CHAPTER 9

PIPE SELECTON, BEDDING AND BACKFILL

9-1 **GENERAL.** A drainage pipe is defined as a structure (other than a bridge) to convey water through a trench or under a fill or some other obstruction. Materials for permanent-type installations include non-reinforced concrete, reinforced concrete, corrugated steel, plastic, corrugated aluminum alloy, and structural plate steel pipe.

9-1.1 **Pipe Selection**

9-1.1.1 The selection of a suitable construction conduit will be governed by the availability and suitability of pipe materials for local conditions with due consideration of economic factors. It is desirable to permit alternates so that bids can be received with contractors' options for the different types of pipe suitable for a specific installation. Allowing alternates serves as a means of securing bidding competition. When alternate designs are advantageous, each system will be economically designed, taking advantage of full capacity, best slope, least depth, and proper strength and installation provisions for each material involved. Where field conditions dictate the use of one pipe material in preference to others, the reasons will be clearly presented in the design analysis.

9-1.1.2 Consider life cycle cost factors in selecting the type of pipe to be used in construction. The factors include strength under either maximum or minimum cover being provided, pipe bedding and backfill conditions, anticipated loadings, length of pipe sections, ease of installation, resistance to corrosive action by liquids carried or surrounding soil materials, suitability of jointing methods, provisions for expected deflection without adverse effect on the pipe structure or on the joints or overlying materials, and cost of maintenance. Although it is possible to obtain an acceptable pipe installation to meet design requirements by establishing special provisions for several possible materials, ordinarily only one or two alternates will economically meet the individual requirements for a proposed drainage system.

9-1.1.3 DOD has approved the use of plastic pipe for low volume roadway applications; however, it is not approved for use under any type of airfield pavement except for subsurface water collection and disposal.

9-1.2 **Selection of *n* Values.** Roughness should be a considered when selecting pipe options. A designer is continually confronted with what coefficient of roughness, *n*, to use in a given situation. The question of whether *n* should be based on the new and ideal condition of a pipe or on an anticipated condition at a later date is difficult to answer. Sedimentation or paved pipe can affect the coefficient of roughness. Roughness coefficients for pipe are covered in Chapter 6.

9-1.3 **Restricted Use of Bituminous-Coated Pipe.** Corrugated metal pipe with any percentage of bituminous coating will not be installed where solvents can be expected to enter the pipe. If corrugated steel is a pipe option where solvents are expected, polymeric coated corrugated steel pipe is recommended.

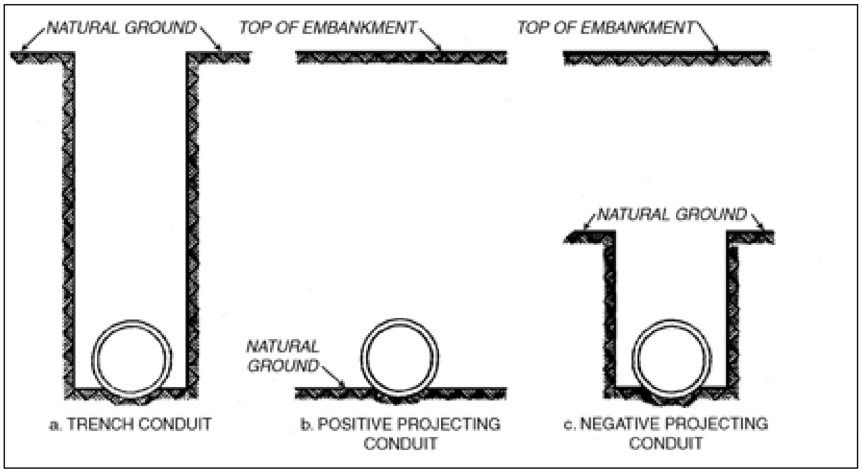
9-1.3.1 The selection of culvert materials to withstand deterioration from corrosion or abrasion will be based on these specific considerations:

9-1.3.1.1 Rigid or plastic pipes are preferable where industrial wastes, spilled petroleum products, or other substances harmful to bituminous paving and coating in corrugated metal pipe are apt to be present. Concrete pipe typically should not be used where soil is more acidic than pH 5.5 or where the fluid carried has a pH less than 5.5 or higher than 9.0. High density polyethylene (HDPE) pipe is unaffected by acidic or alkaline soil conditions. Concrete pipe can be engineered to perform very satisfactorily in the more severe acidic or alkaline environments. Type II or Type V cements should be used where soils and/or water have a moderate or high sulfate concentration, respectively. High-density concrete pipe is recommended when the culvert will be subject to tidal drainage and saltwater spray. Where highly corrosive substances are to be carried, the resistive qualities of vitrified clay pipe or plastic-lined concrete pipe should be considered.

9-1.3.1.2 Corrugated steel pipe will be galvanized and generally will be bituminous coated for permanent installations. Bituminous coating or polymeric coating is recommended for corrugated steel pipe subjected to stagnant water; where dense decaying vegetation is present to form organic acids; where there is continuous wetness or continuous flow; and in well-drained, normally dry, alkali soils. The polymeric-coated pipe is not damaged by spilled petroleum products or industrial wastes. Corrugated aluminum alloy pipe, fabricated in all of the shapes and sizes of the more familiar corrugated steel pipe, evidences corrosion resistance in clear granular materials even when subjected to sea water. Corrugated aluminum pipe will not be installed in soils that are highly acid (pH less than 5) or alkaline (pH greater than 9), or in metallic contact with other metals or metallic deposits, or where known corrosive conditions are present or where bacterial corrosion is known to exist. Similarly, this type pipe will not be installed in material classified as OH (organic clays of medium to high plasticity, organic silts) or OL (organic silts and organic silty clays of low plasticity) according to the Unified Soil Classification System (ASTM D2487-00). Although bituminous coatings can be applied to aluminum alloy pipe, such coatings do not afford adequate protection (bituminous adhesion is poor) under the aforementioned corrosive conditions. Suitable protective coatings for aluminum alloy have been developed but are not economically feasible for culverts or storm drains. When considering a coating for use, performance data from users in the area can be helpful. Performance history indicates various successes or failures of coatings and their probable cause, and such histories are available from local highway departments.

9-1.4 **Classes of Bedding and Installation**. Figures 9-1 through 9-4 indicate the classes of bedding for conduits. Figure 9- 5 is a schematic representation of the subdivision of classes of conduit installation that influence loads on underground conduits.

Figure 9-1. Three Main Classes of Conduits



9-1.5 **Strength of Pipe**. Pipe shall be considered of ample strength when it meets the conditions specified for the loads indicated in Tables 9-1 through 9-7. When railway or vehicular wheel loads or loads due to heavy construction equipment (live loads, LL) impose heavier loads, or when the earth (or dead loads, DL) vary materially from those normally encountered, these tables cannot be used for pipe installation design and separate analyses must be made. The suggested minimum and maximum cover shown in the tables pertain to pipe installations in which the backfill material is compacted to at least 90 percent of ASTM D1557 or AASHTO T99 density (100 percent for cohesionless sands and gravels). This does not modify requirements for any greater degree of compaction specified for other reasons. It is emphasized that proper bedding, backfilling, compaction, and prevention of infiltration of backfill material into pipe are important not only to the pipe, but also to protect overlying and nearby structures. When in doubt about minimum and maximum cover for local conditions, a separate cover analysis must be performed.

9-1.6 **Rigid Pipe**. Tables 9-1 and 9-2 indicate maximum and minimum cover for trench conduits employing pipe and concrete pipe. If positive projecting conduits are employed, they are installed in shallow bedding with a part of the conduit projecting above the surface of the natural ground and then covered with an embankment. Due allowance will be made in amounts of minimum and maximum cover for positive projecting conduits. Table 9-8 suggests guidelines for minimum cover to protect the pipe during construction and the minimum finished height of cover.

Figure 9-2. Free-Body Conduit Diagrams

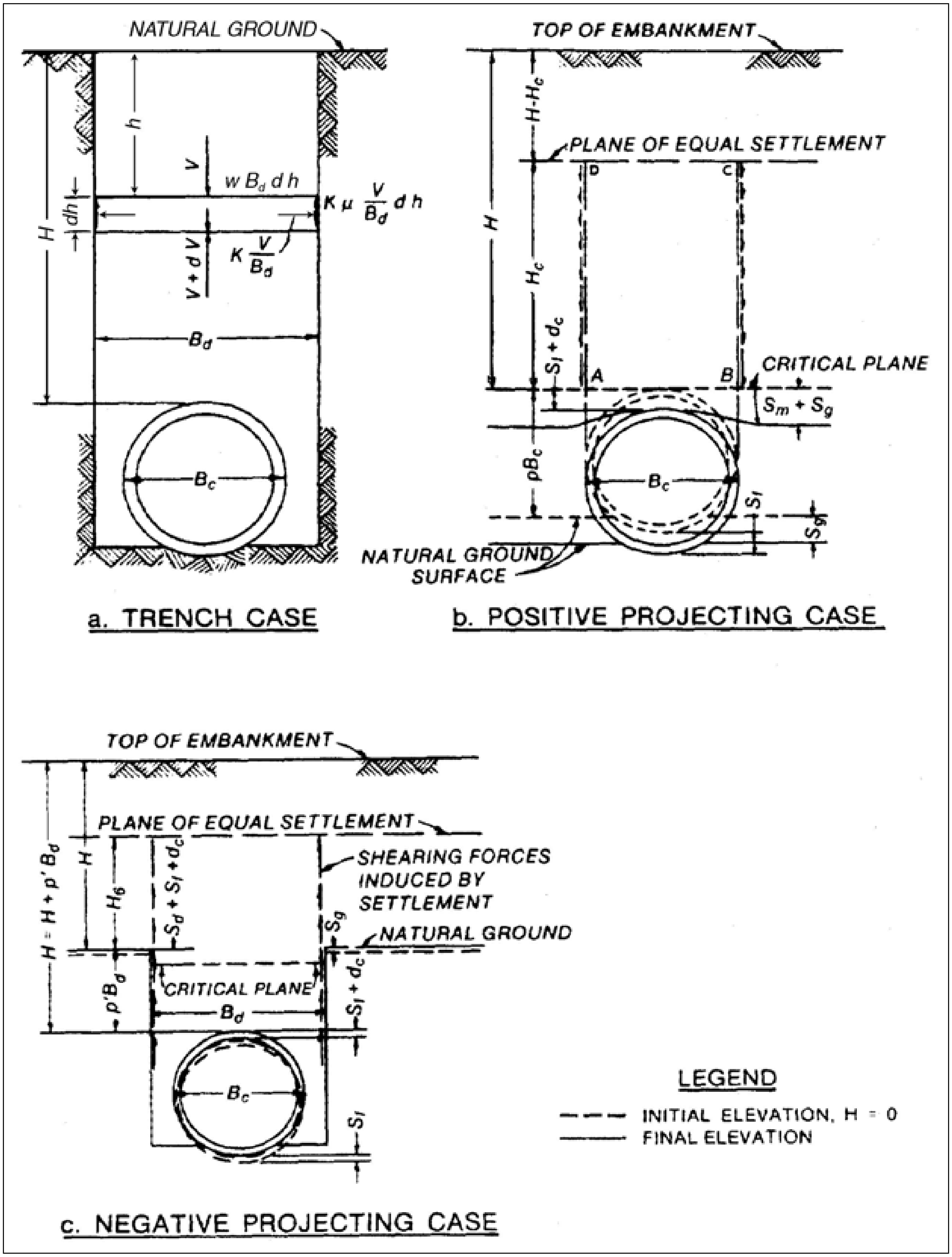
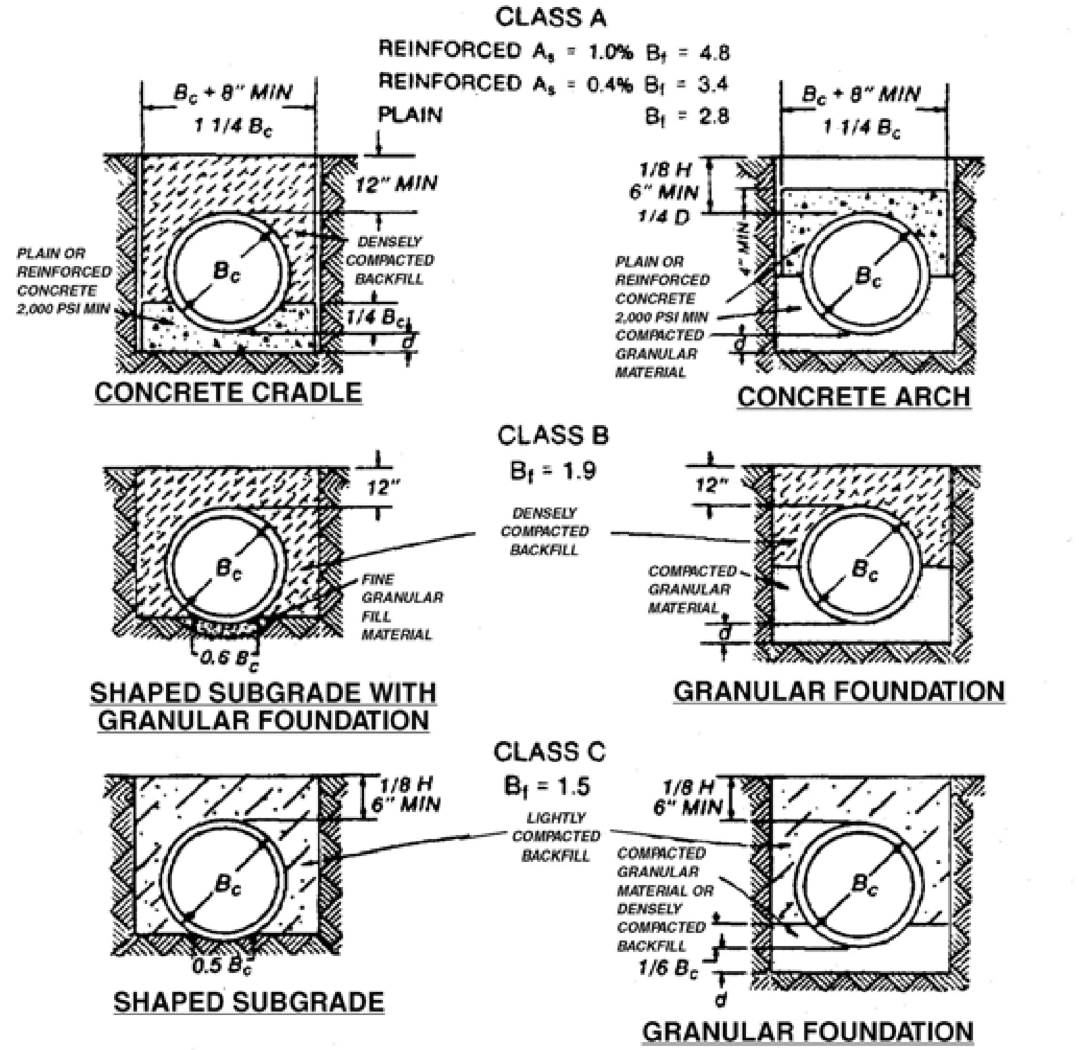
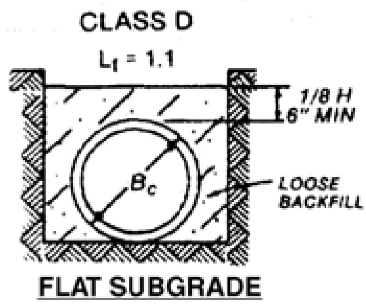


