Research Report
UKTRP - 83-21

STRUCTURAL DESIGN AND INSTALLATION CRITERIA FOR RIGID AND FLEXIBLE CONDUIT

by

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in cooperation with
Transportation Cabinet
Commonwealth of Kentucky

and

Federal Highway Administration
U.S. Department of Transportation

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September 1983

Technical Report Documentation Page

1. Report No.

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Structural Design and Installation Criteria
for Rigid and Flexible Conduit

5. Report Date
September 1983

6. Performing Organization Code

7. Author(s)
Ronald D. Hughes

8. Performing Organization Report No.
UKTRP-83-21

9. Performing Organization Name and Address
Transportation Research Program
College of Engineering
University of Kentucky
Lexington, Kentucky 40506-0043

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
KYHPR-84-103

12. Sponsoring Agency Name and Address
Kentucky Transportation Cabinet
State Office Building
Frankfort, Kentucky 40622

13. Type of Report and Period Covered
Interim

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared in cooperation with the U. S. Department of Transportation, Federal Highway Administration.
Study Title: Fill-Height Tables for Pipe, Pipe-arch, and Arch Culverts

16. Abstract

Structural design criteria according to current AASHTO guidelines for pipe, pipe-arch, and arch culverts are presented. Fill-height tables, based upon those criteria, and proposed bedding details are included.

17. Key Words

Culvert
Pipe
Pipe-arch
Arch
Fill Height
bedding
Structural design
Installation

18. Distribution Statement

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

EXECUTIVE SUMMARY

Significant percentages of highway construction and maintenance funds are expended on installation, maintenance, and restoration of drainage structures. On the average, cast-in-place reinforced concrete box culverts cost about twice as much as comparable rigid or flexible pipe, pipe-arch, and arch structures. Provisions for only limited use of box culverts should prove to be economically advantageous.

Adoption of fill-height tables, based upon current soil-structure interaction design criteria, would provide for more extensive use of flexible pipe and pipe arches and rigid pipe and arches. Current state-of-the-art design methodologies for both soil-reinforced concrete structure interaction systems and soil-corrugated metal structure interaction systems are presented in this report.

Proposed fill-height tables, based upon current AASHTO design criteria, are presented in Appendix A and Appendix B, respectively, for flexible and rigid conduit. Separate bedding details for rigid and flexible conduit are proposed in Appendix C. Current camber design guidelines are presented in Appendix D.

INTRODUCTION

An average of 25 percent of all highway construction funds are expended for drainage structures. Expenditures for maintenance and repair of drainage structures nationwide are approximately four billion dollars yearly. Reductions in costs for construction, repair, and maintenance of those structures would yield substantial savings of financial resources. Conservative structural design of conduits escalates construction costs needlessly. On the other hand, structurally underdesigned conduits generally require expensive remedial actions.

A 1967 economic analysis of several years of records for Kentucky revealed that cast-in-place box culverts cost about twice as much per cubic foot of waterway opening as comparable pipe or pipe-arch structures. A less detailed review of 1979 cost data indicated box culverts were still twice as expensive as pipe or pipe-arch culverts. Efforts directed toward maximizing use of pipe and pipe-arch structures would be economically advantageous.

Current fill-height tables and bedding details for pipe, pipe arches, and arches are very similar to those developed in the late 1950's. Over the years, nominal revisions have been made in the basic table and bedding standards. Extensive revisions in fill-height tables were forwarded to the Federal Highway Administration (FHWA) for review and comments. Much of the material presented in this report is based upon comments and recommendations of FHWA personnel. FHWA's CANDE computer program was not used in development of fill tables because of other considerations. FHWA recommends special designs when fills exceed 100 feet. Maximum permissable fills in excess of 100 feet, as shown in tables in Appendix A and Appendix B, are included for purposes of comparison. AASHTO guidelines do not designate limitations for maximum fill heights.

STRUCTURAL DESIGN CRITERIA

FLEXIBLE PIPE

The current fill-height table, Standard Drawing RDI-001-03, for corrugated steel pipe was developed by averaging suggested permissible fills listed in publications of four pipe manufacturers. Fills listed in those publications were based upon observations of trial installations of pipe formed from sheets having 2-2/3-inch by 1/2-inch corrugations. A similar procedure was used to develop the table for corrugated aluminum pipe. Neither table included reference to corrugation configuration (size) since the 2-2/3-inch 1/2-inch size was considered standard for pipe.

In 1966, the Bureau of Public Roads (now FHWA) issued a report entitled "Corrugated Metal Pipe, Structural Design Criteria and Recommended Installation Practice." The design criteria included investigation of the pipe for deflection or flattening, critical buckling of the pipe wall, and longitudinal seam strength. The report included fill-height tables developed for assumed backfills of 120 pounds per cubic foot compacted to 85-percent "Proctor" density with a passive soil pressure of 700 pounds per square inch and a soil stiffness coefficient of 0.44. A revised version of that report was issued in 1970. Fill-height tables were developed for backfills of 95-percent Proctor density having a passive soil pressure of 1,400 pounds per square inch and a soil stiffness coefficient of 0.22. In addition, a criterion for handling and installation strength was added.

Fill-height tables for corrugated metal pipe were developed in accordance with criteria presented in the 1970 FHWA publication, and those tables were proposed for use in Kentucky. In March 1983, those tables and others were forwarded to FHWA for comments and suggestions. Valuable comments and suggestions were received from FHWA in July 1983. It was noted that AASHTO had liberalized its reccommended design criteria, and it was recommended that fill-height tables be developed using those criteria.

Fundamentals of the current AASHTO design criteria are contained in Section 9 - Soil - Corrugated Metal Structure Interaction Systems of the Interim Specification, Bridges, 1981. Deflection or flattening has been eliminated as a design criterion since pipes do not approach previously specified design deflection limits when installed in accordance with generally accepted construction practices. In cases where deflection controlled the maximum permissible fill for an installation involving a circular conduit, vertically elongated equivalents were used to increase the permissible fill. Elimination of deflection as a design criterion negates any advantage of vertical elongations. As the title of Section 9 suggests, the importance of the soil envelope around a metal pipe is recognized in the criteria.

In accordance with the criteria, thrust in the wall is checked for wall area, buckling stress, and seam strength (structures with longitudinal seams). Provisions also are included for checking handling and installation strengths. A minimum cover height of 2 feet is suggested to prevent damage to the buried structure. Service load design (working stress method) and load factor design (ultimate strength principles) procedures are included under Section 9. The following discussion and tables included in Appendix A are based on the service load design method.

Recommended service load design safety factors (SF) are 3.0, 2.0, and 2.0, respectively, for seam strength, wall area, and buckling. Thrust in the wall is

$$T = P \times S/2 \qquad (1)$$

in which P = design load, lbs/ft^2,

S = span or diameter, ft, and

T = thrust, lbs/ft.

The required seam strength, for pipe fabricated with longitudinal seams (riveted, spot welded, bolted), is

$$SS = T \times SF \qquad (2)$$

in which SS = seam strength, lbs/ft, and

SF = safety factor (3.0).

The required wall area is

$$A = T/fa \qquad (3)$$

in which: A = Wall Area, in.^{2}/ftand

f_a = allowable stress, psi.

The allowable stress, F_a, is the specified minimum yield point, f_y, for the metal divided by the safety factor (SF = 2.0).

Corrugations having the wall area as computed by equation 3 must be checked for the possibility of buckling. If the allowable buckling stress is less than F_a, the required wall area must be recomputed using the allowable buckling stress in lieu of F_a. The allowable buckling stress is the critical buckling stress, f_{cr}, divided by the safety factor (SF = 2.0). Two equations are presented for computation of the critical buckling stress -- one for pipe diameters below a limiting diameter and the other for pipe diameters exceeding the limiting diameter. The limiting diameter is:

$$S = (r/k) \sqrt{24E_m/f_u} \qquad (4)$$

in which S = pipe diameter, in.,
r = radius of gyration of corrugation, in.,
k = soil stiffness factor (0.22),
E_m = modulus of elasticity, psi, and
f_u = specified minimum tensile strength, psi.

For pipe diameters less than the value determined by Equation 4, the critical buckling stress is

$$f_{cr} = (f_u - (f_u^2/48\ E_m)\ (kS/r)^2 \qquad (5)$$

in which f_{cr} = critical bluckling sress, psi, and

f_u = specified minimum tesile strength, psi.

When the pipe diameter exceeds the value computed by Equation 4, the critical buckling stress is

$$f_{cr} = 12E_m/(kS/r)^2 \qquad (6)$$

Handling and installation rigidity is measured by the flexibility factor, which is determined from

$$FF = S^2/E_m I \qquad (7)$$

in which FF = flexibility factor, in/lb,

S = pipe diameter, in.,

I = moment of inertia, $in.^4$ per unit length of cross section of pipe wall.

Maximum values are recommended for the flexibility factor for each corrugation configuration and type of metal. The strength must be sufficient to withstand impact forces during shipment and placement. Both shop assembled and field assembled conduit must have adequate strength to withstand backfill compactive forces.

Fill-height tables presented in Appendix A were developed for backfill densities of 120 pounds per cubic foot. The design load, P, in Equation 1 would be equal to 120 times the height of fill, H, in feet. Values for other design parameters are listed in the 1981 AASHTO Interim Specification. Live loads may be neglected for fill heights in excess of 8 feet.

FLEXIBLE PIPE ARCH

Design equations for flexible pipe are applicable for flexible pipe-arch design. The pipe-arch span dimension is used in lieu of pipe diameter in all equations containing S. Corner pressure must be accounted for in the design of the corner backfill. Corner pressure is considered to be approximately equal to the thrust divided by the radius of the pipe-arch corner. Soil around corners of pipe arches must be capable of supporting the resultant pressure.

