be driven at 90 degree (vertical) orientation to finish grade. If ground rods cannot be driven vertically to their full length, then the installation of grounding dissipation plates needs to be considered.

4.4.4.2 Interconnections

The EES installation shall include the following:

a. Counterpoise Loop. Ground rods shall be interconnected by a direct buried, bare 4/0 AWG copper conductor installed at least 2 ft below grade. Locate the counterpoise conductor and ground rods below the minimum frost depth. The interconnecting conductor shall close on itself forming a complete loop with the ends exothermically welded. Locate the counterpoise conductor and ground rods below the minimum frost depth with the exception of permafrost.

b. Exothermic Welds. Provide exothermic weld connections, except where prohibited by the NEC and at locations where welding creates hazards, such as near fuel tanks. In these cases, connections shall be installed with hydraulically crimped terminations using 12-ton minimum force applied with a tool using matching dies.

c. Building Structural Steel. Building perimeter steel columns shall be bonded to the EES at spacing intervals of approximately every other column, but not more than 60-ft intervals.

d. Reinforced Concrete Structures. Bond reinforcement bars to the EES once every 60 linear feet along the building foundation perimeter with a minimum 4/0 AWG bare stranded copper conductor exothermically welded or by a hydraulically crimped termination.

e. Underground Metallic Structures. Bond underground metallic pipes and tanks, except where cathodic protection systems are used or where prohibited by the NEC, such as gas piping.

f. Telephone Ground. Where present, the ground shall be connected to the EES by a bare copper conductor not smaller than 2 AWG.

4.4.4.3 Ground Dissipation Plates

In shallow soil locations with limited surface space, ground dissipation plates are permitted in lieu of ground rods in the EES. In difficult soils/areas, a combination of trenches filled with metallurgical coke and ground dissipation plates is highly recommended.

Installation of ground dissipation plates shall meet the following requirements:

a. Dissipation Plate Surface Area. Ground dissipation plates have four times the surface area of one ground rod, 3/4 in. diameter and 10 ft long. Therefore, substitute one ground dissipation plate for four ground rods.

b. Material and Size. Plates shall be fabricated and installed in accordance with Figure 6.

c. Spacing. Nominal spacing is 100 ft between ground plates.

d. Depth of Plates. Install plates to the same depth or deeper than the interconnecting EES counterpoise conductor, but maintain a minimum of 1 ft of native soil above the upper edge of the plate.

e. Location. The plates shall be installed at the corners of the EES at the farthest accessible point from the facility to be protected.

f. Orientation. Plates should be installed in a vertical plane to take advantage of seasonal moisture and temperature changes in the soil.

4.4.4.4 [A4] Access Well

Access wells are permitted to enable inspection and maintenance activities. When installed, the well should be located at a ground rod in unpaved areas with access to open soil, to allow for inspection. The access well shall be made from concrete or other approved material, with a removable cover. The access well shall provide a 12-in. minimum radius clearance from the center of the ground rod to the inside wall of the access well.

4.4.5 Grounding Enhancement Materials for Earth Electrode System (EES) Installation

Enhancement materials and methods are listed in order of preference.

4.4.5.1 Metallurgical Coke

Metallurgical coke is a steelmaking byproduct material of coal-to-coke production. Metallurgical coke is environmentally safe, stable, and conductive even when completely dry or frozen, moisture independent, compactable and economical to install.

Normal installation is in a 1-ft square trench filled with metallurgical coke in an EES configuration with a continuous 4/0 AWG stranded copper conductor in the center of the material per Figure 5. The top of the metallurgical coke trench shall be covered by a minimum of 1 ft of native soil. Metallurgical coke shall contain no more than 1 percent sulfur by weight. Charcoal and/or petroleum-based coke breeze shall not be substituted for metallurgical coke derived from coal in coke ovens. Charcoal and petroleum coke typically contain high levels of sulfur, which in the presence of moisture will accelerate corrosion of the EES. Placement of the trench is based on the geometry of the facility and the physical site location. Radial trenches with a center conductor can be used to enhance RF ground planes in communication facilities.

4.4.5.2 Engineered Soil Materials

Engineered soil materials are cements, soils, or clays treated with a variety of materials to enhance soil conductive properties. These materials may be used in bored holes for ground rod installations and in trenches for counterpoise conductors. These engineered soils can be a mixture of moisture-absorbing materials such as Bentonite or homogenous clays in combination with native soils and/or chemicals. Some engineered soil enhancements use cement-based materials, but should be avoided in areas subject to significant soil movement. Engineered soil should have a moisture content of greater than 14 percent to be effective.

4.4.5.3 Chemical Soil Enhancements

Chemical enhancements (doping) using materials such as mineral salts, Epsom salts, and sulfates, should only be used as a last resort to enhance soil conductive properties. These materials may be used in bored holes for ground rod installations and in trenches for counterpoise conductors. Chemical enhancement is dependent on soil moisture content and requires periodic (usually annual) re-treatment and continuous monitoring to be effective. The chemicals can leach into the surrounding soil and can be deposited into the water table.

4.4.5.4 Chemical Ground Rods.

Similar to chemical enhancements, chemical ground rods also require re-treatment and monitoring to ensure continuous effectiveness. Many of these systems require a drip irrigation system in dry soil conditions. Installation and periodic inspections shall be in accordance with manufacturer's instructions.

4.4.6 Installation of Earth Electrode Systems in Corrosive Soils

Careful consideration must be given to the installation of any grounding system in soils with corrosive elements. Two geological areas of known concern are the volcanic soils in Hawaii and Alaska. It is recommended that supplemental cathodic protection be applied to the grounding system at these locations. A buried steel plate acting as a sacrificial anode shall be connected to the EES by a 4/0 AWG stranded bare copper conductor. The 4/0 AWG conductor shall be exothermically welded to the EES and to the sacrificial plate. The conductor shall be welded to the center of the plate. The sacrificial plate shall be a minimum 2 ft by 2 ft by 1/2 in. thick, installed in a vertical orientation.

For enhanced performance in shallow soils, provide a ground dissipation plate design per paragraph 4.4.4.3 or equivalent. Provide sacrificial anodes in addition to these standard ground plates.

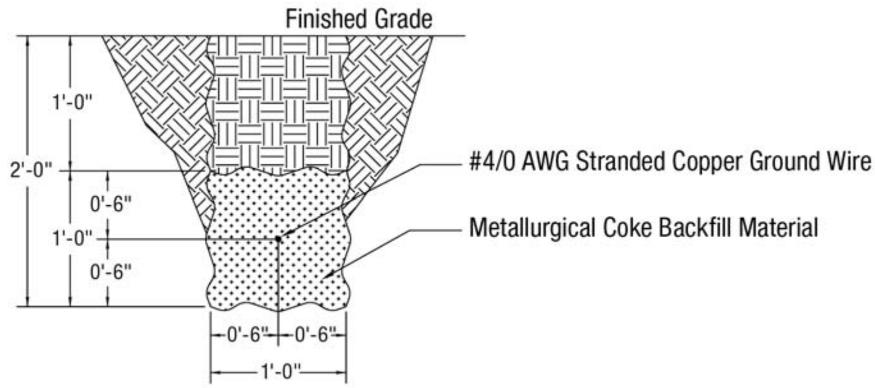


Figure 5. Grounding Trench Detail

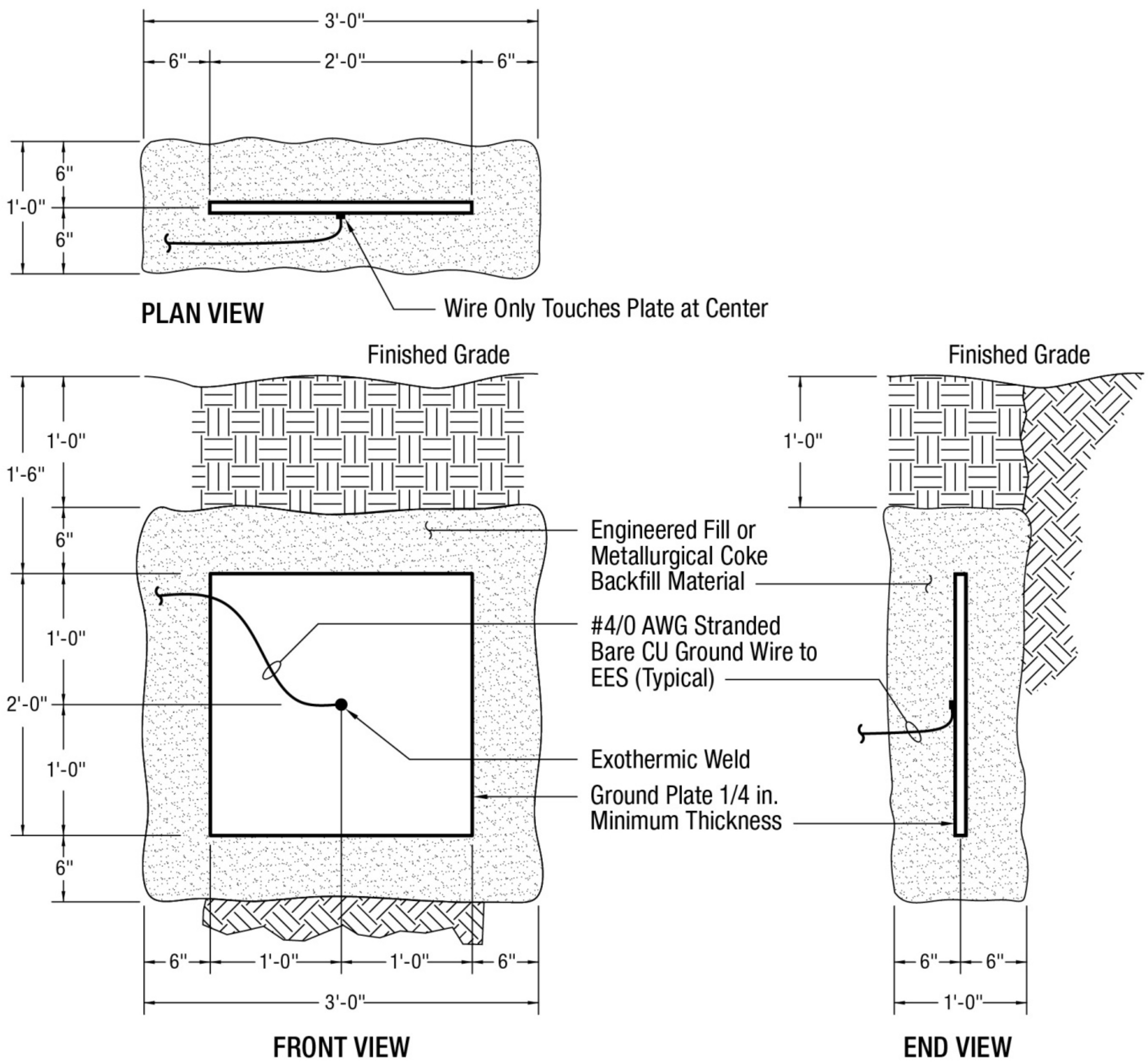


Figure 6. Ground Dissipation Plate Detail

4.5 National Electric Code - Power Distribution System Grounding Compliance

4.5.1 General

The facility electrical grounding shall exceed requirements of NEC Article 250 as specified herein.

4.5.2 Grounding Electrode Conductors (GEC)

Grounding electrode conductors (GEC) shall conform to the following:

a. GEC and Jumper Size. The GEC and system bonding jumper shall be sized in accordance with NEC Article 250.

b. GEC Termination and System Bonding Conductor. The GEC connection shall be terminated in the service disconnecting means (SDM). System bonding conductor shall be installed at the same location as the SDM.

c. GEC Splicing and Routing through Metal Enclosures. If the GEC is spliced using a hydraulically crimped connector, the connector shall comply with paragraph 4.2.3.2. When a GEC is routed through a metal enclosure, such as conduit, the enclosure shall be bonded with the same size conductor at each end to the GEC.

d. Separately Derived Systems. For a separately derived system, the system bonding jumper and the GEC shall be located at the first downstream system disconnecting means or overcurrent device. Connect the GEC directly to the EES, where possible, or terminate the GEC to the nearest effectively grounded structural steel member.

4.5.3 Equipment Grounding Conductors (EGC)

The EGC shall be a green insulated wire routed in the same raceway as the circuit phase and neutral conductors. Where power is supplied to electronic equipment through a cable and connector, the connector shall contain a pin to continue the EGC to the equipment chassis. Conduit or cable shields shall not be used as the sole EGC. Installation shall be in accordance with the NEC, FAA-C-1217, and the following:

a. Grounding Terminals in Receptacles on Multi-Outlet Assemblies. These terminals shall be hardwired to an EGC. Strips that depend on serrated or toothed fingers for grounding shall not be used.

b. Expansion joints. Conduit expansion joints shall be UL listed expansion joint fittings.

Where power conductors and the EGC are to be extended to a second building or structure, the neutral to ground bond of the power system shall originate at the first building electrical service entrance point. The grounded conductor shall not be connected to the EGC or EES at the second building or structure.

4.5.4 Grounding Bushings for Conduit Raceways

A grounding bushing is a conduit fitting that contains a lug for connecting a bonding jumper from the conduit bushing to the equipment ground bus or metal enclosure. This bonding jumper supplements the existing mechanical connection using locknuts and therefore improves the grounding integrity of the installation. The FAA has opted to exceed the minimum NEC raceway grounding bushing installation requirements for power and communication distribution systems that serve NAS facilities.

Provide grounding bushings for conduit raceway systems for the following conditions:

a. IMC and RMC Conduits. A grounding bushing shall be installed on the interior threaded end of the conduit to protect conductor insulation (see Figure 7).

b. EMT Conduits. The connectors shall have an insulated throat, smooth bell shaped end, or a grounding bushing.

c. Communication Conduit Pathways. Provide grounding bushings where conduits enter or leave the building. Additional grounding bushings are not required for electrically continuous conduit pathways located inside the building, unless otherwise required for electronic equipment operations. Bond each conduit with a 6 AWG or larger size conductor to the nearest SRS (with the exception of the single point ground system). If there are multiple conduits in the same junction box, the conduits can be bonded to a new ground bus established within the junction box with a 6 AWG or larger size conductor connected to the SRS (with the exception of the single point ground system).

Exception. *Pullboxes and junction boxes are exempt from the grounding bushing requirement unless required by NEC or equipment installation requirement.*

4.5.4.1 Non-Current-Carrying Metal Equipment Enclosures

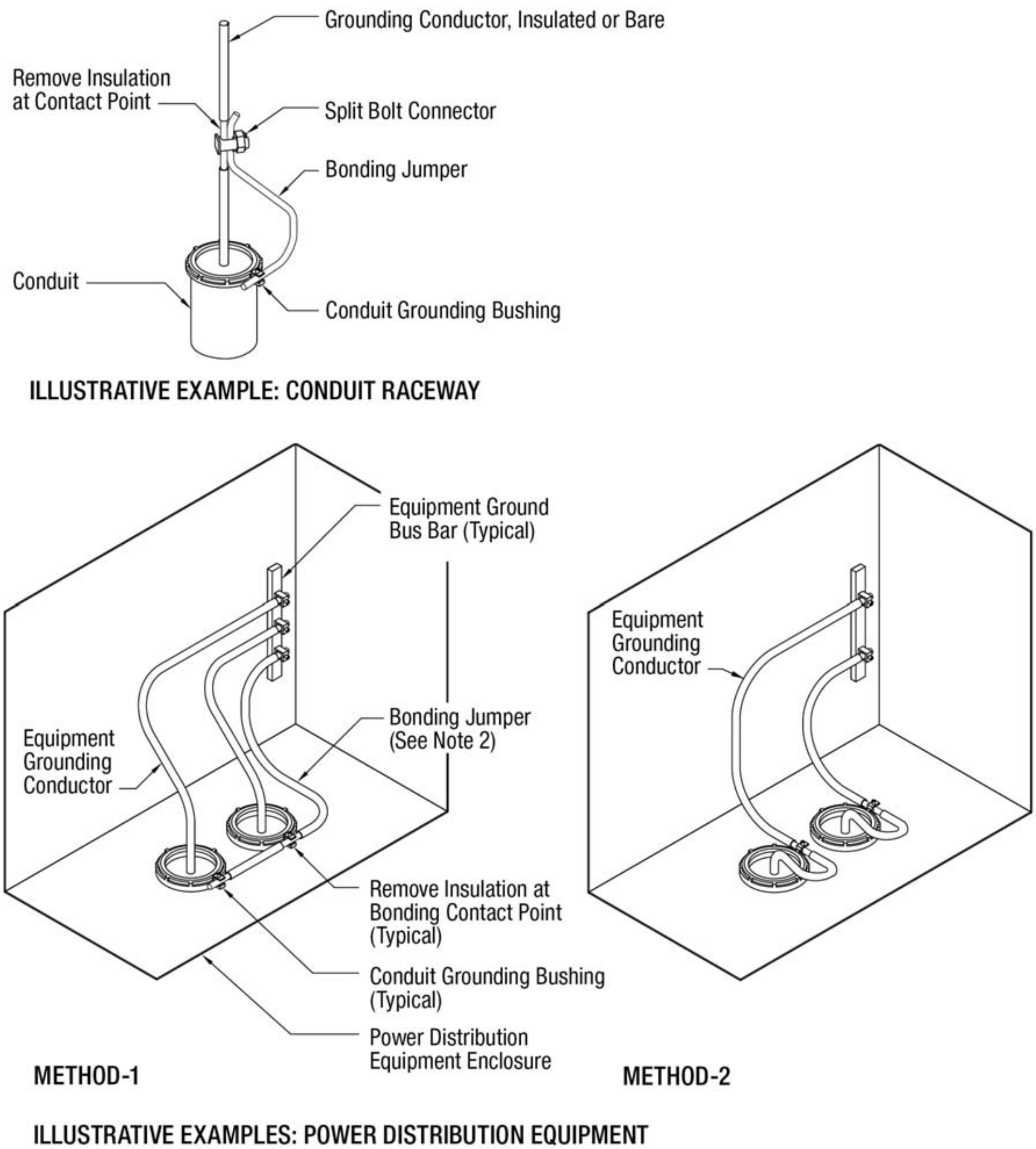
Non-current-carrying metal equipment enclosures include electrical equipment such as switchgear, panelboards, safety disconnect switches, raceways, and cable trays. The insulating finishes shall be removed between grounding and bonding areas of mating surfaces or bonding jumper connection points. The raceway systems shall be made electrically continuous in accordance with the following:

a. Noncontinuous Ferrous Conduit Pathways or Sleeves. Pathways used for routing conductors only shall be equipped with grounding bushings at each end of the conduit pathway. The grounding conductor shall be bonded to the bushings with a bonding jumper the same size as the grounding conductor, see Figure 7 illustrative example.

b. Continuous Conduit Systems. Systems that terminate at electrical equipment with grounding bushings as required in 4.5.4 shall be bonded to equipment ground bus with a bonding jumper the same size as the EGC. This shall be accomplished in accordance with Figure 7.

c. Ferrous Materials. These materials shall be used for enclosures, raceways, and cable trays when required to provide shielding from magnetic fields.

d. Battery Supporting Racks. These racks shall be bonded either directly to the EES or to a grounded structure with a minimum 2 AWG conductor.



<u>Notes:</u>

1. The illustrative examples depict typical bonding concept, other engineered solutions may be possible.
2. The bonding jumper shall be sized as large as the largest EGC going through the conduits being used for grounding bushings.

Figure 7. Bonding of Grounding Conductor to Conduit or Equipment

4.5.5 Interior Metal Piping Systems

Interior metal piping systems shall be bonded in accordance with the NEC.

Interior metal piping systems, such as mechanical and related metal piping systems located within the perimeter of SRS areas for NAS electronic equipment, shall be bonded in accordance with paragraph 4.7.3.2.

4.5.6 Building Structural Steel

Bonding of building structural steel elements shall be in accordance with the following:

a. NEC Compliance. At the electrical power service entrance and separately derived power source equipment, building structural steel shall be bonded in accordance with the NEC.

b. Periphery of NAS Equipment Room. Main building structural steel members of columns and beams at the periphery of NAS electronic equipment rooms shall be electrically continuous. This shall be accomplished by either direct or indirect bonding of the columns and beams. Where direct bonding is not practical, indirect bonds with copper conductor shall be used with a minimum of two 2 AWG conductors per 100 ft^2 of steel decking, metallic wall covering, etc. These connections shall be applied via an exothermic weld or a hydraulically crimped two-hole termination. Surface coatings shall be removed in accordance with paragraph 4.2.4.1**.**

c. Building Perimeter Steel. Building perimeter steel columns shall be bonded to the EES in accordance with paragraph 4.4.4.2c.

Exception. *Concrete-encased steel reinforcement used in precast construction elements is exempt from the bonding requirements.*

4.6 Surge Protection Device (SPD) Requirements

4.6.1 General

SPDs shall be provided at locations where electrical power systems are susceptible to conducted power line surges. SPD equipment functional performance requirements are detailed in section 5.7. Selection of appropriate SPD depends on location and application. The SPDs and transient suppression provided at electronic equipment power line entrances shall be coordinated as required herein and paragraph 5.6.4.

4.6.2 SPD for Power Distribution System

SPDs shall be provided at the following locations:

a. Service Disconnecting Means. Provide SPD on the load side of the SDM.

b. Facility Entrance Point. Provide SPD on the load side of a facility entrance point. For example, if the facility entrance point is within a NAS electronic equipment room, the SPD is required at the first distribution panelboard that supplies the branch panelboards within the room.

c. Transfer Switch, Switchboard, or Panelboard. Provide SPD either on the load side of an engine generator transfer switch, or on the first switchboard or distribution panelboard located downstream of the transfer switch.

d. Panelboards Feeding Building Exterior Loads. Provide SPDs at panelboards that supply branch circuit wiring exiting the building to serve exterior equipment.

e. Secondary Transformer. Provide SPD at separately derived power source that feeds NAS electronic equipment.

A lightning arrester shall be installed on the primary side of FAA-owned distribution transformers. Lightning arresters and SPDs shall be approved by the OPR.

4.6.2.1 SPD for Facility Entrance Equipment

SPDs shall be provided at the SDM, at all facility entrance penetrations, and at feeder and branch panelboards as specified in paragraph 4.6.2.2. Additional SPDs shall be provided at the power line entrances to operational electronic equipment.

4.6.2.2 SPD for Power Distribution Feeders and Panelboards

SPDs shall be installed on switchgear, panelboards, and disconnect switches providing service to NAS operational equipment or supplying exterior circuits.

Examples of exterior circuits include obstruction lights, convenience outlets, guard houses, security systems, electric gates, and feeds to other facilities.

Where feeder and branch panelboards are located close together and their panelboards do not serve exterior circuits, use the SPD location decision tree diagram, Figure 8, to determine if an SPD is required for branch panelboards. SPDs for panelboards that provide service to exterior circuits shall meet requirements of paragraphs 5.7.2.1.1, 5.7.2.1.2, and 5.7.2.1.3 for facility entrance SPDs.

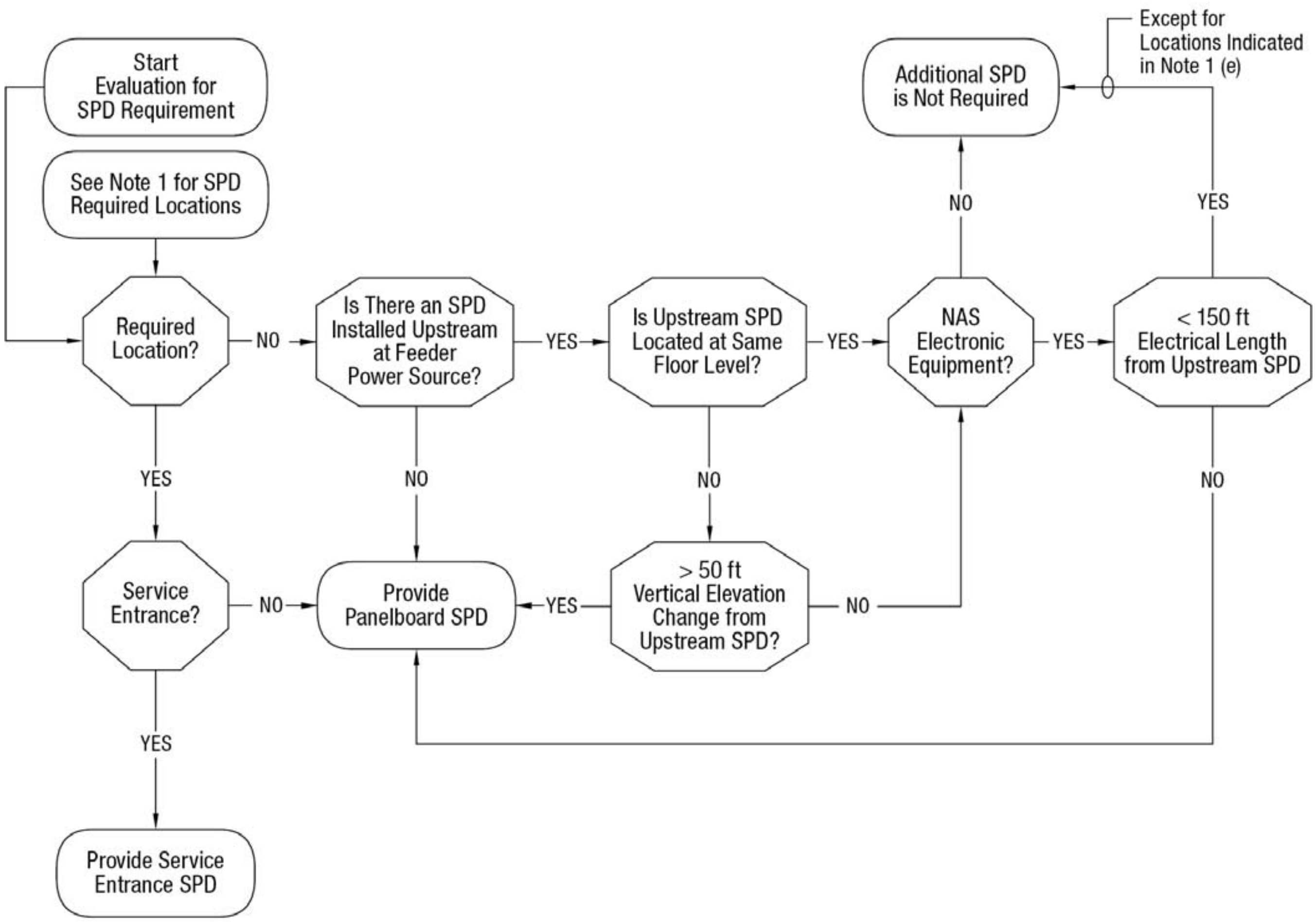
SPDs shall be installed as close as possible to the panelboard they serve and in accordance with the manufacturer's instructions. A feeder or branch panelboard SPD shall be provided with an overcurrent protection device. Overcurrent protective device (OCPD) examples include a fuse or circuit breaker fitted internal to the SPD or fitted to the panelboard and dedicated to the SPD. The overcurrent device shall not increase the clamp voltage of the SPD by more than 5 percent and shall pass the surge current values listed in Table 11 up to the 40 kA level without opening. Overcurrent devices for exterior circuits shall pass all surge current values in Table 11. Overcurrent devices, both internal and external to the SPD, and SPD short circuit current ratings, shall be sized and coordinated in accordance with the NEC and be field resettable or replaceable.

4.6.2.3 SPD Installation Requirements

SPDs shall be installed as close as possible to the panelboard or equipment that is being protected. Conductors shall be made as short as possible. Connections shall be made with UL listed connectors identified for the wire size and type used.

a. Connections. Install the maximum conductor size allowed by the SPD manufacturer, but do not exceed the incoming circuit phase and grounding conductor size permitted by the panelboard, SDM , or protected equipment. Conductors shall be color-coded in accordance with FAA-C-1217, and as short and direct as possible without loops, sharp bends, or kinks. The ground bus in the service entrance enclosure shall be bonded directly to the SPD terminal marked G or ground. The SPD enclosure shall be bonded to the SPD ground terminal.

b. Conduit Sealing. The conduit connecting the SPD enclosure to the SDM enclosure or panelboard shall be sealed with duct seal or other UL listed nonflammable, inorganic potting material to prevent soot from entering the protected enclosure in the event of SPD failure.



<u>Notes:</u>

1. Provide SPDs in accordance with paragraph 4.6.2 and for the following locations.
   a. Power service disconnecting means (SDM).
   b. Load side of automatic transfer switch (ATS).
   c. Transformer, secondary of separately derived power source.
   d. Panelboards with branch circuits that feed building exterior loads.
   e. Power feeder that supplies the panelboards for NAS electronic equipment room. SPD is required at the first panelboard located within the room.

Figure 8. SPD Location Diagram - Close Proximity Allowance Decision Tree

4.6.3 SPD for Signal, Control, and Data Line Surge Protection

Provide SPDs at the following locations:

a. Facility entrances,

b. Entrances to NAS electronic equipment (see paragraph 5.6.3),

c. Entrances to electronic equipment installed by the telecommunication service provider.