Figure 9-3. Trench Beddings for Circular Pipe





LEGEND

- B_c = OUTSIDE DIAMETER OF PIPE
- H = BACKFILL COVER ABOVE TOP OF PIPE
- D = INSIDE DIAMETER OF PIPE
- d = DEPTH OF BEDDING MATERIAL BELOW PIPE
- A_s = AREA OF TRANSVERSE STEEL IN THE CRADLE OR ARCH EXPRESSED AS 3 PERCENT OF THE AREA OF CONCRETE AT THE INVERT OR CROWN
- B_f = RATIO OF SUPPORTED STRENGTH OF PIPE TO THREE-EDGE BEARING STRENGTH

NOTE: FOR ROCK OR OTHER INCOMPRESSIBLE MATERIAL, THE TRENCH SHOULD BE OVEREXCAVATED A MINIMUM OF 6 IN. AND REFILLED WITH GRANULAR MATERIAL.

DEPTH OF BEDDING MATERIAL BELOW PIPE	
D	d (MIN.)
27" & SMALLER	3"
30" TO 60"	4"
66" & LARGER	6"

Figure 9-4. Beddings for Positive Projecting Conduits

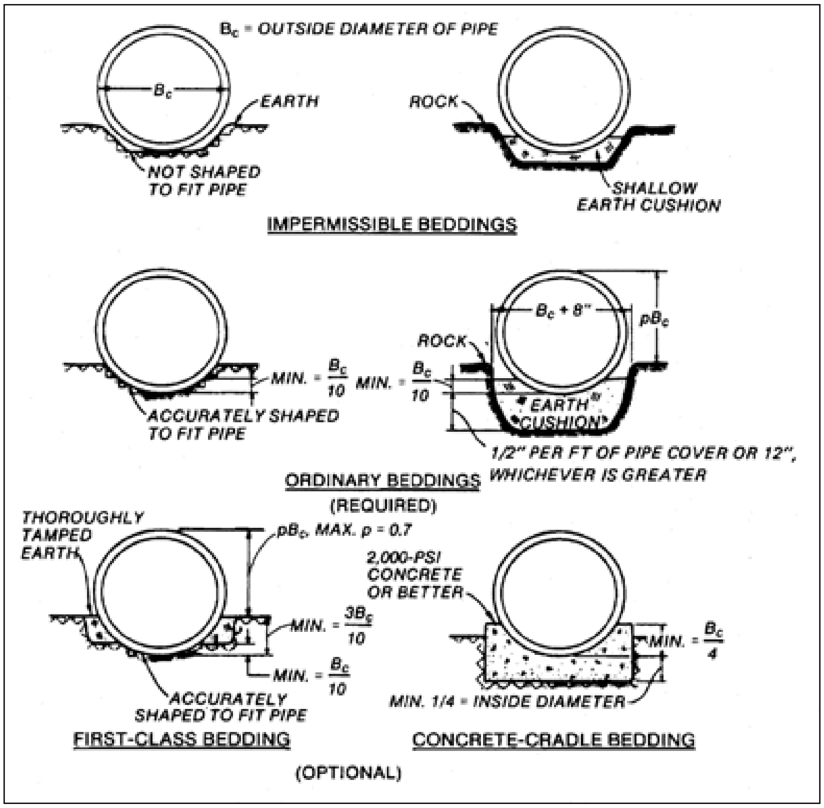


Figure 9-5. Installation Conditions that Influence Loads on Underground Conduits

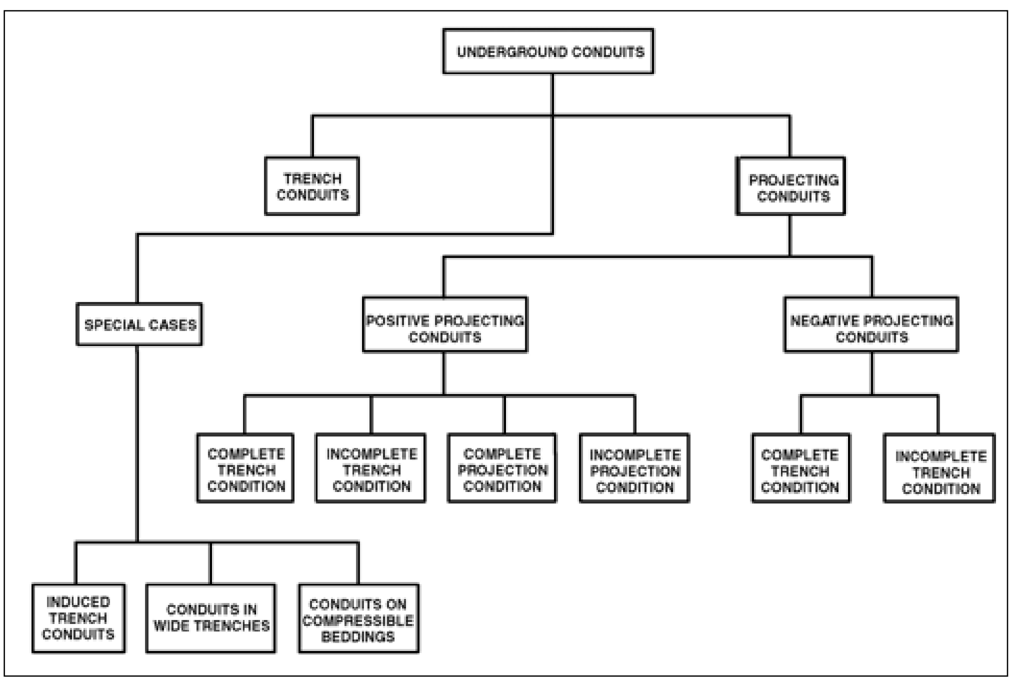


Table 9-1. Suggested Maximum Cover Requirements for Concrete Pipe, Reinforced Concrete, H-20 Highway Loading*

Diameter, in.	Suggested Maximum Cover Above Top of Pipe, ft — Circular Section — Class				
	1500	2000	2500	3000	3750
12	9	13	16	19	24
24	10	13	17	19	24
36	10	13	17	20	25
48	10	13	17	20	25
60	10	14	17	20	25
72	10	14	17	20	25
84	11	14	17	21	24
108	11	14	17	21	26

Non-reinforced Concrete

Diameter, in.	Suggested Maximum Cover Above Top of Pipe, ft — Circular Section		
	I	II	III
12	14	14	17
24	13	13	14
36	9	12	12

*Source: U.S. Army Corps of Engineers

Notes:

1. The suggested values shown are for average conditions and are to be considered as guidelines only for dead load plus H-20 live load.
2. Soil conditions, trench width, and bedding conditions vary widely throughout varying climatic and geographical areas.
3. Calculations to determine maximum cover should be made for all individual pipe and culvert installations underlying roads, streets, and open storage areas subject to H-20 live loads. Cooper E-80 railway loadings should be independently made.
4. Cover depths are measured from the bottom of the subbase of pavements, or the top of unsurfaced areas, to the top of the pipe.
5. Calculations to determine maximum cover for Cooper E-80 railway loadings are measured from the bottom of the tie to the top of the pipe.
6. “D” loads listed for the various classes of reinforced-concrete pipe are the minimum required 3-edge test loads to produce ultimate failure in pounds per linear foot of interval pipe diameter.
7. Each diameter pipe in each class designation of non-reinforced concrete has a different D-load value that increases with wall thickness.
8. If pipe produced by a manufacturer exceeds the strength requirements established by indicated standards, cover depths may be adjusted accordingly.
9. See Table 9-9 for suggested minimum cover requirements.

Table 9-2. Suggested Maximum Cover Requirements for Corrugated Aluminum Alloy Pipe, Riveted, Helical, or Welded Fabrication 2.66-in. Spacing, 0.5-in.-Deep Corrugations, H-20 Highway Loading*

Diameter, in.	Suggested Maximum Cover Above Top of Pipe, ft									
	Circular Section					Vertically Elongated Section				
	Thickness, in.					Thickness, in.				
	.060	.075	.105	.135	.164	.060	.075	.105	.135	.164
12	50	50	86	90	93					
15	40	40	69	72	74					
18	33	33	57	60	62					
24	25	25	43	45	46					
30	20	20	34	36	37					
36	16	16	28	30	31					
42	16	16	28	30	31			50	52	53
48			28	30	31			43	45	47
54			28	30	31					
60				30	31					
66					31					
72					31					

*Source: U.S. Army Corps of Engineers

Notes:

1. Corrugated aluminum alloy pipe will conform to the requirements of ASTM B745/B745M.

2. The suggested values shown are for average conditions and are guidelines only for dead load plus H-20 live load. Cooper E-80 railway loadings should be independently made.