The allowable bearing pressure generally limits the maximum fill height that may be placed above a pipe arch and may also limit the minimum fill. Compacted soils allowed in the design of flexible circular pipe will have an allowable bearing pressure of 4,000 pounds per square foot. The thrust in the pipe arch divided by the corner radius would not exceed 4,000 pounds per square foot. Substituting 4,000 R_c for T in Equation 1, the maximum permissible fill would be

$$H = 66.67\ R_c/S \qquad (8)$$

in which H = maximum permissible fill, ft,

R_c = corner radius, ft, and

S = span, ft.

The equation is not applicable for values of H less than 8 feet since live loads may not be neglected in those cases. Suggested fill-height tables included in Appendix A would not be applicable for bearing pressures less than 4,000 pounds per square foot.

REINFORCED CONCRETE PIPE (CIRCULAR AND ELLIPTICAL) AND ARCHES

Criteria similar to the current state-of-the-art for design and installation of reinforced concrete conduit, excluding box culverts, were issued by the BPR (FHWA) in April 1957. More detailed information was issued in August 1963 in "Reinforced Concrete Pipe Culverts -- Criteria for Structural Design and Installation." Similar details and more numerous tables and figures are presented in "Design Manual, Concrete Pipe," as revised in 1978, by the American Concrete Pipe Association (ACPA). Guidelines presented in those publications were developed cooperatively by the BPR and ACPA. AASHTO design criteria are contained in Section 15 - Soil - Reinforced Concrete Structure Interaction Systems of the Interim Specifications, Bridges, 1983.

support

The strength for a reinforced concrete conduit depends upon the horizontal dimension of the structure; height, unit weight, and character of the backfill at the sides and above the conduit; foundation characteristics; class of bedding; and type of installation.

Backfill loads transmitted to a rigid conduit are largely dependent upon the type of installation. The more common types of installations are positive projecting embankment, negative projecting embankment, induced trench, and trench. The relative elevation of the existing ground surface, prior to installation of the conduit, and the elevation of the exterior top of the structure, after installation, are used to differentiate between positive and negative projections. The top of the conduit is above the existing ground surface for positive projection situations and is below the existing ground surface for negative projection conditions. For situations where the top of the conduit is at the existing ground surface elevation, the installation is commonly referred to as zero projection. Trench installations normally refer to situations where the structure is installed in a relatively narrow trench in undisturbed soil. The induced trench is employed when structures are to be used under relatively high fills. The existing ground surface should be a plane that is horizontal laterally for a distance, on each side of the conduit, of two times the outside span or 12 feet, whichever is less. Longitudinally, that plane should parallel the grade to which the culvert is to be installed.

The distance of the existing ground surface below the exterior top of the conduit divided by the outside span, B_c, is called the projection ratio, p, for positive projecting conditions. For negative projection situations, projection ratio p, is defined as the ratio of the distance of existing ground surface above the exterior top of the conduit to the width of the trench, B_d, in which the conduit is installed.

Earth loads transmitted to the structure are influenced by pipe deflection, settlement into the foundation, and the magnitudes and directions of relative movements between the soil prism above the conduit and the soil prisms to the sides of the conduit. Those movements, settlement and deflections, are combined into an abstract ratio termed the settlement ratio, r_{sd}. Differential settlements within the interior (above) and exterior (to the sides) prisms generate shearing forces that may increase or decrease the load to be borne by the structure. When an embankment is sufficiently high, a plane within the embankment exists above which interior and exterior prism settlements are equal and shearing forces do not exist above that plane. That horizontal plane is called the plane of equal settlement.

An induced trench (imperfect ditch or imperfect trench) is normally used in construction of culverts placed under high embankments. After installation, backfill is placed to an elevation of 1 foot plus the outside height of the structure (or to some other elevation) above the top of the structure. A trench is then excavated directly over the conduit and backfilled with compressible material. In that manner, increased settlement within the interior prism is insured and load to be borne by the conduit is decreased. The load of the interior prism is transferred, in part, to the exterior prisms by arching.

Foundations may range from yielding to unyielding conditions. With all other conditions being equal, a conduit placed on an unyielding foundation must bear more load than one placed on a yielding foundation. In either event, the foundation should be uniform throughout the length of the conduit.

Bedding is the contact between the structure and foundation and has a significant influence upon the ability of the structure to support loads. Four classes of bedding are defined by the width of the band of contact between the conduit and foundations. Bedding classes are A, B, C, and D in that order of superiority. In Class A bedding, the conduit is placed in a concrete cradle to provide for uniformity of support over the lower exterior portion of the conduit. No shaping is required for Class D bedding and point loadings generally prevail throughout the length of the installation.

Design, manufacturing, and testing criteria for reinforced concrete pipe are outlined in AASHTO M 170. Five strength classes, I through V, are designated and corresponding strength requirements are specified. Pipe strengths are expressed in D-loads of pounds per linear foot per foot of inside diameter or hoizontal span. Similar criteria for reinforced concrete arch culverts and reinforced concrete elliptical culverts are contained in AASHTO M 206 and M 207, respectively. Strength classes may be based on D-load to produce a 0.01 inch crack and/or the D-load that causes ultimate failure. The 0.01-inch crack D-load is the maximum three-edge bearing test load supported by a specimen before a crack having a width of 0.01 inch occurs. Ultimate D-load is the three-edge bearing test load that causes failure. The test load, in pounds, divided by the length and internal span, in feet, of the test specimen yields D-load.

Under field conditions of loading, the vertical load is distributed over the outside top of the conduit and the resultant reaction is distibuted over the bedding contact area. As a result of load distribution, the load-supporting capacity of a conduit, as installed, would exceed its three-edge bearing test load supporting capacity. The ratio of the strength of a conduit under specified bedding conditions to its strength when tested by the three-edge bearing test is called the bedding factor, B_f. Equations, figures, and tables for use in determination of loads on conduits for various conditions are presented in FHWA, ACPA, and AASHTO publications.

The 0.01-inch strength requirements for Classes I through V reinforced concrete pipe, respectively, are 800; 1,000; 1,350; 2,000; and 3,000 pounds per linear foot per foot internal diameter. The ultimate strength requirements are 1,200; 1,500; 2,000; 3,000; and 3,750. Diameter, wall thickness, concrete strength, and reinforcement for each class pipe are prescribed in AASHTO M 170. Modified designs for sizes and loads beyond those shown are permissible when approved by the purchaser. AASHTO M 242 contains requirements for reinforced concrete pipe designed to specific D-loads. Section 7.1 of that specification provides that the relationship of the ultimate D-load strengths to the 0.01-inch crack D-load strength designations shall be determined using a factor of 1.5 for strength designations up to 2,000. For 0.01-inch crack strengths in excess of 3,000, the factor is to be 1.25. A factor varying in linear proportions from 1.5 to 1.25 is specified for strength designations from 2,000 through 3,000.

After the required D-load strength has been determined for a specific installation, the class of pipe required for the installation may be determined either on the basis of the 0.01-inch crack strength or on the basis of the ultimate strength, to which a factor of safety is applied. Similar procedures may also be applied for elliptical and arch structures.

Both working stress and ultimate strength design principles are presented in the 1983 AASHTO interim specifications. Articles 1.15.2 and 1.15.3 provide for use of results of three-edge bearing tests in lieu of service-load design or load-factor design. Effects of the soil-structure interaction are based on the design earth cover, sidefill compaction, and bedding characteristics. The total earth load on the conduit is

$$W_E = F_e w B_c H \tag{9}$$

in which W_E = earth load, lbs/ft,

F_e = soil-structure interaction factor,

w = weight of earth per unit length

of span, on width, b, lbs/in.,

B_c = outside horizontal span, ft, and

H = height of fill above top of conduit, ft.

The value of F_e for embankment installations is computed as

$$F_e = (1 + 0.20^{H}/B_c). \tag{10}$$

For trench installations, F_e is determined by

$$F_e = C_d B_d 2/HB_c \tag{11}$$

in which C_d = load coefficient for trench installations and

B_d = horizontal width of trench at top of conduit, ft.

The value of F_e does not have to exceed 1.2 for embankment installations with compacted fills at the sides of the conduit. For embankments with uncompacted fills at the sides of the conduit, the value of F_e need not be greater than 1.5. Values of C_d may be obtained from Figure 1.15.4B of the AASHTO interim specifications. The maximum value of F_e for trench installations need not exceed that of F_e for an embankment installation.

The design load carrying capacity of the conduit must equal the design load determined for the installed conditions, or

$$D = 12\ W_T/SB_f, \tag{12}$$

in which D = 0.01-inch crack D-load, lbs per ft per ft,

W_T = total load (earth plus live loads), lbs/ft,

S = inside horizontal span, in., and

B_f = bedding factor.

For convenience, live loads were not considered in development of the following methodology for determination of maximum permissible fill heights. Ignoring live load, W_E from Equation 9 would equal W_T in Equation 12. An equation for maximum permissible fill heights developed by use of Equations 9 and 12 is

$$H = DSB_f/12F_e wB_c. \qquad (13)$$

An earth load of 120 pounds per cubic foot acting over a width, b, of 12 inches would yield a numerical value of 120 for w in Equation 13. Since maximum fill heights are being considered, the ratio of H/B_c would always exceed one; therefore the maximum value of 1.2 for F_e is applicable for trench and embankment conditions with compacted fills at the sides of conduits. AASHTO Table 1.15.4.B lists bedding factors of 2.9 to 2.5 for embankments and 1.9 for trenches for each having Class B bedding. Equation 14 is applicable for embankment installations with a bedding factor of 2.7; Equation 15 applies to trench installations:

$$H = DS \, / \, 640B_c \text{ and} \qquad (14)$$

$$H = DS \, / \, 909.5B_c. \qquad (15)$$

It should be remembered that values of S are in inches and values of B_c are in feet. For a 48-inch, Class IV (2,000 D-load) reinforced concrete pipe, permissible fills would be 31.0 and 21.8 feet, respectively, for embankment and trench conditions.