4.7 Grounding and Bonding for NAS Electronic Equipment Areas

4.7.1 General

This section describes grounding and bonding requirements for protection of NAS electronic equipment housed in designated NAS electronic equipment areas within FAA Facilities. Aspects of the grounding and bonding system include the following:

a. NAS Facilities Main Grounding Connection. This connection requires a main and supplemental ground plate, designed in accordance with paragraph 4.7.2. See paragraph 5.2.3 for ATCT facilities special requirements.

b. Signal Reference Structures. The SRS system requires grounding elements designed in accordance with paragraph 4.7.3.

4.7.2 Main and Supplemental Ground Plates

A main ground plate shall be established as a common point of connection for SRSs for the entire facility.

A supplemental ground plate shall be established at the opposite side of the facility to the main ground plate. This supplemental ground plate shall be used for a second connection of the multipoint ground system, signal reference grid, or signal reference plane to the EES. The use of multiple supplemental ground plates is permitted at large facilities.

Both the main ground plate and the supplemental ground plates shall conform to the following:

a. Located within 50 ft of the EES.

b. Each plate shall be connected to the EES with a 500 kcmil conductor.

c. Supplemental ground plates and the main ground plate shall be interconnected with an insulated 4/0 AWG cable, color coded with green and orange tracer.

See Table 4 for the main and supplemental ground plate installation requirements. See Figure 9 for typical facility grounding system.

Exception**.** *For buildings of 200 ft^2 or less, only the main ground plate is required. Connect the main ground plate to the EES with two 4/0 AWG stranded copper conductors. One of the conductors shall be 20 percent longer than the other. All signal grounding, single point or multipoint, shall terminate on this plate. No additional ground plates are required.*

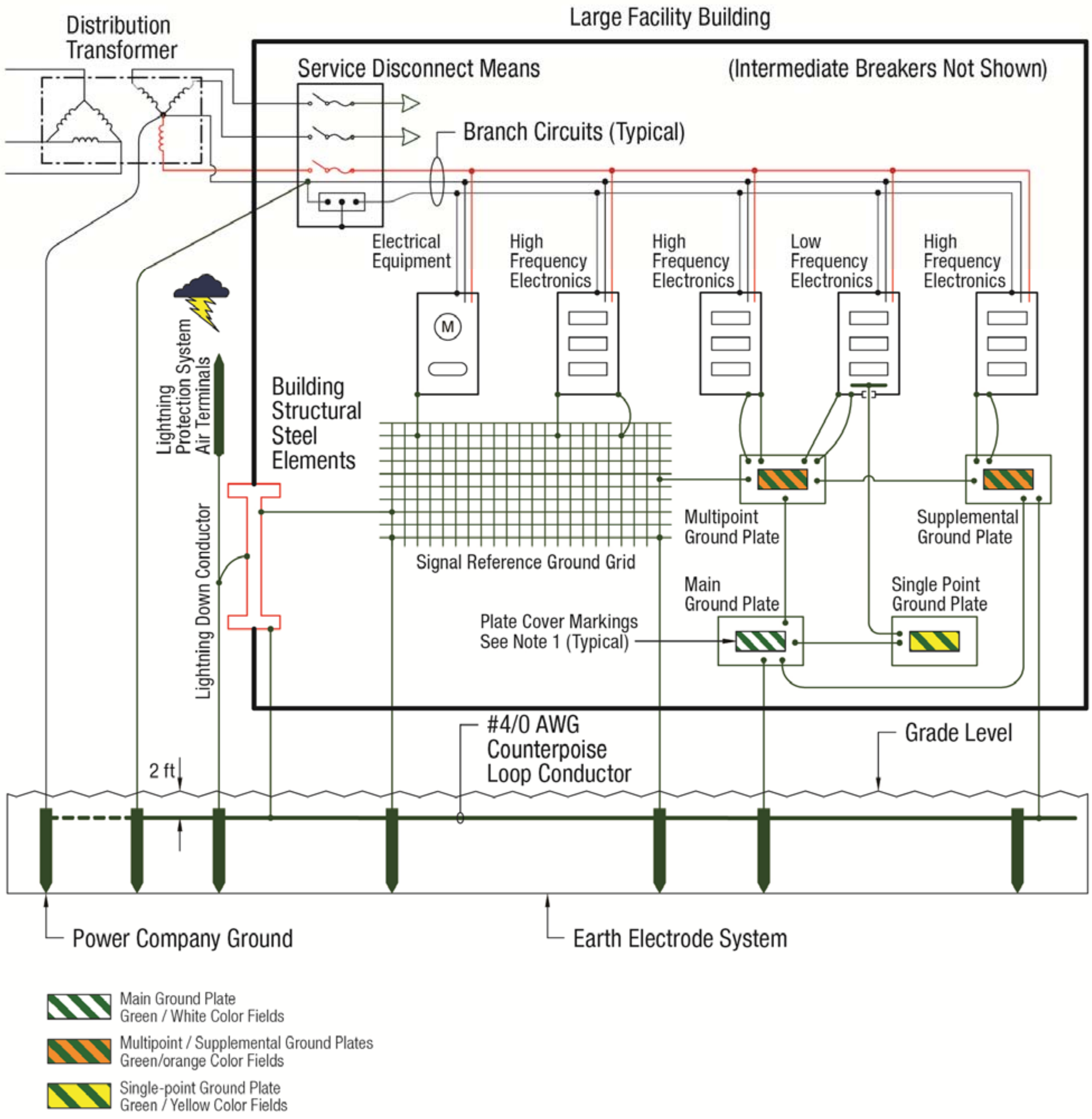


Figure 9. Typical Facility Grounding System

4.7.3 Signal Reference Structures (SRS) – Requirements

Enclosed building facilities used to house NAS electronic equipment shall be equipped with an SRS. Types of SRS include the following systems:

a. Multipoint Ground System (MPG) constructed using conductors and ground plates.

b. Signal Reference Ground Grid (SRGG) constructed using copper strips.

c. Signal Reference Ground Plane (SRGP) constructed using copper sheets.

d. Single Point Ground System (SPG) is a special grounding system defined in section 5.5. This topology shall only be installed as directed in section 5.5 and connected to the MPG, SRGG, or SRGP as directed in section 5.5, and it shall not be used as an applicable SRS as outlined in the rest of 4.7 and its sub-sections.

e. Engineered Hybrid System is a combination of MPG, SRGG, or SRGP grounding systems.

Provide an SRS for the following areas:

a. <u>NAS Operations Areas</u>. Entire room area.

b. <u>Other Electronic Equipment Areas</u>. Areas containing electronic equipment supporting NAS operations. Provide for the entire room area.

c. <u>Other Power Conditioning Equipment Areas</u>. Areas containing power conditioning equipment, such as site wide uninterruptible power supply (UPS), shall be bonded to the SRS system described above.

The above-referenced electronic and electrical equipment shall be bonded to the SRS in the area. SRSs located on the same floor or on different floors shall be bonded together using at least two separate paths. Multiple components of the facility SRS, but not the SPG system, shall be bonded together with a minimum of two 4/0 AWG conductors.

Design SRS systems for site-specific requirements of the facilities and equipment. SRS applications require analysis of equipment bandwidth, and equipment and SRS impedances. SRS analysis shall consider, among other parameters, operating frequencies and impedances, transmission line communication models for bonding wires, noise levels in low-frequency analog-based equipment, and the influence of high-frequency digital signal and logic equipment. All conductors and cabling of NAS electronic equipment systems operating nominally at a wavelength less than $\lambda/20$ of the highest system frequency shall lay on or very close to the SRS. Bonding connections between the electronic equipment and SRS shall be close-coupled so that the bonding jumpers are as short as possible, and routed to the nearest SRS connection point.

The SRS shall be located in the vicinity of the electronic equipment. Signal-carrying conductors, axial lines, waveguides, and cabling interconnections between equipment shall be routed in immediate proximity to the SRS. For overhead feeds, use overhead SRS systems. For underfloor feeds in raised access floors, use underfloor SRS systems. Where equipment is fed from both overhead and underfloor feeds, use a hybrid SRS system made up of MPG, SRGG or SRGP bonded together. MPGs, SRGGs, and SRGPs may be installed on ceilings, walls, or floors.

If NAS electronic equipment is installed in non-NAS electronic equipment rooms such as administrative areas, the NAS electronic equipment shall be bonded to a nearby SRS system. If there is no nearby SRS system, then establish a new MPG based on the footprint area of the NAS electronic equipment. If the square footage of the area is small enough, then install a small MPG system in accordance with paragraph 4.7.2.

The MPG and SRS systems shall be connected to the main and supplemental ground plates with conductors sized in accordance with paragraph 4.7.3.1.3. Each connection shall be to the nearest MPG plate or SRS.

4.7.3.1 Multipoint Ground System (MPG)

The protection of electronic equipment against potential differences and static charge buildup shall be provided by interconnecting non-current-carrying metal objects to an MPG that is effectively connected to the EES. The MPG consists of a network of plates and bonding jumpers, racks, frames, cabinets, conduits, wireways, cable trays enclosing electronic conductors, structural steel members, and conductors used for interconnections. The MPG shall provide multiple low-impedance paths to the EES, between various parts of the facility, and between electronic equipment within the facility so that any point of the system has a low-impedance path to the EES. This will minimize the effects of spurious currents present in the ground system due to equipment operation or malfunction, or from lightning discharges. The MPG shall not be used in lieu of the safety ground required by the NEC or as a signal return path.

4.7.3.1.1 Labeling

The MPG shall be clearly labeled to preserve its identity as described in the following paragraphs.

4.7.3.1.1.1 Conductor Identification

MPG conductors shall be labeled in accordance with paragraph 4.7.3.1.6.

4.7.3.1.1.2 Ground Plate Labeling

Ground plates shall be installed in accordance with Table 4.

4.7.3.1.2 MPG - Ground Plates and Buses

Multipoint ground plates shall be located to facilitate the interconnection of equipment cabinets, racks, and cases within a particular area. If more than one ground plate is necessary, they shall be located throughout the facility. Ground buses may be used when distributed grounding is required along a long continuous row of electronic equipment cabinets.

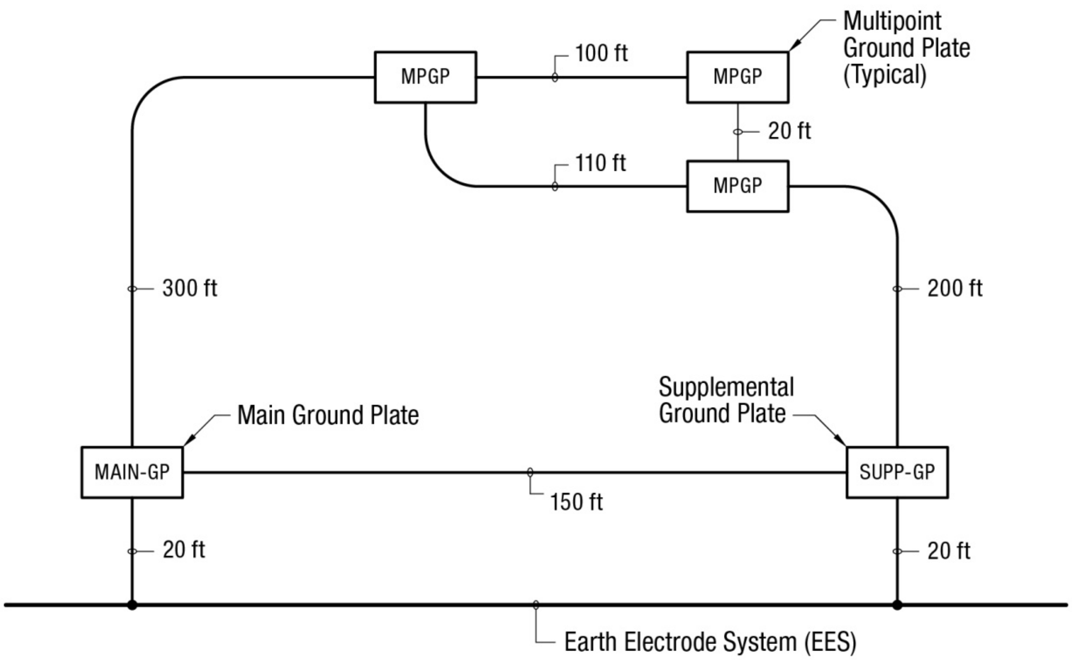
See Table 4 for the multipoint ground plate installation requirements. Ground buses shall be copper material. Ground bus width and thickness shall be selected from Table 3, and shall be as long as required.

Provide a secondary conductor return path for each MPG plate or ground bus. A single-ended, radial connected plate or bus configuration is not permitted. Building structural steel shall not be used as a secondary return path for the MPG.

4.7.3.1.3 MPG Conductors – Plate to Plate and Plate to Bus

Conductors between plates and buses in the multipoint system shall be insulated and sized in accordance with Table 3 based on the maximum path length to the farthest point in the MPG from the EES. To determine the distance to the farthest point in the multipoint system, add the length of conductors in the multipoint system to reach the farthest plate in the system via the longest path as shown in Figure 10. Divide the sum obtained by two to obtain the maximum path length. Use this path length to determine the conductor size from Figure 10, but in no case use a conductor smaller than 4/0 AWG. These conductors shall be insulated, labeled, and color-coded in accordance with paragraph 4.7.3.1.6. In cable trays, ground conductors shall be insulated and separated as far as possible from the other conductors.

Exception. *In plenum spaces, where plenum-rated insulated conductors are not available, bare ground conductors are permitted.*



Notes:

1. Determine the longest cable path between the main and supplemental ground plate connections to the EES by adding the sum of individual cable segments along the pathway.

   Maximum path length = 20+300+100+20+200+20 = 660 ft

2. Divide total obtained in step 1 by two.

   660/2 = 330 ft

3. Determine conductor size from Table 3. Using 330 ft path length, select 750 kcmil size conductor.

Figure 10. Multipoint Ground Conductor Size Determination

Table 3. Size of Electronic Multipoint Ground Interconnecting Conductors

Conductor Size (AWG or kcmil)	Max. Path Length (ft)	Bus Bar Size, See Note 2 (in.)	Max. Path Length (ft)
750, See Note1	375	4 x 1/4	636
600, See Note1	300	4 x 1/8	318
500	250	3 x 1/4	476
350	175	3 x 1/8	238
300	150	2 x 1/4	318
250	125	2 x 1/8	159
4/0	105	2 x 1/16	79
3/0	84	1 x 1/4	159
2/0	66	1 x 1/8	79
1/0	53	1 x 1/16	39
1	41		
2	33		
4	21		
6	14		
8, See Note 3	9		
10, See Note 3	6		
12, See Note 3	4		

Notes:

1. Where these conductors are not available, parallel conductors are permitted, such as three 250 kcmil conductors in place of one 750 kcmil conductor, or two 300 kcmil conductors in place of one 600 kcmil conductor. Conductor sizing is based on providing a cross-sectional area of 2,000 cmil per linear ft. Bus bar sizes are chosen from available cross-sections and shall exceed the cross-sectional requirement of 2,000 cmil per linear ft.
2. Denotes an MPG designed with a continuous bus bar layout in lieu of ground plates and interconnecting conductors.
3. Conductor wire sizes 12 AWG through 8 AWG are permitted only for bond jumper connections between subassemblies and interior cabinet ground plate within the electronic equipment enclosure.

Table 4. Ground Plate Specification Requirements

Plate Type	Acronym	Application Requirements (see article)	Material	Configuration Notes	Identification Notes
Main	Main-GP	4.7.2	Copper	1, 2, 3, 4	5, 6
Supplemental	Supp-GP	4.7.2	Copper	1, 2, 3, 4	5, 6
Multipoint	MPGP	4.7.3.1	Copper	1, 2	5, 6
Single Point	SPGP	5.5.4	Copper	1, 2	5, 6

Notes:	
1.	Plate Dimensions. Ground plate dimensions shall be at least 4 in. wide and 1/4 in. thick. Provide adequate length to accommodate number of bond connections plus at least two spare positions.
2.	Conductor Terminations at Ground Plates. Provide either UL listed hydraulically crimped 2-bolt-hole style terminal lugs or exothermic welds for conductor terminations.
3.	Conductor Terminations at the EES. The connections from ground plates to the EES shall be made with exothermic welds at the EES. The connections shall be as follows: a. Conductor between Main-GP and EES. Provide at least one 500 kcmil conductor. The Main-GP location shall be chosen to minimize conductor length, but shall not be more than 50 ft from the EES. b. Conductor between Supp-GP and EES. Provide at least one 500 kcmil conductor. The Supp-GP location shall be chosen to minimize conductor length, but shall not be more than 50 ft from the EES. The conductor length from Supp-GP to the EES shall be 30 percent longer or shorter than the conductor between the Main-GP and the EES.
4.	Interconnection of Main-GP and Supp-GP. Provide a 4/0 AWG bonding conductor connected between the Main-GP and Supp-GP.
5.	Ground Plate Covers. Provide clear plastic covers with a permanently attached label or metal nameplate. The nameplate text shall be color black with 3/8-in. high letters and Arial font. The cover shall be identified with color-coded overlay markings configured by system type. The nameplate caption and cover identification shall be as follows: a. Main-GP. Provide label caption, “MAIN GROUND PLATE” and cover markings with clear background and green slashed marking tags around the caption. b. Supp-GP. Provide label caption, “SUPPLEMENTAL GROUND PLATE” and cover markings with clear background and green slashed marking tags around the caption. c. MPGP. Provide label caption, “MULTIPOINT GROUND PLATE” and cover markings with green background and bright orange slashed marking tags around the caption. d. SPGP. Provide label caption, “SINGLE POINT GROUND PLATE” and cover markings with green background and bright yellow slashed marking tags around the caption.
6.	Conductor Identification Requirements. See Table 5.

4.7.3.1.4 MPG Conductors - Plate and Bus to Equipment

Conductors from plates and buses in the multipoint system to equipment chassis shall be sized in accordance with Table 3 based on the maximum path length from the plate or bus to the equipment. These conductors shall be insulated, labeled, and color-coded in accordance with paragraph 4.7.3.1.6. In cable trays, ground conductors shall be separated as far as possible from the other conductors. In wireways, ground conductors shall be visible by opening any cover.

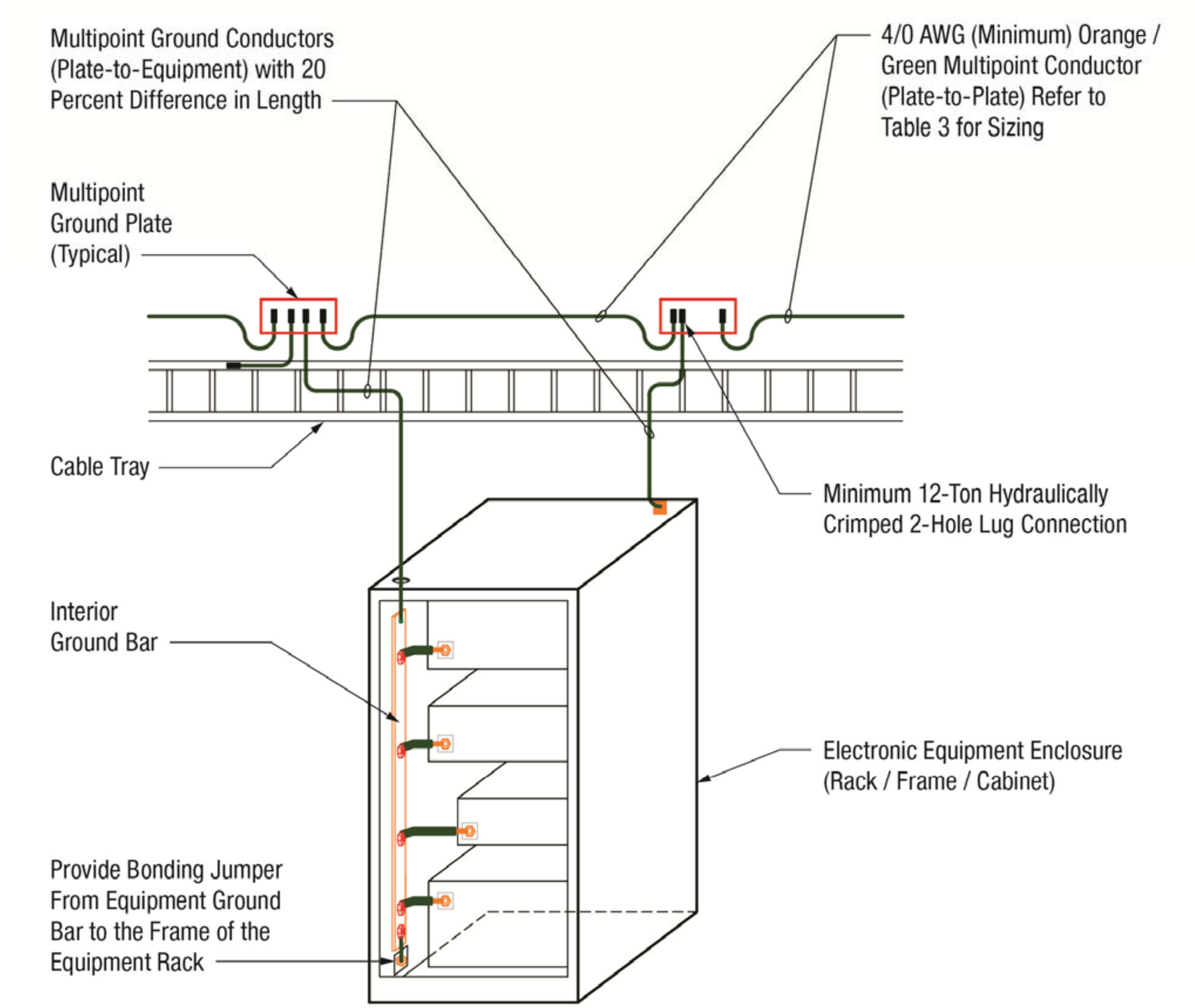
Provide grounding connections between the electronic enclosure and the MPG system in accordance with following:

a. Bonding Connections. Bonding connections shall prevent resonant impedances at equipment operating frequencies. Provide two short low-impedance bonding jumper between the MPG and two corners of the equipment. These bonding jumpers shall be connected as far apart as possible on the equipment (ideally on opposite corners) to reduce mutual inductance, and they shall have few bends or sags. The two bonding connections shall be of unequal length (one of the connections shall be 20 percent longer or shorter than the other) so that if one strap undergoes resonance, by limiting current flow, the other strap will not. Any bend radius in the bonding conductors shall be a minimum of 8 in.

b. Bonding Connectors. Provide bonding conductors size in accordance with Table 3 at MPG system connections.

c. Bonding Connection Length. Bonding connections to the SRS should be as short as possible.

See Figure 11 for typical electronic equipment grounding illustrations.



ILLUSTRATIVE EXAMPLE:

Notes:

1. If MPG conductors are mounted on the side or face of the cable tray, provide cable support at intervals of at least 3 ft. MPG conductor support is not required if the cables are laying on the cable tray system.
2. Paint shall be removed from the bonding surfaces before making grounding connections to the equipment enclosure. The bonding surfaces do not require paint sealing treatment if the connection is made inside an environmentally controlled room.

Figure 11. Electronic Equipment Grounding

4.7.3.1.5 Grounding Conductor Protection

Provide protection for MPG conductors subject to physical damage by use of conduit, floor trenches, routing behind permanent structural members, or other approved means. If grounding conductor is routed through metal conduit, the conduit shall be bonded to the conductor at each end.

4.7.3.1.6 Grounding Conductor Labeling

Provide conductor and pathway identification labeling where cables pass between areas physically separated by walls. Labeling is not required for cables that originate and terminate in the same room, such as a room without wall partitions.

Table 5. Grounding Conductor Insulation Color Codes

Conductor Insulation - Color Identification	Use
Green with red and yellow tracers	Isolated grounds
Green with yellow tracer	Single point ground
Green with orange tracer	Multipoint ground
Green with red tracer	High-Transient ground

Notes:
1. Some commercial off-the-shelf (COTS) equipment uses green with yellow tracer as the color identification for the EGC. These conductors are permitted.
2. Conductor labeling material type and format specification shall be in accordance with FAA-C-1217.

4.7.3.2 Signal Reference Ground Grid (SRGG)

When required, the SRGG shall be provided for raised access floor systems and/or ceiling systems in NAS electronic equipment rooms or areas serving NAS electronic equipment.

The SRGG shall be configured in accordance with the following:

a. Configuration. SRGG shall consist of a grid of 2-in. wide copper strips, 26 gauge or thicker, placed on a 2x2-ft square grid and welded at each grid intersection.

b. Installation Location. SRGG shall be installed below a raised access floor system, below a ceiling or above a suspended ceiling system, or both. The SRGG perimeter shall extend to within 6-in. from the room perimeter or the perimeter of electronic equipment area served.

c. Perimeter Conductor. A minimum 4/0 AWG bare copper conductor loop shall be routed around the SRGG and located within 6 in. from the SRGG perimeter. The SRGG perimeter shall be bonded to the perimeter loop conductor at every grid intersection with a 4 AWG bare copper conductor.

d. Bonding to EES. The perimeter loop conductor shall be bonded to the EES with a minimum of four 4/0 AWG conductors spaced as widely apart as possible.

e. Bonding to Building Steel. Building structural steel located within 6 ft of the SRGG perimeter loop conductor shall be bonded to the loop conductor with minimum 4/0 AWG conductor. Building structural steel located within the perimeter of the SRGG shall be bonded to the SRGG with a minimum 4 AWG conductor.

f. Bonding to Floor and Ceiling Systems. The SRGG shall be bonded to the raised access floor system or the ceiling metalwork at intervals not less than 6 ft using minimum 4 AWG bare copper conductors.

g. Bonding of Multiple SRGGs. Floor and ceiling portions of a SRGG in the served area shall be bonded together with a minimum of four sets of 4/0 AWG conductors spaced as wide apart as possible.

h. Bonding of Raceways and Metal Objects. Conduits, wireways, pipes, cable trays, or other metallic elements that penetrate the SRGG area shall be bonded to the SRGG where they enter the area and every 25 ft for their entire length within the area. Conduits, wireways, pipes, cable trays, and other metallic elements within 6 ft of the grid shall be bonded to the SRGG. These bonds shall be minimum 4 AWG bare copper conductors.

4.7.3.2.1 SRGG to Equipment
Provide bonding straps 1 in. wide and at least 26 gauge solid copper at SRPG or SRGG connections.

4.7.3.3 Signal Reference Ground Plane (SRGP) - Special Conditions
SRGP is a continuous signal reference ground plane constructed of 24 gauge minimum thickness copper sheets. SRGP shall be provided when required by the electronic equipment vendor. SRGP designs shall be approved by the OPR.

4.7.4 Bonding of Electrical Systems in NAS Electronic Equipment Areas
Raceways/conduits, wireways, and electrical distribution equipment shall be bonded to the SRS. Metal framing channel systems used to support conduit/raceway or other equipment are expected to be installed to achieve electrical continuity, and are not required to have additional bonding jumpers between individual assembly components.

4.7.4.1 Conduit Raceways
Every component of metallic conduit runs such as individual sections, couplings, line fittings, pull boxes, junction boxes, and outlet boxes shall be made electrically continuous and bonded, either directly or indirectly, to the SRS or facility steel at intervals not exceeding 25 ft.

If otherwise not indirectly or directly bonded, bond conduits using a minimum 6 AWG bonding conductor. Conduit raceways that are less than 1.5 in. trade size or less than 10 ft in length are exempt from the bonding requirement.

4.7.4.2 Cable Trays and Wireways
If not indirectly or directly bonded, bond individual sections of metallic cable tray and wireway systems together with a minimum 6 AWG insulated copper conductor. Bonds shall be in accordance with section 4.2.

Bonding jumpers between individual sections are not required when all of the following conditions are met:

a. The cable tray or wireway systems are electrically continuous,

b. The systems are UL classified, suitable for use as an EGC,

c. The systems are installed in accordance with manufacturer recommendations.

Where installed in electronic areas, cable trays and wireways shall be bonded to the SRS within 2 ft of each end of the run and at intervals not exceeding 50 ft. The minimum size bonding conductor for connection of a cable tray and wireway to the SRS shall be 2 AWG copper conductor.

4.8 Shielding Requirements

4.8.1 General

The facility design and construction shall include both protective shields to attenuate radiated signals, and separation of equipment and conductors to minimize interference coupling. The equipment design shall incorporate component compartments and overall shields as necessary to meet the electromagnetic susceptibility and emission requirements of MIL-STD-461 as required by NAS-SS-1000 and FAA-G-2100. In addition, the design shall provide personnel safety protection shielding.

4.8.2 Facility Shielding

Shielding of facility buildings, shelters, and equipment spaces shall be provided when other facility or environmental sources of radiation are of sufficient magnitude to degrade the operation and performance of electronic equipment or systems.

4.8.3 Shielding for Conductors and Cabling

Conductor and cable shielding shall comply with the following:

4.8.3.1 Cables and Signal Lines

Cables consisting of multiple twisted pairs shall have individual shields for each twisted pair. The shields shall be isolated from each other. Cables with an overall shield shall have the shield insulated and isolated from individual shields.