3. Soil conditions, trench width, and bedding conditions vary widely throughout varying climatic and geographical areas.

4. Calculations to determine maximum cover should be made for all individual pipe and culvert installations underlying roads, streets, and open storage areas subject to H-20 live loads.

5. Cover depths are measured from the bottom of the subbase of pavements, or the top of unsurfaced areas, to the top of the pipe.

6. Calculations to determine maximum cover for Cooper E-80 railway loadings are measured from the bottom of the tie to the top of the pipe.

7. Vertical elongation will be accomplished by shop fabrication and will usually be 5 percent of the pipe diameter.

8. See Table 9-9 for suggested minimum cover requirements.

Table 9-3. Suggested Maximum Cover Requirements for Corrugated Steel Pipe, 2.66-in. Spacing, 0.5-in.-Deep Corrugations*

H-20 Highway Loading						
Suggested Maximum Cover Above Top of Pipe, ft						
Diameter, in.	Helical – Thickness, in.					
	.052	.064	.079	.109	.138	.168
12	170	213	266	372		
15	136	170	212	298		
18	113	142	173	212		
21	97	121	139	164		
24	85	106	120	137	155	
27	75	94	109	120	133	
30	68	85	101	110	119	
36	56	71	88	98	103	
42	48	60	76	92	95	99
48		53	66	88	91	93
54			59	82	88	90
60				74	86	87
66					85	86
72					79	85
78						84
84						75

*Source: U.S. Army Corps of Engineers

Notes:

1. Corrugated steel pipe will conform to the requirements of ASTM A760/A760M-01a, ASTM A761/A761M-04, ASTM A762/A762M-00, and ASTM A849-00.
2. The suggested maximum heights of cover shown in the tables are calculated on the basis of the current AASHTO *Standard Specifications for Highway Bridges* and are based on circular pipe.
3. Soil conditions, trench width, and bedding conditions vary widely throughout varying climatic and geographical areas.
4. Calculations to determine maximum cover should be made for all individual pipe and culvert installations underlying roads, streets, and open storage areas subject to H-20 live loads. Cooper E-80 railway loadings should be independently made.
5. Cover depths are measured from the bottom of the subbase of pavements, or the top of unsurfaced areas, to the top of the pipe.
6. Calculations to determine maximum cover for Cooper E-80 railway loadings are measured from the bottom of the tie to the top of the pipe.
7. If pipe produced by a manufacturer exceeds the strength requirements established by indicated standards, then cover depths may be adjusted accordingly.
8. See Table 9-9 for suggested minimum cover requirements.

Table 9-4. Suggested Maximum Cover Requirements for Structural Plate Aluminum Alloy Pipe, 9-in. Spacing, 2.5-in. Corrugations*

H-20 Highway Loading							
Diameter, in.	Suggested Maximum Cover Above Top of Pipe, ft						
	Circular Section						
	Thickness, in.						
	0.10	0.125	0.15	0.175	0.20	0.225	0.250
72	24	32	41	48	55	61	64
84	20	27	35	41	47	52	55
96	18	24	30	36	41	45	50
108	16	21	27	32	37	40	44
120	14	19	24	29	33	36	40
132	13	17	22	26	30	33	36
144	12	16	20	24	27	30	33
156		14	18	22	25	28	30
168		13	17	20	23	26	28
180			16	19	22	24	26

*Source: U.S. Army Corps of Engineers

Notes:

1. Structural plate aluminum alloy pipe will conform to the requirements of ASTM B745/B745M.
2. Soil conditions, trench width, and bedding conditions vary widely throughout varying climatic and geographical areas.
3. Calculations to determine maximum cover should be made for all individual pipe and culvert installations underlying roads, streets, and open storage areas subject to H-20 live loads. Cooper E-80 railway loadings should be independently made.
4. Cover depths are measured from the bottom of the subbase of pavements, or the top of unsurfaced areas, to the top of the pipe.
5. Calculations to determine maximum cover for Cooper E-80 railway loadings are measured from the bottom of the tie to the top of the pipe.
6. If pipe produced by a manufacturer exceeds the strength requirements established by indicated standards, cover depths may be adjusted accordingly.
7. See Table 9-9 for suggested minimum cover requirements.

Table 9-5. Suggested Maximum Cover Requirements for Corrugated

H-20 Highway Loading					
Diameter, in.	Suggested Maximum Cover Above Top of Pipe, ft				
	Helical—Thickness, in.				
	.064	.079	.109	.138	.168
48	54	68	95	122	132
54	48	60	84	109	117
60	43	54	76	98	107
66	39	49	69	89	101
72	36	45	63	81	96
78	33	41	58	75	92
84	31	38	54	70	85
90	29	36	50	65	80
96		34	47	61	75
102		32	44	57	70
108			42	54	66
114			40	51	63
120			38	49	60

*Source: U.S. Army Corps of Engineers

Notes:

1. Corrugated steel pipe will conform to the requirements of ASTM A760/A760M-01a, ASTM A761/A761M-04, ASTM A762/A762M-00, and ASTM A849-00.

2. The suggested maximum heights of cover shown in the table are calculated on the basis of the current AASHTO *Standard Specifications for Highway Bridges* and are based on circular pipe.

3. Soil conditions, trench width, and bedding conditions vary widely throughout varying climatic and geographical areas.

4. Calculations to determine maximum cover should be made for all individual pipe and culvert installations underlying roads, streets, and open storage areas subject to H-20 live loads. Cooper E-80 railway loadings should be independently made.

5. Cover depths are measured from the bottom of the subbase of pavements, or the top of unsurfaced areas, to the top of the pipe.

6. Calculations to determine maximum cover for Cooper E-80 railway loadings are measured from the bottom of the tie to the top of the pipe.

7. If pipe produced by a manufacturer exceeds the strength requirements established by indicated standards, cover depths may be adjusted accordingly.

8. See Table 9-9 for suggested minimum cover requirements.

Table 9-6. Suggested Maximum Cover Requirements for Structural Plate Steel Pipe, 6-in. Span, 2-in.-Deep Corrugations*

H-20 Highway Loading							
Diameter, ft	Suggested Maximum Cover Above Top of Pipe, ft						
	Thickness, in.						
	.109	.138	.168	.188	.218	.249	.280
5.0	46	68	90	103	124	146	160
5.5	42	62	81	93	113	133	145
6.0	38	57	75	86	103	122	133
6.5	35	52	69	79	95	112	123
7.0	33	49	64	73	88	104	114
7.5	31	45	60	68	82	97	106
8.0	29	43	56	64	77	91	100
8.5	27	40	52	60	73	86	94
9.0	25	38	50	57	69	81	88
9.5	24	36	47	54	65	77	84
10.0	23	34	45	51	62	73	80
10.5	22	32	42	49	59	69	76
11.0	21	31	40	46	56	66	72
11.5	20	29	39	44	54	63	69
12.0	19	28	37	43	51	61	66
12.5	18	27	36	41	49	58	64
13.0	17	26	34	39	47	56	61
13.5	17	25	33	38	46	54	59
14.0	16	24	32	36	44	52	57
14.5	16	23	31	35	42	50	55
15.0	15	22	30	34	41	48	53
15.5	15	22	29	33	40	47	51
16.0		21	28	32	38	45	50
16.5		20	27	31	37	44	48
17.0		20	26	30	36	43	47
17.5		19	25	29	35	41	45
18.0			25	28	34	40	44
18.5			24	27	33	39	43
19.0			23	27	32	38	42
19.5			23	26	31	37	41
20.0				25	31	36	40
20.5				25	30	35	39
21.0					29	34	38
21.5					28	34	37
22.0					28	33	36
22.5					27	32	35
23.0						31	34
23.5						31	34
24.0						30	33
24.5							32
25.0							32
25.5							31

*Source: U.S. Army Corps of Engineers

Notes:

1. Corrugated steel pipe will conform to the requirements of ASTM A760/A760M-01a, ASTM A761/A761M-04, ASTM A762/A762M-00, and ASTM A849-00.

2. The suggested maximum heights of cover shown in the table are calculated on the basis of the current AASHTO *Standard Specifications for Highway Bridges* and are based on circular pipe.

3. Soil conditions, trench width, and bedding conditions vary widely throughout varying climatic and geographical areas.

4. Calculations to determine maximum cover should be made for all individual pipe and culvert installations underlying roads, streets, and open storage areas subject to H-20 live loads. Cooper E-80 railway loadings should be independently made.

5. Cover depths are measured from the bottom of the subbase of pavements, or the top of unsurfaced areas, to the top of the pipe.

6. Calculations to determine maximum cover for Cooper E-80 railway loadings are measured from the bottom of the tie to the top of the pipe.

7. If pipe produced by a manufacturer exceeds the strength requirements established by indicated standards, cover depths may be adjusted accordingly.

8. See Table 9-9 for suggested minimum cover requirements.

Table 9-7. Suggested Maximum Cover Requirements for Corrugated

H-20 Highway Loading										
Diameter, in.	Suggested Maximum Cover Above Top of Pipe, ft									
	Riveted - Thickness, in.					Helical – Thickness, in.				
	.064	.079	.109	.138	.168	.064	.079	.109	.138	.168
36	53	66	98	117	130	81	101	142	178	201
42	45	56	84	101	112	69	87	122	142	157
48	39	49	73	88	98	61	76	107	122	132
54	35	44	65	78	87	54	67	95	110	117
60	31	39	58	70	78	48	61	85	102	107
66	28	36	53	64	71	44	55	77	97	101
72	26	33	49	58	65	40	50	71	92	96
78	24	30	45	54	60	37	47	65	84	93
84	22	28	42	50	56	34	43	61	78	91
90	21	26	39	47	52	32	40	57	73	89
96		24	36	44	49		38	53	69	84
102		23	34	41	46		35	50	64	79
108			32	39	43			47	61	75
114			30	37	41			45	58	71
120			29	35	39			42	55	67

*Source: U.S. Army Corps of Engineers

Notes:

1. Corrugated steel pipe will conform to the requirements of ASTM A760/A760M-01a, ASTM A761/A761M-04, ASTM A762/A762M-00, and ASTM A849-00.
2. The suggested maximum heights of cover shown in the table are calculated on the basis of the current AASHTO *Standard Specifications for Highway Bridges* and are based on circular pipe.
3. Soil conditions, trench width, and bedding conditions vary widely throughout varying climatic and geographical areas.
4. Calculations to determine maximum cover should be made for all individual pipe and culvert installations underlying roads, streets, and open storage areas subject to H-20 live loads. Cooper E-80 railway loadings should be independently made.
5. Cover depths are measured from the bottom of the subbase of pavements, or the top of unsurfaced areas, to the top of the pipe.
6. Calculations to determine maximum cover for Cooper E-80 railway loadings are measured from the bottom of the tie to the top of the pipe.
7. If pipe produced by a manufacturer exceeds the strength requirements established by indicated standards, cover depths may be adjusted accordingly.
8. See Table 9-9 for suggested minimum cover requirements.

Table 9-8. Suggested Guidelines for Minimum Cover*

H-20 Highway Loading			
Pipe	Minimum Cover to Protect Pipe		Minimum Finished Height of Cover (From Bottom of Subbase to Top of Pipe)
	Pipe Diameter, in.	Height of Cover During Construction, ft	
Concrete Pipe Reinforced	12 to 108	Diameter/2 or 3.0 ft, whichever is greater	Diameter/2 or 2.0 ft, whichever is greater
Non-Reinforced	12 to 36	Diameter/2 or 3.0 ft, whichever is greater	Diameter/2 or 2.0 ft, whichever is greater
Corrugated Aluminum Pipe 2.66 in. by 0.5 in.	12 to 24 30 and over	1.5 ft Diameter	Diameter/2 or 1.0 ft, whichever is greater Diameter/2
Corrugated Steel Pipe 3 in. by 1 in.	12 to 30 36 and over	1.5 ft Diameter	Diameter/2 or 1.0 ft, whichever is greater Diameter/2
Structural Plate Aluminum Alloy Pipe 9 in. by 2.5 in.	72 and over	Diameter/2	Diameter/4
Structural Plate Steel 6 in. by 2 in.	60 and over	Diameter/2	Diameter/4

*Source: U.S. Army Corps of Engineers

Notes:

1. All values shown above are for average conditions and are guidelines only.
2. Calculations should be made for minimum cover for all individual pipe installation for pipe underlying roads, streets, and open storage areas subject to H-20 live loads.
3. Calculations for minimum cover for all pipe installations should be made separately for all Cooper E-80 railroad live loading.
4. In seasonal frost areas, minimum pipe cover must meet requirements of Table 2-3 of UFC 3-230-16FA for protection of storm drains.
5. Pipe placed under rigid pavement will have minimum cover from the bottom of the subbase to the top of pipe of 1.0 ft for pipe up to 60 in. and greater than 1.0 ft for sizes above 60 in. if calculations so indicate.
6. Trench widths depend upon varying conditions of construction but may be as wide as is consistent with the space required to install the pipe and as deep as can be managed from practical construction methods.
7. Non-reinforced concrete pipe is available in sizes up to 36 in.
8. See Table 9-9 for suggested minimum cover requirements.