In accordance with Article 1.15.4 (D)(2)(c) of the AASHTO 1983 interim specifications, loads for induced trench installations may be determined by accepted methods based on tests, soil-structure interaction analyses, or previous experience. Permissible fill heights for induced trench installations could be determined using Chart I (b) in the 1963 BPR (FHWA) publication. The ray line for Class B, p=1 would apply. The equation for that line is

$$H = 0.0359\,(D - 134). \qquad (16)$$

From the chart or Equation 16, the permissible fill for a Class IV reinforced concrete pipe for an induced trench installation would be 67.0 feet.

Chart I (a) of the 1963 BPR (FHWA) publication is for permissable fills for positive and zero projection installations. The ray line for Class B, p = 0 would apply to embankment installations comparable to those described in the AASHTO interim specification. The equation for the Class B, p = 0 ray line is

$$H = 0.0155D. \qquad (17)$$

The permissible fill for a Class IV reinforced concrete pipe using Equation 16 would be 31.0 feet. The comparison of AASHTO and BPR (FHWA) criteria for embankment installations lends support for use of the 1963 criteria for induced trench installations.

Permissible fill-height tables for reinforced concrete structures are presented in Appendix B. AASHTO specifications provide for special designs for conduit sizes and/or D-load strengths beyond those listed in the tables in Appendix B.

BEDDING

Separate bedding standards, Appendix C, are proposed for flexible and rigid conduit installations. According to design criteria for rigid conduit, strength requirements are different for embankment, induced trench, and trench installations even when other design factors are similar. Flexible design criteria do not distinguish between embankment and trench installations and do not provide for induced trench construction.

Bedding similar to that designated as Class B in the 1981 AASHTO Interim Specifications - Bridges is recommended for all installations. The foundation should be yielding and relatively uniform throughout the length of the structure. Provision for uniformity of the groundline (original, excavated, or embankment) to each side of the proposed installation is recommended. Backfill designated in the 1982 FHWA proposed criteria is incorporated on the standards. Zero projection is shown for each type rigid conduit installation.

DURABILITY

Indirectly, abrasion and corrosion are structural considerations since either or both may adversely affect the structural integrity of a conduit. In June 1979, the engineering firm of Byrd, Tallamy, MacDonald, and Lewis issued a report titled "Kentucky Culvert Study -- An Engineering Review of Policies and Practices Related to Procurement of Culvert and Sewer Pipe." That report was prepared in fulfillment of requirements of the Kentucky Department of Finance's Contract CA 00738 issued at the request of the Department of Transportation. A report titled "Culvert Material Selection Policy -- Kentucky Department of Transportation" was issued in May 1981. That report was prepared by consultants Kenneth S. Eff and Dr. Harry J. Sterling.

Information presented in those reports was used in preparation of current guidelines, relative to durability, for use in selection of culvert materials. Those guidelines should be reviewed periodically and revised in accordance with technological advancements and field performance data.

CAMBER

Most culverts which are constructed on or near the natural ground surface and then covered by an embankment will eventually subside as the embankment weight compresses and consolidates the foundation soil. Damages resulting from subsidence may be greatly minimized by placing the culvert on a cambered grade. The Division of Construction's Guidance Manual contains guidelines for camber design under Exhibit 63-4-8 which are included herein in Appendix D. It is recommended that consideration be given to adoption of those guidelines as standards and including them in the Standard Drawings.

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APPENDIX A

Fill-Height Tables for Flexible Conduit

TABLE 1

FILL HEIGHTS (FT) FOR 2 2/3" x 1/2" CORRUGATED STEEL PIPE WITH HELICAL LOCK SEAM OR HELICAL WELDED SEAM (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch)				
	0.064	0.079	0.109	0.138	0.168
12	213	266	373	480	586
15	170	213	298	384	469
18	142	177	248	320	390
21	122	152	213	274	335
24	106	133	186	240	293
27	94	118	166	213	260
30	85	106	149	192	234
36	71	88	124	160	195
42	61	76	106	137	167
48	53	66	93	120	146
54	-	59	82	106	130
60	-	-	74	95	117
66	-	-	-	87	106
72	-	-	-	79	97
78	-	-	-	-	90
84	-	-	-	-	83

TABLE 2

FILL HEIGHTS (FT) FOR 2 2/3" x 1/2" CORRUGATED STEEL PIPE WITH LONGITUDINAL RIVETED OR SPOT WELDED SEAM (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch) 0.064	0.079	0.109	0.138	0.168
12	92	101	130	136	142
15	74	80	104	109	114
18	61	67	86	90	94
21	53	57	74	77	81
24	46	50	65	68	71
27	41	44	57	60	63
30	37	40	52	54	56
36	30	33	43	45	47
42	34	47	74	77	81
48	30	41	65	68	71
54	-	36	57	60	63
60	-	-	52	54	57
66	-	-	-	49	51
72	-	-	-	45	47
78	-	-	-	-	43
84	-	-	-	-	40

TABLE 3

FILL HEIGHTS (FT) FOR 3" x 1" CORRUGATED STEEL PIPE WITH HELICAL LOCK SEAM OR HELICAL WELDED SEAM
(MINIMUM FILL - 2.0 FT)

Diameter	Metal Thickness (inch)				
(inches)	0.064	0.079	0.109	0.138	0.168
36	81	102	143	184	225
42	70	87	123	158	193
48	61	76	107	138	169
54	54	68	95	123	150
60	49	61	85	110	135
66	44	55	78	100	123
72	40	51	71	91	113
78	37	47	66	84	104
84	35	43	61	78	97
90	32	40	57	73	90
96	-	38	53	68	84
102	-	36	50	64	79
108	-	-	47	61	75
114	-	-	45	58	71
120	-	-	42	55	67
126	-	-	-	52	64
132	-	-	-	50	61
138	-	-	-	-	58
144	-	-	-	-	56
150	-	-	-	-	52

TABLE 4

FILL HEIGHTS (FT) FOR 3" x 1" CORRUGATED STEEL PIPE WITH LONGITUDINAL RIVETED OR SPOT WELDED SEAM

(MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch) 0.064	0.079	0.109	0.138	0.168
36	53	66	98	118	131
42	45	57	84	101	112
48	39	49	73	88	98
54	35	44	65	78	87
60	31	39	58	70	78
66	29	36	53	64	71
72	26	33	49	58	65
78	24	30	45	54	60
84	22	28	42	50	56
90	21	26	39	47	52
96	-	24	36	44	49
102	-	23	34	41	46
108	-	-	32	39	43
114	-	-	31	37	41
120	-	-	29	35	39
126	-	-	-	33	37
132	-	-	-	32	35
138	-	-	-	-	34
144	-	-	-	-	32
150	-	-	-	-	31

TABLE 5

FILL HEIGHTS (FT) FOR 5" x 1" CORRUGATED STEEL PIPE WITH HELICAL LOCK SEAM OR HELICAL WELDED SEAM (MINIMUM FILL - 2.0 FT)

Diameter	Metal Thickness (inch)				
(inches)	0.064	0.079	0.109	0.138	0.168
36	72	90	127	164	200
42	62	77	109	140	172
48	54	68	95	123	150
54	48	60	84	109	133
60	43	54	76	98	120
66	39	49	69	89	109
72	36	45	63	81	100
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
126	-	-	-	46	57
132	-	-	-	44	54
138	-	-	-	-	52
144	-	-	-	-	50
150	-	-	-	-	48

TABLE 6

FILL HEIGHTS (FT) FOR 6" x 2" CORRUGATED STEEL PIPE WITH LONGITUDINAL SEAMS HAVING FOUR 3/4" BOLTS PER FOOT (MINIMUM FILL - 2.0 FT FOR DIAMETERS THROUGH 198 IN. AND 3.0 FT FOR DIAMETERS 204 IN. THROUGH 306 IN).

Diameter (inches)	Metal Thickness (inch) 0.109	0.138	0.168	0.188	0.218	0.249	0.280
60	46	68	90	103	124	146	160
66	42	62	81	94	113	133	145
72	38	57	75	86	103	122	133
78	35	52	69	79	95	112	123
84	33	49	64	73	88	104	114
90	31	45	60	68	82	97	106
96	29	43	56	64	77	91	100
102	27	40	52	60	73	86	94
108	25	38	50	57	69	81	88
114	24	36	47	54	65	77	84
120	23	34	45	51	62	73	80
126	22	32	42	49	59	69	76
132	21	31	40	46	56	66	72
138	20	29	39	44	54	63	69
144	19	28	37	43	51	61	66
150	18	27	36	41	49	58	64
156	17	26	34	39	47	56	61
162	17	25	33	38	46	54	59
168	16	24	32	36	44	52	57
174	16	23	31	35	42	50	55
180	15	22	30	34	41	48	53
186	15	22	29	33	40	47	51
192	-	21	28	32	38	45	50
198	-	20	27	31	37	44	48
204	-	20	26	30	36	43	47
210	-	19	25	29	35	41	45
216	-	-	25	28	34	40	44
222	-	-	24	27	33	39	43
228	-	-	23	27	32	38	42

TABLE 6 (continued)

Diameter (inches)	Metal Thickness (Inch) 0.109	0.138	0.168	0.188	0.218	0.249	0.280
234	-	-	23	26	31	37	41
240	-	-	-	25	31	36	40
246	-	-	-	25	30	35	39
252	-	-	-	-	29	34	38
258	-	-	-	-	28	34	37
264	-	-	-	-	28	33	36
270	-	-	-	-	27	32	35
276	-	-	-	-	-	31	34
282	-	-	-	-	-	31	34
288	-	-	-	-	-	30	33
294	-	-	-	-	-	-	32
300	-	-	-	-	-	-	32
306	-	-	-	-	-	-	31