<u>Exception</u>. *Structured cabling for computer and telephone networks, such as Ethernet over balanced-line twisted pair with differential signaling design for noise rejection, are permitted to be used without individual shields for each twisted pair.*

4.8.3.2 Cables - Termination of Individual Shields

Shields of pairs of conductors, line shields, and the shield of cables containing unshielded conductors shall be terminated in accordance with the following:

a. <u>Shield Terminations</u>. Shields shall be terminated to ensure correct equipment operation.

b. Shield Termination Lengths. Shield terminations shall consist of minimum length pigtails between the shield and the connection to the bonding halo or ferrule ring and between the halo or ferrule ring and the shield pin on the connector. The unshielded length of a signal line shall not exceed 1 in. with not more than 1/2 in. of exposed length as the desired goal.

c. Shield Isolations. Shields, individually and collectively, shall be isolated from overall shields of cable bundles and from electronic equipment cases, racks, cabinets, junction boxes, conduit, cable trays, and elements of the MPG. Except for one interconnection, individual shields shall be isolated from each other. This isolation shall be maintained in junction boxes, patch panels, and distribution boxes throughout the cable run. When a signal line is interrupted such as in a junction box, the shield shall be carried through. The length of unshielded conductors shall not exceed 1 in. To meet this requirement, the length of shield pigtail longer than 1 in. shall be allowed but shall be the minimum required.

d. Circuits and Chassis. Circuits and chassis shall be designed to minimize the distance from the connector or terminal strip to the point of attachment of the shield grounding conductor to the electronic signal reference. The size of the wire used to extend the shield to the circuit reference shall be as large as possible but not less than 16 AWG or the maximum wire size that will fit the connector pin. A common shield ground wire shall not be used for input and output signals, high and low level signals, signal lines, electronic signal lines, control lines, and power conductors.

e. Extensions. Extension of shields through the connector or past the terminal strip to individual circuits or chassis is permitted if required to minimize unwanted coupling inside the electronic equipment. Where extensions of this type are necessary, overall cable or bundle shields shall be grounded in accordance with paragraph 4.8.3.3.

4.8.3.3 Cables - Termination of Overall Shields

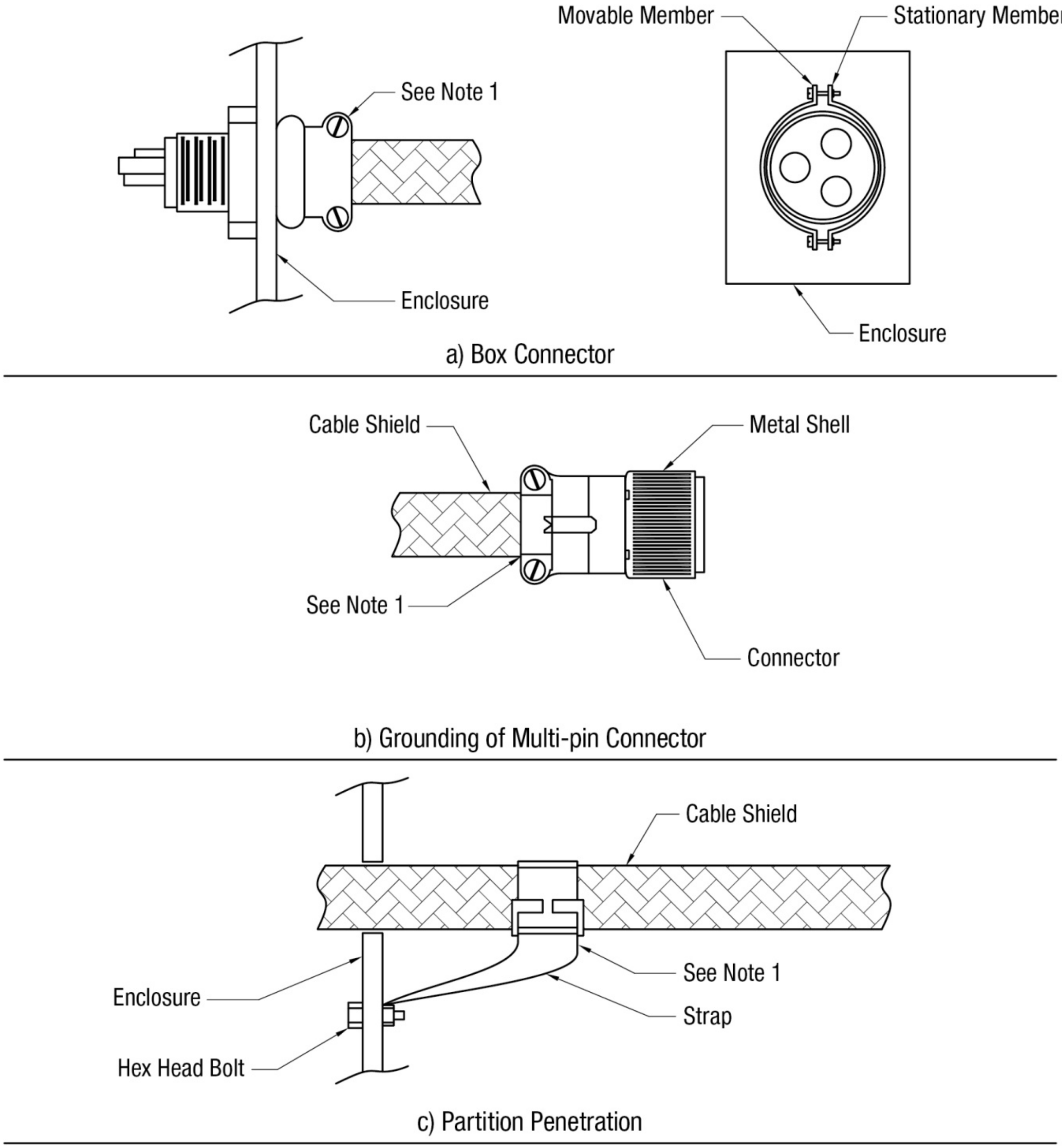
Cables that have an overall shield over individually shielded pairs shall have the overall shield grounded at each end unless otherwise required by the equipment. Grounding through an SPD is permissible if grounding both ends of the conductors degrades system performance. If present, the drain wire shall be grounded in the same manner as the shield.

a. Cable Shields. Cable shields terminated to connectors shall be bonded to the connector shell as shown in Figure 12 (a) or (b). The shield shall be carefully cleaned to remove dirt, moisture, and corrosion products. The connector securing clamp shall be tightened to ensure that a low-resistance bond to the connector shell is achieved along the entire circumference of the cable shield. The bond shall be protected against corrosion in accordance with paragraph 4.2.4.3. The panel-mounted part of the connector shall be bonded to the mounting surface in accordance with paragraph 5.6.6.2.

b. Interruption of Continuity. Where the cable shield continuity is interrupted, such as in a junction box, the shield shall be extended through and grounded at the box. The length of unshielded cable conductors shall not exceed 1 in. Where dictated by constructability constraints, shield pigtails may be longer than 1 in., but shall be as short as possible.

c. Cables Bonded to Penetrated Surfaces. Cables that penetrate walls or panels of cases or enclosures without the use of connectors shall have their shields bonded to the penetrated surface in the manner shown in Figure 12 (c). Overall shields shall be terminated at the outer surface of cases to the maximum extent possible.

d. Overall Shield Grounding. Grounding of overall shields to terminal strips shall be as shown in Figure 13.



Note:

1. Ensure that cable shield is clean and that securing clamp is tightened to provide a suitable ground.

Figure 12. Grounding of Overall Cable Shields to Connectors and Penetrating Walls

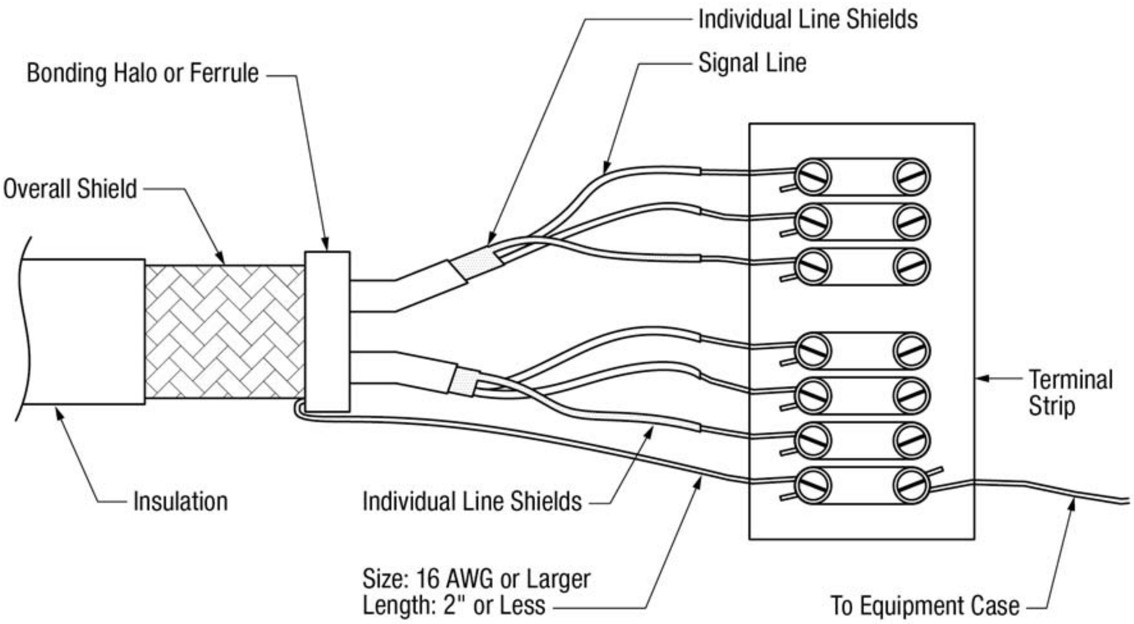


Figure 13. Grounding of Overall Cable Shield to Terminal Strip

4.8.4 Electromagnetic Environment Control

Shielding shall be integrated with other interference control measures such as filtering, wire routing, cable and circuit layout, signal processing, spectrum control, and frequency assignment to achieve the highest operational reliability of the equipment. Implementation procedures necessary to achieve the required filtering and shielding shall be detailed in the control plan described in 5.9.2 to include material requirements, shield configurations, placement and installation limitations, gasket utilization, filter integration, aperture control, bonding and grounding requirements, and wire routing and circuit layout constraints.

4.8.4.1 Space Separation

The design and layout of facilities shall physically separate electronic equipment and conductors that produce interference from other equipment and conductors that are susceptible to interference. The minimum separation distance between power and signal cables shall be in accordance with Table 6.

4.8.4.2 Wire and Cable Routing

The routing and layout of wires, conductors, and cables shall be performed in a manner that does not jeopardize the integrity of the equipment shield. Signals with power level differences of greater than 20 dB shall be routed as far apart as possible. Alternating current power conductors and control lines shall be routed away from sensitive digital or other susceptible circuits. Shielded cables shall be used where required to prevent emissions and/or to provide shielding. Cable shields shall be grounded in accordance with the requirements of paragraphs 4.8.3.2 and 4.8.3.3.

Table 6. Minimum Separation Distance between Signal and Power Conductors

Condition	Circuit Power Level		
	< 2 kVA	2-5 kVA	> 5 kVA
Unshielded power lines or electrical equipment in proximity to signal conductors in open cable tray or nonmetal raceway.	5 in.	12 in.	24 in.
Unshielded power lines or electrical equipment in proximity to signal conductors in a grounded metal raceway.	2.5 in.	6 in.	12 in.
Power lines enclosed in a metal raceway (or equivalent shielding) in proximity to signal conductors in a metal raceway.	-	3 in.	6 in.

4.8.4.3 Bonding and Grounding of Compartment Shields

All shields shall be grounded. Bonding shall be in accordance with section 4.2.

4.9 Electrostatic Discharge (ESD) Requirements

4.9.1 General

Modern electronic and electronically controlled electrical equipment are susceptible to damage from ESD. The requirements of this section are intended to reduce the frequency and minimize the effects of ESD events. Electronic circuitry that contains miniaturized or solid-state components shall be considered ESD susceptible.

4.9.2 Requirements

NAS electrical and electronic equipment, subassemblies, and components subject to damage from exposure to electrostatic fields or ESD shall be protected in accordance with section 5.8. ESD controlled areas shall be provided for operations, storage, repair, and maintenance spaces used for electrical and electronic equipment or subassemblies that are subject to damage from static electricity or ESD.

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5 DETAILED REQUIREMENTS

5.1 Introduction

This chapter describes detailed performance requirements, which are specific to FAA facility applications, organized by facility special conditions and equipment as follows:

a. Airport Traffic Control Tower (ATCT) Facilities

b. Lightning Protection System – Special Conditions

c. Facility Transient Protection – Special Conditions

d. Single Point Ground System (SPG) – Special Conditions

e. NAS Electronic Equipment – Interface and Procurement Requirements

f. Surge Protection Device (SPD) – Procurement Requirements

g. Electrostatic Discharge (ESD) Equipment – Interface and Specification Requirements

h. Electromagnetic Compatibility Requirements

5.2 Airport Traffic Control Tower (ATCT) Facilities

Figure 14 depicts the elemental relationship of areas located at the top of a typical ATCT. Operation of NAS electronic equipment areas located in the cab, junction, and subjunction levels present a unique set of challenges for implementation of lightning and transient protection. NAS electronic equipment areas are spaces where the equipment is physically located or associated passageways that distribute utilities within the tower. Power and telecommunication distribution systems (NAS supporting utilities) either originate from the base of the tower or an attached base building.

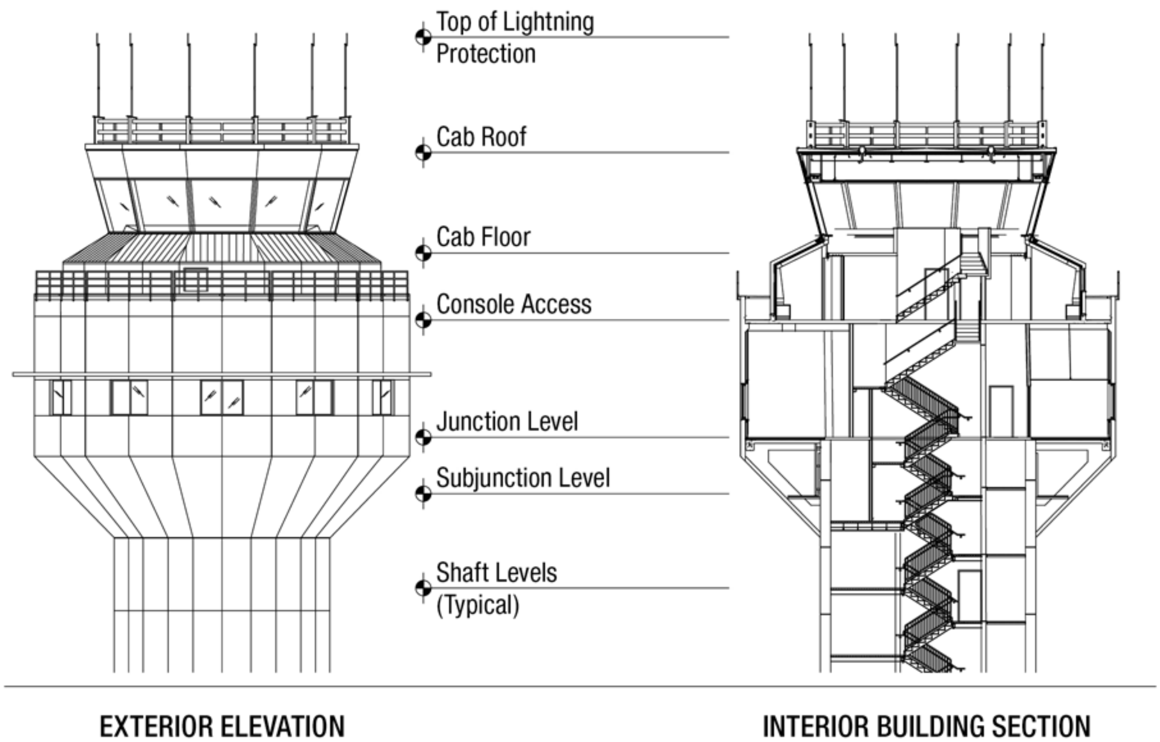


Figure 14. Airport Traffic Control Tower – Typical Floor Levels

5.2.1 General

During lightning strikes, there is a potential difference between the reference voltage at the top of the tower and the base of the tower. It is therefore necessary to reference all systems at the top of the tower to each other and treat this area as a separate facility. The NAS electronic equipment and associated supporting utility distribution system are subject to large electromagnetic fields during a lightning strike. For this reason, special techniques are required to provide an environment that minimizes the damaging effects of lightning. ATCT systems requiring special consideration include:

a. Lightning and Transient Protection

b. Main Ground Connections

c. Power Distribution System

d. NAS Electronic Equipment Areas

5.2.2 Lightning Protection System

Provide lightning protection in accordance with section 4.3, and this section.

5.2.2.1 Common Bonding of Grounded Systems

The lightning protection, electrical, electromechanical, electronic systems, and building structural steel shall be bonded together for safety.

5.2.2.2 Potential Equalization Loop

Provide a continuous potential equalization loop conductor at the following locations:

a. Roof or Roof Parapet. Install a loop conductor within 24 in. of the periphery of the structure. Interconnect air terminals and down conductors to the equalization loop. Any secondary roof area or parts of the structure that extends beyond the upper most roof zone of protection scheme shall be provided with additional air terminals in accordance with NFPA 780.

b. Exterior Platforms, Catwalks, and Personnel Access Areas. Provide a potential equalization loop for platforms that extend beyond the ATCT building perimeter. Interconnect down conductors to the equalization loop.

c. Tower Shaft Intermediate Floor Levels. Install a loop conductor at tower intermediate levels, evenly spaced no more than 60 ft apart, measured from the roof equalization loop. Interconnect down conductors to the equalization loop.

5.2.2.2.1 Horizontal (Side Strike Protection) Air Terminals for Equalization Loop

Provide horizontal air terminals on equalization loops, in addition to the zone of protection scheme, for exterior platforms and catwalks located at the cab, cab roof, or occupied areas along the ATCT shaft. Install the horizontal air terminals positioned at building corners and along the periphery of the loop where required by the lightning protection zone of protection scheme.

Exception. *Horizontal (side strike) air terminals are not required for equalization loops located at intermediate floor levels of the tower shaft within the zone of protection scheme where there are no platforms for personnel access, or electronic or electromechanical equipment.*

5.2.2.2.2 Connection of Down Conductor to Equalization Loop

The connection method between the down and equalization loop conductors shall be in accordance with paragraph 4.3.5.

5.2.2.3 Number of External Down Conductors for ATCT

MIL-HDBK-419A, Volume II, paragraph 1.3.2.2.2(d), provides that "buildings and structures shall add one down conductor for every 60 ft of height or fraction thereof, but horizontal spacing between down conductors need not be less than 50 ft."

The number of down conductors shall be based on both the ATCT height and its largest horizontal perimeter dimensions. For the purposes of this document, the above referenced 50-ft dimension is the horizontal distance between down conductors along the largest projected perimeter area. The following guidelines shall be used in determining the number and configuration of external down conductors:

a. External Down Conductors for ATCTs. All ATCTs shall have a minimum of four down conductors. ATCTs greater than or equal to 180 ft above ground level to cab roof shall add one down conductor for every 60 ft of height or fraction thereof above 180 ft. For ATCTs greater than or equal to 180 ft, the number of down conductors may be substituted, but not less than four, by using larger sized individual conductors to achieve equivalent overall conductor cross-sectional area.

   Exception. *Existing ATCTs are exempt from the minimum number of external down conductor requirement, if less than 60 ft above ground level to the cab roof and the horizontal perimeter dimension spacing between down conductors is less than 50 ft. However, when removal of the down conductors is performed as part of a major project, such as when replacing siding of an ATCT, reinstallation shall incorporate the minimum number of down conductors as stated in this paragraph.*

b. Building Structural Steel. Building structural steel is permitted as a substitute for only one down conductor for lightning protection. Concrete encased structural reinforcing bars or precast construction systems are not qualified for use as building structural steel. It is permissible to substitute substantial metal structural elements of buildings for regular lightning conductors where, inherently or by suitable electrical bonding, they are electrically continuous from the air terminal to the earth electrode connection. The structural elements shall have a conducting cross-sectional area, including at the structural connections, at least twice that of the lightning conductor that would otherwise be used. Lightning conductors may be installed on the interior or exterior to the building enclosure. Steel frame buildings enclosed in architectural precast concrete or masonry products shall have external air terminals and roof conductors installed and bonded directly to the structural members to keep the lightning discharge from having to penetrate the masonry shell to reach the frame members. Refer to MIL-HDBK-419A, Volume II, paragraph 1.3.2.2.2(i).

5.2.2.4 Transient Surge Protection
Provide SPDs in accordance with section 4.6 for NAS facility entrance points located at the base building/tower shaft and at the top of the shaft.

5.2.3 Main Ground Connections
A low-impedance connection shall be provided to the EES to ensure good high-frequency grounding during normal operation. Ground connections shall be established in the ATCT as a common point of connection within the facility. Provide ground plates in accordance with paragraph 4.7.2 and as specified herein.

5.2.3.1 ATCT MPG Configuration – Preferred Method
Refer to Figure 15 for MPG configuration topology and connection requirements. A main ground plate shall be established on the lowest level with electrical, electromechanical, or electronic equipment serving the ATCT cab. Grounding systems located at or above this level of the ATCT shall be connected to this main ground plate. Provide a combination of conductors, in accordance

with Table 7, and two parallel paths as indicated in Figure 15. Install each conductor path within separate chases located in the tower shaft. Conductors shall be routed continuously between ground plates without sharp bends, loops, or kinks.

Recombine risers to an MPG plate at each maintenance level of the ATCT shaft. These conductors shall be mechanically bonded to the main ground plate and the base plate. Connect base plate(s) exothermically to the EES with the same number and size of conductors used for the riser conductors in accordance with Table 7.

5.2.3.2 ATCT MPG Configuration - Alternative Method

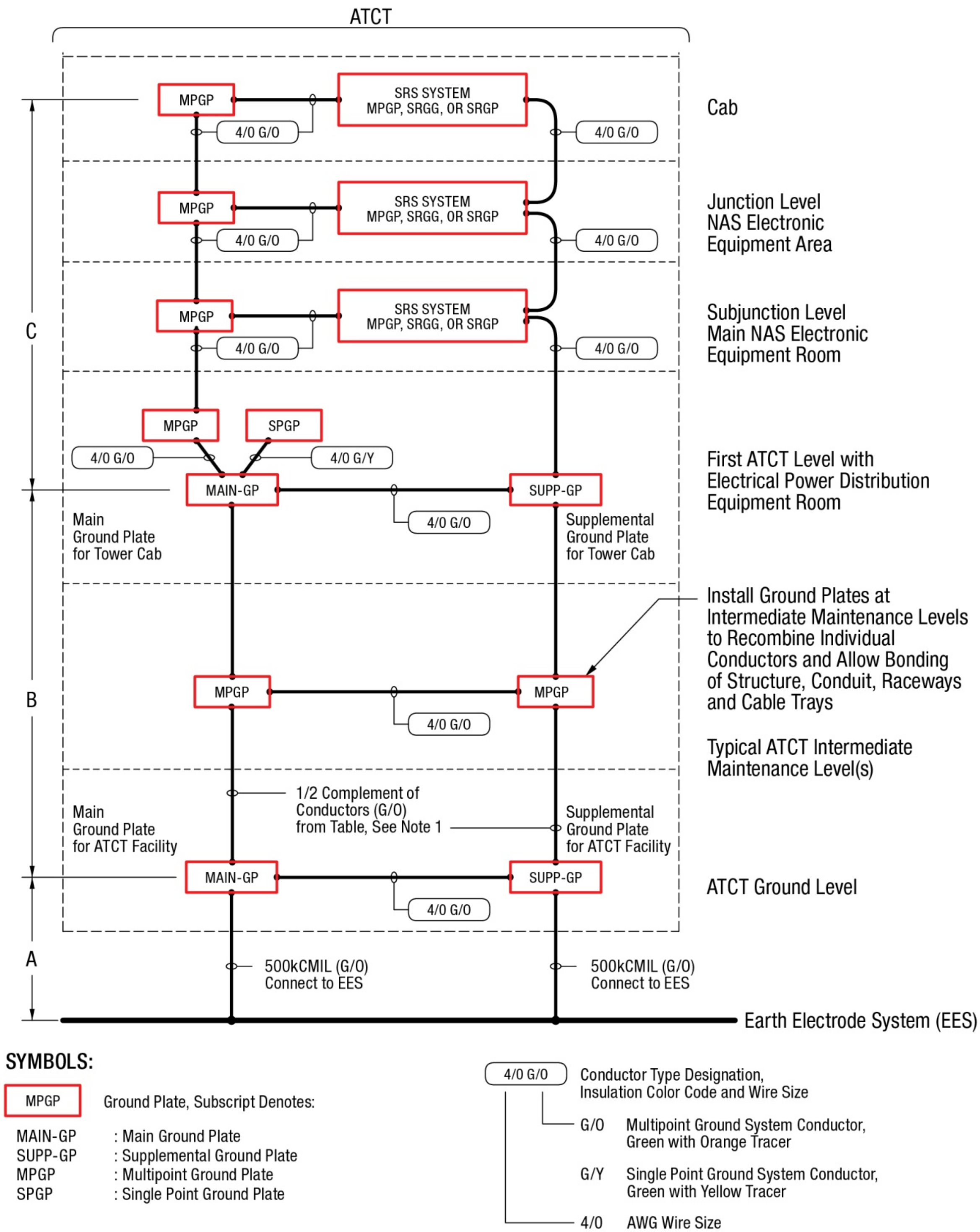
Refer to Figure 16 for MPG configuration topology and connection requirements. A main ground plate shall be established on the lowest level with electrical, electromechanical, or electronic equipment serving the ATCT cab. Grounding systems located at or above this level of the ATCT shall be connected to this main ground plate. Provide a combination of conductors, in accordance with Table 7, and connect this main ground plate to a plate at the base of the ATCT. These conductors shall be routed continuously from the main ground plate to the base plate without sharp bends, loops, or kinks.

Table 7. ATCT MPG Configuration – Parallel Conductor Complements

Electrical Distance from EES to Farthest MPG Plate Measured in Feet, See Note 1	Two (2) Conductor (kcmil)	Three (3) Conductor (kcmil)	Four (4) Conductor (kcmil)	Five (5) Conductor (kcmil)	Six (6) Conductor (kcmil)	Number of 4/0 (AWG)
Up to 250	500	350	250	4/0	-	5
251 to 300	600	400	300	250	4/0	6
301 to 350	700	500	350	300	250	7
351 to 400	800	600	400	350	300	8
401 to 450	900	600	500	400	300	9

Note:

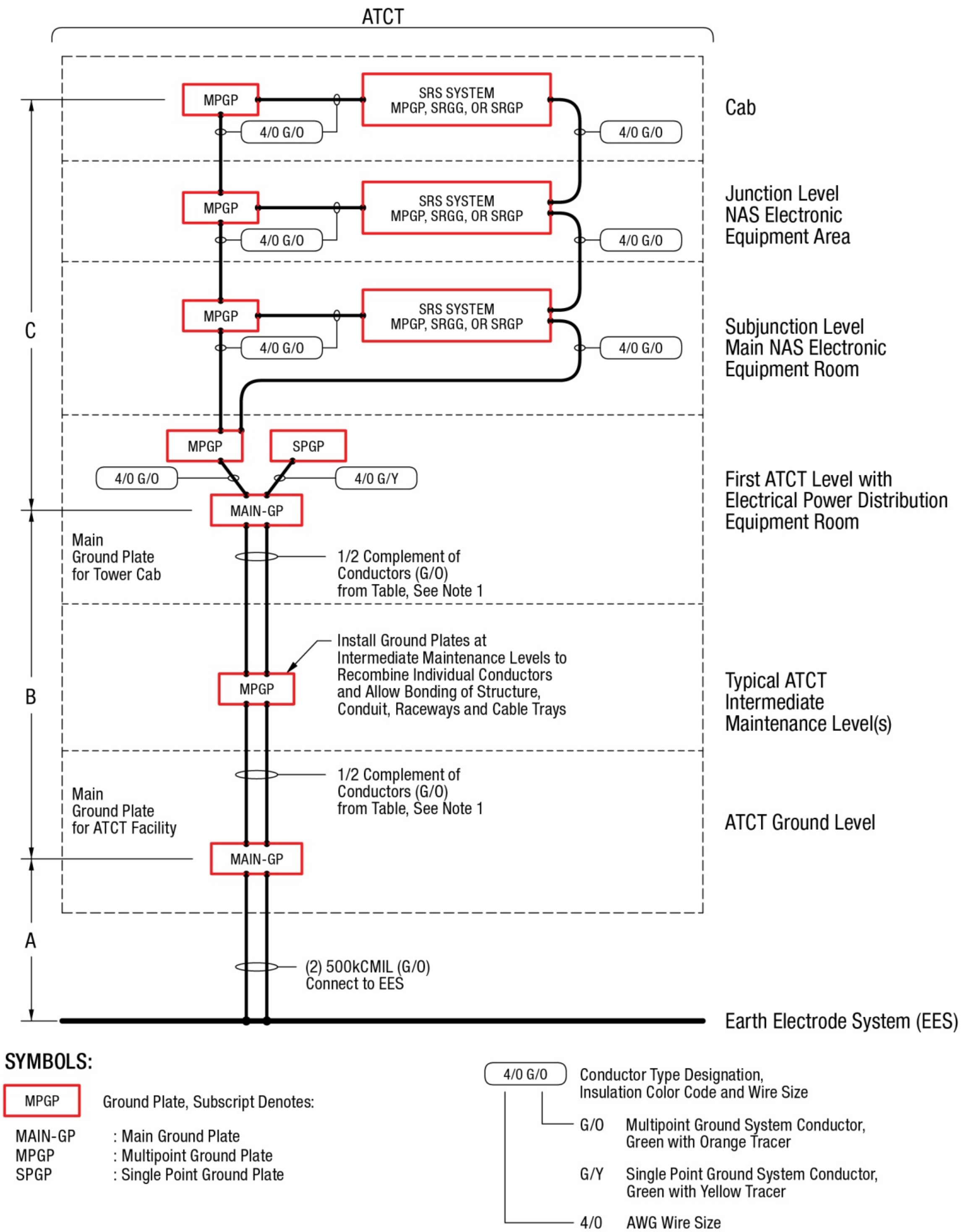
1. Refer to Figure 15 and Figure 16 for conceptual MPG configurations.