Table 9-9. Minimum Depth of Cover in Feet for Pipe Under Flexible Pavement (Part 1)

CORRUGATED ALUMINUM 2 2/3" x 1/2" or 2" x 1/2" CORRUGATIONS

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.060	2.0	2.5	2.5						
0.075	1.5	2.0	2.5	2.5	3.0				
0.105		1.5	1.5	1.5	2.0	2.5	3.0		
0.135			1.0	1.0	1.5	1.5	1.5		
0.165					1.0	1.5	1.5	2.0	2.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.060	2.0	2.5	2.5						
0.075	1.5	2.0	2.5	2.5	3.0				
0.105		1.5	1.5	1.5	2.0	2.5	3.0		
0.135				1.5	1.5	2.0	2.5	3.0	
0.165					1.5	1.5	2.0	2.0	2.5

AIRCRAFT WHEEL LOAD—110,000 lb. dual to 200,000 lb. dual; 190,000 lb. dt. to 350,000 lb. dt; up to 750,000 lb. ddt & 1,500,000 lb

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.060	3.0	3.0	3.0						
0.075	3.0	3.0	3.0	3.5	5.0				
0.105		2.0	2.0	2.5	3.5	4.5			
0.135				2.0	3.0	4.0	4.5	5.5	
0.165					2.5	3.5	4.0	5.0	5.5

CORRUGATED ALUMINUM 6" x 1" CORRUGATIONS

AIRCRAFT WHEEL LOAD—up to 30,000 lb. single and up to 40,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.060	2.0	2.0	2.5	3.0				
0.075	1.0	1.5	2.0	2.5	3.5			
0.105	1.0	1.0	1.5	2.0	3.0	3.5		
0.135			1.5	2.0	2.5	3.0	4.0	
0.165					2.0	2.5	3.5	4.5

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.060	2.5	3.0	3.5	4.0				
0.075	1.5	2.0	2.5	3.0	4.0			
0.105	1.5	1.5	2.0	2.5	3.5	4.0		
0.135			2.0	2.5	3.0	3.5	4.5	
0.165					2.5	3.0	4.0	5.0

AIRCRAFT WHEEL LOAD—110,000 lb. d. to 200,000 lb. d; 190,000 lb. dt. to 350,000 lb. dt.; up to 750,000 lb. ddt. & 1,500,000 lb.

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.060	4.0	4.5	5.0	5.0				
0.075	3.0	3.5	3.5	4.0	4.0			
0.105	2.0	2.0	3.0	2.5	4.0	4.5		
0.135			2.5	3.0	3.5	4.0	5.0	
0.165					3.0	3.5	4.5	5.5

CLAY

AIRCRAFT WHEEL LOAD—up to 30,000 lb. single and up to 40,000 lb. dual

Pipe type	Pipe diameter (in.) 6	10	12	15	18	21	24	30	36
Std.strength clay	2.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Extra strength clay	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Pipe type	Pipe diameter (in.) 6	10	12	15	18	21	24	30	36
Std. strength clay	4.0	5.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Extra strength clay	2.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5

ASBESTOS CEMENT

AIRCRAFT WHEEL LOAD—up to 30,000 lb. single and up to 40,000 lb. dual

Asbestos cement-class	Pipe diameter (in.) 6	10	12	16	18	24	30	36	42
1500	2.5	2.5	2.5	2.5					
2400	2.5	2.5	2.5	2.5	2.5	2.5			
3300	1.5	1.5	1.5	1.5	1.5	1.5	1.5		
4000		1.5	1.5	1.5	1.5	1.5	1.5	1.5	
5000		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
6000								1.0	1.0
7000								1.0	1.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Asbestos cement-class	Pipe diameter (in.) 6	10	12	16	18	24	30	36	42
1500	5.5	5.5	5.5	5.5					
2400	6.0	6.0	6.0	6.0	6.0	5.0			
3300	3.5	3.5	3.5	3.5	3.5	3.5			
4000		3.5	3.5	3.5	3.5	3.5	3.5	3.5	
5000		3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
6000								2.5	2.5
7000								2.5	2.5

Table 9-9. Minimum Depth of Cover in Feet for Pipe Under Flexible Pavement (Part 2)

CORRUGATED STEEL 2 2/3" x 1/2" CORRUGATIONS

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.052	1.0	1.0	1.5	1.5					
0.064	1.0	1.0	1.0	1.5	1.5				
0.079	1.0	1.0	1.0	1.5	1.5	1.5			
0.109			1.0	1.0	1.0	1.0	1.5		
0.138				1.0	1.0	1.0	1.0	1.5	
0.168				1.0	1.0	1.0	1.0	1.5	1.5

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.052	1.5	2.0	2.0	2.5					
0.064	1.5	1.5	2.0	2.5	2.5				
0.079	1.5	1.5	2.0	2.5	2.5	2.5			
0.109			1.5	2.0	2.0	2.0	2.5		
0.138				2.0	2.0	2.0	2.0	2.5	
0.168				2.0	1.5	2.0	2.0	2.0	2.5

AIRCRAFT WHEEL LOAD—110,000 lb. dual to 200,000 lb. dual; 190,000 lb. dt. to 350,000 lb. dt.; up to 750,000 lb. ddt.

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.052	2.0	2.5	3.0	3.0					
0.064	2.0	2.5	2.5	3.0	3.0				
0.079	2.0	2.0	2.5	2.5	2.5	3.0			
0.109			2.0	2.5	2.5	2.5	3.0		
0.138				2.0	2.0	2.5	3.0	3.0	
0.168				2.0	2.0	2.5	3.0	3.0	3.0

AIRCRAFT WHEEL LOAD—Up to 1,500,000 lb.

Metal thickness (in.)	Pipe diameter (in.) 12	18	24	36	48	60	72	84	96
0.052	2.5	2.5	3.0	3.0					
0.064	2.5	2.5	2.5	3.0	3.0				
0.079	2.5	2.5	2.5	2.5	2.5	3.0			
0.109			2.5	2.5	2.5	2.5	.3.0		
0.138				2.5	2.5	2.5	3.0	3.0	
0.168					2.5	2.5	3.0	3.0	3.0

CORRUGATED STEEL 3" x 1" CORRUGATIONS

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.052	1.5	2.0	2.0	2.0				
0.064	1.0	1.5	1.5	2.0	2.0	2.0		
0.079	1.0	1.0	1.5	1.5	2.0	2.0	2.0	
0.109	1.0	1.0	1.0	1.0	1.5	1.5	2.0	2.0
0.138	1.0	1.0	1.0	1.0	1.0	1.5	2.0	2.0
0.168	1.0	1.0	1.0	1.0	1.0	1.5	2.0	2.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.052	2.5	3.0	3.0	3.0				
0.064	2.0	2.5	2.5	3.0	3.0	3.0		
0.079	1.5	2.0	2.5	2.5	3.0	3.0	3.0	
0.109	1.5	1.5	2.0	2.0	2.0	2.5	3.0	3.0
0.138	1.5	1.5	1.5	2.0	2.0	2.0	2.5	2.5
0.168	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.5

AIRCRAFT WHEEL LOAD—110,000 lb. dual to 200,000 lb. dual; 190,000 lb. dt. to 350,000 lb. dt; up to 750,000 lb. ddt.

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.052	3.0	3.5	3.5					
0.064	2.5	3.0	3.5	3.5	3.5			
0.079	2.0	2.5	3.0	3.0	3.5	3.5		
0.109	2.0	2.0	2.5	2.5	3.0	3.5	3.5	3.5
0.138	2.0	2.0	2.0	2.5	3.0	3.0	3.5	3.5
0.168	2.0	2.0	2.0	2.0	2.5	2.5	3.0	3.0

AIRCRAFT WHEEL LOAD—Up to 1,500,000 lb.

Metal thickness (in.)	Pipe diameter (in.) 36	48	60	72	84	96	108	120
0.052	3.0	3.5	3.5					
0.064	2.5	3.0	3.5	3.5	3.5			
0.079	2.5	2.5	3.0	3.0	3.5	3.5		
0.109	2.5	2.5	2.5	2.5	3.0	3.5	3.5	3.5
0.138	2.5	2.5	2.5	2.5	3.0	3.0	3.5	3.5
0.168	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.0

STRUCTURAL PLATE PIPE—9" x 2 1/2" CORR. FOR ALUMINUM; 6" x 2" CORRUGATIONS FOR STEEL

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. s. or 40,000 lb. d.	AIRCRAFT WHEEL LOAD—40,000 lb. d. to 110,000 lb. d.	AIRCRAFT WHEEL LOAD—110 k.d. to 200 k.d.; 190 k d.t. to 350 k. d.t.; to 750 k. d.d.t.	AIRCRAFT WHEEL LOAD—Up to 1,500,000 lb.
Pipe dia. ÷ 8 but not less than 1.0′	Pipe dia ÷ 6 but not less than 1.5′	Pipe dia. ÷ 5 but not less than 2.0′	Pipe dia ÷ 4 but not less than 2.5′

Table 9-9. Minimum Depth of Cover in Feet for Pipe Under Flexible Pavement (Part 3)

NONREINFORCED CONCRETE

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Pipe type	Pipe diameter (in.)								
	4	6	8	10	12	15	18	21	24
Std. strength	2.0	2.0	2.0	2.0	2.5	2.5	2.5	2.5	2.5
Extra strength	1.0	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Pipe type	Pipe diameter (in.)								
	4	6	8	10	12	15	18	21	24
Std. strength	3.5	4.0	4.0	4.5	5.5	6.0	6.0	6.0	6.0
Extra strength	1.5	2.0	2.5	3.0	3.5	3.5	3.5	3.5	3.5

REINFORCED CONCRETE

AIRCRAFT WHEEL LOAD—Up to 30,000 lb. single and up to 40,000 lb. dual

Reinf. concrete 0.01" crack D-load	Pipe diameter (in.)																			
	12	15	18	21	24	27	30	33	36	42	48	54	60	72	84	96	108	120	132	144
800													1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1000	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1350	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2000	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3000	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

AIRCRAFT WHEEL LOAD—40,000 lb. dual to 110,000 lb. dual

Reinf. concrete 0.01" crack D-load	Pipe diameter (in.)																			
	12	15	18	21	24	27	30	33	36	42	48	54	60	72	84	96	108	120	132	144
800													6.5	5.5	4.5	3.5	2.0	1.5	1.5	1.0
1000	5.5	5.5	5.5	5.5	5.5	5.0	5.0	5.0	4.5	4.5	4.0	4.0	3.5	3.0	2.0	1.5	1.0	1.0	1.0	1.0
1350	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.0	3.0	2.5	2.0	2.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0
2000	3.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3000	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

AIRCRAFT WHEEL LOAD—110,000 lb. dual to 200,000 lb. dual; 190,000 lb. dual tandem to 350,000 lb. dual tandem; up to 750,000 lb. d.d.t.

Reinf. concrete 0.01" crack D-load	Pipe diameter (in.)																			
	12	15	18	21	24	27	30	33	36	42	48	54	60	72	84	96	108	120	132	144
800																				
1000																				
1350	7.0	7.0	7.0	7.0	7.0	6.5	6.5	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	5.5	5.5	5.0	4.5	4.0
2000	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.0	2.5	2.0	2.0	2.5	2.5	2.0	2.0	2.0	1.5
3000	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.0	1.0	1.0	1.5	1.5	1.0	1.0	1.0	1.0

AIRCRAFT WHEEL LOAD—Up to 1,500,000 lb.