TABLE 7

FILL HEIGHTS (FT) FOR 2 2/3" x 1/2" CORRUGATED STEEL PIPE-ARCHES

Span x Rise (in. x in.)	Metal Thickness (in.)	Minimum Corner Radius (in.)	Fill (ft) Min	Fill (ft) Max*
17 x 13	0.064	3	1.5	12 (2.0)
21 x 15	0.064	3	1.5	10 (2.0)
24 x 18	0.064	3	2.0	7 (2.0)
28 x 20	0.064	3	2.0	5 (2.0)
35 x 24	0.064	3	2.5	7 (3.0)
42 x 29	0.064	3 1/2	2.5	7 (3.0)
29 x 33	0.079	4	2.5	6 (3.0)
57 x 38	0.109	5	2.5	8 (3.0)
64 x 43	0.109	6	2.5	9 (3.0)
71 x 47	0.138	7	2.0	10 (3.0)
77 x 52	0.168	8	2.0	5 (2.0)
83 x 57	0.168	9	2.0	5 (2.0)

*Figures in parenthesis are minimum permissable soil bearing pressure - tons/ft^2

TABLE 8

FILL HEIGHTS (FT) FOR EITHER 3" x 1" or 5" x 1" CORRUGATED STEEL PIPE-ARCHES (REQUIRED SOIL BEARING PRESSURE - 2.0 TONS/FT^2, MINIMUM)

Span x Rise (in. x in.)	Metal Thickness (in.)	Minimum Corner Radius (in.)	Fill (Ft) Min	Fill (Ft) Max
40 x 31	0.064	5	2.5	8
46 x 36	0.064	6	2.0	8
53 x 41	0.064	7	2.0	8
60 x 46	0.064	8	2.0	8
66 x 51	0.064	9	1.5	9
73 x 55	0.064	12	1.5	11
81 x 59	0.064	14	1.5	11
87 x 63	0.064	14	1.5	10
95 x 67	0.079	16	1.5	11
103 x 71	0.109	16	2.0	10
112 x 75	0.109	18	2.0	10
117 x 79	0.109	18	2.0	10
128 x 83	0.138	18	2.0	9
137 x 87	0.138	18	2.0	8
142 x 91	0.168	18	2.0	7

TABLE 9

FILL HEIGHTS (FT) FOR 6" x 2" CORRUGATED STEEL PIPE-ARCHES (REQUIRED SOIL BEARING PRESSURE - 2.0 TONS/FT^2, MINIMUM)

Span x Rise (ft-in. x ft-in.)	Metal Thickness (in.)	Minimum Corner Radius (in.)	Fill (Ft) Min	Fill (Ft) Max
6-1 x 4-7	0.109	18	1.5	16
7-0 x 5-1	0.109	18	1.5	14
7-11 x 5-7	0.109	18	1.5	13
8-10 x 6-1	0.109	18	2.0	11
9-9 x 6-7	0.109	18	2.0	10
10-11 x 7-1	0.109	18	2.0	9
11-10 x 7-7	0.109	18	2.0	7
12-10 x 8-4	0.109	18	2.5	6
14-1 x 8-9	0.109	18	2.5	5
13-3 x 9-4	0.109	31	2.0	13
14-2 x 9-10	0.109	31	2.0	12
15-4 x 10-4	0.138	31	2.0	11
16-3 x 10-10	0.138	31	2.0	11
17-2 x 11-4	0.138	31	2.5	10
18-1 x 11-10	0.168	31	2.5	10
19-3 x 12-4	0.168	31	2.5	9
19-11 x 12-10	0.188	31	2.5	9
20-7 x 13-2	0.188	31	3.0	7

TABLE 10

FILL HEIGHTS (FT) FOR 2 2/3" x 1/2" CORRUGATED ALUMINUM PIPE WITH HELICAL LOCK SEAM (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch) 0.060	0.075	0.105	0.135	0.164
12	155	194	271	349	426
15	124	155	217	279	341
18	103	128	181	233	284
21	88	110	154	199	243
24	77	96	136	175	213
27	68	86	120	155	189
30	62	77	108	140	170
36	51	64	90	116	141
42	44	55	77	99	122
48	-	47	66	86	107
54	-	-	54	70	87
60	-	-	-	57	71
66	-	-	-	46	57
72	-	-	-	-	45

TABLE 11

FILL HEIGHTS (FT) FOR 2 2/3" x 1/2" CORRUGATED ALUMINUM PIPE WITH RIVETED LONGITUDINAL SEAM (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch) 0.060	0.075	0.105	0.135	0.164
12	50	50	86	90	93
15	40	40	69	72	74
18	33	33	57	60	62
21	28	28	49	51	53
24	25	25	43	45	46
27	22	22	38	40	41
30	20	20	34	36	37
36	16	16	28	30	31
42	22	28	50	52	53
48	-	25	43	45	47
54	-	-	38	40	41
60	-	-	-	36	37
66	-	-	-	33	34
72	-	-	-	-	31

TABLE 12

FILL HEIGHTS (FT) FOR 3" x 1" CORRUGATED ALUMINUM PIPE WITH HELICAL LOCK SEAM (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch) 0.060	0.075	0.105	0.135	0.164
36	59	74	104	138	164
42	50	63	89	118	141
48	44	55	78	104	123
54	39	49	69	89	109
60	35	44	62	80	98
66	32	40	56	73	89
72	30	37	52	66	81
78	-	34	43	61	75
84	-	-	44	57	70
90	-	-	41	53	65
96	-	-	38	49	60
102	-	-	-	44	54
108	-	-	-	40	49
114	-	-	-	-	44
120	-	-	-	-	40

TABLE 13

FILL HEIGHT (FT) FOR 3" x 1" CORRUGATED ALUMINUM PIPE WITH RIVETED LONGITUDINAL SEAM (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch) 0.060	0.075	0.105	0.135	0.164
36	30	37	51	77	101
42	26	32	44	66	86
48	22	28	38	58	75
54	20	25	34	51	67
60	18	22	31	46	60
66	16	20	28	42	55
72	15	18	25	38	50
78	-	17	23	35	46
84	-	-	22	33	43
90	-	-	20	31	40
96	-	-	19	29	37
102	-	-	-	27	35
108	-	-	-	25	33
114	-	-	-	-	31
120	-	-	-	-	30

TABLE 14

FILL HEIGHTS (FT) FOR 6" x 1" CORRUGATED ALUMINUM PIPE WITH HELICAL LOCK SEAM (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch) 0.060	0.075	0.105	0.135	0.164
30	62	77	108	140	172
36	51	64	90	117	143
42	44	55	77	99	122
48	38	48	67	87	107
54	34	43	60	77	94
60	31	38	54	69	85
66	28	35	49	63	77
72	25	32	45	58	71
78	-	29	41	53	65
84	-	-	38	49	60
90	-	-	36	46	56
96	-	-	-	43	53
102	-	-	-	40	49
108	-	-	-	36	44
114	-	-	-	-	40

TABLE 15

FILL HEIGHTS (FT) FOR 6" x 1" CORRUGATED ALUMINUM PIPE WITH RIVETED LONGITUDINAL SEAM (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch) 0.060	0.075	0.105	0.135	0.164
30	35	44	62	79	96
36	29	36	51	66	80
42	25	31	44	56	69
48	22	27	38	49	60
54	19	24	34	44	53
60	17	22	31	39	48
66	16	20	28	36	43
72	14	18	25	33	40
78	-	17	23	30	37
84	-	-	22	28	34
90	-	-	20	26	32
96	-	-	-	24	30
102	-	-	-	23	28
108	-	-	-	22	26
114	-	-	-	-	25

TABLE 16

FILL HEIGHTS (FT) FOR 9" x 2 1/2" CORRUGATED ALUMINUM PIPE WITH LONGITUDINAL SEAM WITH ALUMINUM BOLTS (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch) 0.100	0.125	0.150	0.175	0.200	0.225	0.250
60	29	38	49	58	58	58	58
66	26	35	44	53	53	53	53
72	24	32	41	48	48	48	48
78	22	29	37	45	45	45	45
84	20	27	35	41	41	41	41
90	19	25	32	39	39	39	39
96	18	24	30	36	36	36	36
102	17	22	29	34	34	34	34
108	16	21	27	32	32	32	32
114	15	20	25	30	30	30	30
120	14	19	24	29	29	29	29
126	13	18	23	27	27	27	27
132	13	17	22	26	26	26	26
138	12	16	21	25	25	25	25
144	12	16	20	24	24	24	24
150	-	15	19	23	23	23	23
156	-	14	18	22	22	22	22
162	-	-	18	21	21	21	21
168	-	-	17	20	20	20	20
174	-	-	17	20	20	20	20
180	-	-	-	19	19	19	19

TABLE 17

FILL HEIGHTS (FT) FOR 9" x 2 1/2" CORRUGATED ALUMINUM PIPE WITH LONGITUDINAL SEAM WITH STEEL BOLTS (MINIMUM FILL - 2.0 FT)

Diameter (inches)	Metal Thickness (inch)						
	0.100	0.125	0.150	0.175	0.200	0.225	0.250
60	31	45	60	70	81	92	103
66	28	41	54	64	74	84	94
72	25	37	50	58	67	77	86
78	23	35	46	54	62	71	79
84	22	32	42	50	58	66	73
90	20	30	40	47	54	61	68
96	19	28	37	44	50	57	64
102	18	26	35	41	47	54	60
108	17	25	33	39	45	51	57
114	16	23	31	37	42	48	54
120	15	22	30	35	40	46	51
126	14	21	28	33	38	44	49
132	14	20	27	32	37	42	47
138	13	19	26	30	35	40	44
144	12	18	25	29	33	38	43
150	-	18	24	28	32	36	41
156	-	17	23	27	31	35	39
162	-	-	22	26	30	34	38
168	-	-	21	25	29	33	36
174	-	-	20	24	28	31	35
180	-	-	-	23	27	30	34

TABLE 18

FILL HEIGHTS (FT) FOR 2 2/3" x 1/2" CORRUGATED ALUMINUM PIPE-ARCHES

Span x Rise (in. x in.)	Metal Thickness (in.)	Minimum Corner Radius (in.)	Fill (ft) Min	Fill (ft) Max*
17 x 13	0.060	3	1.5	12 (2.0)
21 x 15	0.060	3	1.5	10 (2.0)
24 x 18	0.060	3	2.0	7 (2.0)
28 x 20	0.060	3	2.0	5 (2.0)
35 x 24	0.060	3	2.5	7 (3.0)
42 x 29	0.060	3 1/2	2.5	7 (3.0)
49 x 33	0.079	4	2.5	6 (3.0)
57 x 38	0.135	5	2.5	8 (3.0)
64 x 43	0.135	6	2.5	9 (3.0)
71 x 47	0.164	7	2.0	10 (3.0)