Note:

1. Total height calculation (A+B+C) shall be used to determine cable size parameter indicated in Table 7.

Figure 15. Typical Electronic Equipment Grounding Riser Diagram for ATCT (Preferred Method)



Note:

1. Total height calculation (A+B+C) shall be used to determine cable size parameter indicated in Table 7.

Figure 16. Typical Electronic Equipment Grounding Riser Diagram for ATCT (Alternative Method)

5.2.4 Power Distribution System

Provide power distribution for ATCT in accordance with section 4.5 and as specified herein.

a. NAS Electronic Equipment Power Loads. Provide separately derived power sources for NAS electronic equipment loads when the ATCT height is greater than 100 ft measured to the cab floor level.

b. Separately Derived Power Systems. The separately derived systems shall be grounded in accordance with the requirements of NEC article 250 and paragraph 4.5.2d at the first downstream disconnecting means or overcurrent device. This point of connection is mandated to facilitate the effective installation of an SPD.

c. Surge Protection. Provide SPDs, in accordance with paragraph 4.6.2. The SPD shall be installed on the load side of the first downstream disconnecting means or overcurrent device of each separately derived system. The ground bus at the first disconnecting means or overcurrent device shall be bonded to the main ground plate established in accordance with the requirements of paragraph 5.2.3. This connection is in addition to the grounding electrode conductor requirements of NEC article 250.

d. Bonding of Metallic Piping Systems. The interior metallic piping supply systems located at the top and bottom of the ATCT mechanical piping chase, such as water, plumbing, and mechanical piping systems, shall be bonded to the main ground plates established in accordance with the requirements paragraph 5.2.3. If interior metallic piping systems are not located near the main ground plate, bond interior piping to the nearest MPGP. This connection is in addition to the bonding requirements of NEC article 250.

5.2.5 NAS Electronic Equipment Areas

Provide grounding and bonding for NAS electronic equipment in accordance with section 4.7 and paragraph 5.2.3 and as specified herein.

5.2.5.1 ATCT Building Structural Steel Bonding Requirements

Structural steel columns and beams of the ATCT shall be bonded together and to the EES in accordance with paragraph 4.5.6 and as specified herein.

The design of the ATCT shaft shall make provisions to ensure that all concrete reinforcing steel used throughout the shaft is electrically bonded together, continuously, horizontally and vertically, and to the EES.

Horizontal metal transitions, such as floors, stairs, and walkways shall be bonded to the ATCT structural steel members or concrete reinforcing steel bars at every level. Elevator support structures shall be bonded to horizontal metal transitions and to the EES. All bonding jumpers shall be a minimum 2 AWG copper conductor.

5.2.5.2 Signal, Communications, Axial Cables, and Control Line Protection

Transient protection shall be applied at each end of vertical cables routed between the equipment room located near the top of the ATCT and the associated base building. Cables between the tower cab and equipment room areas shall be protected in accordance with paragraph 4.6.3. Both facility and equipment levels of protection shall be provided for these lines. Enclosing metallic cabling in ferrous conduit or the use of all dielectric fiber optic cable can significantly reduce the threat of lightning related damage to ATCT and base building circuits.

5.2.5.3 Signal Reference Structure

An SRS shall be constructed in accordance with applicable requirements of paragraph 4.7.3, including the cab and other areas at the top of the ATCT that contain electrical, electromechanical, or electronic equipment serving the cab.

a. SRGG Installation. The main and supplemental ground plates and building steel may be used to establish equipotential bonding for the SRGG perimeter loop conductor in lieu of the EES for facilities located at the top of the ATCT. Provide one connection between the perimeter loop conductor to the main and supplement ground plates. Provide at least two additional connections between the perimeter loop conductor and building steel.

5.2.5.4 Floor Coverings for Electronic Equipment and Operational Areas

Floor coverings for cab and areas serving the cab shall either be tile or carpeting and shall be composed of static dissipative material. The floor coverings and installation shall be per the manufacturers' specifications and paragraph 5.8.9 and shall be connected to a component of the SRS, but not to the SPG system.

5.2.5.5 Single Point Grounding

SPGs, if required, shall be constructed in accordance with section 5.5. SPGs and independent ground systems required by equipment manufacturers shall be bonded to the ATCT main ground plate, located at the top of the tower, in accordance with the requirements of paragraph 5.2.3. The SPG shall be constructed in a radial configuration and not form a loop.

5.3 Lightning Protection System – Special Conditions

5.3.1 General

This section describes facilities or systems that require additional design considerations for installation of lightning protection systems. The following applications are addressed:

a. Antenna Towers

b. Antenna Protection

c. Tower Guying

d. Waveguide, Axial Cable, and Conduit Grounding

e. Staircase/Ladder Protection

f. Facilities without Buildings or Antennas

g. Lightning Protection for Fences and Gates

h. Lightning Protection for Photovoltaic Solar Arrays

5.3.2 Antenna Towers

5.3.2.1 Number of Down Conductors for Towers

Towers consisting of multiple, parallel segments or legs that are erected on a single pad or footing not over 9 ft^2 in area are considered pole type towers. Other towers shall have at least two down conductors. Large towers, such as radar towers, shall have one down conductor per leg. Down conductors on towers shall be bonded to each tower section. Down conductors shall be routed down the outside of the legs wherever possible and secured at intervals not exceeding 3 ft.

5.3.2.2 Pole Type Towers

Pole type towers shall be protected by at least one air terminal and have at least one down conductor. This is to provide a zone of protection for antennas located on the tower.

5.3.2.3 Towers without Radomes

Protection shall be provided for large radar antennas by extending structural members above the antenna and mounting the air terminal on top as shown in Figure 17 unless directed otherwise by the radar system OPR. Structural members shall be braced as necessary and shall not be used as part of the air terminal or down conductor. The air terminal shall be supported from structural framing and shall have a UL listed fitting on its base. The down conductor from the air terminal shall be connected to a perimeter conductor that forms a loop around the perimeter of the tower platform. Down conductors shall extend from the perimeter conductor to the EES. Each air terminal shall be provided with at least two paths to the ground. Conductors shall be in accordance with NFPA 780. Tower legs shall be bonded to the EES with a 4/0 AWG copper conductor exothermically welded at each end. This bonding conductor shall be either a separate conductor, or permitted to be a part of the down conductor, as described in paragraph 4.3.5.1.

5.3.2.4 Radomes

Radomes shall be located within a zone of protection established according to the 100-ft radius "rolling sphere model" described in NFPA 780. This protection is provided by air terminals mounted on the radome, or by air terminals or catenary wires mounted independently of the radome. Air terminals mounted on the radome must have two paths to the EES. A perimeter conductor shall be provided at the radar antenna deck level.

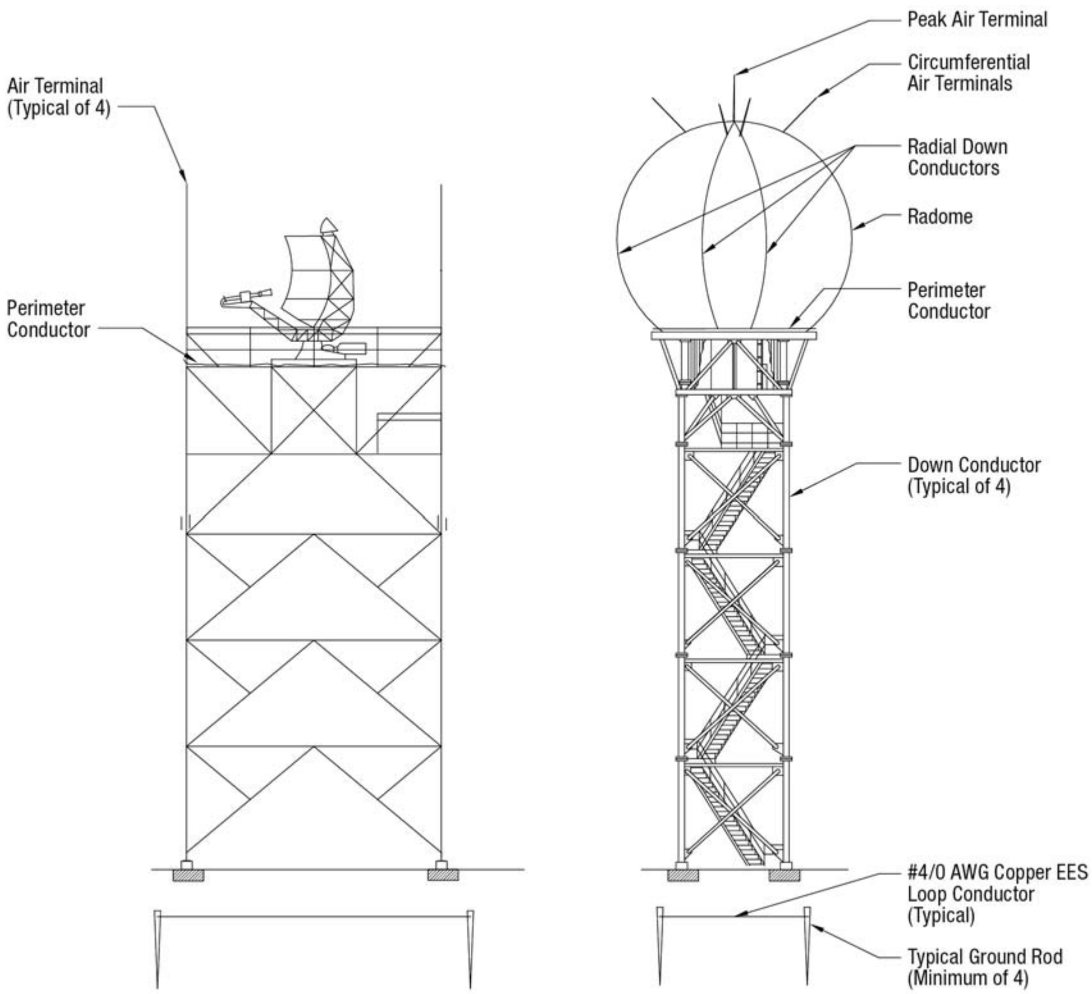
Lightning protection systems for standalone radomes shall be designed and installed in consultation with the OPR of the radar system and the OPR of this document. Paragraph 5.3.2.5 shall be used as guidance in developing lightning protection systems for these radomes.

5.3.2.5 Towers with Radomes

Lightning protection systems for towers with radomes shall be designed and installed in consultation with the OPR of the radar system and the OPR of this document.

Towers with radomes shall be protected with a minimum of one 2-ft-long air terminal at the peak and four or more air terminals equally spaced along the circumference of the radome and oriented perpendicular to the radome. The spacing and quantity of circumferential air terminals shall be adjusted if the antenna pattern is affected, but their sizing, position, and height shall establish a protection zone as specified in paragraph 5.3.2.4. Circumferential air terminals shall be interconnected with main-sized conductors.

Radial down conductors, as indicated in Figure 17, shall be connected to the air terminal on the peak. The radial down conductors shall also be connected to the perimeter conductor that forms a loop around the base of the radome. Radial down conductors on the radome shall be routed from the air terminal at the peak of the radome, in a path following the contour of the radome, to a connection with the circumferential air terminals and then to a connection with the perimeter conductor as shown in Figure 17. Deviations from the shortest possible path are permitted where nearfield radar analyses determine that interference from the conductors will degrade the performance of the radar. Bends in the radial down conductors on the radome shall maintain the largest possible radii and in no case shall be less than 12 in. One down conductor per leg shall connect the perimeter conductor at the base of the radome to the EES. Down conductors shall be bonded to each leg section. Tower legs shall be bonded to the EES with a 4/0 AWG copper conductor exothermically welded at each end. This bonding conductor can be the same conductor required in paragraph 4.3.5.1.



Notes:

1. Bond down conductors to each tower leg section. Exothermically weld down conductor to a 4/0 AWG copper conductor above grade. Route 4/0 AWG conductor though a 1-in. PVC conduit around the foundation concrete pier to 12 in. below grade and connect the conductor to the EES.
2. Where a radome has an electrically continuous frame, the framing may be used in lieu of the lower air terminals.
3. All lightning protection connections shall be free of paint and galvanizing. Scrape all steel free of surface contaminants prior to making exothermic welds or mechanical connections.

Figure 17. Lightning Protection for Radomes and Radar Antenna Platforms

5.3.3 Antenna Protection

Air terminals shall be located to protect structural towers and buildings, and antennas mounted to towers and on buildings.

Most antennas throughout the FAA can be installed or engineered to be installed within the lightning zone of protection. However, there are select times where engineered solutions cannot be easily installed. Antennas may be deemed sacrificial if either of the following conditions exist:

a. A 20 foot air terminal (or air terminal installed on a support with the combined height of 20 feet) does not provide proper zone of protection; or

b. Lightning protection for an antenna will cause radiation pattern distortion.

Sacrificial antennas shall comply with the following:

a. Bonding and surge protection in accordance with 4.6.3, 5.3.5, and 5.4.3.2; and

b. The antenna or base is bonded to the lightning protection system.

All sacrificial antennas must be identified by the designer/program office to the SSC (e.g. ASSC). An SRM is one established method that is permitted to meet this requirement.

5.3.4 Tower Guying

Provide grounding and bonding for tower guying in accordance with TIA-222.

5.3.5 Waveguide, Axial Cable, and Conduit Grounding

Waveguide, axial cable, and conduit located on the tower and feeding into the facility shall be bonded to a bulkhead ground plate mounted on the tower and configured in accordance with 5.4.3.2.

a. <u>Overhead Cable Runs</u>. Bulkhead plate bonding connections shall be located above the cable path at transition/turning point (90 degree bend point) near the tower's base where the cable transitions horizontally from the tower and enters the facility. Above-ground ferrous conduit located at the facility entrance shall be bonded in accordance with 5.4.3.1.1.

b. <u>Underground Cable Runs</u>. Bulkhead plate bonding connections shall be located above the cable transition point where the cables enter the facility conduit riser. If cables enter ferrous conduit, the conduit shall be bonded to the EES in accordance with 5.4.3.1.

5.3.6 Staircase and Ladder Protection

The metallic staircase or ladder access to the tower shall be exothermically bonded near its base to the EES with a 4/0 AWG copper conductor installed in a location that avoids accidental tripping or striking hazards that could result in personnel injury. Where the staircase or ladder material is not thick enough for an exothermic weld, provide a two-hole hydraulically crimped connection. To ensure electrical continuity, sections of stairs or platforms that are not welded together shall be connected by bonding jumpers.

5.3.7 Lightning Protection for Facilities without Buildings or Antennas

Small facilities such as Runway Visual Ranges (RVR) commonly are built without buildings or antennas. Since loss of these facilities can have a significant impact on NAS operations, these facilities shall be included within a zone of protection with either air terminals or overhead catenary wires.

5.3.8 Lightning Protection for Fences and Gates

General airport fencing is not subject to the requirements of this standard. Non-FAA owned fencing that is adjacent to FAA facilities shall be protected as mandated by agreement with the owner of the fencing.

Fences shall be constructed using electrically conducting materials (for example, chain link fabric, metal crossbar, stranded wire, etc) using metal posts that extend a minimum of 2 ft below grade into a concrete base. Metallic fence fabric with nonconductive coatings is not permitted, except where corrosive climatic conditions require corrosion protection.

5.3.8.1 Fence Grounding

Provide fence grounding in accordance with the following:

a. Fence Post Grounding. Provide a ground rod adjacent to the fence post. Locate ground rods at horizontal linear spacing intervals not greater than 100 ft along the perimeter fence line. Provide a 4/0 AWG bare stranded copper conductor, exothermically welded to each ground rod and fence post.

b. Ground Rod Installation. Ground rod material and installation parameters shall be in accordance with paragraph 4.4.4.1. If soil conditions will not permit installation of ground rods, provide ground dissipation plate(s) in accordance with paragraph 4.4.4.3.

c. Fence Gate. Provide a 1-in. by 1/8-in. flexible tinned copper bond strap or an insulated 4/0 AWG flexible welding type copper conductor connected between the gate and adjacent fence post. Exothermic welding is recommended for these connections. Install the bonding strap between the gate and post so it will not limit full motion of a swing or slide gate.

d. Fence Gate Post. Provide a ground rod adjacent to each gate post. Install a 4/0 AWG bare stranded copper conductor, exothermically welded to the ground rod and gate post. Locate the post connection at not greater than 1-ft above grade. Interconnect ground rods located between the gate opening with an exothermically welded 4/0 AWG bare copper conductor buried below frost depth, but not less than 18-in. below ground.

e. Fence Gate Fabric. Provide a horizontal 6 AWG bare stranded tinned copper conductor threaded continuously through the gate fabric and mechanically bonded to the gate vertical support rails.

f. Fence Security - Barbed Razor Wire. Bond security wires to the fence post using 6 AWG bare stranded tinned copper conductor and UL listed bonding connectors. Bond across terminations in the security wire using a short piece of the security wire material and UL listed bonding connectors at the same locations in 5.3.8.1 (a), (c), and (d).

g. Fence Wire Fabric - Chain Link. Attach metallic fence fabric to fence posts with wire ties of the same material.

h. Proximity to a Facility EES. Portions of a fence that are located within 22 ft of a facility EES shall be bonded to that EES with a 4/0 AWG bare copper conductor exothermically welded to a fence post ground rod. Connections shall be made at a maximum spacing of 100 ft, with a minimum of two connections.

See Figure 18 for illustration of fence grounding installation methods.

5.3.8.1.1 Architectural Style Fences

Where architectural fences are installed, bond the nearest post with a two-hole hydraulically crimped lug to the ground rod. The security barbed razor wire bonding requirement does not apply to architectural fences.

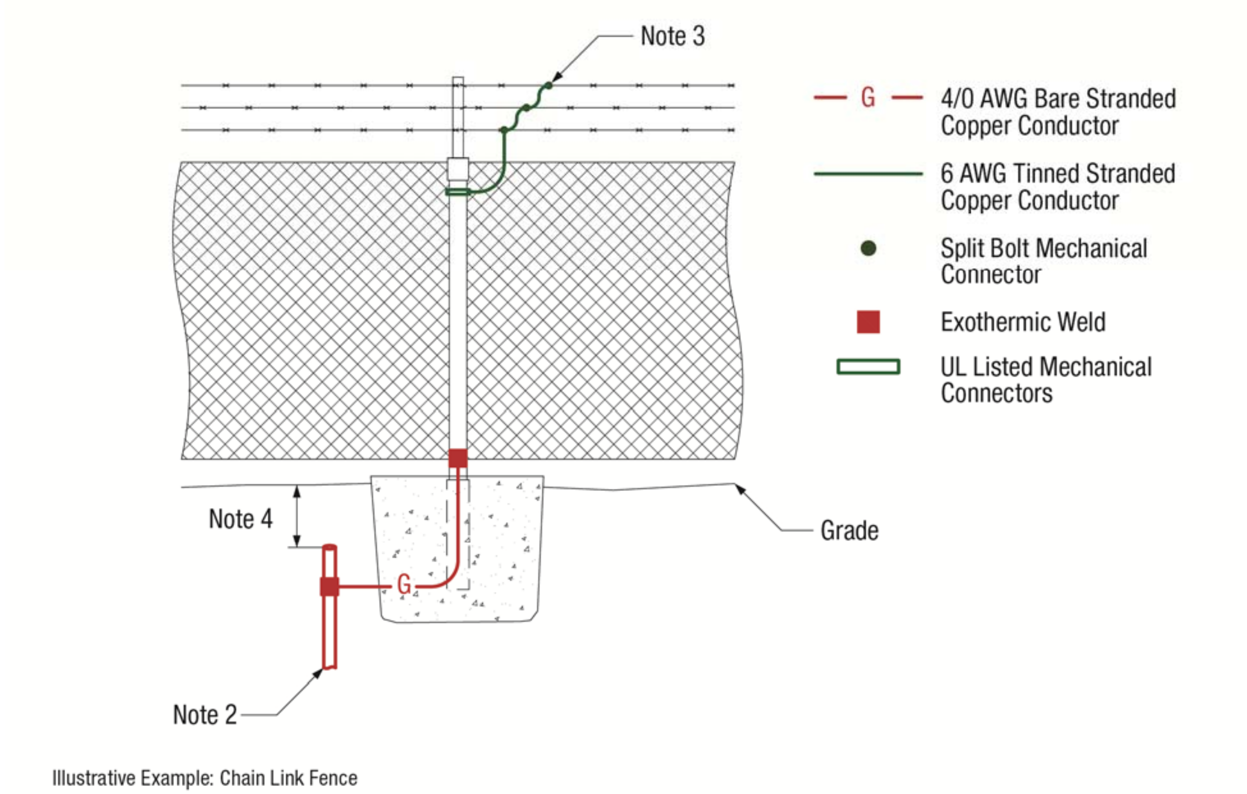
5.3.8.2 Fences Crossed by Overhead Power Lines

At locations where overhead power lines cross a fence, bond a fence post no more than 20 ft on each side of the crossing to a ground rod with a bare 4/0 AWG copper conductor. Bond the fence fabric at the top, middle, and bottom of the fence, and bond each strand of security wire placed above the fencing fabric to the grounded post with a bare 6 AWG tinned copper conductor. Where cross-bars or stranded wire is used to support the fence posts, bond the cross-bars or wire supports to the posts.

These connections shall be located 20 ft on side of the overhead power line crossing.

5.3.9 Lightning Protection for Photovoltaic Solar Arrays

Lightning protection for photovoltaic solar arrays shall be provided in accordance with NFPA-780.



Notes:

1. Diagram depicts elemental parts of a typical fencing grounding and bonding installation. Other architectural style fence configurations are possible.
2. Install 10 ft long by 3/4 in. diameter copper clad ground rods at all corners, gate posts, and at intervals not to exceed 100 feet. Exothermically weld each ground rod to the post.
3. Mechnically bond each strand of security wire to the fence post at all corners, gate posts, and at intervals not to exceed 100 feet.
4. 12 in. minimum below grade, but not less than frost depth.

Figure 18. Fence Grounding

5.4 Facility Transient Protection – Special Conditions

5.4.1 General

This section describes additional design considerations for facility transient protection against induced currents from nearby, direct, or indirect lightning strikes. All metallic conduits, conductors, and cables in NAS operational facilities can be subject to currents induced by nearby lightning strikes. These induced effects can adversely affect the operation of sensitive electronic equipment.

5.4.2 Existing Metallic Conduit, Conductors, and Cables

Unless not approved by the facility manager, all unused conduits, conductors, and cables shall be removed.

For any remaining unused items, the voltage differential between ends shall be minimized by the following bonding methods:

a. Unused Metallic Conduits. Metallic conduits shall be bonded to adjacent grounded metalwork at both ends. If not directly bonded, the connection shall use a minimum 6 AWG jumper not longer than 18 in.

b. Unused Conductors and Cables. These conductors and cables shall be bonded to adjacent grounded metalwork at both ends. Multiple unused conductors shall be grouped together and bonded to the adjacent metalwork, directly or with a bonding jumper.

   Exception. *Bonding is not required for unused conductors of a structured cable system and vertical risers installed for spare purposes for the following conditions:*

   1. *Vertical cable risers are located no more than 50 ft from grounded metalwork.*
   2. *Cable circuit length totals are not more than 300 ft and do not pass between facilities.*
   3. *Cable circulating currents are present; installation of a SPD at one end of the cable may be used for this condition.*

c. Cables With Shields. Unused shielded cables shall be bonded to adjacent grounded metalwork at both ends.

5.4.3 Electromagnetic Shielding for Lines, Conductors, and Cables

5.4.3.1 Facility Entrance Conduit

Direct routed conductors and cables, both buried or above ground, shall enter the facility through a minimum of 10-ft ferrous RGS conduit at the exterior face of the building. For above-ground conditions, provide a minimum 10-ft ferrous RGS conduit on the exterior face of the facility at the entrance point. Entrance conduits shall be bonded to the EES with a bare copper stranded conductor, 2 AWG minimum. This entrance conduit, if buried, shall extend a minimum of 5 ft beyond the EES. Entrance conduits can be bonded below or above grade.

<u>Exception</u>. *Power feeders maintained by and installed to the requirements of the electric utility provider are exempt from the facility entrance RGS requirement.*

5.4.3.1.1 Above-Ground Conduit Entrance to Facility

At the conduit entrance point, a bonding connection shall be made either to the EES or to a bulkhead connector plate that is bonded to the EES in accordance with paragraph 5.4.3.2. If neither of these bonds is feasible, the bond shall be made to the main or supplemental multipoint ground plate. Provide a minimum 2 AWG stranded copper conductor using exothermic welds or UL-listed pressure connectors for this connection.

5.4.3.1.2 Conduit Joints and Fittings

Conduit joints and fittings shall be electrically continuous with bonding resistance of 5 mΩ or less between joined parts. Conduit enclosing signal, control, status, power, or other conductors to electronic equipment shall be terminated using conductive fittings to their respective junction boxes, equipment cabinets, enclosures, or other grounded metal structures.

5.4.3.2 Metal Bulkhead Connector Plates

A metal bulkhead connector plate shall be provided where overhead axial-type cables and waveguides enter the facility. The bulkhead connector plate shall be mounted on the outside surface of the facility or inside the facility within 2 ft of an exterior wall.

a. <u>Bulkhead Plate Dimensions</u>. Ground plates shall be 1/4-in. thick copper or aluminum, and shall have the required number and type of feed-through connectors for axial cable terminations. Plates shall have adequate surface area for bonding all components, such as waveguides, cable shields, and conduits, plus at least two spare positions.

b. <u>Bulkhead Plate Connections</u>. Provide either hydraulically crimped two-bolt-hole style terminal lugs or exothermic welds for conductor connections to the ground plate. Bonding jumpers shall be as short as possible.

c. <u>Cable Shields</u>. Cable shields shall be bonded and grounded, except where the shield must be isolated for proper equipment operation. If external and internal cables are of different sizes, the changeover in cable size is permitted by feed-through connectors at the plate.

Bulkhead plates shall be bonded to the EES with a minimum 4/0 AWG copper cable, color-coded green with a red tracer. When the bulkhead connector plate is located within 6 ft of the building steel, the bulkhead plate shall be connected to the building steel with a 4/0 AWG insulated copper conductor, color-coded green with a red tracer. The building structural steel shall be bonded to the EES using exothermic welds.

Axial type cables, waveguides, and conduits that are not directly bonded to the EES shall be bonded to bulkhead plates with a minimum 6 AWG bonding jumper. The waveguide bonding cable can be connected to the bulkhead waveguide flange with a ring terminal specifically sized for the application. Conduits shall be bonded with a UL-listed U-bolt bonding connector. Axial cable shields shall be bonded with bonding kits sized for the specific cable type. Where SPDs are installed for axial cables, they shall be installed on the antenna or surge side of the metal bulkhead plate. The SPD ground bus bar shall not be connected to the lightning protection system.

Where a bulkhead plate is installed on top of an ATCT, then the ground conductor can be bonded to building steel as opposed to the EES. Reinforcing bars shall not be used in lieu of building steel.

Where a bulkhead plate is installed on top of a building or base building and the path is longer than a tenth of the difference between building steel and the EES (i.e. building steel is 5 feet away and the EES is more than 50 feet away), then the ground conductor can be bonded to building steel. Reinforcing bars shall not be used in lieu of building steel.

5.4.3.3 Facility External - Buried Power Cables and Conductors

Buried external power cables and conductors shall have magnetic shielding to prevent damage from coupling of transient currents due to lightning or other electrical sources. This shielding shall be provided by a ferrous metal sheath, ferrous armor, or ferrous RGS conduit.

Cables are permitted to be installed in metallic or nonmetallic conduit where permitted by the NEC. When a conduit is not used for installation of buried cables, the cables shall be identified for direct earth burial (DEB).