Reinf. concrete 0.01" crack D-load	Pipe diameter (in.)																			
	12	15	18	21	24	27	30	33	36	42	48	54	60	72	84	96	108	120	132	144
2000	7.0	7.0	7.0	7.0	7.0	6.5	6.5	6.5	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
3000	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

1. Cover depths are measured from top of flexible pavement, however, provide at least 1 foot between bottom of pavement structure and top of pipe.
2. The types of pipe shown are available in intermediate sizes, such as 6", 8", 15", 27", 33", etc.
3. For pipe installation in turfed areas use cover depths shown for 30,000 pound single; 40,000 pound dual.
4. Cover depths shown do not provide for freezing conditions. Usually the pipe invert should be below maximum frost penetration.
5. Blanks in tables indicate that pipe will not meet strength requirements.
6. Minimum cover depths shown for flexible pipe are based on use of excellent backfill.
7. Minimum cover depths shown for rigid pipe are based on use of class B bedding.
8. Minimum cover requirements for concrete arch or elliptical pipe may be taken from tables for reinforced concrete circular pipe, providing the outside horizontal span of the arch or elliptical pipe is matched to outside diameter of the circular pipe (assumes that classes of the pipes are the same).
9. Pipe cover requirements for "up to 1,500,000 pounds" are theoretical as gear configuration is not known.

RIGID PAVEMENT

For all types and sizes of pipe use 1.5 foot as minimum cover under rigid pavement (measure from bottom of slab, providing pipe is kept below subbase course). Rigid pipe for loads categorized as "up to 1,500,000 lb." must, however, be either class IV or class V reinforced concrete.

9-1.7 **Flexible Pipe**. Suggested maximum cover for trench and positive projecting conduits are indicated in Tables 9-3 through 9-7 for corrugated aluminum alloy pipe, corrugated steel pipe, structural plate aluminum alloy pipe, plastic, and structural plate steel pipe. Conditions other than those stated in the tables, particularly other loading conditions, will be compensated for as necessary. For unusual installation conditions, a detailed analysis will be made so that ample safeguards for the pipe will be provided with regard to strength and resistance to deflection due to loads. Determinations for deflections of flexible pipe should be made if necessary. For heavy live loads and heavy loads due to considerable depth of cover, it is desirable that a selected material, preferably bank-run gravel or crushed stone where economically available, be used for backfill adjacent to the pipe. Table 9-8 suggests guidelines for minimum cover to protect the pipe during construction and the minimum finished height of cover. ASTM D2321-04e1 provides standards for the installation of plastic pipe.

9-1.8 **Bedding of Pipe (Culverts and Storm Drains)**. The contact between a pipe and the foundation on which it rests is the pipe bedding. It has an important influence on the supporting strength of the pipe. For drainpipes at military installations, the method of bedding shown in Figure 9-3 is generally satisfactory for both trench and positive projecting (embankment) installations. Some designs standardize and classify various types of bedding for the shaping of the foundation, use of granular material, use of concrete, and similar special requirements. Although such refinement is not considered necessary, at least for standardized cover requirements, select, fine granular material can be used as an aid in shaping the bedding, particularly where foundation conditions are difficult. Also, where economically available, granular materials can be used to good advantage for backfill adjacent to the pipe. When culverts or storm drains are to be installed in unstable or yielding soils, under great heights of fill, or where pipe will be subjected to very heavy live loads, a method of bedding can be used in which the pipe is set in plain or reinforced concrete of suitable thickness extending upward on each side of the pipe. In some instances, the pipe may be totally encased in concrete or concrete may be placed along the side and over the top of the pipe (top or arch encasement) after proper bedding and partial backfilling. Pipe manufacturers will be helpful in recommending type and specific requirements for encased, partially encased, or specially reinforced pipe in connection with design for complex conditions.

Figures 9-1, 9-2, 9-3, and 9-4 indicate the three main types of rigid conduit burial, the free-body conduit diagrams, trench beddings for circular pipe, and beddings for positive projecting conduits, respectively. Figure 9-5 is a schematic representation of the subdivision of classes of conduit installation that influences loads on underground conduits.

9-2 **FROST CONDITION CONSIDERATIONS**. The detrimental effects of heaving of frost-susceptible soils around and under storm drains and culverts are principal considerations in the design of drainage systems in seasonal frost areas. In such areas, water freezing within the drainage system, except icing at inlets, is of secondary importance provided the hydraulic design assures minimum velocity flow.

9-2.1. Drains, culverts, and other utilities under pavements on frost-susceptible subgrades are frequently locations of detrimental differential surface heaving. Heaving causes pavement distress and loss of smoothness because of abrupt differences in the rate and magnitude of heave of the frozen materials. Heaving of frost-susceptible soils under drains and culverts can also result in pipe displacement with consequent loss of alignment, joint failures, and in extreme cases, pipe breakage. Placing drains and culverts beneath pavements should be minimized to the extent possible. When this is unavoidable, to obtain maximum uniformity the pipes should be installed before the base course is placed. The practice of excavating through base courses to lay drain pipes and other conduits is unsatisfactory because attaining uniformity between the compacted trench backfill and the adjacent material is almost impossible.

9-2.2 No special measures are required to prevent heave in non-frost-susceptible subgrades. In frost-susceptible subgrades where the highest groundwater table is 5 ft or more below the maximum depth of frost penetration, the centerline of the pipe should be placed at or below the depth of maximum frost penetration. Where the highest groundwater table is less than 5 ft below the depth of maximum frost penetration and the pipe diameter is 18 in. or more, one of these measures should be taken:

- Place the centerline of the pipe at or below the depth of maximum frost penetration, and backfill around the pipe with a highly free-draining non-frost-susceptible material.

- Place the centerline of the pipe one-third diameter below the depth of maximum frost penetration.

9-2.3 To prevent water from freezing in the pipe, the invert of the pipe should be placed at or below the depth of maximum frost penetration. In arctic and subarctic areas, it may not be feasible economically to provide sufficient depth of cover to prevent freezing of water in subdrains; also, in the arctic, no residual thaw layer may exist between the depth of seasonal frost penetration and the surface of permafrost. Subdrains in such areas may be blocked with ice during the spring thawing period; however, subdrains will function normally the rest of the time. Water freezing in culverts also presents a serious problem in arctic and subarctic regions. The number of such structures should be held to a minimum and should be designed based on twice the normal design capacity. Thawing devices should be provided in all culverts up to 48 in. in diameter. Large-diameter culverts are usually cleaned manually immediately prior to the spring thaw. Drainage requirements for arctic and subarctic regions are presented in Chapter 10.

9-2.4 These design notes should be considered for installations located in seasonal frost areas:

- Note 1. The cover requirement for traffic loads will apply when such depth exceeds that necessary for frost protection.

- Note 2. Sufficient granular backfill will be placed beneath inlets and outlets to restrict frost penetration to nonheaving materials.

- Note 3. Design of short pipes with exposed ends, such as culverts under roads, will consider local icing experience. If necessary, larger pipe will be provided to compensate for icing.

- Note 4. The depth of frost penetration in well-drained, granular, non-frost-susceptible soil beneath pavements kept free of snow and ice will be determined from data in the appropriate UFC for pavement design. In all cases, estimates of frost penetration will be based on the design freezing index, which is defined as the average air-freezing index of the three coldest winters in a 30-yr period, or the air-freezing index for the coldest winter in the past 10-yr period if 30 years of records are unavailable. Additional design support can be obtained from the PCASE computer program.

- Note 5. Under traffic areas, and particularly where frost condition pavement design is based on reduced subgrade strength, gradual transitions between frost-susceptible subgrade materials and non-frost-susceptible trench backfill will be provided within the depth of frost penetration to prevent detrimental differential surface heave.

9-3 **INFILTRATION OF FINE SOILS THROUGH DRAINAGE PIPE JOINTS.** For DOD facilities, watertight joints are recommended under airfield pavements.

9-3.1 Infiltration of fine-grained soils into drainage pipelines through joint openings is one of the major causes of ineffective drainage facilities. This is a serious problem along pipes on relatively steep slopes such as those encountered with broken-back culverts or stilling wells or when the pipe operates under pressure flow conditions. Infiltration is not confined to non-cohesive soils. Dispersive soils have a tendency to slake and flow into drainage lines.

9-3.2 Infiltration, prevalent when the HGL (e.g., water table) is at or above the pipeline, occurs in joints of rigid pipelines and in joints and seams of flexible pipe unless these are made watertight. Watertight jointing is especially necessary in culverts and storm drains placed on steep slopes to prevent infiltration and/or leakage and piping that normally results in the progressive erosion of the embankments and loss of downstream energy dissipators and pipe sections.

9-3.3 Culverts and storm drains placed on steep slopes should be large enough and properly vented so that full pipe flow can never occur. This maintains the hydraulic gradient above the pipe invert but below crown of the pipe, thereby reducing the tendency for infiltration of soil water through joints. Pipes on steep slopes may tend to prime and flow full periodically because of entrance or outlet condition effects until the hydraulic or pressure gradient is lowered enough to cause venting or loss of prime at either the inlet or outlet. The alternating increase and reduction of pressure relative to atmospheric pressure is considered a primary cause of severe piping and infiltration. A vertical riser should be provided upstream of or at the change in slope to provide sufficient venting for establishment of partial flow and stabilization of the pressure gradient in the portion of pipe on the steep slope. The riser may also be equipped with an inlet and used simultaneously to collect runoff from a berm or adjacent area.

9-3.4 Infiltration of backfill and subgrade material can be controlled by watertight flexible joint materials in rigid pipe and with watertight coupling bands in flexible pipe. Successful flexible watertight joints have been obtained in rigid pipelines with rubber gaskets installed in close-tolerance tongue-and-groove joints and factory-installed plastic gaskets installed on bell-and-spigot pipe. Bell-and-spigot joints caulked with oakum or other similar rope-type caulking materials and sealed with hot-poured joint compound have also been successful. Metal pipe seams may require welding, and the rivet heads may have to be ground to lessen interference with gaskets. Several kinds of connecting bands are adequate both hydraulically and structurally for joining corrugated metal pipes on steep slopes.

9-3.5 A conclusive infiltration test will be required for each section of pipeline involving watertight joints, and installation of flexible watertight joints will conform closely to manufacturers' recommendations. Although system layouts presently recommended are considered adequate, particular care should be exercised to provide a layout of subdrains that does not require water to travel appreciable distances through the base course due to impervious subgrade material or barriers. Pervious base courses with a minimum thickness of about 6 in. with provisions for drainage should be provided beneath pavements constructed on fine-grained subgrades and subject to perched water table conditions. Base courses containing more than 10 percent fines cannot be drained and remain saturated continuously.

9-4 MINIMUM AND MAXIMUM COVER FOR AIRFIELDS

9-4.1 Heliport and airport layout will typically include underground conduits that pass under runways, taxiways, aprons, helipads, and other hardstands. In the design and construction of the drainage system, it will be necessary to consider both minimum and maximum earth cover allowable in the underground conduits to be placed under both flexible and rigid pavements as well as beneath unsurfaced airfields and medium-duty landing-mat-surfaced fields. Underground conduits are subject to two principal types of loads: dead loads (DL) caused by embankment or trench backfill plus superimposed stationary surface loads, uniform or concentrated; and live or moving loads (LL), including impact. FAA cover tables shall be used for all airfields' pipe cover requirements. These tables are included in this UFC as Table 9-9. Cover depths are valid for the specified loads and conditions, including average bedding and backfill. Deviations from these loads and conditions significantly affect the allowable maximum and minimum cover, requiring a separate design calculation.

9-4.2 Drainage systems should be designed to provide the greatest possible capacity to serve the planned pavement configuration. Additions to or replacements of drainage lines following initial construction are both costly and disrupting to aircraft traffic.

9-5 MINIMUM AND MAXIMUM COVER FOR ROADWAYS

9-5.1 In the design and construction of the drainage system, it will be necessary to consider both minimum and maximum earth cover allowable on the underground conduits to be placed under both flexible and rigid pavements. Underground conduits are subject to two principal types of loads: DL, caused by embankment or trench backfill plus superimposed stationary surface loads, uniform or concentrated; and LL, including impact. LL assume increasing importance with decreasing fill height.