*Figures in parenthesis are minimum permissible soil bearing pressure - tons/ft_2

TABLE 19

FILL HEIGHTS (FT) FOR 3" x 1" CORRUGATED ALUMINUM PIPE-ARCHES (REQUIRED SOIL BEARING PRESSURE - 2.0 TONS/FT^2, MINIMUM)

Span x Rise (in. x in.)	Metal Thickness (in.)	Minimum Corner Radius (in.)	Fill (ft) Min	Fill (ft) Max
40 x 31	0.060	5	2.5	8
46 x 36	0.060	6	2.0	8
53 x 41	0.060	7	2.0	8
60 x 46	0.060	8	2.0	8
66 x 51	0.060	9	1.5	9
73 x 55	0.075	12	1.5	11
81 x 59	0.075	14	1.5	11
87 x 63	0.105	14	1.5	10
95 x 67	0.105	16	1.5	11
103 x 71	0.135	16	2.0	10
112 x 75	0.135	18	2.0	10
117 x 79	0.164	18	2.0	10

TABLE 20

FILL HEIGHTS (FT) FOR 9" x 2 1/2" CORRUGATED ALUMINUM PIPE-ARCHES, 31.8" CORNER RADIUS, WITH 3/4" ALUMINUM OR STEEL BOLTS AT 4 1/3 PER FOOT (REQUIRED SOIL BEARING PRESSURE - 2.0 TONS/FT^2, MINIMUM)

Span x Rise (ft-in. x ft-in.)	Metal Thickness (in.)	Fill (ft) Min	Fill (ft) Max
6-7 x 5-8	0.100	1.5	23
7-9 x 6-0	0.100	1.5	20
8-5 x 6-3	0.100	1.5	18
9-3 x 6-5	0.100	2.0	16
9-11 x 6-8	0.100	2.0	15
10-9 x 6-10	0.100	2.0	14
11-5 x 7-1	0.100	2.0	13
12-3 x 7-3	0.100	2.0	12
12-11 x 7-6	0.100	2.5	11
13-1 x 8-4	0.100	2.5	11
13-11 x 9-5	0.100	2.5	11
14-8 x 9-8	0.100	2.5	10
15-4 x 10-0	0.125	2.5	11
16-1 x 10-4	0.125	2.5	10
16-9 x 10-8	0.125	2.5	10
17-3 x 11-0	0.150	2.5	10
18-0 x 11-4	0.150	2.5	9
18-8 x 11-8	0.150	3.0	9

APPENDIX B

Fill-Height Tables for Rigid Conduit

TABLE 21. FILL HEIGHTS (FT) FOR CIRCULAR REINFORCED CONCRETE PIPE (DIAMETERS 15 THROUGH 144 INCHES)

EMBANKMENT INSTALLATIONS

	STANDARD			INDUCED TRENCH	
Fill Height (ft)	2.0 - 21.0	21.1 - 31.0	31.1 - 47.0	47.1 - 67.0	67.1 - 103.0
D-Load Class	III	IV	V	IV	V

TRENCH INSTALLATIONS

Fill Height (ft)	2.0 - 15.0	15.1 - 22.0	22.1 - 33.0
D-Load Class	III	IV	V

TABLE 22

FILL HEIGHTS (FT) FOR HORIZONTAL ELLIPTICAL REINFORCED CONCRETE PIPE (SIZES 14 x 23 THROUGH 67 x 106 INCHES)

EMBANKMENT INSTALLATIONS

	STANDARD		INDUCED TRENCH	
Fill Height (ft)	1.0-21.0	21.1 - 31.0	31.1 - 44.0	44.1 - 67.0
D-Load Class	HE III	HE IV	HE III	HE IV

TRENCH INSTALLATION

Fill Height (ft)	2.0 - 15.0	15.1 - 22.0
D-Load Class	HE III	HE IV

TABLE 23

FILL HEIGHTS (FT) FOR VERTICAL ELLIPTICAL REINFORCED CONCRETE PIPE (SIZES 45 x 29 THROUGH 106 x 57 INCHES)

EMBANKMENT INSTALLATIONS

	STANDARD			INDUCED TRENCH		
Fill Height (ft)	2.0-21.0	21.1-31.0	31.1-47.0	47.1-62.0	62.1-103.0	103.1-138.0
D-Load Class	VE III	VE IV	VE V	VE IV	VE V	VE VI

TRENCH INSTALLATION

Fill Height (ft)	2.0 - 15.0	15.1 - 22.0	22.1 - 33.0	33.1 - 44.0
D-Load Class	VE III	VE IV	VE V	VE VI

TABLE 24

FILL HEIGHTS (FT) FOR REINFORCED CONCRETE ARCH PIPE (SIZES 11 x 18 THROUGH 106 x 168 INCHES)

EMBANKMENT INSTALLATIONS

	STANDARD		INDUCED TRENCH	
Fill Height (ft)	2.0 - 21.0	21.1 - 31.0	31.1 - 47.0	47.1 - 67.0
D-Load Class	III	IV	III	IV

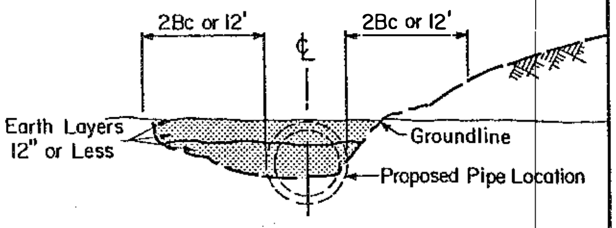
TRENCH INSTALLATION

Fill Height (ft)	2.0 - 15.0	15.1 - 22.0
D-Load Class	III	IV

APPENDIX C

Proposed Bedding Standards

STEP 1

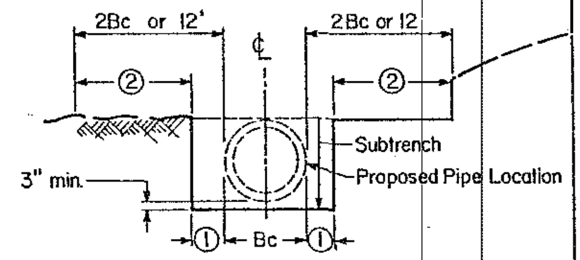


a. If groundline is at or above top of proposed pipe for width of 2Bc or 12' on each side of the pipe, go directly to Step 2.

b. If groundline is not at or above top of proposed pipe, compact embankment in layers 12" or less to elevation and width shown ▒. Meet density requirements for proposed embankment.

NOTE: Groundline may be (a) existing or original, (b) excavated surface or (c) embankment surface.

STEP 2



a. Excavate to within top of proposed pipe a width of 2Bc or 12' on each side of pipe.

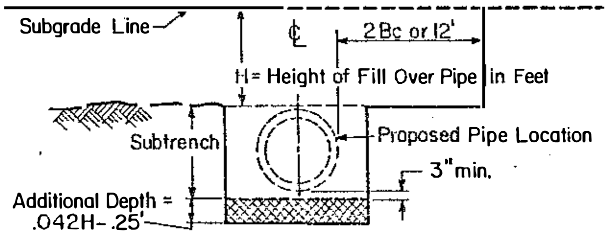
b. Excavate subtrench to width and depth shown.

① At least 12", but not more than 15".

② Elevations within this limit shall not vary more than 12" laterally, and shall parallel the proprosed flowline grade longitudinally.

ROCK FOUNDATION DETAILS

STEP 3

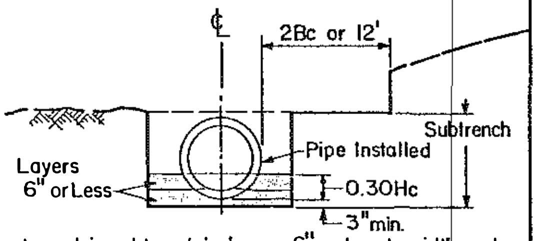


a. If Rock Foundation is not encountered, go directly to Step 4.

b. If Rock Foundation is encountered, excavate subtrench additional depth using formula given. This additional depth ▦ shall always be at least 0.75' and will not be required to be more than 0.75Hc-.25', regardless of above formula result.

c. Backfill additional excavated area with cushion of firmly compacted soil meeting requirements of AASHTO M 145 for either A-1, A-3, A-2-4, or A-2-5 in layers 6" or less.

STEP 4

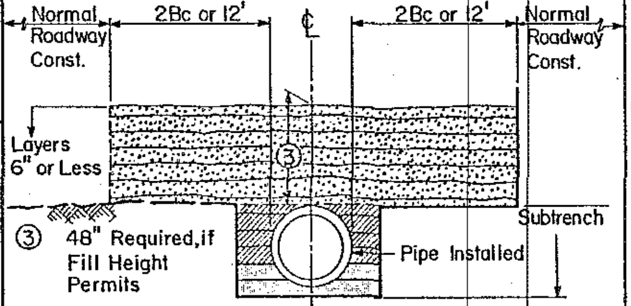


a. Compact sand in subtrench in layers 6" or less to width and elevation shown ▒.

b. Excavate a groove in the compacted sand to conform to the outside of the pipe. After excavation of the groove, approximately 3" of sand should remain below the outside invert of the pipe. The cradle shall be gaged for shape and slope by striking or drawing a template through the groove immediately before placing each section of pipe.

c. Install pipe at correct alignment and elevation. Recompact any loose sand disturbed during installation.