Ferrous shielding is recommended for portions of buried power cables and conductors located beyond 300 ft cable length from the facility entrance point. Facility entrance surge protection shall be in accordance with paragraph 4.6.2.1.

5.4.3.3.1 Armored DEB Cables

Steel armor is the preferred assembly for Armored DEB cables. DEB cable armor shall be bonded to the EES with a 2 AWG conductor prior to entry into a facility or where transitioning to conduit.

DEB cable armor shall also be bonded to the main or supplemental ground plate. If bonding to the main or supplemental multipoint ground plates is not feasible, the armor shall be bonded to the electrical ground bus located at the SDM.

If armor is continued to the electronic equipment, bond the cable armor to the equipment MPG plate.

When the electronic equipment is required to be isolated, bond the cable armor to the equipment SPG plate in accordance with section 5.5.

For initial cable installations, bond resistance shall be less than 5mΩ between joined parts. Complete cable replacement is not required if only a short length of the installation does not meet this requirement.

5.4.3.3.2 Guard Wires

A 1/0 AWG bare copper stranded guard wire shall be provided for buried cables and conductors not routed in ferrous conduit, except as noted below.

Exception. *Guard wires are not required for penetration under runways, taxiways, or topographical features or for 15 kV concentric neutral power cables constructed in accordance with FAA-C-1391d, paragraphs 5.5.7 and 5.5.8. This exception does not apply to concrete-encased PVC duct bank with communication, data, or control cables or to spare ducts that do not contain a corrugated innerduct reserved exclusively for fiber optic cables.*

The guard wire shall be configured as follows:

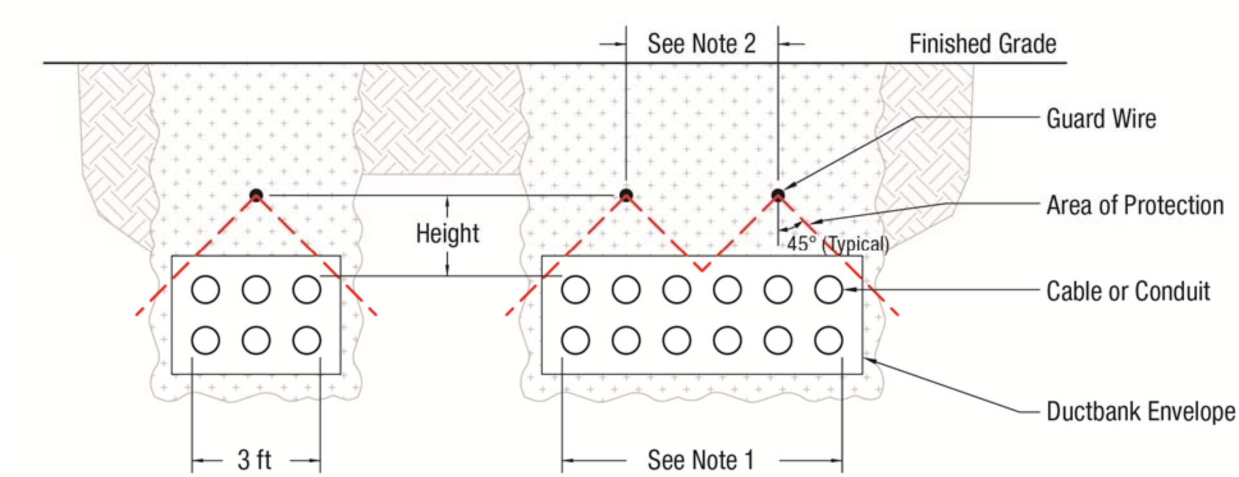
a. Location. The guard wire should be located at least 8 in. below the finished grade, at minimum height of 10 in. above the cable or cable ductbank, and shall run parallel to the cable or cable ductbank path that is being protected.

b. Number of Wires. Provide one guard wire when the width of the cable ductbank is less than 3-ft wide. Provide additional parallel guard wire runs for cables or cable ductbanks wider than 3 ft, in accordance with the Area of Protection criteria. The guard wires should be spaced approximately 12-in. apart to provide an area of protection for the cable ductbank.

c. Area of Protection. This is the protected area encompassed within a 45 degree zone on either side of the guard wire as illustrated in Figure 19.

d. Bonding to EES. Guard wires shall be bonded to the EES at each end, and to ground rods located at approximately 90-ft intervals along the guard wire path using exothermic welds. The spacing between ground rods must vary by 10 to 20 percent to prevent resonance. Install the ground rods approximately 6 ft on either side of the ductbank trench.

e. Airfield Runway Lighting. Where the cable or cable ductbank runs parallel to the edge of a runway, the ground rods shall be located at least 10 ft clear of the navigation lights in the direction of open available space away from the runway or lighting pathways.



Notes:

1. Provide additional parallel guard wire runs for cables or cable ductbanks wider than 3 ft.
2. The spacing intervals between the center lines of the guard wires should not exceed twice the height distance between the guard wire and ductbank.

Figure 19. Buried Guard Wire Detail for Underground Cables or Cable Ductbanks

5.4.3.3.3 Buried Landlines

The preferred type of buried landline that represents best engineering practice is fiber optic type. Fiber optic cable does not require electromagnetic shielding and is exempt from these requirements.

Metallic buried landlines that carry NAS critical, essential, or mission support services to a facility shall have a ferrous shield or be enclosed in ferrous RGS conduit. Ferrous shielding is recommended for portions of these buried landlines located beyond 300-ft cable length from the facility entrance. Facility entrance surge protection shall be provided for these landlines in accordance with paragraph 4.6.3.

5.4.4 Balanced Pair Cables

When possible, shielded circuits should be provided for signal and control circuits routed external to electronic equipment. Balanced pair cables shall be two-conductor circuits.

5.4.5 Fiber Optic Cable

When possible, fiber optic cables should be used in lieu of metallic cables. Fiber optic cables are inherently not susceptible to electromagnetic interference (EMI) or the induction fields produced by lightning, and are not required to be installed in ferrous conduit or have conductive armor for shielding. The use of fiber optic cables without a conductive shield or armor is permitted. Suppression components are not required for fiber optic cables.

a. Facility Entrance. The conductive armor of external fiber optic cables at the facility entrance point shall be bonded to the EES. Use 2 AWG bare copper conductor when bonding directly to the EES. When bonding connection to the EES uses an SPD, the

SPD bonding conductor shall be a 4 AWG stranded copper conductor insulated green with an orange tracer.

b. Facility Cabling. When the cable is internal to the facility and includes metallic electrically conductive sheaths or strength members, the sheaths shall be grounded to any SRS. When the electronic equipment is required to be isolated, bond the cable armor to the equipment SPG plate in accordance with section 5.5. To prevent circulating ground currents in the cable armor, an SPD located at one end of the cable may be used for grounding.

c. Transmitter and Receiver Modules. Fiber optic transmitter and receiver modules shall be contained in ferrous enclosures and bonded to the nearest SRS. Penetrations of the equipment enclosures shall be gasketed or constructed to limit RF coupling. SPDs for the metallic signal and power circuits shall be installed as equipment level protection at the fiber optic receiver or transmitter equipment entrance, and bonded to the equipment enclosure chassis. The transmitter and receiver modules shall have 90 dB of attenuation against EMI.

5.4.6 Interior Wiring, Conductors, and Cables

Permanent single conductors, cables and wiring shall be in ferrous raceway systems, such as RGS conduit, intermediate metal conduit (IMC), electrical metallic tubing (EMT) conduit, cable tray, or wireway, except when prohibited by NEC. Flexible metal conduit (FMC) is permitted when installed in accordance with FAA-C-1217.

Cable tray systems comprising single rail or wire construction are permitted where the installation of conventional ladder cable tray is impractical, provided the cable tray system meets the following requirements:

a. Suitable for use and classified by UL as an EGC.

b. Installed in accordance with manufacturer instructions to maintain the UL classification.

5.4.6.1 Metal-Clad Cable - Type MC

Type MC cable is permitted when installed in accordance with FAA-C-1217 and where all of the following conditions are met:

a. The MC cable shall include a steel armor of interlocking metal tape or sheath construction to form a ferrous magnetic exterior shield. MC cable with an aluminum exterior shield is prohibited.

b. Both ends of the MC cable shall be terminated using UL-listed compression fittings recommended by the OPR of this document.

c. The MC cable shall include a separate internal equipment grounding conductor or wire.

When MC cables are installed in MC cable tray, the following conditions shall be met:

a. The MC cable shall be UL-listed and marked suitable for use in metallic cable tray (hereinafter referred to as MC cable tray).

b. The MC cable tray shall be used exclusively for MC cable and type UL-listed raceways for power distribution.

c. The MC cable tray shall be separated from all other cable trays that transport non-axial communications, signal, and/or control cables or conductors by at least 12 in. The MC cable tray shall not carry more than 90 individual power branch circuits.

d. The MC cable bend radius shall be in accordance with the NEC and cable manufacturer installation instructions, but not less than 8 in.

5.5 Single Point Ground System (SPG) – Special Conditions

5.5.1 General

An SPG shall be provided when required by the electronic equipment or requested by the electronic equipment vendor. FAA facilities that do not use single-point-ground equipment are not required to install an SPG. The SPG shall be isolated from the power grounding system, the lightning protection system, MPG, or SRGG and SRGP systems, except at the main ground plate. The SPG shall be terminated at the main ground plate or to the EES, whichever is closer. The SPG shall be configured to minimize conductor lengths. Conductive loops shall be avoided by maintaining a trunk and branch arrangement as shown in Figure 20.

5.5.2 Isolation between SPG and Other SRS Systems

The minimum resistance between the SPG and the MPG, SRGG, or SRGP systems shall be 10 MΩ. The resistance shall be measured after the complete network is installed and before connection to the EES or SRS system at the main ground plate.

5.5.3 Resistance of Bonds

The maximum resistance of a bond connection from a conductor to a ground plate shall not be greater than 1 mΩ.

5.5.4 SPG - Ground Plates

Main, branch, and feeder ground plates shall be copper and at least 4 in. wide and 1/4 in. thick. The plates shall be mounted to nonconductive material of sufficient cross-section to rigidly support the plates after all conductors are connected. Bolts or other devices used to secure the plates in place shall be insulated or shall be of a nonconducting material. The plates shall be mounted in a manner that provides ready accessibility for inspection and maintenance.

See Table 4 for the single ground plate installation requirements.

5.5.5 SPG - Ground Conductors

Ground conductors shall be insulated copper conductors color-coded green with a yellow tracer.

5.5.5.1 Main SPG Conductor

Where an SPG is established directly from the EES, the SPG main conductor shall be an insulated 500 kcmil copper conductor not exceeding 50 ft in length. The main ground conductor shall be connected to the EES by an exothermic weld in accordance with paragraph 4.2.3.1.

5.5.5.2 Trunk and Branch Ground Conductors

Provide an insulated trunk ground conductor to interconnect all branch ground plates to the main ground plate as illustrated in Figure 20. Provide insulated copper branch ground conductors to interconnect feeder plates to branch ground plates. Conductor insulation shall be green with yellow tracer. Trunk and branch conductors shall be connected to ground plates by exothermic welds or UL-listed double-bolted connections in accordance with paragraph 4.2.3.4, and shall be mounted as shown on the facility drawings.

Trunk and branch conductors shall be routed using the shortest possible path.

a. <u>Conductors Shorter than 400 ft</u>. Trunk conductors shall be 4/0 AWG insulated copper conductors where the conductor length to the farthest feeder plate in the system is no more than 400 ft from the EES via the conductor runs.

b. <u>Conductors Longer than 400 ft</u>. For longer runs, select a conductor size to provide a cross-sectional area of 500 cmil per linear foot of conductor, but in no case that the conductor is smaller than 250 kcmil.

5.5.5.3 Electronic Equipment SPG Conductors

The conductor from the feeder ground plate (branch ground plate when there are no feeder ground plates in the conductor run) shall be connected to the isolated ground terminal or bus on the electronic equipment. This conductor shall be sized in accordance with Table 3.

5.5.5.4 Interconnections

Connections to the SPG shall be made on ground plates or buses. Split bolts and other connections to existing conductors are not allowed.

5.5.6 Labeling

The SPG shall be clearly labeled to preserve its identity as described in the following paragraphs.

5.5.6.1 Conductor Identification

SPG conductors shall be labeled in accordance with paragraph 4.7.3.1.6.

5.5.6.2 Ground Plate Labeling

Ground plates shall be installed according to Table 4.

5.5.7 Protection

Provide protection for conductors in the SPG subject to physical damage by use of conduit, floor trenches, routing behind permanent structural members, or other approved means. Single-point ground conductors shall be isolated from contact with any metal elements.

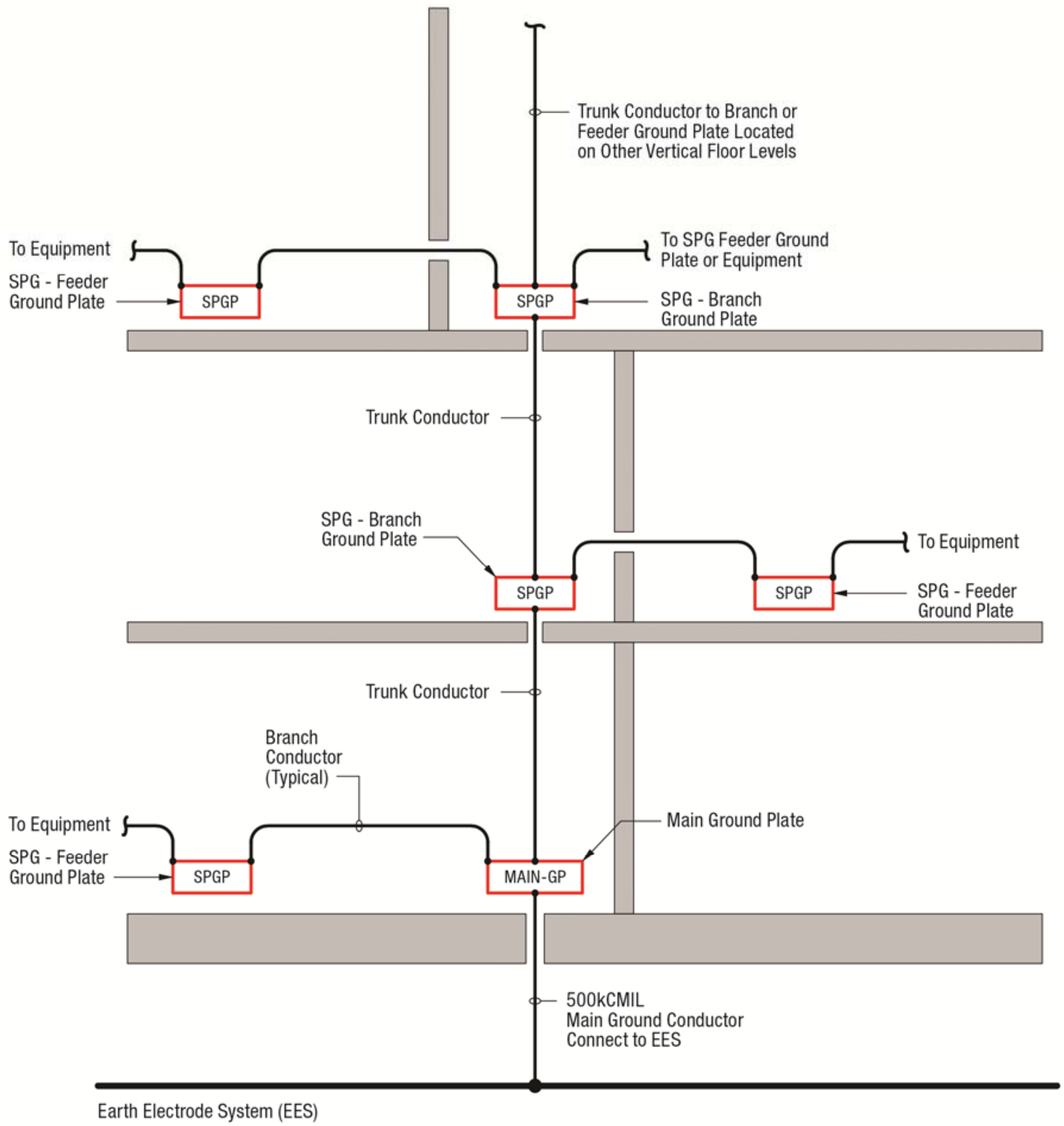


Figure 20. Single-Point Ground System Installation – Illustrative Example

5.6 NAS Electronic Equipment – Interface and Procurement Requirements

5.6.1 General

This section provides detailed performance and interface requirements for installation and procurement of NAS electronic equipment. Electronic equipment installed in NAS facilities shall comply with the requirements herein that address the following:

a. Electronic Signal Lines and Cables – Shielding

b. Signal, Control, and Data Line Entrance – Transient Protection

c. Equipment Power Entrance – Transient Protection

d. Electronic Equipment – Grounding and Bonding

e. Equipment – Signal Grounding and Bonding

f. Equipment Shielding Requirements

g. Circuit and Equipment ESD Design Requirements

5.6.2 Electronic Signal Lines and Cables - Shielding

Electronic signal lines shall be shielded twisted pairs with an insulated covering. Cables consisting of multiple twisted pairs shall have the individual shields isolated from each other. Cables shall have an overall shield with an overall insulated covering.

5.6.2.1 Electronic Signal Return Path

The electronic signal return path shall be routed with the circuit conductor. For axial circuits, the shield serves this purpose. The electronic equipment case and SRS shall not be used as a signal return conductor.

5.6.2.2 Termination of Individual Shields

Termination of individual shields shall be in accordance with paragraph 4.8.3.2.

5.6.2.3 Termination of Overall Shields

Termination of overall shields shall be in accordance with paragraph 4.8.3.3.

5.6.3 Signal, Control, and Data Line Entrance – Transient Protection

Procurement organizations are responsible for ensuring that electronic equipment, such as radars, NAVAIDS, and transmitters shall be provided with transient protection to reduce surges and transients to below the equipment transient susceptibility level. Signal, control, data line, and antenna cabling entrance transient protection shall be provided at the facility entrance point and at electronic equipment. Equipment SPDs shall be an integral part of the equipment, installed either internally or on the exterior of the equipment. Coordination of these protectors shall be addressed and completed in the system design stage and should not be delegated to field personnel during construction.

Equipment susceptibility level is defined as the transient level on the signal, control, or data lines that cause damage, degradation, or upset to electronic circuitry connected to the line. Transient protection for these lines is in addition to the facility transient protection levels specified in paragraphs 5.7.2 through 5.7.4. Procurement organizations are responsible for ensuring that testing is performed to establish voltage, current, and energy levels that will damage components, shorten operating life, or cause operational upset to the equipment. These tests shall include electrical and electronic equipment components exposed to the effects of surges or transients.

The procurement organization shall ensure that facility and electronic equipment entrance transient protection is coordinated to limit transients at the equipment to below the equipment susceptibility level. Requirements of this paragraph shall be included in the comprehensive control and test plans included in paragraph 5.9.2. The following characteristics shall be evaluated:

a. Component Damage Threshold. The component damage threshold is the transient level that renders the component nonfunctional or operationally deficient. Voltage is usually the relevant parameter for solid-state components.

b. Component Degradation Level. The component degradation level is the transient voltage or energy level that shortens the useful life of the component.

c. Operational Upset Level. The operational upset level is the transient voltage or energy level that causes an unacceptable change in operating characteristics for longer than 10 milliseconds for analog equipment or a change of logic state for digital equipment.

5.6.3.1 Lines and Cables Requiring Protection

Surge protective devices shall be placed on both ends of signal, data, antenna, and control lines and cables longer than 10 ft where connecting pieces of electronic equipment are not located and bonded to the same SRS, or where the SRS ground system is located in different rooms or on different building floor levels, as illustrated in Figure 21. Electronic equipment shall be protected as specified in paragraph 5.6.3.

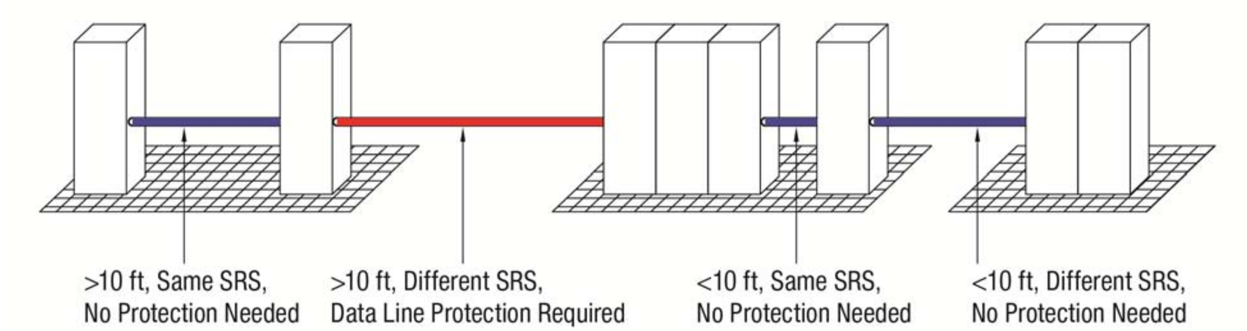


Figure 21. Lines and Cables Requiring Protection

5.6.4 Equipment Power Entrance – Transient Protection

SPDs, components, or circuits for the protection of electronic equipment power lines shall be provided by the equipment manufacturer as an integral part of electronic equipment mounted internally or on the exterior of the equipment at the cable entrance point. These devices shall be located at the ac power conductor entrance to electronic equipment housed in a shielded, compartmentalized enclosure. SPDs at equipment shall provide a clamping level less than the equipment operational upset susceptibility level as defined in paragraph 5.6.3c and shall conform to Table 8, Table 9, and Table 10.

a. Maximum Continuous Operating Voltage (MCOV). The MCOV is the maximum rms voltage an SPD can withstand while operating continuously at maximum temperature without degradation or change to any of its parameters greater than +/-10 percent. The MCOV shall be at least 10 percent above the nominal system voltage, and leakage current, as defined below, shall not be exceeded.

b. Leakage Current. The dc leakage current shall be less than 1 mA for voltages at or below the dc voltage value of 1.414 x MCOV.

c. Clamping Discharge Voltage (CDV). The CDV is the maximum voltage that appears across an SPD output terminal while conducting surge currents. To ensure performance in the linear region without impacting the device lifetime performance, the CDV values measured at 3 kA for an 8/20 µs current impulse waveform shall not change more than 10 percent over the operating life of the SPD as defined in Table 10.

d. Overshoot Voltage. Overshoot voltage is the surge voltage level that appears across the SPD terminals before the device turns on and clamps the surge to the specified voltage level. Overshoot voltage shall not exceed two times the SPD clamping voltage for more than 10 ns.

e. Self-restoring Capability. The SPD shall automatically return to its off state after surge dissipation when line voltage returns to normal.

f. Operating Lifetime. The SPD shall safely dissipate the number and amplitude of surges listed in Table 10.

g. Fusing. The SPD overcurrent protection shall not increase the clamp voltage of the SPD and shall pass the surge current levels listed in Table 10 up to the 20 kA level without opening. Fusing shall be coordinated with the power source overcurrent protection scheme.

5.6.4.1 Slope Resistance

The purpose of this parameter is to establish a system that ensures SPD device coordination for equipment protection. The slope resistance R_{slope}, as calculated by the formula below, shall comply with Table 8:

$R_{slope} = (V_{10} - V_1)/9000$

Where V_{10} is the clamping voltage measured at 10 kA for an 8/20 µs waveform and V_1 is the clamping voltage measured at 1 kA for an 8/20 µs waveform.

The values of V_{10} and V_1 shall be based on actual measured values of SPD performance testing and not calculated values.

Table 8. Electronic Equipment Power Entrance SPD - Slope Resistance (R_{slope})

Location	Slope Resistance Value
Electronic equipment power entrance	60 mΩ minimum

5.6.4.2 SPD Voltage Protection Rating - V_3

SPD voltage protection rating shall be based on actual measured values of SPD performance testing and not calculated values. Voltages to be achieved during testing at 3 kA for an 8/20 µs current impulse waveform are shown in Table 9. All voltages shall be measured at the device terminals. The 8/20 µs waveform shall not lead or lag the voltage waveform by more than 30 degrees.

Table 9. Electronic Equipment Power Entrance SPD - Voltage Protection Rating (V_3)

Location	System Voltage (V)	SPD Voltage Protection Rating (V_3 per mode)	Limit
Electronic equipment power entrance	120/208 or 120/240	550 L-N, L-G 850 L-L	Minimum
	277/480	850 L-N, L-G 1350 L-L	Minimum
	380 Delta	1350 L-L, L-G	Minimum
	480 Delta	1350 L-L, L-G	Minimum

Table 10. Electronic Equipment Power Entrance SPD – Surge Current Lifetime Rating

Surge Current Level Amplitude with an 8/20 µs Waveform (see note 1) (kA)	**Number of Surges** Lifetime
1	100
10	25
20	1
Note: 1. Each level of surge current and the number of lifetime surges required represents a single lifetime of the SPD.	

5.6.4.3 Electronic Equipment dc Power Supplies – Transient Protection

Procurement organizations are responsible for ensuring that equipment power supplies that use 60 Hz power to derive dc operating voltages for solid-state electronic equipment supporting the NAS shall have transient suppression components installed for each power supply output line. The suppression components shall be bonded to the protection equipment chassis. The chassis side of the suppressor enclosure shall be bonded to the rectifier output ground connection. The suppressor should be located as close as possible to the rectifier grounding connection. Suppression components for power supply's rectifier output lines shall comply with following operating characteristics:

a. Operating Lifetime. Transient suppressors shall safely dissipate 1,000 surges at 200 A amplitude for a 1.2/50 μs current impulse waveform. Methods of testing shall be in accordance with the guidance in IEEE C62.45.

b. Limiting Voltage. Voltage shall be limited to a point 20 percent below the maximum peak inverse voltage (PIV) of the dc rectifier.

5.6.5 NAS Electronic Equipment Enclosures and Assemblies - Grounding and Bonding

Bonding connections for electronic equipment enclosures and assemblies shall be prepared and completed in accordance with the installation conditions and requirements provided herein.

5.6.5.1 Electronic Equipment Cabinets, Racks, and Cases

Cabinets, racks, and cases shall be provided with a grounding terminal or bus assembly whereby a bonding jumper or wire can be mechanically connected through an electrically conductive surface to the chassis frame. The metal enclosure of each individual unit or piece of electronic equipment shall be bonded to its cabinet, rack, or directly to the SRS or MPG system.

5.6.5.2 Equipment Enclosures - Isolated Grounding Receptacles

Isolated receptacles installed in accordance with the NEC are permitted for reduction of electrical noise. Isolated EGCs used for these receptacles shall be color-coded green with red and yellow tracers at each termination, and where passing through an enclosure without termination.

5.6.5.3 Portable Equipment (with Grounding Conductor)

Portable electrical or electronic equipment cases, enclosures, and housings shall be considered to be effectively grounded for fault protection through the EGC of the power cord, if positive continuity is provided between the case, enclosure or housing, and the receptacle ground terminal. The power cord EGC shall not be used for signal grounding.

5.6.5.4 Alternating Current Power Filters

Filter cases shall be bonded directly to the equipment case or enclosure in accordance with paragraph 5.6.5.5. Filter leakage current shall not exceed 5 mA per filter. Transient suppression devices, components, or circuits shall be installed in accordance with paragraph 4.6.3.

5.6.5.5 Electronic Equipment Enclosure Bonding

Where subassemblies and equipment are in physical contact with the equipment enclosure, they shall be bonded directly with the enclosure and mounting surfaces.

5.6.5.5.1 Enclosure Subassemblies for Equipment Mounting

Use the maximum possible contact area when bonding subassemblies to the equipment chassis. Raceway penetrations, filters, and connectors shall be bonded at the periphery to the subassembly enclosure to maintain shield effectiveness. Enclosure covers and mounting trim shall be securely fastened to the enclosure. COTS equipment is considered a sealed unit and does not require additional internal bonding for the purposes of this requirement.