9-5.2 AASHTO *Standard Specifications for Highway Bridges* should be used for all H-20 highway loading analyses. The American Railway Engineering and Maintenance of Way Association (AREMA) *Manual for Railway Engineering* should be used for all Cooper's E-80 railway loadings. Appropriate pipe manufacturer design manuals should be used for maximum cover analyses.

9-5.3 Drainage systems should be designed to provide an ultimate capacity sufficient to serve the planned installation. Addition to, or replacement of, drainage lines following initial construction is costly.

9-5.4 Investigations of in-place drainage and erosion control facilities at fifty military installations were made during the period of 1966 to 1972. The age of the facilities varied from one to more than thirty years. The study revealed that buried conduits and associated storm drainage facilities installed from the early 1940s until the mid-1960s appeared to be in good to excellent structural condition; however, many installations reported failures of buried conduits during construction. Note, therefore, that minimum conduit cover requirements are not always adequate during construction. When construction equipment, which may be heavier than LL for which the conduit has been designed, is operated over or near an already in-place underground conduit, it is the responsibility of the contractor to provide any additional cover during construction to avoid damage to the conduit. Major improvements in the design and construction of buried conduits in the two decades include, among other items, increased strength of buried pipes and conduits, increased compaction requirements, and revised minimum cover tables.

9-5.5 The necessary minimum cover in certain instances may determine pipe grades. A safe minimum cover design requires consideration of a number of factors, including selection of conduit material, construction conditions and specifications, selection of pavement design, selection of backfill material and compaction, and the method of bedding underground conduits. Emphasis on these factors must be carried from the design stage through the development of final plans and specifications.

9-5.6 Tables 9-1 through 9-6 identify certain suggested cover requirements for storm drains and culverts. These suggested requirements should be considered as guidelines only. Cover requirements have been formulated for reinforced and non-reinforced concrete pipe, corrugated aluminum alloy pipe, corrugated steel pipe, structural plate aluminum alloy pipe, and structural plate steel pipe. The different sizes and materials of conduit and pipe have been selected to allow the reader to be aware of the many and varied items that are commercially available for construction purposes. The cover depths listed are suggested only for average bedding and backfill conditions. Deviations from average conditions may result in significant minimum cover requirements, and separate cover analyses must be made in each instance of a deviation from average conditions. Specific bedding, backfill, and trench widths may be required in certain locations; each condition deviating from the average condition should be analyzed separately. Where warranted by design analysis, the suggested maximum cover may be exceeded.

9-5.7 As a minimum, pipe in non-paved areas shall be designed for expected maintenance equipment.

CHAPTER 10

GUIDELINES FOR DESIGN IN THE ARCTIC AND SUBARCTIC

10-1 **GENERAL.** The design criteria provided in this UFC are generally applicable to arctic and subarctic regions; however, the general information in this chapter on icings and special design considerations for arctic and subarctic conditions are applicable.

The arctic is the northern region in which the mean temperature for the warmest month is less than 50 degrees Fahrenheit (F) and the mean annual temperature is below 32 degrees F. In general, the arctic coincides with the tundra region north of the limit of trees.

The subarctic is the region adjacent to the arctic in which the mean temperature for the coldest month is below 32 degrees F, the mean temperature for the warmest month is above 50 degrees F, and in which there are fewer than 4 months with a mean temperature above 50 degrees F. In general, the subarctic land areas coincide with the circumpolar belt of dominant coniferous forests.

10-2 **ICING**

10-2.1 **Description**. The term "icing" (sometimes misnamed “glaciering”) applies to a surface ice mass formed by the freezing of successive sheets of water, the source of which may be a river or stream, a spring, or seepage from the ground. When icing occurs at or near airfields, heliports, roadways, or railroads, the drainage structures and channels gradually fill with ice, which may spread over pavements or structures, endangering and disrupting traffic and operations. Ice must be removed from pavements or structures and drainage facilities must be cleared to avoid or limit the re-forming of icing. Obstruction of flow through drainage facilities—culverts, bridges, pipelines, or channels—can lead to washout of pavement embankments or undermining of structures. The spring thaw period is most critical in this regard. Prevention or control of icing at or near drainage structures and the related effects on pavements and other facilities are key considerations of drainage design and maintenance in the arctic and subarctic. Because icing can occur throughout both seasonal frost and permafrost areas, they are a widespread cause of recurring operational and maintenance problems. Drainage designs based only on conventional criteria will not fulfill the abnormal hydraulic conveyance requirements of icing-prone regions and will be subject to troublesome maintenance problems. Special design and maintenance concepts, based mainly on field experience under similar situations, are required.

10-2.2 **Types**. Icing is classed conveniently as river or stream icing, ground icing, or spring icing, although sometimes it is difficult to assign a specific type to a particular situation. There are three general types of icing:

10-2.2.1 **River or Stream Icing.** River or stream icing occurs more commonly on shallow streams with large width/depth ratios. Braided or meandering channels are more prone to icing formation than well defined single channels. River or stream icing normally begins to develop soon after normal ice cover forms on a stream surface, usually during October to December. The icing begins with the appearance of unfrozen water on the surface of the normal ice cover. This water may originate from cracks in the ice cover, from seepage through unfrozen portions of soil forming the channel banks, from adjacent springs that usually discharge into the channel, or other sources. This water, flowing in sheets of an inch or less in thickness to a foot or more, freezes in a layer. Each overflow event is followed by another, with new flow atop the previously frozen sheet, the icing growing higher layer upon layer with its boundaries extending laterally according to the topography. River icing may grow for only part of the winter or throughout the period of below-freezing temperatures. Icing behavior usually varies a little year by year, depending on availability of the feeding water. An icing surface is typically flat but can be gently terraced, with each step marking the frozen edge of a thin overflow layer. Occasionally ice mounds form and develop cracks that provide outlets for the confined water forming the mounds. The water flows out, continuing the growth of the icing for a limited period. Smaller icing is typically confined to the stream or drainage channel; larger icing may spread over floodplains or pavements. With the onset of the spring thawing season, runoff cuts channels through the icing to the streambed. Channels are widened by thawing, collapse of the ice forming the sides, and erosion. Depending on the size of the icing and its geographic location, its remnants may last only until May or June, or in colder regions remnants may last all summer. In extreme locations, they never completely melt and are known as perennial icing. River or stream icing occurring at culverts is objectionable in that fish migration is obstructed.

10-2.2.2 **Ground Icing.** Unlike river or stream icing, ground icing, while developing on certain topographic features, does not have clearly defined areas of activity. These icings are commonly referred to as seepage icings, due to the way their feed waters appear on the ground surface. Seepage icings may develop on nearly level ground or at points of contact of two different types of relief (such as at the base of a slope) or as encrustations on slopes. Ground icing begins to form at different times of the year depending on the sources and modes of discharge of the feeding waters. Where water seeps from the ground often or continuously, icing may begin to form in September or October, in which case it might also be termed a spring icing. Those forming where water does not usually issue from the ground typically begin to form in November or December, or even later in the winter. A characteristic of ground icing is that its development begins with unfrozen water appearing on the ground surface or with the saturation and subsequent freezing of snow on the ground. This water may seep from the soil or from fractures in the bedrock, or it may travel along the roots of vegetation, or it may issue from frost-induced cracks in the ground. As the seepage flows are exposed to the cold atmosphere, they freeze. Additional seepages follow repeatedly onto the icing surface and also freeze, building up successive thin ice layers, seldom over an inch thick. Ground icings may grow during the winter, being extremely sensitive to weather and local hydrologic conditions of the winter and its preceding seasons. Normally ground icings are limited in size as compared with stream spring icing since their source of supply is limited. Some rapid growth may occur with the advent of thawing weather. When general thawing occurs, the ground icing will slowly waste away. This disintegration is unlike that of stream icings, in which sizable runoff streams can rapidly erode icing.

10-2.2.3 **Spring Icing.** Springs found in a variety of topographic situations sustain continuous discharge, leading to early winter formation of icing, usually prior to ground icing. Spring outlets typically remain fixed in location and continue to grow throughout the winter, ultimately reaching a larger size than ground icing. A flow of 1 ft^3/min can create a 1-ft-deep icing covering an acre in one month. Spring icings melt away slowly on all sides, and these icings are also eroded by spring water channel flow.

10-2.3 **Natural Factors Conducive to Icing Formation**. Certain natural factors are conducive to icing:

10-2.3.1 A rainy season prior to freeze-up producing an abundance of groundwater in the annual frost zone of the soil or in the ground above the permafrost.

10-2.3.2 Low air temperatures and little snow during the first half of the winter, i.e., through January. Early heavy snow minimizes the occurrence of icing.

10-2.3.3 Nearness of an impervious horizon such as the permafrost table to the ground surface.

10-2.3.4 Heavy snow depth accumulations during the latter part of winter.

10-2.4 **Effects of Human Activities on Icing.** Airfields and heliports, by altering the natural physical environment, have profound effects on icing. The widespread clearing of vegetative cover, cutting and filling of soil, excavation of rock, and provisions for drainage, for example, greatly affect the natural thermal regime of the ground and the hydrologic regimes of both groundwater and surface water. Some of the effects are discussed in paragraphs 10-2.4.1 to 10-2.4.6.

10-2.4.1 Removal of vegetation and organic soil, with their typically higher insulation values than those of the construction materials replacing them, results in increased seasonal frost penetration. This may create or aggravate nearby damming of groundwater flow and cause icing. Airfield and heliport pavement areas, kept clear of snow, lack its insulating value and are subject to deeper seasonal frost penetration, causing icing.

10-2.4.2 Cut faces may intersect the water table, and fill sections may block natural drainage channels. Construction compaction operations can reduce permeability of natural soils, blocking natural discharge openings.

10-2.4.3 In cut sections, water comes into contact with the cold atmosphere, forming ground icing where none occurred prior to the construction. Icing grows on the cut face, fills the adjacent drainage ditches with ice, and eventually reaches the pavement surface. In these conditions, deep snow on the slope and ditch insulates seepage from the cut face. Seepage water passes under the snow without freezing and reaches the snow-free pavement where it is sufficiently exposed to freeze. This type of man-made icing is the most common and troublesome type along pavements.

10-2.4.4 Snowplowing and snow storage greatly affect the location and extent of icing by changing insulation values and damming seepage waters.

10-2.4.5 Channel realignment and grading into wider, more shallow sections, commonly done in airfield and heliport construction, renders the stream more susceptible to high heat losses, extensive freezing, and formation of icing.

10-2.4.6 Drainage designers customarily size hydraulic structures to accommodate runoff from a specified design storm. In the arctic and subarctic, the size of hydraulic structures based solely on these well-founded hydrologic principles will usually result in inadequate capacity, which will contribute or intensify icing formation. Culverts, small bridges, storm drains, and inlets designed to accommodate peak design discharges are usually much too small to accommodate icing volumes before becoming completely blocked by ice. Once the drainage openings become blocked, icing upstream from the affected structures grows markedly. The inadequacy of drainage facilities, both in capacity and number, because of failure to accommodate icing, leads to more serious effects of icing on engineering works.

10-2.5 **Methods of Counteracting Icing.** Several techniques are available for avoiding, controlling, or preventing icing. Although sound in principle, the methods are often applied without adequate understanding of the icing problems, leading to unsuccessful or poor results. Selection of a particular method from the many that might be applied for the given set of conditions is based principally on economics. One must use a systems approach considering costs of installation plus costs of operation and maintenance, energy conservation, and environmental impact. Where feasible, methods requiring no fuel or electrical energy output or little or no service by maintenance personnel are preferred. The techniques for dealing with icings fall into two categories: *avoidance and control* and *prevention*.

10-2.5.1 **Methods of Icing Avoidance and Control**. These methods deal with the effects of the icing at the location being protected, so that the type of icing (river or stream, ground, or spring) is of little significance. There are several methods of icing avoidance and control:

10-2.5.1.1 **Change of Location.** Site facilities where icings do not occur. This is an economic consideration that is difficult to resolve in siting an airfield because of its extensive area, grading, and lateral clearance requirements.