STEP 5

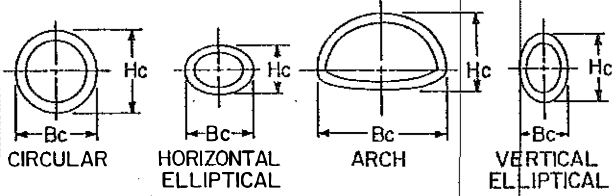


a. Compact soil meeting requirements of AASHTO M 145 for either A-1, A-3, A-2-4 or A-2-5 in layers 6" or less to top of the pipe ▨.

b. If induced trench is specified, go directly to Step 6.

c. If induced trench not specified then compact selected fine soil to elevotion ③ above top of pipe ▒. Meet density requirements for adjacent embankment.

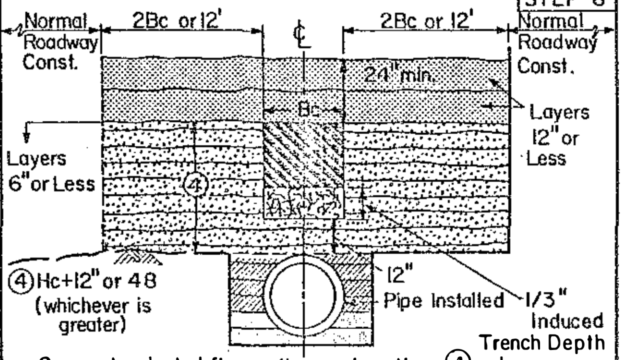
d. Proceed with normal roadway construction.



PIPE SHAPES

INDUCED TRENCH

STEP 6



a. Compact selected fine soil, to elevation ④ above top of pipe ▒. Meet density requirements for adjacent embankment.

b. Excavate induced trench Bc wide down to 12" above top of pipe.

c. Fill bottom 1/3 of induced trench with loose straw or hay ▩.

d. Fill top 2/3 of induced trench with lightly compacted soil ▧.

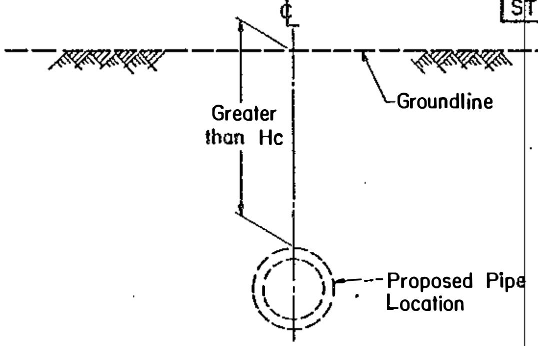
e. Place embankment in layers 12" or less to 24" minimum above top of induced trench to width shown. ▒ Meet density requirements for adjacent embankment.

f. Proceed with normal embankment construction.

RIGID PIPE
EMBANKMENT INSTALLATIONS
(STEPS-1-5)

INDUCED TRENCH INSTALLATIONS
(STEPS-1-6)

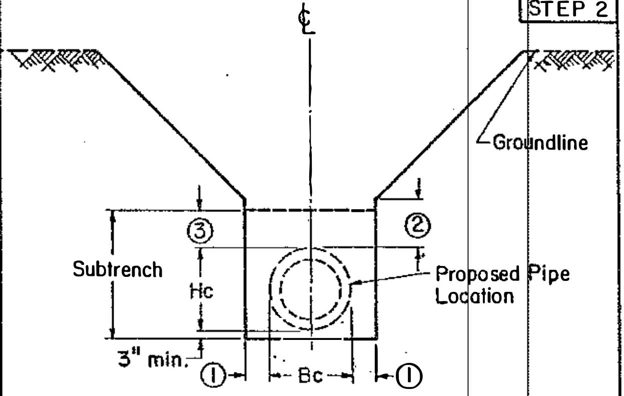
STEP 1



a. Trench condition Is when groundline elevation is greater than Hc above top of proposed pipe.

NOTE: Groundline may be (a) existing or original (b) excavated surface or (c) embankment surface.

STEP 2



a. Excavate subtrench to width and depth shown.

b. Trench walls may be constructed vertical. For illustration purposes the detail depicts a sloping wall trench. Whichever method is used, the trench walls shall remain symmetrical about the centerline of the pipe.

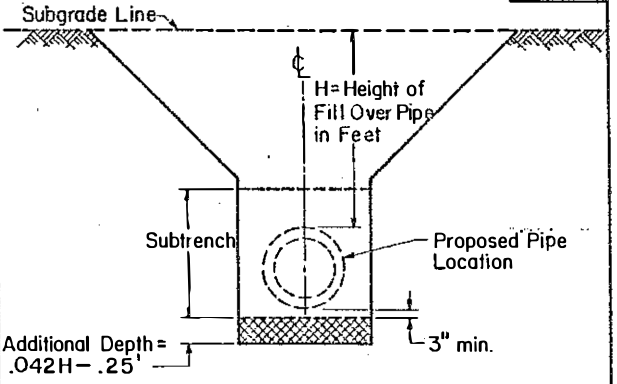
① 12" Min., 15" Max.

② Sloping of trench walls may begin at any elevation greater than 12" above top of pipe. The subtrench shall always be required.

③ 12" Min. to Hc Max.

ROCK FOUNDATION DETAILS

STEP 3

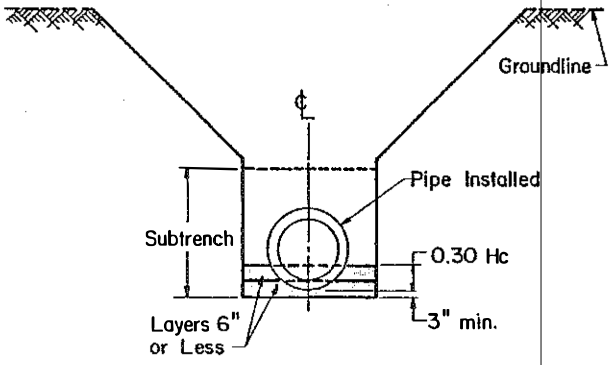


a. If Rock Foundation isnot encountered, go directly to Step4.

b. If Rock Foundation is encountered, excavate subtrench additional depth using formula given. This additional depth ▩ shall always be at least 0.75' and will not be required to be more than 0.75Hc − .25', regardless of above formula result.

c. Backfill additional excavated area with earth cushion of firmly compacted soil meeting requirements of AASHTO M 145 for either A-1, A-3, A-2-4, or A-2-5 in layers 6" or less.

STEP 4

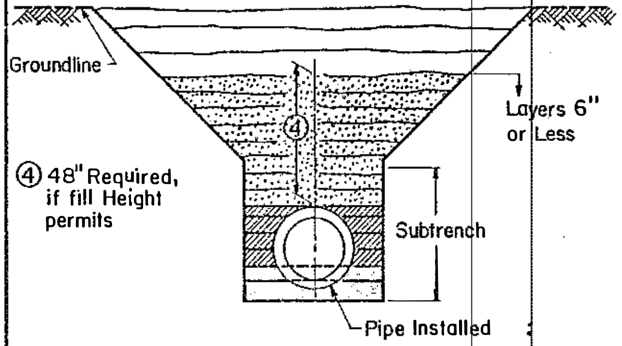


a. Compact sand in subtrench in layers 6" or less to width and elevation shown ▭.

b. Excavate a groove in the compacted sand to conform to the outside of the pipe. After excavation of the groove, approximately 3" of sand should remain below the outside invert of the pipe. The cradle shall be gaged for shape and slope by striking or drawing a template through the groove immediately before placing each section of pipe.

c. Install pipe at correct alignment and elevation. Recompact any loose sand disturbed during installation.

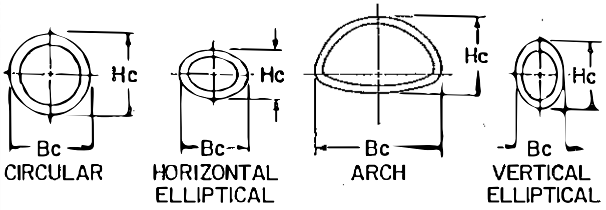
STEP 5



a. Compact selected soil meeting requirements of AASHTO M 145 for either A-1, A-3, A-2-4, or A-2-5 in layers 6" or less to Top of pipe ▨.

b. In a uniform symmetrical manner compact selected fine soil to elevation ④ above top of pipe in layers 6" or less ⬚.

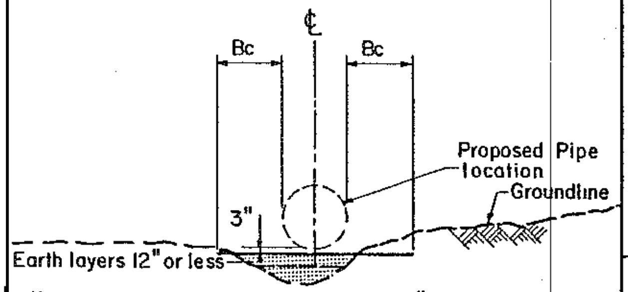
c. Proceed with trench backfill in a symmetrical manner in layers 12" or less to the original groundline as defined in Step 1.



PIPE SHAPES

RIGID PIPE
TRENCH
INSTALLATIONS

STEP 1

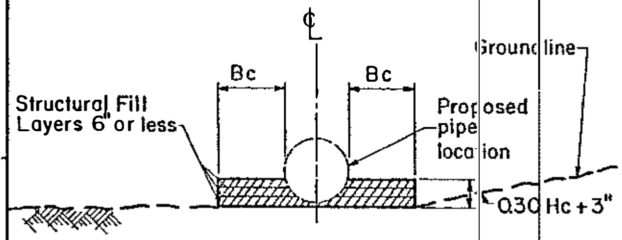


a. If groundline is at or above an elevation 3" below the bottom of the proposed pipe, prepare the groundline by leveling or excavating to provide a surface elevation 3" below the bottom of the proposed pipe for Bc on each side.

b. If the groundline is below the required elevation, compact embankment in layers 12" or less to elevation shown and Bc on each side ▤. Meet density requirements for proposed embankment.

NOTE: Groundline may be (a) existing or original, (b) excavated surface or (c) embankment surface.