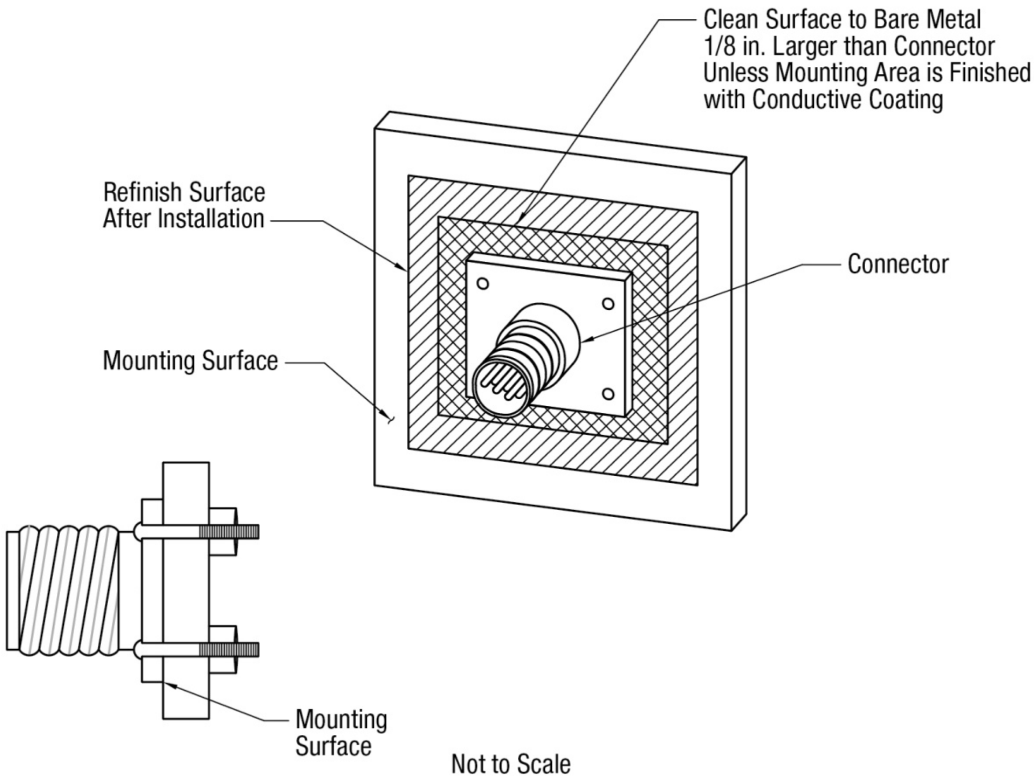
5.6.5.5.2 Electronic Equipment

The equipment chassis components shall be bonded together and directly to the rack, frame, or cabinet to which they are mounted. Clean flange surfaces and the bonding contact surface in accordance with paragraph 4.2.4.1. Fasteners shall maintain sufficient pressure to ensure surface contact to meet the bond resistance requirements in paragraph 4.2.1.1. Captive nuts, sheet metal screws, and tapping screws shall not be used for fasteners. If equipment operation is necessary when partially or completely withdrawn from its mounted position, the bond shall be maintained by an effective area of direct metal-to-metal contact or by the use of a flexible bonding strap. Mechanical designs shall employ direct bonding, without bonding jumpers, whenever possible.

***Exception*.** *Self-drilling (tapping) metal screws are permitted to make a physical connection between metal back panels within equipment cabinet/enclosures for conditions where equipment access is not available to the opposite side of the bond connection.*

5.6.5.5.3 Connector Mounting

Connectors shall be mounted so that electrical contact is maintained between the connector body and the metal mounting panel. The connector flange shall be fastened to equipment enclosure to ensure direct contact between components for effective bonding. The connector flange surface and the enclosure contact area shall be cleaned in accordance with paragraph 4.2.4.1. Nonconductive material shall be removed from the contact area as illustrated on Figure 22. After mounting each connector, the completed bond shall be sealed and finished for corrosion protection in accordance with paragraph 4.2.4.3.



Notes:

1. The connection detail depicts an illustrative example and is exaggerated for clarity.

Figure 22. Bonding of Connectors to Mounting Surface

5.6.5.5.4 Shield Terminations

Cable shields shall be terminated in accordance with paragraphs 4.8.3.2 and 4.8.3.3. Axial cable shields shall be fastened to the cable connector shell with a compression fitting. A soldered connection is permitted to improve conductivity of the shielding joints in accordance with paragraph 4.2.3f. The cable shall withstand the anticipated use without degradation in shielding efficiency performance. Axial cable connectors shall be corrosion resistant in accordance with FAA-G-2100. Low frequency shields shall be soldered in place or, if solderless terminals are used, the compressed fitting shall afford maximum contact between the shield and the terminal sleeve. The cable shield casing shall be exposed less than 1 in. from the internal conductors of the cable as illustrated in Figure 13.

5.6.5.5.5 RF Gaskets

Conductive gaskets shall be corrosion resistant, electrically conductive to meet the resistance requirements of paragraph 4.2.1.1, and resilient to ensure the shielding effectiveness of the bond. Surfaces in contact with the gasket shall be smooth and free of insulating films, corrosion, moisture, and paint. The gasket shall be firmly affixed to the bonding surface by conductive cement and screw fasteners, a milled slot or other means that do not interfere with the effectiveness of the gasket. These methods shall prevent lateral movement or dislodging of the gasket when the bond is disassembled. Gaskets shall be a minimum of 1/8-in. wide. The gasket and the contact surfaces shall be protected from corrosion.

5.6.6 NAS Electronic Equipment – Equipment Grounding and Bonding

5.6.6.1 Equipment Input and Output Electronic Signals

If a common signal reference is used, low-frequency analog input and output signals shall be balanced with respect to the signal reference. Maintain complete isolation between the SPG and the MPG, SRGG or SRGP system, except at the main ground plate or EES.

5.6.6.2 Multipoint Grounding of Electronic Equipment

Where permitted by circuit design requirements, internal ground references shall be bonded directly to the chassis and the equipment case. Where mounted in a rack, cabinet, or enclosure, the electronic equipment case shall be bonded to the racks, cabinet, or enclosure in accordance with paragraph 5.6.5.1. The dc resistance between any two points within a chassis or electronic equipment cabinet serving as ground shall be less than 25 mΩ total and not more than 2.5 mΩ per joint. Shields shall be provided where required for personnel protection and EMI reduction.

5.6.6.2.1 Prevention of Resonance in Bonding Straps

Due to resonance from a single bonding strap, two widely spaced straps of unequal length shall be used to connect equipment to the multipoint grounding bus in the equipment cabinet. Bonding connections shall be as short as possible and sized in accordance with Table 3.

5.6.6.3 Single-Point Grounding of Electronic Equipment

If electronic equipment performance necessitates an isolated SPG system for proper operation, then equipment and installation shall comply with the following:

a. <u>SPG System</u>. The SPG or plane shall be isolated from the electronic equipment case. If a metal chassis is used as the SPG, the chassis shall be floated relative to the case. The SPG system shall be designed such that electronic equipment SPG may be interfaced with other electronic equipment without compromising the system. Provide filtering if this SPG is required to be isolated from high frequencies.

b. <u>SPG Conductor and Plate System</u>. The system shall not form a conductive ground loop and it should be set up as a signal drain.

5.6.6.3.1 Single-Point Isolation of Input and Output Signal Requirements

The “high” and “low” sides of input and output signals shall be isolated from the electronic equipment case and balanced with respect to the signal reference. Operating and adjusting controls, readouts, indicating devices, protective devices, monitoring jacks, and signal connectors shall be designed to isolate both the high and low side of the signal from the case.

5.6.6.3.2 Single-Point Isolation of Case Requirements

The isolation between the SPG terminals and the case shall be 10 MΩ or greater with external power, signal, and control lines disconnected from the electronic equipment.

5.6.6.3.3 Equipment Power Input Isolation Requirements

The isolation between the SPG terminal and each power conductor (including ac neutral) shall be 10 MΩ or greater with the equipment power switch in the "on" position and the equipment disconnected from its power source.

5.6.6.3.4 Equipment Single-Point Ground Terminals

An insulated SPG terminal shall be provided on each electronic equipment case where an isolated signal reference is required. The SPG reference for the internal circuits shall be connected to the SPG terminal. This terminal shall be used to terminate cable shields as appropriate, and to connect the isolated signal ground of the electronic equipment to the SPG in the facility. A connector pin, screw, terminal strip, insulated stud, jack or feed-through, or an insulated wire are acceptable terminations if each terminal is clearly marked, labeled, or coded in a manner that does not interfere with its function. These marks, codes, or labels shall be permanently affixed and use green identification with yellow stripes. Wire insulation shall be green with a yellow tracer.

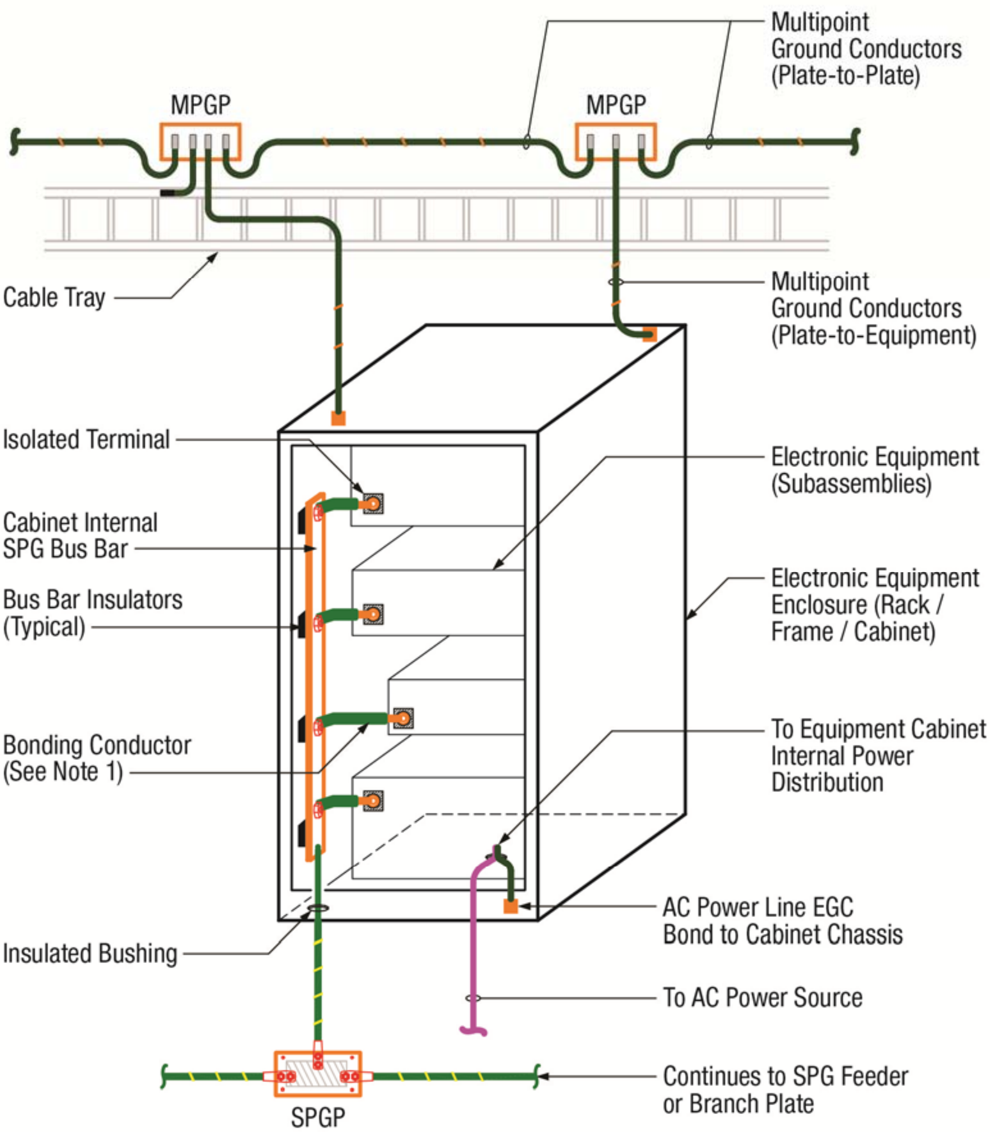
5.6.6.3.5 Connection of Electronic Equipment to the SPG

Each equipment SPG terminal shall be connected to the facility SPG in accordance with the following:

a. Individually Mounted Equipment. Individual units or pieces of electronic equipment that should not be mounted with other electronic equipment due to their location or function shall have an insulated copper conductor bonded from SPG terminal as specified in paragraph 5.6.6.3.4 to the nearest SPG system. This conductor shall be sized in accordance with Table 3.

b. SPG Bus Bar. If two or more units or pieces of electronic equipment are mounted together in a rack or cabinet, then a single-point ground bus bar shall be installed as shown in Figure 23. The bus bar shall be copper and shall provide a minimum cross-sectional area of 125,000 cmils, e.g., a 1x1/8-in. bus bar. The bus bar shall be drilled and tapped for No. 10 screws, and the holes shall be located as required by the relative location of the isolated SPG terminals on the electronic equipment. The bus bar shall be mounted on insulating supports that provide at least 10 MΩ resistance between the bus bar and the rack or cabinet.

c. Interconnecting SPG Terminals to SPG Bus Bar. Each electronic equipment isolated SPG terminal shall be interconnected to the SPG bus bar by means of a solid conductor of sufficient cross-sectional area to provide a maximum resistance of 5 mΩ, or a flexible tinned copper bond jumper sized in accordance with Table 3. The bond jumper shall be insulated or mounted in such a manner to maintain the required degree of isolation between the reference conductor and the enclosure. The bond jumper shall be connected to the equipment SPG bus bar at a point nearest the equipment SPG terminal in order to minimize the conductor length. An insulated copper conductor shall be installed from the equipment SPG bus bar to the nearest SPG grounding system as illustrated in Figure 23.



Note:

1. The conductor wire size for bonding conductors from electronic equipment to internal cabinet SPG bus bar shall be based on Table 3.

Figure 23. Single Point Ground Bus Bar Installation in Rack or Cabinet

5.6.7 Equipment Shielding Requirements

5.6.7.1 Control of Apertures

Unnecessary apertures shall be avoided. Only those shield openings required to achieve proper functioning and operation of the equipment may be provided. Controls, switches, and fuse holders shall be mounted such that metal-to-metal contact is maintained between the cover housing of the devices and the case. Metal control shafts shall be grounded in accordance with paragraph 5.6.7.2. Close-fitting metal sleeves peripherally bonded to the case shall be provided only where nonconductive control shafts are necessary. The length of the sleeve shall be no less than four times its diameter. Lights shall be filtered or shielded as needed to maintain the required degree of shielding effectiveness. Openings provided for enclosure ventilation and moisture drainage shall be configured to maintain the effectiveness of the overall enclosure shielding.

5.6.7.2 Metal Control Shafts

Metal control shafts shall be grounded to equipment cases through a low impedance path provided by close-fitting conductive gaskets, metal finger stock, or grounding nuts.

5.6.7.3 Shielded Compartments

Shields shall be bonded to the chassis for fault protection in accordance with section 4.2.

5.6.7.4 Gaskets for Shielding Systems

Conductive gaskets conforming to paragraph 5.6.5.5.5 may be provided at joints, seams, access covers, removable partitions, and other shield discontinuities to the extent necessary to provide interference-free operation of the equipment under normal use and environmental conditions. Finger stock used on doors, covers, or other closures subject to frequent openings shall be installed in a manner that permits routine cleaning and maintenance.

5.6.7.5 Filter Integration

Filters on power, control, and signal lines shall be installed in a manner that maintains the integrity of the shield. Alternating current power filters shall be shielded completely with the filter case grounded in accordance with paragraph 5.6.5.4. Filters for control and signal lines shall be placed as close as possible to the point of penetration of the case to avoid long, unprotected paths inside the equipment.

5.6.8 NAS Electronic Equipment - Electrostatic Discharge Protection

ESD protection shall be provided in accordance with section 5.8.

a. <u>Equipment Circuit Design and Layout.</u> The design, layout, and packaging of assemblies, circuits, and components integrated into electrical and electronic equipment shall incorporate methods and techniques to reduce susceptibility to ESD.

b. <u>Component Protection.</u> External protection shall be provided for integrated circuits, discrete components, and other parts not having internal ESD protection that are inherently susceptible to ESD. Protective components shall be installed as close as possible to the ESD susceptible item.

c. <u>ESD Withstand Requirements.</u> In the installed and operational configuration equipment such as cabinets, enclosures, racks, controls, meters, displays, test points, and interfaces shall withstand a static discharge of 15,000 V in accordance with ANSI/ESDA/JEDECD JS-001, Standard for ESD Sensitivity Testing – Human Body Model (HBM). To successfully pass ESD testing requirements, the tested equipment shall not incur any operational upset, component, or assembly damage.

5.6.9 Secure Facilities

In areas of facilities required to maintain communications security, equipment and power systems shall be grounded in accordance with NACSIM-5203 and MIL-HDBK-232A.

5.6.10 High RF Field Bonding Requirements

FAA facilities that are located in proximity to other facilities that generate high RF levels need additional shielding to protect personnel and sensitive equipment from these external RF sources. When a determination is made that the signal level is sufficient to cause concern, incorporate the following requirements:

Metal building components and attachments such as walls, roofs, floors, door and window frames, gratings and other metallic architectural features shall be bonded directly to structural steel or to reinforcing bar if structural steel is not present. Where direct bonding is not possible, indirect bonds with copper conductor shall be used. Removable or adjustable parts and objects shall be grounded with an appropriate type bond strap. Metal building components with a maximum dimension of 3 ft or less are exempt from the requirements of this paragraph.

5.7 Surge Protective Device (SPD) – Equipment Specification Requirements

5.7.1 General

This section provides SPD performance requirements.

5.7.2 Surge Protective Device (SPD) for Power Distribution Equipment Protection

The SPD installation shall comply with the following:

a. <u>Application Listing.</u> The SPD shall be listed in accordance with the latest UL 1449 Standard for SPDs.

b. <u>Integral Unit Mounted Assemblies</u>. Panelboards and switchgear equipment with integral unit mounted SPD enclosures are permitted if the SPD and panelboard or switchgear integrated components are UL listed and recognized as an assembly.

c. <u>Enclosure Rating</u>. The SPD components shall be housed in a single steel enclosure, and classified by NEMA as type-12 for indoor use, or type-4 for indoor or outdoor use.

d. <u>Enclosure Door Hardware</u>. The enclosure door shall be hinged and electrically bonded with a bonding jumper connected to the enclosure. The internal components of the SPD, such as fusing, indicator lights, wiring, and protection elements, shall be accessible for inspection and replacement. The manufacturer's installation and maintenance instructions shall be provided with each SPD unit.

e. <u>SPD Accessories</u>. Indicator lamps shall be provided for each power phase on the SPD enclosure cover. The lamps shall indicate visually the normal condition when power is applied to the SPD with the component fusing intact. Lamps shall be provided at a minimum service life of 50,000 hours, otherwise two lamps per phase shall be provided.

f. <u>Potting Material</u>. The SPD enclosure shall be sealed at the power entry points with potting material in accordance with paragraph 4.6.2.3. The use of potting material within SPD components is prohibited, such that all SPD components are accessible at all times for visual inspection, evaluation, maintenance, or replacement by qualified FAA personnel.

g. Conductor Terminations. Provide heavy-duty screw terminal studs or lugs for input and output conductor connections. The SPD phase and neutral terminals, when not connected, shall be electrically isolated from the enclosure by a minimum of 10 MΩ resistance measured at 100 Vdc.

5.7.2.1 SPD - Operational Requirements

The SPD equipment performance shall conform to Table 11, Table 12, and Table 13, and the following parameters:

a. Maximum Continuous Operating Voltage. The MCOV is the maximum rms voltage an SPD can withstand while operating continuously at maximum temperature without degradation or change to any of its parameters greater than +/-10 percent. The MCOV shall be at least 10 percent above the nominal system voltage. Leakage current, as defined below, shall not be exceeded.

b. Leakage Current. The dc leakage current shall be less than 1 mA for voltages at or below the dc voltage value of 1.414 x MCOV.

c. Clamping Discharge Voltage. The CDV is the maximum voltage that appears across an SPD output terminal while conducting surge currents. To ensure performance in the linear region without impacting the device's lifetime performance, the CDV values measured at 3 kA for an 8/20 µs current impulse waveform shall not change more than 10 percent over the operating life of the SPD as defined in Table 11.

d. Overshoot Voltage. Overshoot voltage is the surge voltage level that appears across the SPD terminals before the device turns on and clamps the surge to the specified voltage level. Overshoot voltage shall not exceed two times the SPD clamping voltage for more than 10 ns.

e. Self-restoring Capability. The SPD shall automatically return to its off state after surge dissipation when line voltage returns to normal.

f. Operating Lifetime. The SPD shall safely dissipate the number and amplitude of surges listed in Table 11.

g. In-line Inductors. In-line inductance is not permitted, except from the inductance normally created by the power connection conductors.

h. Overcurrent Protection. Fuses or circuit breakers that are part of an SPD installation shall be able to pass the surge currents specified in Table 11 without opening.

i. Short Circuit Current Rating. The SPD short circuit current rating shall be greater than the power distribution system available short circuit current where the equipment is applied in the power distribution system.

5.7.2.1.1 SPD Equipment Performance Data - Surge Current Levels

Table 11 defines the line-to-ground, line-to-neutral, neutral-to-ground, and line-to-line surge current values, and number of surge occurrences for ac power distribution SPD equipment operating below 600 V. In this table, the 8/20 µs waveform defines a transient reaching peak value in 8 µs and decaying to 50 percent of peak value 20 µs after inception. These devices shall be able to tolerate surges of shorter duration without malfunction.

The following performance change measurements define SPD device failure modes. For the listed parameters, the clamping voltages for each device and assembly are measured at 1 kA and 10 kA for an 8/20 µs current impulse waveform.

a. Change in Clamping Voltage. Any change greater than 10 percent in the 8/20 µs clamping voltage at 3 kA during service or when the pre-life service test and post-life or in-service test results are compared is a device failure. The pre-life test value shall be taken as the 100 percent value.

b. Change in rms Voltage. Any change greater than 10 percent in the rms voltage required to drive 1 mA of rms current through the device when the pre-life service test and post-life or in-service test results are compared is a device failure. The pre-life test value will be taken as the 100 percent value.

c. Change in dc Voltage. Any change greater than 10 percent in the dc voltage required to drive 1 mA dc through the device when the pre-life service test and the post-life or in-service test results are compared is a device failure. The pre-life test value will be taken as the 100 percent value.

Table 11. Power Distribution Equipment SPD – Surge Current Lifetime Rating

Surge Current Level Amplitude with an 8/20 µs Waveform, See Note 1 (kA)	**Number of Surges** Lifetime for Any Facility Entrance SPD	**Number of Surges** Lifetime for Feeder and Branch Panelboard SPDs
10	1500	1000
20	700	500
30	375	250
40	50	25
50	8	1
60	6	N/A
70	4	N/A
100	2	N/A
200	1	N/A

Table Note:
1. Each level of surge current and the number of lifetime surges required represents a single lifetime of the SPD.

5.7.2.1.2 SPD - Slope Resistance

The purpose of this parameter is to establish a system that ensures SPD device coordination for equipment protection. The slope resistance R_{slope}, as calculated by the formula below shall comply with Table 12:

$R_{slope} = (V_{10} - V_1)/9000$

Where V_{10} is the clamping voltage measured at 10 kA for an 8/20 µs waveform and V_1 is the clamping voltage measured at 1 kA for an 8/20 µs waveform.

The values of V_{10} and V_1 shall be based on actual measured values of SPD performance testing and not calculated values.

Table 12. Power Distribution Equipment SPD - Slope Resistance (R_{slope})

Location	Slope Resistance Value
Any Facility Entrance	8 mΩ Maximum
Feeder and Branch Panelboards	30 mΩ +/- 15 mΩ

5.7.2.1.3 SPD - Voltage Protection Rating V_3

SPD voltage protection rating shall be based on actual measured values of SPD performance testing and not calculated values. Voltages to be achieved during testing at 3 kA for an 8/20 µs current impulse waveform are shown in Table 13. All voltages shall be measured at the device terminals. The 8/20 µs waveform shall not lead or lag the voltage waveform by more than 30 degrees.

Table 13. Power Distribution SPD Voltage (V_3) Protection Rating

Location	System Voltage (V)	SPD Voltage Protection Rating (V_3 per mode)	Limit
Facility Entrances	120/208 120/240	400 L-N, L-G 700 L-L	Maximum
	277/480	700 L-L, L-G	Maximum
	380 Delta	1200 L-L,L-G	Maximum
	480 Delta	1200 L-L, L-G	Maximum
Feeder and Branch Panelboards	120/208 120/240	475 L-N, L-G 775 L-L	+/- 45 V
	277/480	775 L-N, L-G 1275 L-L	+/- 45 V
	380 Delta	1275 L-L, L-G	+/- 45 V
	480 Delta	1275 L-L, L-G	+/- 45 V

5.7.3 SPDs for NAS Electronic Equipment – Design and Procurement Requirements

Provide surge protection for NAS electronic equipment in accordance with paragraph 5.6.3.

5.7.4 SPD - Design Specification for Axial Cable Protection

The design analysis for axial-type cable transient protection shall address the critical RFs and cable insertion losses. Axial cable protection shall comply with the following:

a. Testing. Performance testing shall be conducted to ensure that suppression components do not degrade signals or cause disruption to the electronic equipment.

b. RF Signal Testing Criteria. The analyses shall address cable impedance, insertion loss, phase distortion, and system voltage standing wave ratio.

c. Transient Protection for Electronic Equipment. SPD protection for coaxial, tri-axial, and twin-axial cables shall be provided at the facility entrance point and at the electronic equipment. The transient suppression shall be provided for each axial conductor and for shields that are not bonded directly to the electronic equipment chassis.

5.8 Electrostatic Discharge (ESD) Protection – Interface and Specification Requirements

5.8.1 General

This section provides performance and interface requirements for installation of ESD protective systems. ESD controlled areas shall be provided for operations, storage, repair, and maintenance spaces used for electrical and electronic equipment or subassemblies that are subject to damage from static electricity or ESD. NAS electrical and electronic equipment, subassemblies, and components subject to damage from exposure to electrostatic fields or ESD shall be protected as indicated herein. Approval of any exception to the guidance herein shall be by the OPR.

The requirements of this section are designed to reduce frequency and minimize effects of ESD events. Electronic circuitry that contains miniaturized or solid-state components shall be considered ESD susceptible.

5.8.2 Electrostatic Discharge (ESD) Sensitivity Classification

Classification of items as ESD sensitive shall be in accordance with the HBM testing procedures and requirements of ANSI/ESDA/JEDECD JS-001. Electronic parts, components, and assemblies shall be classified as either sensitive or supersensitive. Items that fail from ESD at 1,000 to 16,000 V shall be classified as ESD sensitive. Items that fail below 1,000 V shall be classified as supersensitive. Devices with a sensitivity of less than +/- 200 V require additional ESD protection measures beyond those specified in this standard. ESD susceptible items shall not be exposed to an electrostatic field greater than 100 V/m, nor located within 24 in. from known static generators or nonessential insulated materials.

5.8.3 Classification of Materials

Most materials and products that are used to control and prevent ESD are classified by their resistive properties as conductive or static dissipative. Antistatic materials are classified by their ability to avoid generating static electricity from triboelectric charging.

Materials used for construction of ESD protected areas (with the exception of antistatic materials) shall meet the resistive properties specified for type and use of the material.

5.8.3.1 Static Conductive Materials

Those materials with a surface resistivity less than 1.0×10^5 ohms per square when tested per ANSI/ESD STM11.11 shall be considered conductive. Conductive ESD control materials shall not be used for ESD control work surfaces, tabletop mats, floor mats, flooring, or carpeting where the risk of personnel contact with energized electrical or electronic equipment exists. Conductive ESD control materials shall not be used in any other application where their use could result in EMI or radio frequency interference (RFI) that would be created by rapid, high-voltage ESD spark discharges.

5.8.3.2 Electrostatic Shielding Materials

Electrostatic shielding materials are a subset of conductive materials with a surface resistance equal to or less than 1.0×10^3 ohms when tested per ANSI/ESD STM11.11. Electrostatic shielding materials are permitted as barriers for protection of ESD sensitive items from electrostatic fields.

5.8.3.3 Electromagnetic Shielding Materials
Electromagnetic shielding materials with highly conductive surfaces less than 10 ohms, or composite materials that absorb and reflect electromagnetic radiation over a broad range of frequencies, are permitted for protection of ESD sensitive items from electromagnetic fields.

5.8.3.4 Static Dissipative Materials
Materials with a surface resistivity greater than 1.0×10^5 ohms per square but less than or equal to 1.0×10^{12} ohms per square when tested per ANSI/ESD STM11.11 are classified as static dissipative materials. Static dissipative materials with a surface resistance less than or equal to 1.0×10^9 ohms shall provide controlled bleed-off of accumulated static charges in ESD controlled areas. Static dissipative materials with a surface resistance of greater than 1.0×10^9 ohms are not permitted for applications where controlled bleed-off of accumulated static charges is required.

5.8.3.5 Antistatic Materials
Materials that inhibit or have a low propensity to generate static electricity from triboelectric charging shall be considered antistatic. Antistatic ESD control items and materials used for construction of ESD controlled areas shall not tribocharge to greater than +/-200 V when being used for their intended application. Antistatic materials with a surface resistance greater than 1×10^9 ohms shall not be used for ESD protective work at surfaces, tabletop mats, floor mats, flooring, and carpeting when charge dissipation is the primary consideration. If the surface resistance (R_{tt}) of an antistatic material is greater than 10^{12} ohms, it shall be considered too resistive for use in ESD controlled areas. Use of antistatic items and materials that use hygroscopic surfactants that depend on ambient humidity to promote absorption of water is discouraged. Only antistatic materials that are intrinsically antistatic and retain their antistatic properties shall be used in ESD controlled areas.

5.8.3.6 Static-Generative Materials, Nonconductors, and Insulators
Materials having a surface resistance greater than 1.0×10^{12} ohms (ANSI/ESD STM11.11) shall be considered to be insulators and a potential source of triboelectric charging. These materials include common plastics, Plexiglas, Styrofoam, Teflon, nylon, rubber, untreated polyethylene, and polyurethane. Use of these materials shall be minimized where ESD sensitive items are located.