10-2.5.1.2 **Raising the Grade.** This will deter or postpone icing formation but is costly and depends on the availability of ample fill. There is also the threat of embankment washouts resulting from ice-blocked facilities, and the possibility of objectionable seepage effects.

10-2.5.1.3 **More and Larger Drainage Structures.** Susceptibility to icing problems can be reduced by providing more and larger drainage facilities. Openings as much as 2 or 3 times as large as those required by conventional hydraulic design criteria will accommodate sizable icing volumes without encroaching on design flows. Culverts with large vertical dimensions, or small bridges in lieu of culverts, are advantageous. Provision for adequate drainage channels and conduits will facilitate diversion of meltwater runoff from icings, protecting the installation from washouts.

10-2.5.1.4 **Storage Space**. This can be provided as a ponding basin or by shifting a cut face further back from the airfield or heliport. There, an icing can grow in an area where it will not encroach on operational facilities.

10-2.5.1.5 **Dams, Dikes, or Barriers.** Known also as ice fences, these are used often to limit the horizontal extent of icings. Permanent barriers of earth, logs, or lumber may be built between the source of the icing and the area to be protected. Temporary barriers may be erected of snow embankments, movable wooden fencing, corrugated metal, burlap, plastic sheeting, or expedient lumber construction. In some situations, a second or even third fence is required above the first as the icing grows higher.

10-2.5.1.6 **Culvert Closures.** To prevent a culvert being filled with snow and ice, which requires a laborious spring clearing operation, closures are sometimes placed over the culvert ends in the fall. These closures can be of rocks that will permit minor flows prior to freeze-up.

10-2.5.1.7 **Staggered (or Stacked) Culverts.** This involves placement of two (or more) culverts, one at the usual location at the base of the fill, the other(s) higher in the fill. When the lower culvert becomes blocked by an icing accumulation, the higher ones carry initial spring runoff over the icing. As the spring thaw progresses, the lower one becomes cleared, eventually carrying the entire flow. In cases where there is limited height, the second culvert is placed to the side with its invert at a slightly higher elevation. The ponding area available for icing accumulations must be large enough to store an entire winter's ice without having the icing reach the upper culverts or the elevation of the area being protected.

10-2.5.1.8 **Heat.** Icing is commonly controlled by the application of heat in any of several ways, the objective being not to prevent icing but to establish and maintain thawed channels through it to minimize its growth and to pass spring runoff.

10-2.5.1.9 **Steam.** This method, common in North America, is used to thaw culvert openings and to thaw channels into icing for collecting icing feed water or early spring runoff. Steam, generated in truck-mounted boilers, is conducted through hoses to portable steam lances, or through hoses temporarily attached to permanently installed thaw pipes supported inside the tops of the culverts. Thaw pipes of 0.375- to 2-in. diameter have been used. The thaw pipe is terminated by a vertical riser at each end of the culvert, extending high enough to permit access above accumulated ice and snow. The pipe is filled with antifreeze, with the risers capped when not in use.

10-2.5.1.10 **Fuel Oil Heaters.** These heaters, known as firepots, are in common use. They consist of a 55-gallon oil drum equipped with an oil burner unit (railroads often use coal or charcoal as fuel). The drum, fed from a nearby fuel supply, is usually suspended from a tripod at the upstream end of the culvert. A continuous fire maintains a thaw pit in the icing. Fuel consumption varies, averaging about 30 gallons per day. Water, flowing over the icing, enters the pit where it receives heat, passes through the culvert, ideally without refreezing before it flows beyond the area to be protected. While firepots are simple devices, they are inefficient energy sources due to loss of most heat to the atmosphere rather than to the water or icing. Firepots are in decreasing favor due to their high maintenance requirements and the difficulty in preventing the theft of the fuel in remote locations.

10-2.5.1.11 **Electrical Heating.** Use of insulated heating cables to heat culverts is a recent adaptation successfully used where electrical power is available or, in important locations, where small generating stations are feasible. Heating cables have been used, not to prevent icing but to create and maintain a thawed tunnel-like opening in an icing to minimize its growth and to provide for spring runoff. Cable can be strung in the fall within the culvert and, in some cases, along its upstream drainageway, and removed in the spring. Cable can also be installed permanently in a small diameter metal pipe inside the culvert or buried at shallow depth under a drainage ditch or channel. Common heat output is 40 to 50 watts/lineal feet, with minimum heat lost to the atmosphere. A tunnel approximately 2 to 3 ft wide and 4 to 5 ft high is achieved by later winter. Electrical heating requires much less attention by maintenance personnel than steam thawing.

10-2.5.1.12 **Breaking and Removing Accumulated Ice.** This common technique, whether by manual or mechanical equipment, should be practiced only as an expedient or emergency measure. The timing of such operations, like that for the following two methods, critically limits their effectiveness.

10-2.5.1.13 **Blasting.** This has a twofold objective: the physical removal of ice and the fracturing of ice to provide paths for water flow deep in the icing. This flow can enlarge openings and still remain protected from the atmosphere and refreezing.

10-2.5.1.14 **Deicing Chemicals.** Chemicals such as sodium or calcium chloride are sometimes used to prevent refreezing of a drainage facility once it has been freed of ice by other means. A common practice is to place a burlap bag containing the salt at a culvert inlet, allowing the compound to be dissolved slowly by the flow, with the solution lowering the freezing point of the water. Objections are the detrimental effects on fish and wildlife, vegetation, and other downstream water uses and the corrosive effects on metal pipe.

10-2.5.2 **Methods of Icing Prevention.** These preventive techniques are best classified according to the general type of icing:

10-2.5.2.1 **River or Stream Icing**

- **Channel Modification**. Straightening and deepening a channel can prevent icing, although frequent maintenance is usually required to counteract the stream's tendency to resume its natural configuration by erosion and deposition. Rock-fill gabions have been used to create a deep, narrow channel for low winter discharges. Such deepened channels permit formation of ice cover to normal thickness while providing adequate space beneath for flow. Deepening at riffles, rapids, or drop structures is especially important because icing is more likely to form in these shallow areas.

- **Insulation of Critical Sections**. River or stream icing may be prevented by insulating critical sections of the stream where high heat losses cause excessive thickening of the normal ice cover, constricting or completely blocking flow and resulting in icing formation. These sections may be located under a bridge or taxiway or at riffles or rapids. The insulation, which may be placed on the initial ice cover, may consist of soil, snow, brush, peat, sawdust, or other material, typically 1 to 2 feet thick. Another method is to cover the stream before ice forms, using logs, timber, or corrugated metal as a support for insulating material, later augmented by snowfall. Insulating covers, while beneficial in lessening heat losses from the stream, must be removed each spring before annual freshets. They may also be washed downstream to become obstructions if high water occurs prior to cover removal.

- **Frost Belts**. Known also as "permafrost belts," these are addressed further in paragraph 10-2.5.2.2, Ground Icing. A frost belt is essentially a ditch or cleared strip of land upstream or upslope from the icing problem area. If organic soil and vegetative cover are removed and the area is kept clear of snow during the first half of the winter, deep seasonal frost will act as a dam to water seeping through the ground, forcing it to the surface where it will form an icing upstream or upslope from the belt. In applying this technique to a drainage channel, a belt is formed by periodically cutting transversely into the ice to cause the bottom of the ice cover to lower and merge with the bed. In this way, the icing is induced to form away from the bridge or culvert entrance being protected.

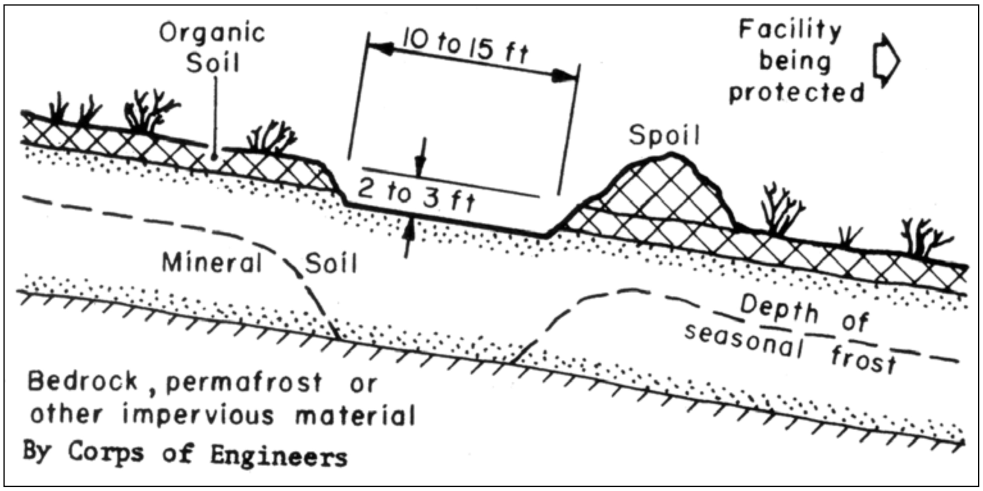
10-2.5.2.2 **Ground Icing.** The most successful methods of preventing ground icing involve drainage. Other procedures depend on preventing formation in one location by inducing formation elsewhere. There are several principal methods:

- **Surface Drainage**. This may be accomplished by a network of ditches located to drain the soil surface in the region of icing development. Ideally these ditches will be sited in compliance with airfield/heliport lateral safety clearance criteria and be narrow and deep enough to drain the soil to an appreciable depth and to expose only a small surface area to heat loss to the atmosphere. In some cases, these drainage ditches are covered and insulated to maintain flow in winter. Open ditches can be as narrow as 1 ft or, if insulated, approximately 3 ft wide by 3 ft deep.

- **Insulation of the Ground**. In some cases, ground icings can be prevented by insulating the ground in areas where deep seasonal frost penetration forms a dam, blocking groundwater flow. Insulating material may be snow, soil, brush, or peat. This technique may merely shift the location where an impervious frost dam occurs. It is essential that the insulation of the ground extend under the pavement being protected to assure that groundwater flow is maintained past it. Otherwise, seasonal frost penetration under a snow-free airfield pavement would act as a frost dam and cause an icing to form upslope from the area. Suitable insulation materials for pavements are available and have been used effectively.

- **Permanent-type Frost Belts**. Successful use of frost belts requires careful siting, planning, and maintenance. Frost belts may be either permanent or seasonal. The permanent-type belt, as mentioned in paragraph 10-2.5.2.1 for control of river or stream icing, is a strip of land cleared of organic soil and vegetation, extending across a slope normal to the direction of seepage flow. Seasonal frost beneath this belt, merging with or approaching some impervious base, causes an icing to form upslope from the belt location. The belt must be long enough to prevent the icing from extending around the ends of the belt and approaching the airfield or other area being protected. Such a belt is usually approximately 2 to 3 ft deep and 10 to 15 ft wide. Spoil from the excavation is placed as a low ridge on the downslope side of the belt (Figure 10-1). The shape of the frost belt depends on the topography; often it is slightly convex downslope, or made of two straight segments meeting at an angle of 160 to 170 degrees on the upslope side of the belt. Sometimes more than one belt is necessary, with the belts arranged parallel to each other with their spacing depending on the channel slope. Permanent frost belts require attention to avoid degradation of the permafrost table underneath because the insulation of the ground has been reduced by removing the organic soil and vegetative cover. After a few years, the permafrost table may lower so much that the seasonal frost penetration in the winter will not reach it. In such a case, seepage flow in the soil is not stopped at the belt, and an icing does not develop at the belt but occurs instead downslope at the airfield or other facility intended to be protected. This can be avoided by covering the belt area in the spring with an insulating material and removing it in the fall before the onset of winter frosts. The belt must be kept clear of snow through the first half of the winter to permit rapid and deep seasonal frost penetration.