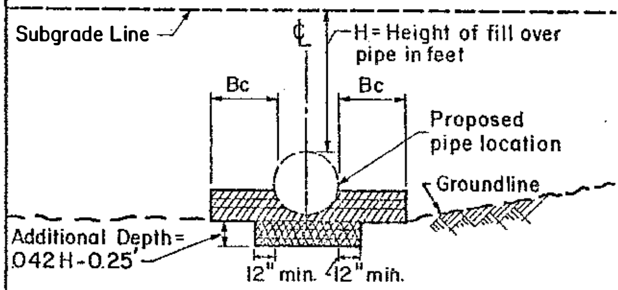
STEP 2



Place structural fill to elevation shown and to width Bc or more on each side of proposed pipe ▨. Structural fill shall be firmly compacted soil meeting requirements of AASHTO M145 for either A-1, A-3, A-2-4, or A-2-5.

STEP 3

ROCK FOUNDATION DETAILS

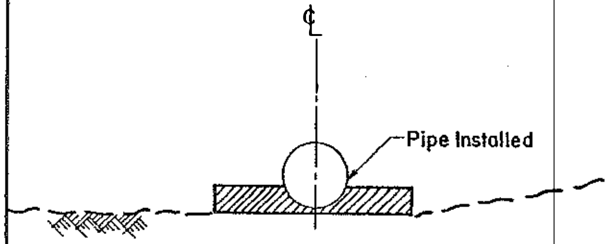


a. If Rock Foundation is not encountered, go directly to Step 4.

b. If Rock Foundation is encountered, excavate subtrench additional depth using formula given. This additional depth ▩ shall always be at least 0.75' and will not be required to be more than 0.75Hc-.25', regardless of above formula result.

c. Backfill additional excavated area with structural fill as designated in Step 2.

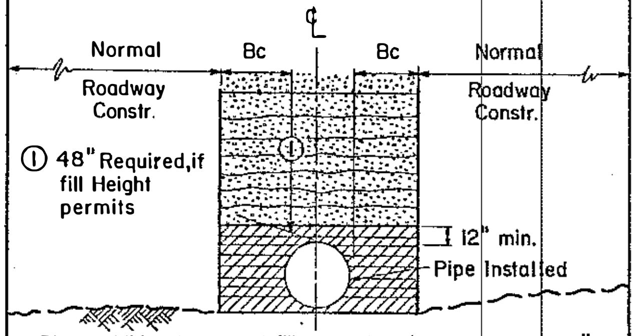
STEP 4



b. Excavate a groove in the compacted structural fill conform to the outside of the pipe After excavation of the groove, approximately 3" of structural fill should remain below the outside invert of the pipe. The cradle shall be gaged for shape and slope by striking or drawing a template through groove immediately before placing each section of pipe.

c. Install pipe at correct alignment and elevation. Recompact any loose structural fill disturbed during installation.

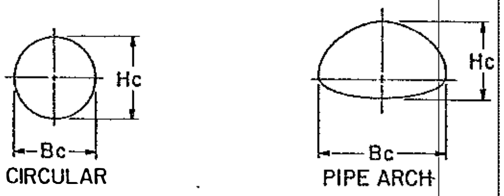
STEP 5



a. Place additional structuol fill to an elevation no less than 12" above top of pipe to no less than Bc on each side of pipe. Lifts within the limits of the pipe shall be placed alternately.

b. Compact selected fine soil to elevation ① above top of pipe ▤. Meet density requirements of adjacent embankment.

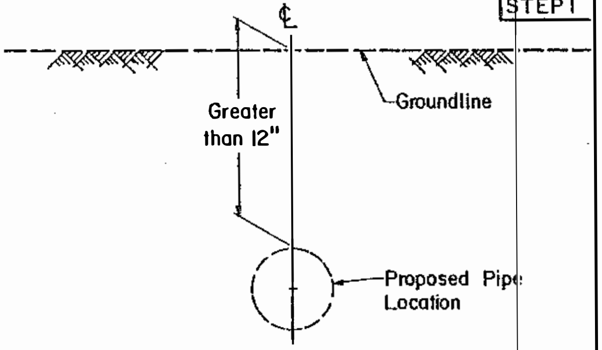
c. Proceed with normal roadway construction.



PIPE SHAPES

FLEXIBLE PIPE
EMBANKMENT
INSTALLATIONS

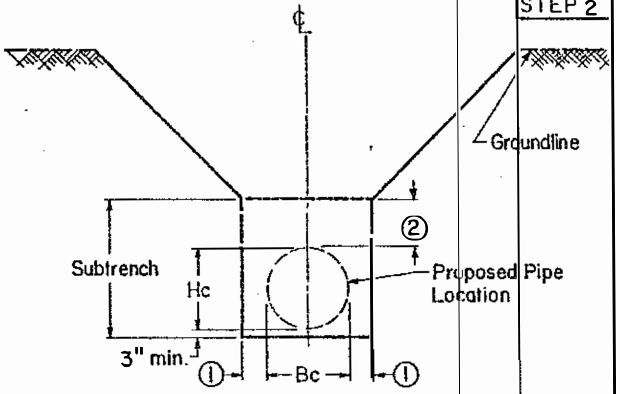
STEP 1



a Trench condition is when groundline elevation is greater than 12" above top of proposed pipe and/or is not prepared as required for flexible pipe embankment instal.

NOTE: Groundline may be (a) existing or original
(b) excavated surface or (c) embankment surface.

STEP 2



a. Excavate subtrench to width and depth shown

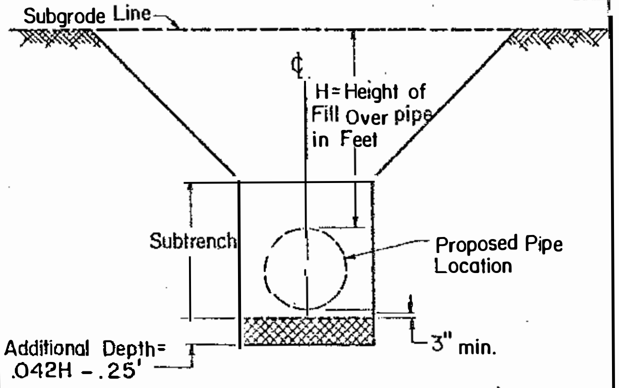
b. Trench walls may be constructed vertical. For illustration purposes, the detail depicts a sloping wall trench. Whichever method is used, the trench walls shall remain symmetrical about the centerline of the pipe.

① 24" Min.

② Sloping of trench walls may begin at any elevation greater than 12" above top of pipe. The subtrench shall always be required.

ROCK FOUNDATION DETAILS

STEP 3

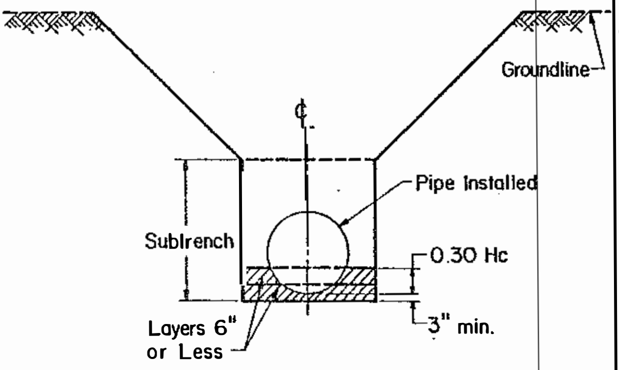


a. If Rock Foundation is not encountered, go directly to Step 4.

b. If Rock Foundation is encountered, excavate subtrench additional depth using formula given. This additional depth ▩ shall always be at least 0.75' and will not be required to be more than 0.75Hc - .25', regardless of above formula result.

c. Backfill additional excavated area with cushion of firmly compacted soil meeting requirements of AASHTO M145 for either A-1, A-3, A-2-4, or A-2-5 in layers 6" or less.

STEP 4

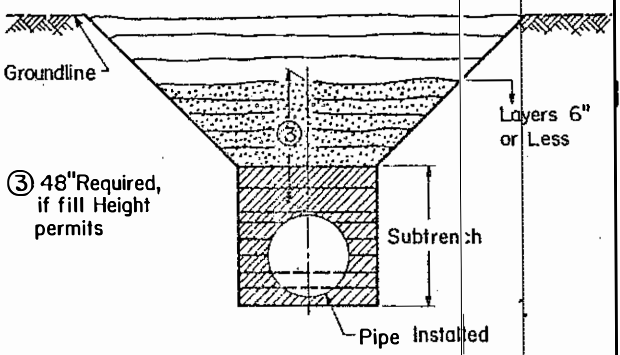


a. Compact structural fill meeting requirements of AASHTO M 145 for either A-1, A-3, A-2-4, or A-2-5 in subtrench in layers 6" or less to width and elevation shown ▨.

b. Excavate a groove in the compacted structural fill to conform to the outside of the pipe. After excavation of the groove, approximately 3" of structural fill should remain below the outside invert of the pipe. The cradle shall be gaged for shape and slope by striking or drawing a template through the groove immediately before placing each section of pipe.

c. Install pipe at correct alignment and elevation. Recompact any loose structural fill disturbed during installation.

STEP 5

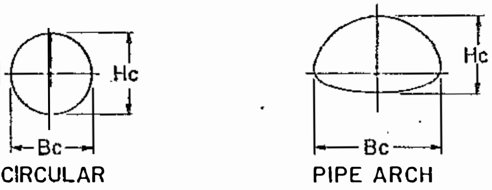


③ 48" Required, if fill Height permits

a. Compact structural fill in layers 6" or less to elevation 12" above top of pipe. Lifts within limits of pipe shall be placed alternately.

b. In a uniform symmetrical manner compact selected fine soil to elevation ③ above top of pipe in layers 6" or less ░.

c. Proceed with trench backfill in a symmetrical manner in layers 12" or less to the original groundline as defined in Step 1.