5.8.4 Hard and Soft Grounds

5.8.4.1 Hard Grounds
Any item, material, or product that is a part of the ESD control system that is intentionally or unintentionally connected to an ESD ground, or connected directly to any SRS in the area served, but not to an SPG system, shall be considered to be hard grounded. Unless specified otherwise or approved by the OPR, all items that comprise the ESD control system shall be hard grounded, such as worksurfaces, cabinets, flooring, carpeting, and test equipment.

5.8.4.2 Soft Grounds

A soft ground is an intentional connection to ground through a series current limiting resistor. Soft grounding shall only be used for personnel grounding skin contact devices, such as wrist straps, leg or ankle straps, conductive shoes, and heel or toe grounders. The nominal resistance of the resistor used for soft grounding of personnel shall be greater than 1.0×10^6 ohms unless otherwise approved by the OPR. All other elements of the ESD control system shall be hard grounded.

5.8.5 Protection of Electrostatic Discharge (ESD) Susceptible and Sensitive Items

5.8.5.1 Static Protected Zone

A static protected zone shall be a volume or area where there is no direct contact between unprotected ESD sensitive items and electrostatic potentials greater than +/-200 V, electrostatic fields greater than 100 V/m, or radiated EMI and RFI produced by rapid high-voltage ESD spark discharges. Static protected zones shall be incorporated into the construction of ESD special protection areas, ESD protected storage areas, and ESD protected workstations.

5.8.5.2 ESD Special Protection Areas

Special protection areas shall be designated areas that require the following ESD control measures:

a. Minimize triboelectric charging.

b. Control bleed-off and dissipation of accumulated static charges.

c. Neutralize charges.

d. Minimize the effects of e-fields, h-fields, and EMI/RFI from ESD spark discharges.

Areas within a facility that shall be designated as ESD special protection areas are:

a. Air Traffic Operations Areas. These include tower cab, TRACON, ARTCC control rooms, and automated flight service station (AFSS) areas.

b. Electronic Equipment Rooms.

c. Storage Areas. Areas to store ESD-susceptible components such as subassemblies and circuit cards.

d. Computer/LAN Interface Areas. Areas that contain personal computers and LANs that are connected to or interface directly with NAS electronic equipment.

e. Other Locations. Locations where jacks, plug-in connectors, or interfaces of ESD sensitive electronic equipment are exposed and vulnerable to ESD damage by direct human contact.

5.8.6 ESD Controls Required for ESD Special Protection Areas

The following ESD control measures shall be implemented in areas designated as ESD special protection areas.

5.8.6.1 ESD Groundable Point (GP)

Each ESD control material, surface, or item used in an ESD controlled area shall have a designated GP to provide ease of connection to the nearest SRS.

5.8.6.2 Grounded Static Dissipative Surfaces

Work surfaces which include work surface laminates, paints and sealers, writing surfaces, tabletops, consoles, ESD protected workbenches, and tabletop mats shall be static dissipative and connected to an SRS in the area served, but not to an SPG system. The point-to-point resistance and surface-to-ground resistance of static dissipative work surfaces shall be greater than 1.0×10^6 ohms and less than 1.0×10^9 ohms (ANSI/ESD S4.1).

5.8.6.3 Limiting the Use of Non-ESD Control Materials

Materials that will tribocharge, i.e., generate electrostatic potentials by contact and separation with themselves or other materials, shall not be used for construction in ESD special protection areas. Insulative materials and any other non-essential triboelectric charge generators that generate potentials in excess of +/-200 V are not permitted within 24 in. of ESD special protection areas.

5.8.6.4 Static Dissipative Chairs

Chairs provided for ESD special protection areas shall incorporate a continuous path between chair elements, such as the cushion and arm rests, to the ground points in the range of greater than 1.0×10^5 ohms to less than 1.0×10^9 ohms. The ground points for ESD chairs shall be static dissipative or conductive casters that provide electrical continuity from all elements of the chair to ESD control carpeting, tile, or floor mats. These ground points shall be properly bonded to any SRS in the area, but not to an SPG system. ESD control chairs shall be tested and meet the requirements of ANSI/ESD STM12.1.

5.8.6.5 Static Dissipative ESD Control Floor Coverings

Static dissipative ESD control floor coverings shall include static dissipative tile, carpeting, static limiting floor finishes, and floor mats. Floor coverings in ESD special protection areas shall have a point-to-point resistance and surface-to-ground resistance of greater than 1.0×10^6 ohms and less than 1.0×10^9 ohms (ANSI/ESD STM 7.1). These floor coverings shall be bonded to any SRS in the area served in accordance with paragraphs 5.8.6.1 and 5.8.9, but not an SPG system.

In circumstances involving extremely static sensitive equipment, a static conductive floor covering with a lower resistance limit of 2.5×10^4 ohms (UL 779) shall be provided when it is part of a system designed for ESD control for the equipment. The system design shall meet all requirements of this standard to produce an electrically safe working environment, and be approved by the OPR.

5.8.6.6 Relative Humidity Control

Relative humidity in ESD special protection areas shall be maintained within the range of 40 to 60 percent.

5.8.7 ESD Signs, Labels, Cautions, and Warnings for ESD Protection Areas

ESD warning signs shall be posted in ESD special protection areas and other ESD controlled areas. Sign labels shall be marked with an ESD sensitive electronic device warning symbol and other warning and caution labeling information appropriate for personnel safety. ESD warning signs shall be colored yellow with black marking labels and lettering. ESD signs for exterior cabinets housing ESD sensitive electronic equipment shall be visible from at least 3 ft. The sign and labeling style and format shall be consistent, and comply with ANSI/ESD S8.1.

5.8.8 Electrostatic Discharge (ESD) Protective Storage Areas

5.8.8.1 Shelves, Bins, and Drawers

Shelves, bins, and drawers shall be static dissipative and electrically continuous with the support structure for the storage shelves, bins, or containers.

5.8.8.2 Grounding

The storage container metal support structure shall have a GP connected to the nearest SRS in the area, but not to an SPG system. The resistance from the ground point of storage containers, shelving, cabinets, and bins used to store ESD sensitive items to the nearest SRS shall be less than 1 ohm.

5.8.8.3 Personnel Grounding

Wrist straps shall be equipped with 1 megohm or greater series resistance to protect personnel. Standard 0.157-in. banana jacks for personnel grounding wrist straps shall be connected to the ESD ground or directly to any SRS in the area served, but not to an SPG system. The resistance between the banana jack and the GP, and the GP to the nearest SRS, but not to an SRS system, shall be less than 1 ohm.

5.8.8.4 Materials Prohibited in ESD Protective Storage Areas

Static generative insulators materials are prohibited for construction in areas where ESD sensitive items will be stored. Materials that can generate potentials greater than +/-200 V shall be located a minimum of 24 in. from ESD protected storage areas.

5.8.8.5 Resistance to ESD Ground for Shelves, Drawers, and Bins

Surfaces and drawers of storage media shall be composed of static dissipative materials and shall conform to the resistance testing requirements for worksurfaces (ESD S4.1). The surface-to-surface resistance (R_{tt}) and surface-to-ground resistance (R_{tg}) from the shelves, bins, and drawers of storage containers used to store unprotected ESD sensitive items shall be greater than 1.0 x 10^6 ohms and less than 1.0 x 10^9 ohms (ESD ADV53.1).

5.8.8.6 Identification of ESD Protective Storage Areas

Boundaries of ESD protective storage areas shall be clearly identified. Boundaries of ESD protective storage areas shall extend a minimum of 24 in. beyond the area where ESD sensitive items are located and marked with yellow tape. Highly visible ESD warning signs that are colored yellow with black markings and lettering shall be posted at entrances to these areas. Signs shall include an ESD sensitive electronic device warning symbol and other warning and caution labeling information for personnel safety.

5.8.9 Electrostatic Discharge (ESD) Control Flooring and Floor Coverings

ESD control floors and floor coverings shall have a point-to-point resistance and a surface-to-ground resistance of greater than 1.0×10^6 ohms and less than 1.0×10^9 ohms (ANSI/ESD STM7.1). ESD control flooring, floor coverings, and floor tile laminates include materials such as vinyl tile, vinyl sheet, carpet, carpet tile, and carpet tile with positioning buttons, but not the applied coatings on the material.

ESD control floors and floor coverings shall be installed, grounded, and initially tested by trained installers in accordance with the manufacturer's recommendations. A representative 10-ft-square section of the flooring system shall be tested and approved by the FAA personnel prior to installation of the full flooring system.

ESD control floors and floor coverings shall be bonded to the nearest SRS in the area served, but not to an SPG system, at a minimum of four locations. The installation methods and testing shall be in accordance with the manufacturer's installation recommendations.

5.8.9.1 Surface Resistance (R_{tt})

Surface resistance R_{tt} of ESD control floors, carpets, or floor mats shall be greater than 1.0×10^6 ohms and less than 1.0×10^9 ohms (ANSI/ESD STM7.1). The system surface resistance shall be validated by testing. A minimum of five readings shall be taken at different locations on the floor surface and averaged together for each 500 ft^2, or fraction thereof, equivalent floor surface. These readings shall be recorded and documented in the Facility Reference Data File (FRDF).

5.8.9.2 Resistance Surface-to-Ground (R_{tg})

Resistance from the floor surface-to-ground R_{tg} of ESD control floors, carpets or floor mats shall be greater than 1.0×10^6 ohms and less than 1.0×10^9 ohms (ANSI/ESD STM7.1). The system shall be validated by testing. A minimum of five readings shall be taken at different locations on the floor surface and averaged together for each 500 ft^2, or fraction thereof, equivalent floor surface. These readings shall be recorded and documented in the FRDF.

5.8.9.3 Triboelectric Charging Limitation

ESD control floors, carpets, or floor mats shall limit and control generation and accumulation of static charges to less than +/-200 V in ESD controlled areas.

5.8.10 Electrostatic Discharge (ESD) Requirements for Raised Access Floor Systems

5.8.10.1 Resistance between Carpet Surface to Pedestal and Support Substructure

The resistance between carpet tile surface and the raised access floor pedestal and panel support substructure shall be greater than 1.0×10^6 ohms and less than 1.0×10^9 ohms.

5.8.10.2 Contact Resistance between Panel to Access Floor Support Substructure

The contact resistance between the access floor panel system metal parts and the floor substructure shall be less than 10 ohms.

5.8.10.3 Carpet Tile Installation on Raised Access Floor Panels
Install individual carpet tiles on raised floor panels with either permanent or releasable conductive adhesive depending on the application.

5.8.10.4 Grounding of Raised Access Floor System
A minimum of four connections shall be provided per 1,000 ft^2 of installed ESD control carpeting from the carpeting undersurface and conductive adhesive to the raised access floor panel support substructure. The connections and installation method shall be in accordance with the manufacturer's recommendations, and the testing requirements of paragraphs 5.8.10.1 and 5.8.10.2.

5.8.11 Electrostatic Discharge (ESD) Protective Worksurfaces
All worksurfaces, including consoles and ESD-protected workstations and writing surfaces in all areas designated as ESD special protection areas and static-safe zones shall be static dissipative materials or electrostatic dissipative laminates.

5.8.11.1 Requirements for ESD Protective Worksurfaces
Static dissipative worksurfaces shall be provided for new or upgrade facilities unless otherwise specified. Permanent static dissipative worksurfaces shall be connected to any SRS in the area served, but not to an SPG system. Permanent ESD protective static dissipative worksurfaces shall have a resistance greater than 1.0 x 10^6 ohms point-to-point (R_{tt}) and less than 1.0 x 10^9 ohms (ESD S4.1). Permanent ESD protective worksurfaces shall have a resistance from their surface to the groundable point (R_{tg}) greater than 1.0 x 10^6 ohms and less than 1.0 x 10^9 ohms (ESD S4.1).

5.8.11.2 Worksurface Types
ESD protective worksurfaces used for ESD protected workstations shall meet the requirements of MIL-PRF-87893 *Performance Specification, Workstation, ESD Control*, and MIL-W-87893 *Military Specification, Workstation, ESD Control*.

5.8.11.2.1 Type I Worksurface - Hard
Type I worksurfaces shall be constructed of rigid static dissipative materials of any color having an average Shore D hardness in excess of 90. Two male or female 0.395-in. ground snap (female) or stud (male) fasteners shall be installed on both corners on one of the longest sides of the worksurface to accommodate the male or female snap or stud fastener of the common point grounding cord. The locations of the two snaps or studs shall be 2 in. from each corner.

5.8.11.2.2 [A5] Type II Worksurface - Soft
Type II worksurfaces shall be constructed of cushioned static dissipative materials of any color having an average Shore A (ATSM D2240) hardness between 45 and 85. Two male or female 0.395-in. ground snap (female) or stud (male) fasteners shall be installed on both corners on one of the longest sides of the worksurface to accommodate the male or female snap or stud fastener of the common point grounding cord. The locations of the two male or female snaps or studs shall be 2 in. from each corner. Low-density open-cell materials are not permitted for Type II worksurfaces.

5.8.11.3 Static Dissipative Laminates
High-pressure, multilayer static dissipative laminates shall be used to cover surfaces such as plywood, fiber board, particle board, benchtops, countertops, and consoles in ESD controlled areas and special protection areas. Laminates shall include a buried conductive layer to provide for ease of grounding using a through-bolt pressure-type ESD grounding terminal.

5.8.11.4 Grounding of Laminated Surfaces
The resistance across the surface (R_{tt}) of the static dissipative laminate shall be greater than 1.0 x 10^6 ohms and less than 1.0 x 10^9 ohms. The resistance from the surface of the laminate to ground (R_{tg}) shall be greater than 1.0 x 10^6 ohms and less than 1.0 x 10^9 ohms (ESD S4.1). The system shall be validated through testing. A minimum of five readings of each shall be taken and averaged together. These readings and averages shall be recorded in the FRDF.

5.8.12 Static Dissipative Coatings
Permanent clear or colored static dissipative coatings used in ESD controlled areas, including painted surfaces, shall have a point-to-point resistance greater than 1.0 x 10^6 ohms and less than 1.0 x 10^9 ohms.

5.8.13 Electrostatic Discharge (ESD) Protected Workstations
ESD protected workstations are workbenches used for the maintenance and repair of ESD sensitive equipment.

5.8.13.1 ESD Protected Workstation Minimum Requirements
ESD control items at an ESD protected workstation shall be connected to a common ESD system GP and bonded to any SRS in the area served, but not to an SPG system. ESD protected workstations shall be free from all nonessential static charge generators, and provide a means of personnel grounding. Workstations shall have a grounded static dissipative work surface, and grounded static dissipative ESD control floor or mat. Storage containers located at ESD protected workstations shall be provided with ESD protection and connected to the ESD system GP. Power outlets for ESD protected workstations shall be protected with a ground fault circuit interruption (GFCI) device to minimize the risk of electrical shock to grounded personnel.

5.8.13.2 Use of Ionization
Selective use of benchtop or area ionizers is permitted at ESD-protected workstations if static generative insulator items are deemed essential and cannot be removed from the ESD protected workstation area, or the grounding of mobile personnel is not possible or creates a safety hazard.

5.8.13.3 Identification of ESD Protected Workstations
Boundaries of ESD protected workstations shall be clearly identified with highly visible ESD warning signs. Boundaries of ESD protected workstations shall be identified with yellow tape marking labels. The ESD boundary shall extend a minimum of 24 in. beyond the area where ESD sensitive items are located.

ESD warning signs shall be posted in ESD special protection areas and other ESD controlled areas. Sign labels shall be marked with an ESD sensitive electronic device warning symbol and other warning and caution labeling information appropriate for personnel safety. ESD warning signs shall be colored yellow with black marking labels and lettering.

5.9 Electromagnetic Compatibility Requirements

5.9.1 General

A comprehensive plan for the application of this standard is required to ensure the compatible operation of equipment in complex systems. Considerations in this section shall be implemented to reduce susceptibility to emissions of electronic equipment.

5.9.2 [A6] Requirements

The emission and susceptibility limits contained in MIL-STD-461 shall be applied unless otherwise specified. An electromagnetic interference (EMI) Control and Test Plan shall be developed in accordance with MIL-HDBK-237 to ensure compliance with the applicable requirements. The plan shall include a verification matrix to track the satisfaction of requirements by test, analysis, or inspection.

5.9.3 Approval

Control and Test Plans shall be submitted to the OPR for approval.

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6 NOTES

6.1 Acronyms and Abbreviations

The following are acronyms and abbreviations used in this standard.

A		
	A	Ampere
	ac	alternating current
	AFSS	automated flight service station (FAA Acronym)
	ANSI	American National Standards Institute
	ARTCC	Air Route Traffic Control Center
	ASSC	airport surface surveillance capability system
	ATCT	Airport Traffic Control Tower
	AWG	American Wire Gauge
C		
	CDV	clamping discharge voltage
	cmil	circular mils
	COTS	commercial off-the-shelf
D		
	dB	Decibel
	dc	direct current
	DEB	direct earth burial
	diam	Diameter
E		
	e.g.	for example
	EES	earth electrode system
	EGC	equipment grounding conductor
	EMI	electromagnetic interference
	EMT	electrical metallic tubing
	ESD	electrostatic discharge
	et al.	and others
	etc	et cetera
F		
	FAA	Federal Aviation Administration
	FRDF	facility reference data file (FAA Acronym)
	ft	foot (feet)
G		
	GEC	grounding electrode conductors
	GFCI	ground fault circuit interruption
	GP	groundable point
H		
	Hz	hertz
	HBM	human body model

I		
	i.e.	that is
	IFR	Instrument Flight Rules (FAA Acronym)
	IMC	intermediate metal conduit
	in.	inch
	IEEE	Institute of Electrical and Electronics Engineers
K		
	kA	kiloampere
	kcmil	thousand circular mils
	kHz	kilohertz
L		
	LAN	local area network
	lb	pound
	LPGBS	Lightning Protection, Grounding, Bonding and Shielding
	L-G	Line-to-Ground
	L-L	Line-to-Line
	L-N	Line-to-Neutral
	LLWAS	low level wind shear alert system (FAA Acronym)
M		
	m	meter
	mm	millimeter
	mA	milliampere
	mΩ	milliohm
	MΩ	megohm
	MCOV	Maximum continuous operating voltage
	MHz	megahertz
	MPG	multipoint ground system
	MPGP	multipoint ground plate
	µs	microsecond
N		
	NAS	National Airspace System
	NAVAIDS	navigation aids
	NEC	National Electrical Code
	NEMA	National Electrical Manufacturers Association
	NFPA	National Fire Protection Association
	ns	nanosecond
O		
	OCPD	overcurrent protective device
	OM	outer marker (FAA Acronym)
	OPR	Office of Primary Responsibility
	Ω	ohm
P		
	PIV	peak inverse voltage
	PVC	polyvinyl chloride

R		
	RF	radio frequency
	RGS	rigid galvanized steel
	RFI	radio-frequency interference
	RMC	rigid metal conduit
	rms	root-mean-square
	R_{slope}	slope resistance
	R_{tg}	surface-to-ground resistance
	R_{tt}	surface resistance
	RVR	runway visual range (FAA Acronym)
S		
	SDM	service disconnecting means
	SPD	surge protective device
	SPG	single point ground system
	SPGP	single point ground plate
	SRGG	signal reference ground grid
	SRGP	signal reference ground plane
	SRM	safety risk management
	SRS	signal reference structure
	SSC	system support center (FAA Acronym)
T		
	TELCO	telephone company (FAA Acronym)
	ton	unit of mass or weight
	TRACON	terminal radar approach control facility
	TVSS	transient voltage surge suppressors
U		
	UL	Underwriters Laboratories
	UPS	uninterruptible power supply
V		
	V	volt
	V_{dc}	volts direct current
	VOR	very high frequency (VHF) omni directional range (FAA Acronym)
W		
	λ	Frequency Wavelength

6.2 Guidelines and Reference Notes

[A1] **Paragraph 4.2.1.1**
See FAA-HDBK-010 for evaluation, inspection, and testing procedures.

[A2] **Paragraph 4.2.3.4.1**
See MIL-STD-889, paragraphs “Precautions and methods for joining” and “Recommended Treatments in Order of Protective Effectiveness” for additional guidance for completing bond joints where base metals for couples are not permitted in Table 1.

[A3] **Paragraph 4.4.2**
The site survey geotechnical investigation data and EES design configuration are expected to be documented and retained within the facility’s as-built documentation set, in accordance with FAA Order 630.45, Facility Reference Data File.

[A4] **Paragraph 4.4.4.4**
Access wells located in nontraffic areas should be medium duty rated per AASHTO H-20 design load criterion up to 40,000 lb. Access wells subject to vehicular traffic should be traffic rated per AASHTO M306 proof loading criterion up to 100,000 lb. Access wells subject to aircraft loading should be Airport rated per AASHTO M306 proof loading criterion up to 200,000 lb.

[A5] **Paragraph 5.8.11.2.2**
Guidance for measurement of material hardness properties is in ATSM-D2240, Standard Test Method for Rubber Property - Durometer Hardness, ASTM International, West Conshohocken, PA, 2015, www.astm.org.

[A6] **Paragraph 5.9.2**
Guidance for EMI protection is in MIL-HDBK-253, and for ESD in NFPA 77, DODHDBK-263, DOD-STD-1686, and IEEE 1100.

6.3 Version Cross-Reference

Due to the major reorganization of FAA-STD-019F it is not feasible to provide an exact cross-reference between this standard and the previous versions of FAA-STD-019. The OPR should be consulted for assistance in determining references to the original requirements in previous editions of FAA-STD-019.

6.4 Bibliography

[B1] NFPA 70, National Electrical Code, National Fire Protection Association, Current Edition.

[B2] NFPA 75, Standard for the Fire Protection of Information Technology Equipment, National Fire Protection Association, Current Edition.

[B3] NFPA 780, Standard for the Installation of Lightning Protection Systems Handbook, National Fire Protection Association, Current Edition.

[B4] IEEE 1100, IEEE Recommended Practice for Powering and Grounding Electronic Equipment, Institute of Electrical and Electronics Engineers, Inc., Current Edition.

[B5] IEEE C2, National Electrical Safety Code, Institute of Electrical and Electronics Engineers, Inc., Current Edition.

[B6] MIL-HDBK-419, Department of Defense, Military Handbook: Grounding, Bonding, and Shielding for Electronic Equipments and Facilities, Volume I, Current Edition.

[B7] MIL-HDBK-419, Department of Defense, Military Handbook: Grounding, Bonding, and Shielding for Electronic Equipments and Facilities, Volume II, Current Edition.

[B8] MIL-HDBK-237, Department of Defense, Military Handbook: Electromagnetic Environmental Effects and Spectrum Supportability Guidance for the Acquisition Process, Current Edition.

[B9] MIL-STD-188-124, Department of Defense, Military Standard: Grounding, Bonding and Shielding for Common Long Haul/Tactical Communication Systems Including Ground Based Communications Electronics Facilities and Equipments, Current Edition.

[B10] MIL-STD-461, Department of Defense, Interface Standard: Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, Current Edition.

[B11] MIL-STD-464, Department of Defense, Interface Standard: Electromagnetic Environmental Effects Requirements for Systems, Current Edition.

[B12] MIL-STD-889, Department of Defense, Military Standard: Dissimilar Metals, Current Edition.

[B13] MIL-STD-962, Department of Defense, Standard Practice: Format and Content, Current Edition.

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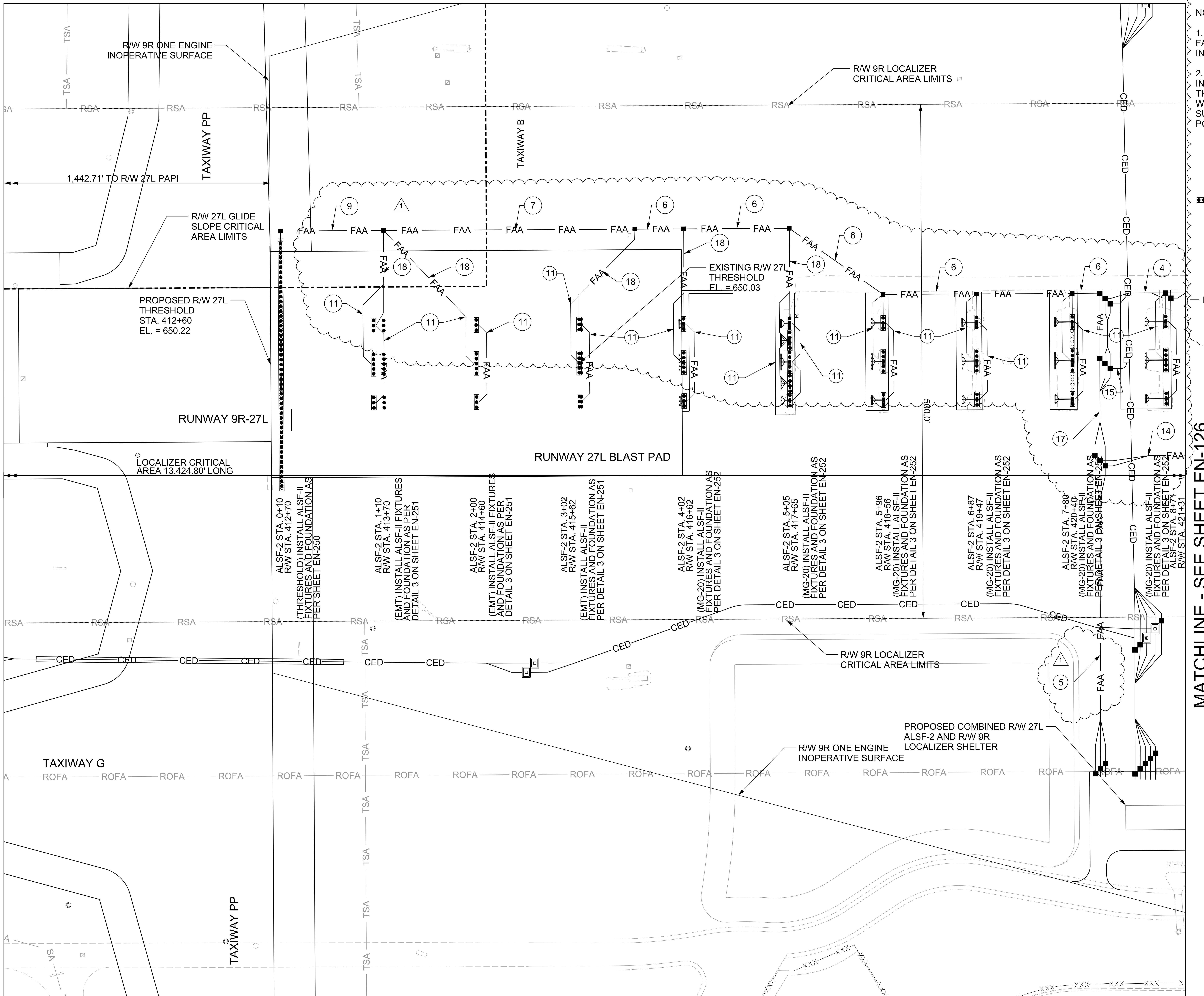


NOTES: 1

1. ALSF-2 STATIONS SHALL RECEIVE NEW FAA FOTS AND POWER IN EXISTING INFRASTRUCTURE.

2. ALSF-2 STATIONS SHALL BE RE-USED IN NEW LOCATIONS WHEREVER POSSIBLE. THE CONDITION OF EXISTING STATIONS WILL BE EVALUATED AT A LATER DESIGN SUBMITTAL TO VERIFY THE RE-USE, OR POSSIBLE REPLACEMENT.