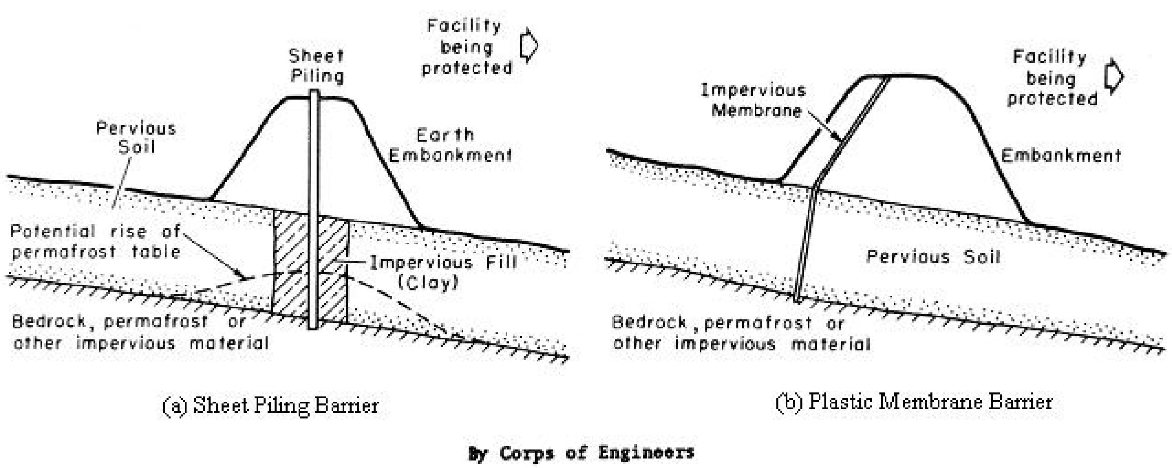
Figure 10-1. Typical Cross Section of a Frost Belt Installation



- **Seasonal-type Frost Belts**. Seasonal-type frost belts are free from most maintenance requirements associated with the permanent type and are much simpler and more economical to construct. Instead of preparing a ditch in the ground, one merely clears a strip of snow at the desired belt location and keeps it free of snow during the first half of the winter. The cleared snow is piled downslope of the belt, forming a ridge. The chief advantage of the seasonal belt is that it is less likely to degrade the underlying permafrost. This objective can be further assured by relocating the belt upslope or downslope in successive winters. A disadvantage of the seasonal belt is that seasonal frost penetrates below it more slowly because of the high specific heat of the wet organic soil and the insulation afforded by the vegetation left in place. It therefore takes longer for a frost dam to form and stop the flow of seepage water. This may permit formation of some icing at the downslope protected area early in the winter before the seasonal frost belt attains full effectiveness. Frost belts have not been widely accepted because of neglect in placement of summer insulation and priority attention to snow removal from pavements rather than from frost belt areas in the winter. Frost belts are much easier to maintain in locations where the impervious base that restricts groundwater flow is other than permafrost and thus is not subject to degradation.

- **Earth Embankments and Impervious Barriers**. Ground icing formation can also be prevented by use of earth embankments combined with impervious barriers to groundwater flow. These are placed well away from the area to be protected and function similarly to frost belts by damming seepage flow through the soil, causing it to rise to the ground surface where it freezes to form an icing. In southern permafrost zones where permafrost is close to freezing temperatures, embankments may cause the permafrost to melt, leading to subsidence. Methods of developing the impervious barrier include trenching across the slope down to the impervious stratum, filling the trench with clay and then driving a row of sheet piling through it extending several feet above the surface to aid in ponding (Figure 10-2a). Other expedients include use of plastic membrane instead of piling (Figure 10-2b) or burial or horizontal air duct pipe (12 to 18 in.), usually located 4 to 6 ft below the bottom of the embankment. Vertical air shafts from the horizontal ducts permit cold winter air to permeate the system, removing heat from the ground and freezing the soil beneath the embankment to create an impervious barrier. The vertical air shafts are sealed in the summer to prevent excessive thawing in the soil. A problem that has arisen in some duct installations is that if they are not completely watertight, infiltrated water will freeze in the duct, causing an obstruction that is typically difficult to clear. Because this type installation would obstruct seepage flow year-round rather than just in winter, gated openings must be provided to allow accumulated water to flow downslope during the summer. The openings are closed all winter to ensure that the icing will form upslope from the embankment. An innovation is the use of a steel mesh grid with apertures 8 to 32 in^2. These permit water passage when the air is warm, but gradually freeze until a blockage forms in subfreezing weather. Grids must be removed in the summer to avoid debris accumulation.

Figure 10-2. Earth Embankments with Impervious Barriers



10-3 **GUIDELINES FOR DESIGN OF STORM DRAINS IN THE ARCTIC AND SUBARCTIC.** Certain principles used in design are particularly applicable to drainage facilities in arctic and subarctic regions. The planner should be cognizant of several features related to drainage to assure a successful design:

10-3.1 Sites should be selected in areas where cuts, or the placement or base course fills, will not intercept or block existing natural drainageways or subsurface drainageways. Adequate provision should be made for the changed drainage conditions.

10-3.2 Areas with fine-grained, frost-susceptible soils should be avoided if possible. In arctic and subarctic regions, most soils are of single grain structure with only a very small percentage of clay. Since the cohesive forces between grain particles are very small, the material erodes easily. Fine-grained soil profiles may also contain large numbers of ice lenses and wedges when frozen.

10-3.3 If the upper surface of the permafrost layer is deep, design features of a drainage system can be similar to those used in frost regions of the continental United States if due provisions are made for lower temperatures.

10-3.4 The avoidance, control, and prevention of icing are addressed in section 10-2.

10-3.5 The flow of water in a drainage channel accelerates the thawing of frozen soil and bedrock. This may cause the surface of the permafrost to dip considerably beneath streams or channels that convey water, and may result in the thaw of ice such as that contained in rock fissures and cracks. The latter could develop subsurface drainage channels in bedrock. Bank sloughing and significant changes in channels become prominent. Sloughing is often manifested by wide cracks paralleling the ditches. For this reason, drainage ditches should be located as far as practicable from runway and road shoulders and critical structures.

10-3.6 In many subarctic regions, freezing drainage channels of drifted snow and ice become a significant problem before breakup each spring. In these areas, it is advantageous to have ditch shapes and slopes sufficiently wide and flat to accommodate heavy snow-moving equipment. In other locations where flow continues year-round, narrow, deep ditches are preferable to lessen the amount of exposed water surface and avoid icing.

10-3.7 Large cut sections should be avoided in planning the drainage layout. Thawed zones or water-bearing strata may be encountered and later cause serious icing. Vegetative cover in permafrost areas should be preserved to the maximum degree practicable; where disturbed, it should be restored as soon as construction permits.

10-3.8 Fine-grained soils immediately above a receding frost zone are very unstable; consequently, much sliding and caving is to be expected on unprotected ditch side slopes in such soils.

10-3.9 Locating ditches over areas where permafrost lies on a steep slope should be avoided if possible. Slides may occur because of thawing and consequent wetting of the soil at the interface between frozen and unfrozen ground.

10-3.10 Provisions should be made for removal and disposal or storage of snow and ice, with due consideration to control of snowmelt water. Drainage maintenance facilities should include heavy snow-removal equipment and electric cables with energy sources or a steam boiler with accessories for thawing structures that become clogged with ice.

Pipes or cables for this purpose are often fastened inside the upper portions of culverts prior to their placement.

10-3.11 Usually inlets to closed conduits should be sealed before freeze-up and opened prior to breakup each spring.

10-4 **GRADING**. Proper grading is a very important factor contributing to the success of any drainage system. The development of grading and drainage plans must be coordinated most carefully. In arctic and subarctic regions, the need for elimination of soft, soggy areas cannot be overemphasized.

10-5 **TEMPORARY STORAGE.** Trunk drains and laterals should have sufficient capacity to accommodate the project design runoff. Supplementary detention ponds upslope from drain inlets should not be considered in drainage designs for airfields or heliports in the arctic and subarctic. Plans and schedules should be formulated in sufficient detail to avoid flooding even during the time of actual construction.

10-6 **MATERIALS.** Selection of suitable types of drainage materials for specific projects will be based on design requirements—hydraulic, structural, and durability—and economics for the specific drainage installation. In the arctic and subarctic, the flexible, thin-walled pipe materials—corrugated metal (galvanized steel or clad aluminum alloy)—have been most widely used for drainage applications because of their availability, weight and transportability considerations, relative ease of installation, and dependability of jointing. Heavier rigid-type pipe, reinforced and nonreinforced concrete, particularly with recently developed, flexible, gasketed joints, and the newer types of plastic pipe are used under certain conditions in the subarctic.

10-7 **MAINTENANCE.** Access for maintenance equipment and personnel is necessary for major drainage channels, debris control barriers, and icing control installations. Structures should be inspected periodically, particularly before fall freeze-up and after annual spring thaw breakup periods.

10-8 **JOINTING.** Disjointing, leakage, or failure in pipe joints can occur, especially where drainage lines are subject to movement caused by backfill settlement, live loads (LL), or frost action. Flexible, watertight joint pipe is available for use in such situations. Most watertight joints rely on the use of close-tolerance pipe ends connected over a closely fitting gasket.

10-9 **END PROTECTION.** End structures, factory-made or constructed in the field, are attached to the ends of storm drains or culverts to provide structural stability, hold the fill, reduce erosion, and improve hydraulic characteristics. A drain projecting beyond the slope of an airfield or roadway embankment is a hazard and is subject to damage or failure caused by ice, drift, or the current. Drain ends can be mitered to fit embankment slopes or provided with prefabricated, flared end sections. Headwalls and wingwalls to contain pipe ends are often constructed, usually of concrete, to meet the several design requirements, including provision of weight to offset uplift or buoyancy and to inhibit piping. Headwalls or wingwalls should be oriented or skewed to fit the drain line for maximum hydraulic efficiency and to lessen icing formation and drift or debris accumulation. The effect of pipeline entrance design on the hydraulic efficiency of drainage systems is examined in Chapter 4. A properly shaped culvert entrance can be an important factor in reducing ponding at an inlet that can wash out an airfield or roadway embankment.

10-10 **ANCHORAGE AND BUOYANCY.** Forces on a drain line inlet during high flows, especially during spring breakup, are variable and unpredictable. Currents and vortexes cause scour, which can undermine a drainage structure and erode or fail embankments. These conditions are accentuated in the arctic and subarctic by accumulated ice and debris. Corrugated metal pipe sections, because they are thin-walled and flexible, are particularly vulnerable to entrance distortion or failure. Ends can be protected by providing secure heavy anchorage. This could be a concrete or grouted rock endwall or slope pavement. Rigid-type pipe with its shorter sections is subject to disjointing if undermined by scour unless provided with steel tiebars to prevent movement and separation. Buoyant forces must be determined for possible conditions such as blockage of a drainage line end by ice or debris, flow around the outside of a pipe, or, in coastal locations, tidal effects. These forces must be counteracted by adequately weighting the line, tying it down, or providing vents. Catastrophic drainage failures have resulted from failure to safeguard against such occurrences, even in temporary situations during construction.

10-11 **DEBRIS AND ICING CONTROL.** It is essential to control debris and icing to achieve desired hydraulic and structural performance and to avoid damages and operational interruption from flooding and uncontrolled icing. The debris problem can be solved by providing a structure large enough to pass the material or by retaining it at a convenient adequate storage and removal location upstream from the drainage structure.

10-12 **TIDAL AND FLOOD EFFECTS.** Airfields, with their requirements for large level areas, are often sited on coastal or alluvial floodplains where their drainage systems are subject to tidal and stream flood effects. In arctic and subarctic regions, ice jam and spring break-up dynamic forces and flood heights create major problems, including stream migration, which can adversely affect airfield embankments and protective levees, degrade permafrost, and shift or block drainage outlets. Stream meander control is difficult and costly, especially in the arctic. Flap gates may be required to prevent backflow into drainage systems, a situation particularly undesirable in tidal or brackish water locations due to corrosive action on drainage pipelines. These gates require a high level of maintenance to assure their operation despite ice, debris, sand, or silt accumulation.

10-13 **INSTALLATION.** Pipe construction in the arctic and subarctic, as in other regions, requires shaped bedding and systematic, layer-by-layer backfilling and compaction, and maintaining equal heights of fill along both sides of the pipe. Many culvert and storm drain failures during construction are caused by operating equipment too close to the pipe, failure to remove large projecting stones from backfill near the pipe, or inadequate caution in handling frozen backfill material.