LEGEND

- NEW ALSF-2 STATION IN PAVEMENT
- NEW ALSF-2 THRESHOLD BAR IN PAVEMENT
- R — RELOCATED ALSF-2 STATION
- EXISTING ALSF-2 STATION TO REMAIN IN CURRENT LOCATION
- ALSF-2 AIRCRAFT RATED HANDHOLE
- FAA — ALSF-2 DUCT BANK
- XX — SEE SHEET EN-130 FOR DUCT BANK ASSIGNMENTS

CDA CHICAGO DEPARTMENT OF AVIATION

O'HARE INTERNATIONAL AIRPORT
CITY OF CHICAGO
DEPARTMENT OF AVIATION

LORI E. LIGHTFOOT
MAYOR

JAMIE L. RHEE
COMMISSIONER

CARD JV
CHICAGO AVIATION RUNWAY DESIGNERS

APPROVED AS WORKING PLAN BY:

REV	DATE	DESCRIPTION
1	2/26/20	ADDENDUM NO. 3
0	12/31/19	ISSUED FOR BID

PROJECT NAME:

O'HARE MODERNIZATION PROGRAM COMPLETION PHASE

RUNWAY 9R-27L EXTENSION - EAST

SHEET TITLE:

AIRFIELD NAVAIDS LAYOUT PLAN

DESIGNED:	DRAWN:	CHECKED:
DYE	SMF	MAR

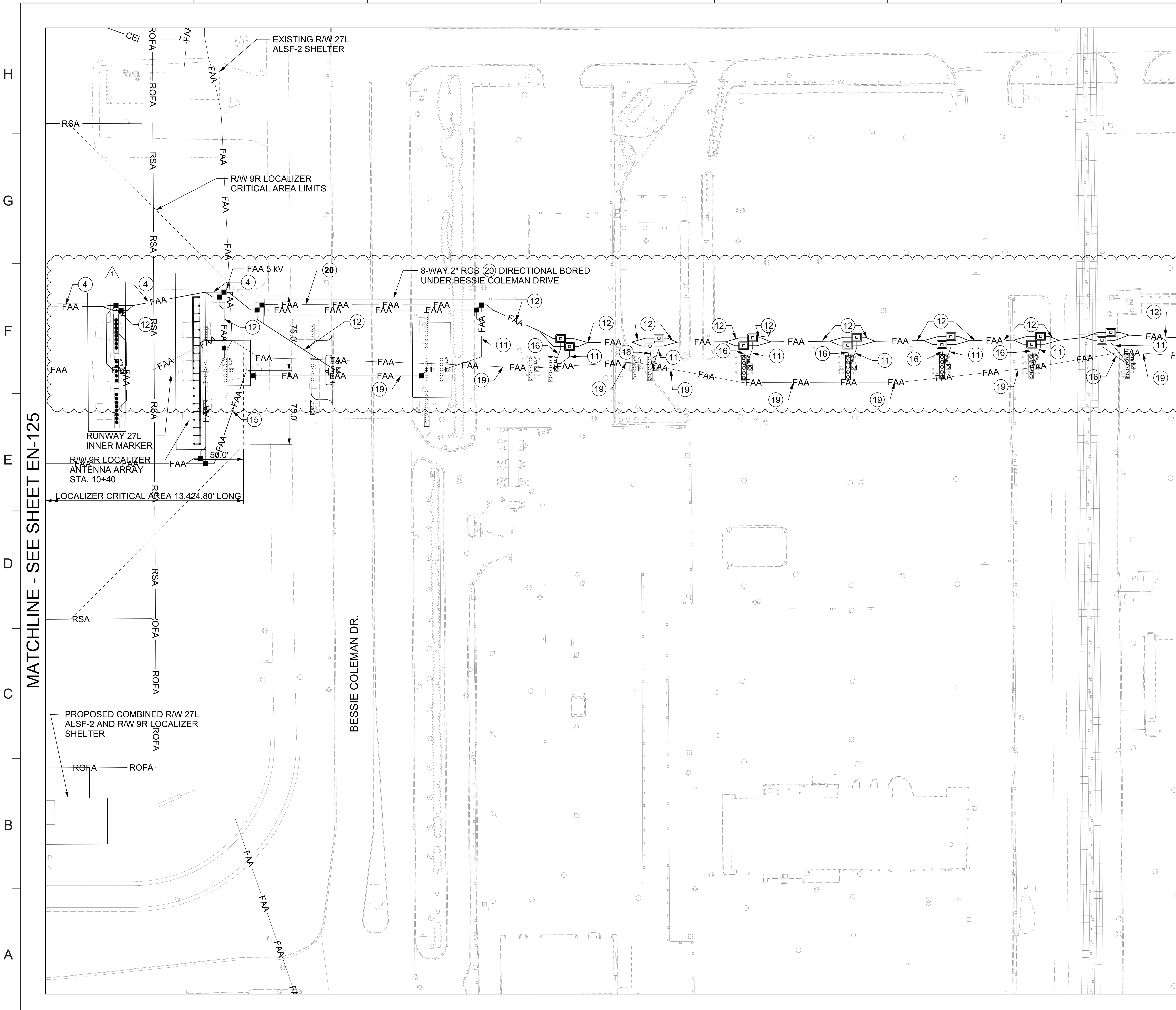
PROJECT NO.: OH6144.200.422

DATE: DECEMBER 31, 2019

SHEET NO.: EN-125

REVISION

$TIMES $DATE$ $FILE$



NOTES: 1

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2. ALSF-2 STATIONS SHALL BE RE-USED IN NEW LOCATIONS WHEREVER POSSIBLE. THE CONDITION OF EXISTING STATIONS WILL BE EVALUATED AT A LATER DESIGN SUBMITTAL TO VERIFY THE RE-USE, OR POSSIBLE REPLACEMENT.

LEGEND

- NEW ALSF-2 STATION IN PAVEMENT
- NEW ALSF-2 THRESHOLD BAR IN PAVEMENT
- R — RELOCATED ALSF-2 STATION
- EXISTING ALSF-2 STATION TO REMAIN IN CURRENT LOCATION
- ALSF-2 AIRCRAFT RATED HANDHOLE
- FAA — ALSF-2 DUCT BANK
- XX — SEE SHEET EN-130 FOR DUCT BANK ASSIGNMENTS

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COMMISSIONER

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CHICAGO AVIATION RUNWAY DESIGNERS

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PROJECT NAME:
O'HARE MODERNIZATION PROGRAM COMPLETION PHASE
RUNWAY 9R-27L EXTENSION - EAST

SHEET TITLE:
AIRFIELD NAVAIDS LAYOUT PLAN

DESIGNED:	DRAWN:	CHECKED:
DYE	SMF	MAR

PROJECT NO.: OH6144.200.422
DATE: DECEMBER 31, 2019

SHEET NO.: EN-126
REVISION

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NOTES: 1

1. ALSF-2 STATIONS SHALL RECEIVE NEW FAA FOTS AND POWER IN EXISTING INFRASTRUCTURE.

2. ALSF-2 STATIONS SHALL BE RE-USED IN NEW LOCATIONS WHEREVER POSSIBLE. THE CONDITION OF EXISTING STATIONS WILL BE EVALUATED AT A LATER DESIGN SUBMITTAL TO VERIFY THE RE-USE, OR POSSIBLE REPLACEMENT.

LEGEND

NEW ALSF-2 STATION IN PAVEMENT

NEW ALSF-2 THRESHOLD BAR IN PAVEMENT

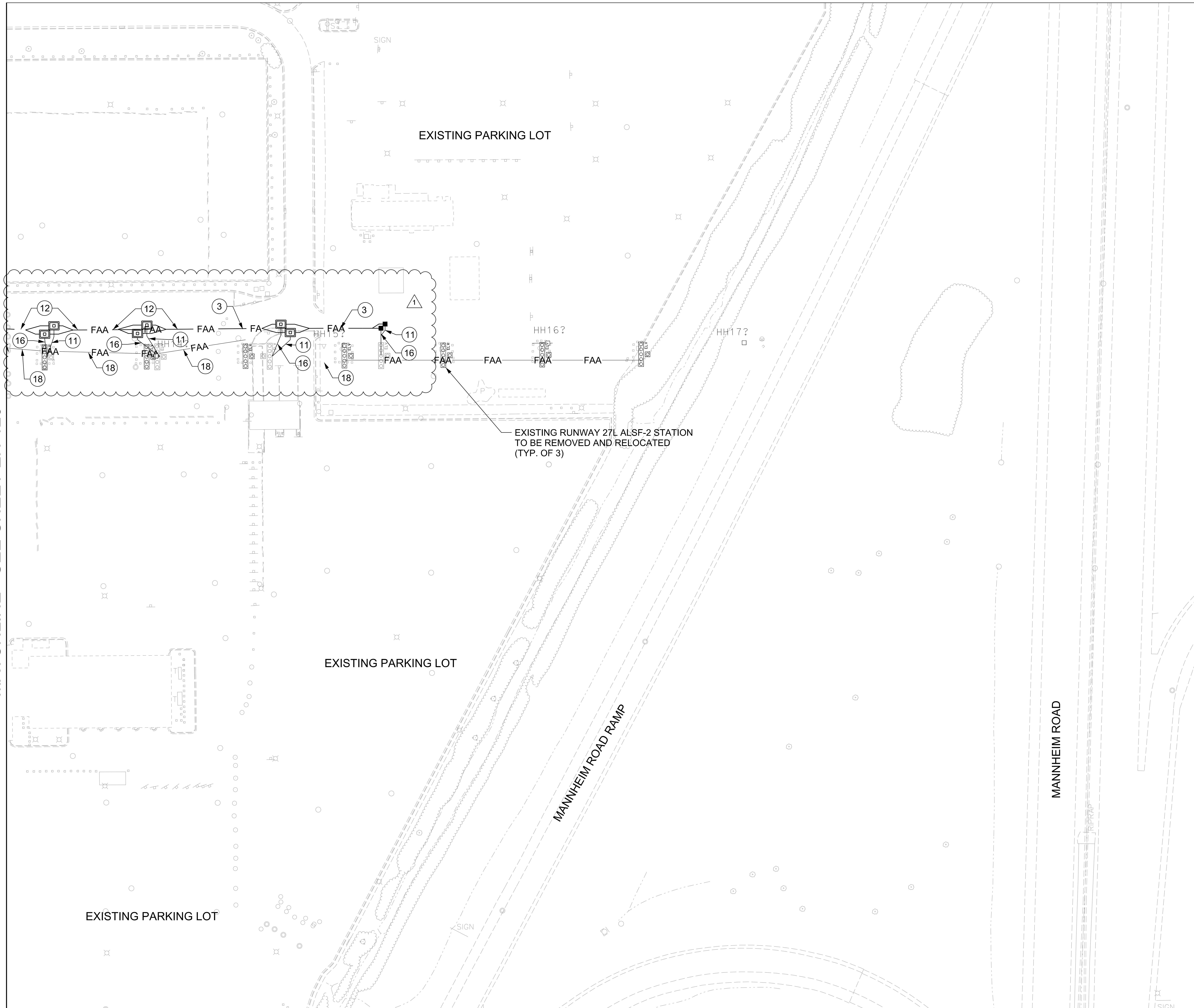
RELOCATED ALSF-2 STATION

EXISTING ALSF-2 STATION TO REMAIN IN CURRENT LOCATION

ALSF-2 AIRCRAFT RATED HANDHOLE

FAA — ALSF-2 DUCT BANK

XX SEE SHEET EN-130 FOR DUCT BANK ASSIGNMENTS



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0	12/31/19	ISSUED FOR BID

PROJECT NAME:

O'HARE MODERNIZATION PROGRAM COMPLETION PHASE

RUNWAY 9R-27L EXTENSION - EAST

SHEET TITLE:

AIRFIELD NAVAIDS LAYOUT PLAN

DESIGNED:	DRAWN:	CHECKED:
DYE	SMF	MAR

PROJECT NO.: OH6144.200.422

DATE: DECEMBER 31, 2019

SHEET NO.: EN-127

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NUMBER LEGENDS: 1

(2) 8-WAY 2" PVC CONCRETE ENCASED DUCTBANK WITH 6" SEPERATION
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" WITH 3-1/C #2, 600V (FLASHER POWER) & #6 INSL GRN GND
1-2" WITH 1-12 PAIR, TWISTED, SHIELDED #19 SIGNAL CABLE (FLASHER ICC SIGNAL) & #6 INSL GRN GND
1-2" SPARE WITH PULL CORD
1-2" SPARE WITH PULL CORD
1-2" SPARE WITH PULL CORD
1-2" SPARE WITH PULL CORD
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
8 - PULL WIRES

(3) 8-WAY 4" PVC CONCRETE ENCASED DUCTBANK WITH 6" SEPERATION
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 3-1/C #2, 600V (FLASHER POWER) & #6 INSL GRN GND
1-4" WITH 1-12 PAIR, TWISTED, SHIELDED #19 SIGNAL CABLE (FLASHER ICC SIGNAL) & #6 INSL GRN GND
1-4" SPARE WITH PULL CORD
1-4" SPARE WITH PULL CORD
1-4" SPARE WITH PULL CORD
1-4" SPARE WITH PULL CORD
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
8 - PULL WIRES

(4) 8-WAY 4" PVC CONCRETE ENCASED DUCTBANK WITH 6" SEPERATION
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 3-1/C #2, 600V (FLASHER POWER) & #6 INSL GRN GND
1-4" WITH 1-12 PAIR, TWISTED, SHIELDED #19 SIGNAL CABLE (FLASHER ICC SIGNAL) & #6 INSL GRN GND
1-4" SPARE WITH PULL CORD
1-4" SPARE WITH PULL CORD
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
8 - PULL WIRES

(5) 14-WAY 4" PVC CONCRETE ENCASED DUCTBANK WITH 6" SEPERATION
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 3-1/C #2, 600V (FLASHER POWER) & #6 INSL GRN GND
1-4" WITH 1-12 PAIR, TWISTED, SHIELDED #19 SIGNAL CABLE (FLASHER ICC SIGNAL) & #6 INSL GRN GND
1-4" WITH 3-1/C #10, 600V, TYPE XHHW-2 (LOC POWER) & 1#6 INSULATED GND
1-4" WITH 4-5/8" HELIAX (RF) CABLES AND 1-12 PR SHIELDED CONTROL CABLE
5-4" SPARE WITH PULL CORD
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
14 - PULL WIRES

(6) 4-WAY 4" PVC CONCRETE ENCASED DUCTBANK
1-4" WITH 4-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 4-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
4 - PULL WIRES

(7) 4-WAY 4" PVC CONCRETE ENCASED DUCTBANK
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
4 - PULL WIRES

(8) 1-WAY 2" PVC CONCRETE ENCASED DUCTBANK
1-5/8" HELIAX CABLE & 1-1/C #6 GREEN GND
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
1 - PULL WIRE

(9) 4-WAY 4" PVC CONCRETE ENCASED DUCTBANK
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" SPARE WITH PULL CORD
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
4 - PULL WIRES

(10) 1-WAY 2" PVC CONCRETE ENCASED DUCTBANK
1-2" WITH 4-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
1 - PULL WIRES

(11) 1-WAY 2" PVC CONCRETE ENCASED DUCTBANK
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
1 - PULL WIRE

(12) 2-WAY 2" PVC CONCRETE ENCASED DUCTBANK WITH 6" SEPERATION
1-2" WITH 3-1/C #2, 600V (FLASHER POWER) & #6 INSL GRN GND
1-2" WITH 1-12 PAIR, TWISTED, SHIELDED #19 SIGNAL CABLE (FLASHER ICC SIGNAL) & #6 INSL GRN GND
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
2 - PULL WIRES

(13) 8-WAY 2" PVC CONCRETE ENCASED DUCTBANK WITH 6" SEPARATION
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" WITH 3-1/C #2, 600V (FLASHER POWER) & #6 INSL GRN GND
1-2" WITH 1-12 PAIR, TWISTED, SHIELDED #19 SIGNAL CABLE (FLASHER ICC SIGNAL) & #6 INSL GRN GND
4-2" SPARE WITH PULL CORD.
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
8 - PULL WIRES

(14) 4-WAY 4" PVC CONCRETE ENCASED DUCTBANK WITH 6" SEPARATION
1-4" WITH 4-5/8" HELIAX (RF) CABLES
1-4" WITH 1-12 PR SHIELDED CONTROL CABLE
1-4" WITH 3-1/C #10, 600V, TYPE XHHW-2 (LOC POWER) & 1#6 INSULATED GND
1-4" SPARE
4 - PULL WIRE

(15) 1-WAY 2" PVC CONCRETE ENCASED DUCTBANK
1-2" WITH `-5/8" HELIAX (RF) CABLES
1 - PULL WIRE

(16) 2-WAY 2" PVC CONCRETE ENCASED DUCTBANK WITH 6" SEPARATION
1-2" WITH 3-1/C #2, 600V (FLASHER POWER) & #6 INSL GRN GND
1-2" WITH 1-12 PAIR, TWISTED, SHIELDED #19 SIGNAL CABLE (FLASHER ICC SIGNAL) & #6 INSL GRN GND
2 - PULL WIRES

(17) 14-WAY 4" PVC CONCRETE ENCASED DUCTBANK WITH 6" SEPERATION
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-4" WITH 3-1/C #2, 600V (FLASHER POWER) & #6 INSL GRN GND
1-4" WITH 1-12 PAIR, TWISTED, SHIELDED #19 SIGNAL CABLE (FLASHER ICC SIGNAL) & #6 INSL GRN GND
7-4" SPARE WITH PULL CORD
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
14 - PULL WIRES

(18) 2-WAY 2" PVC CONCRETE ENCASED DUCTBANK
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
2 - PULL WIRES

(19) EXISTING 6-WAY 2" PVC CONCRETE ENCASED DUCTBANK
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" WITH 2-1/C NO. 8, 5KV, TYPE C AND NO. 6 INSL GRN GND
1-2" SPARE
6 - PULL WIRES

(20) 8-WAY 2" PVC DIRECTIONAL BORE ENCASED DUCTBANK
1-2" WITH 3-1/C #2, 600V (FLASHER POWER) & #6 INSL GRN GND
1-2" WITH 1-12 PAIR, TWISTED, SHIELDED #19 SIGNAL CABLE (FLASHER ICC SIGNAL) & #6 INSL GRN GND
1-1/C #1/0 BARE COPPER GUARD WIRE OVER DUCT
6-2" SPARE
8 - PULL WIRES

NOTES:

1. CABLE TAGS APPLY TO AREA PLANS.

2. PULL WIRES WILL BE INSTALLED TO FACILITATE INSTALLATION OF ALSF-2 CABLING. PULL WIRES WILL BE INSTALLED WHERE END POINTS OF THE DUCTBANK EXIST. PULL WIRE WILL NOT BE INSTALLED WHERE CONDUITS ARE CAPPED FOR FUTURE USE.

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COMMISSIONER

CARD JV
CHICAGO AVIATION RUNWAY DESIGNERS

APPROVED AS WORKING PLAN BY:

REV	DATE	DESCRIPTION
1	2/26/20	ADDENDUM NO. 3
0	12/31/19	ISSUED FOR BID

PROJECT NAME:
O'HARE MODERNIZATION PROGRAM COMPLETION PHASE
RUNWAY 9R-27L EXTENSION - EAST

SHEET TITLE:
ALSF-2 DUCTBANK AND CABLE LEGEND

DESIGNED:	DRAWN:	CHECKED:
DYE	EJZ	MAR

PROJECT NO.: OH6144.200.422
DATE: DECEMBER 31, 2019

SHEET NO. EN-130
REVISION

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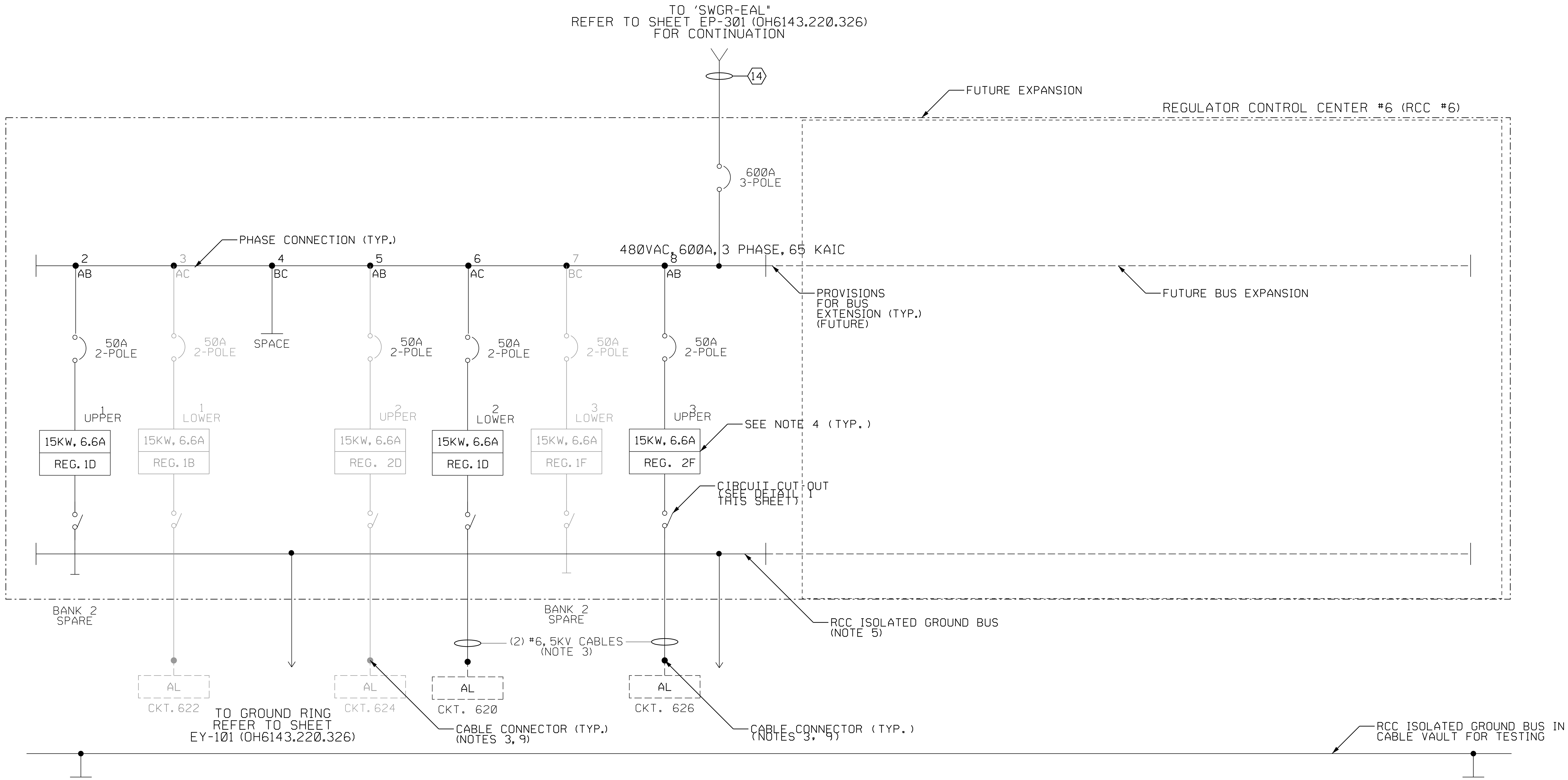


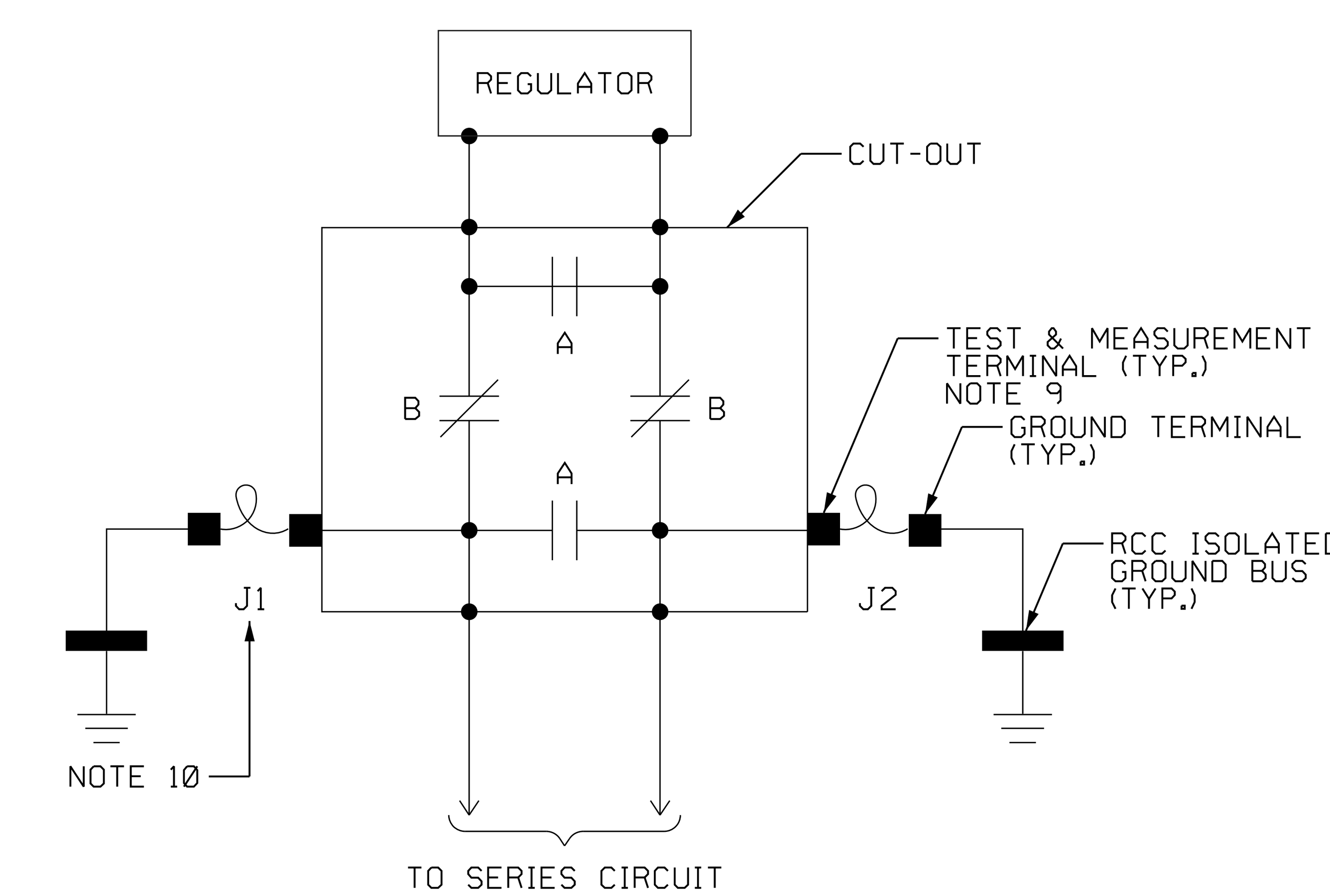
NOTES:

1. MANUFACTURER TO PROVIDE MEANS TO CONNECT TO BUS STRUCTURE FOR FUTURE REGULATOR SECTIONS.
2. NOT USED.
3. CABLES SHALL CONFORM TO FAA SPECIFICATIONS FOR L-824 UNDERGROUND ELECTRICAL CABLE FOR AIRPORT LIGHTING CIRCUITS. CABLE SPLICES MUST CONFORM TO FAA ADVISORY CIRCULAR 150/5340-30, DESIGN AND INSTALLATION FOR AIRPORT VISUAL AIDS.
4. REGULATOR I.D. GIVEN IS GENERIC. CONTRACTOR MUST COORDINATE SPECIFIC REGULATOR I.D. WITH THE CDA. CONTRACTOR SHALL PROVIDE LABEL WITH SPECIFIC I.D. FOR EACH REGULATOR.
5. ISOLATED GROUND BUS SHALL BE PROVIDED IN REGULATOR CONTROL CENTER. EACH REGULATOR WILL HAVE ISOLATED GROUND BAR WHICH SHALL BE CONNECTED TO THE MAIN ISOLATED GROUND BUS IN THE REGULATOR CONTROL CENTER.
6. ALL WORK, EQUIPMENT, MATERIALS, TESTING, ETC. REQUIRED FOR THE INSTALLATION OF THE REGULATOR CONTROL CENTER, AS DETAILED ON THIS SHEET, IS TO BE PAID UNDER ITEM 16010. REFER TO SPECIFICATIONS FOR ADDITIONAL DETAILS.
7. MANUFACTURER TO PERFORM CALCULATIONS TO OPTIMIZE BUS PHASE BALANCING.
8. NOT USED.
9. EXISTING LIGHTING CIRCUIT CABLES FROM RCC TO CABLE VAULT WITH L-823 CONNECTOR AT ENDS IN CABLE VAULT. PROVIDE ONE (1) TYPE 10 CONNECTOR.
10. CUT-OUT TO HAVE GROUND & TEST TERMINAL FOR INSTALLATION OF JUMPER J1 & J2. WITH JUMPERS REMOVED, TEST & MEASUREMENT TERMINAL CAN BE USED TO MANUALLY MEASURE INSULATION RESISTANCE OF SERIES CIRCUIT.

CIRCUIT CUT-OUT STATE TABLE

MODE OF OPERATION	CONTACT/ JUMPER STATE			
	A	B	J1	J2
NORMAL MODE	OPEN	X	OPEN	OPEN
SHORTED MODE	X	OPEN	OPEN	OPEN
SUPPLY GROUNDED	OPEN	X	OPEN	X
RETURN GROUNDED	OPEN	X	X	OPEN

NOTE: BOX WITH X IN IT DENOTES "CLOSED".



1 CUT-OUT SWITCH WIRING DIAGRAM
NTS
(TYPICAL FOR RCC #2 TO RCC #5)

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MAYOR
JAMIE L. RHEE
COMMISSIONER

CARD JV CHICAGO AVIATION RUNWAY DESIGNERS

APPROVED AS WORKING PLAN
BY:

REV	DATE	DESCRIPTION
0	02/26/20	ADDENDUM NO. 3

PROJECT NAME:
O'HARE MODERNIZATION PROGRAM
COMPLETION PHASE
RUNWAY 9R-27L EXTENSION - EAST

SHEET TITLE:
RCC #6
SINGLE LINE DIAGRAM

DESIGNED: DYE DRAWN: JY CHECKED: MAR

PROJECT NO.: OH6144.200.422
DATE: DECEMBER 31, 2019

SHEET NO.: EP-300 REVISION

2/25/2020 8:39:21 AM
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