CIRCULAR

PIPE ARCH

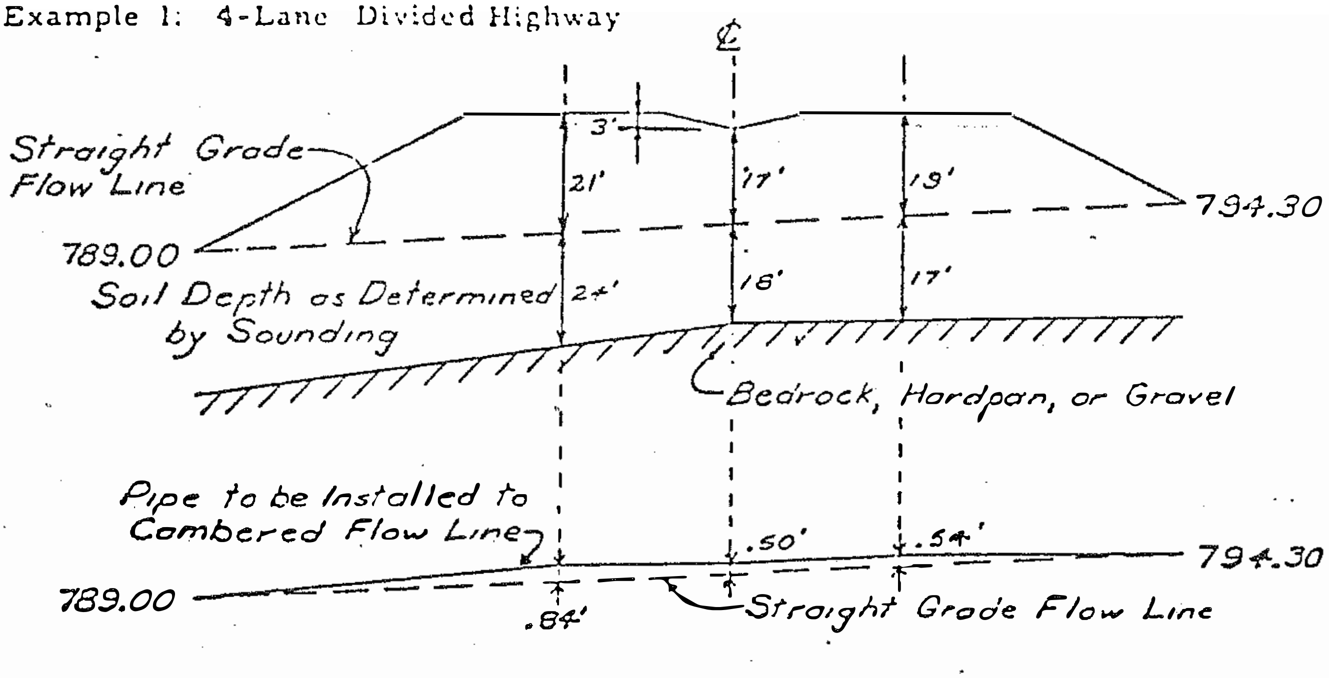
PIPE SHAPES

FLEXIBLE PIPE
TRENCH
INSTALLATION

APPENDIX D

Camber Design Guidelines
(from Division of Construction's Guidance Manual)

Example 1: 4-Lane Divided Highway



Median:

1. From the fill ht. vs settlement curve, read settlement of .028 ft. per foot of soil below flow line to be expected under 17' fill.

2. Total settlement = 18(.028) = .50' = camber.

Centerline of Roadway Over Inlet Portion of Culvert:

1. From the fill ht. vs settlement curve, read settlement of .032 ft. per foot of soil below flow line to be expected uner 19' fill.

2. Total settlement = 17 (.032) = .54' = camber.

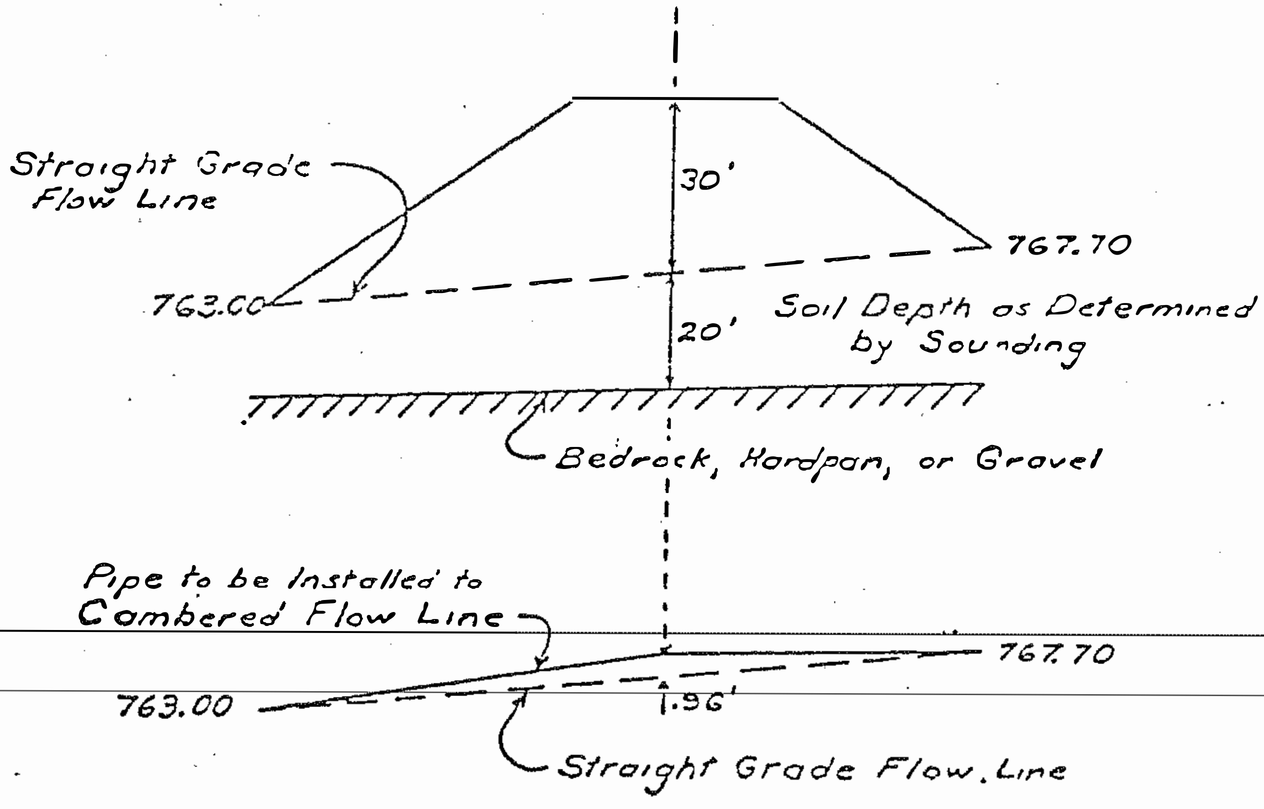
Centerline of Roadway Over Outlet Portion of Culvert:

1. From the fill ht. vs settlement curve, read settlement of .035 ft. per foot of soil below flow line to be expected uner 21' fill.

2. Total settlement = 24 (.035) = .84' = camber.

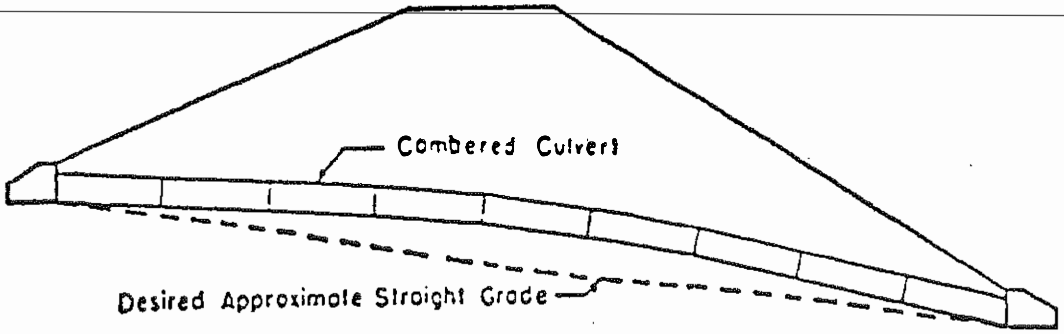
Note: In no case should camber be installed to the extent that a downstream elevation is higher than some upstream point of elevation. This problem may occur if a culvert has a small difference in inlet and outlet elevations. In such a case, the maximum camber permitted by these limiting elevations should be installed. Occasionally, the inlet portion of a culvert may have to be placed on a straight horizontal grade line at an elevation equal to that of the inlet.

Example 2: 2-Lane Highway



1. From the fill ht. vs settlement curve, read settlement of .048 ft. per foot of soil below flow line to be expected uner 30' fill.

2. Total settlement = 20 (.048) = .96' = camber.



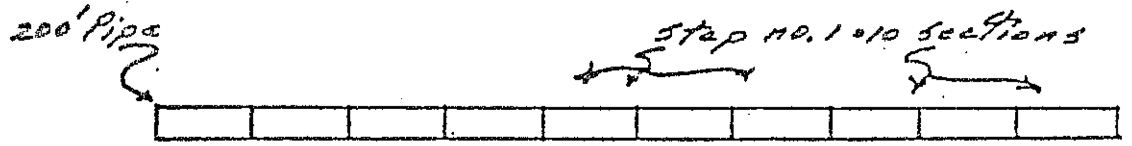
Cambered Culvert and desired Straight Grade.

Example of Camber Calculations

Assume: .84' of Camber as in Example No. 1
200 L.F. of pipe

Step. 1: Devide pipe length in even number of sections
Step 2: Number the points, starting at 0, 1, 2, etc. from both ends
Step 3: Multiply
Step 4: Devide each product by the single largest product
Step 5: Multiply each quotient by the maximum camber to go in the pipe to obtain the amount of camber to go in the pipe at the applicable point

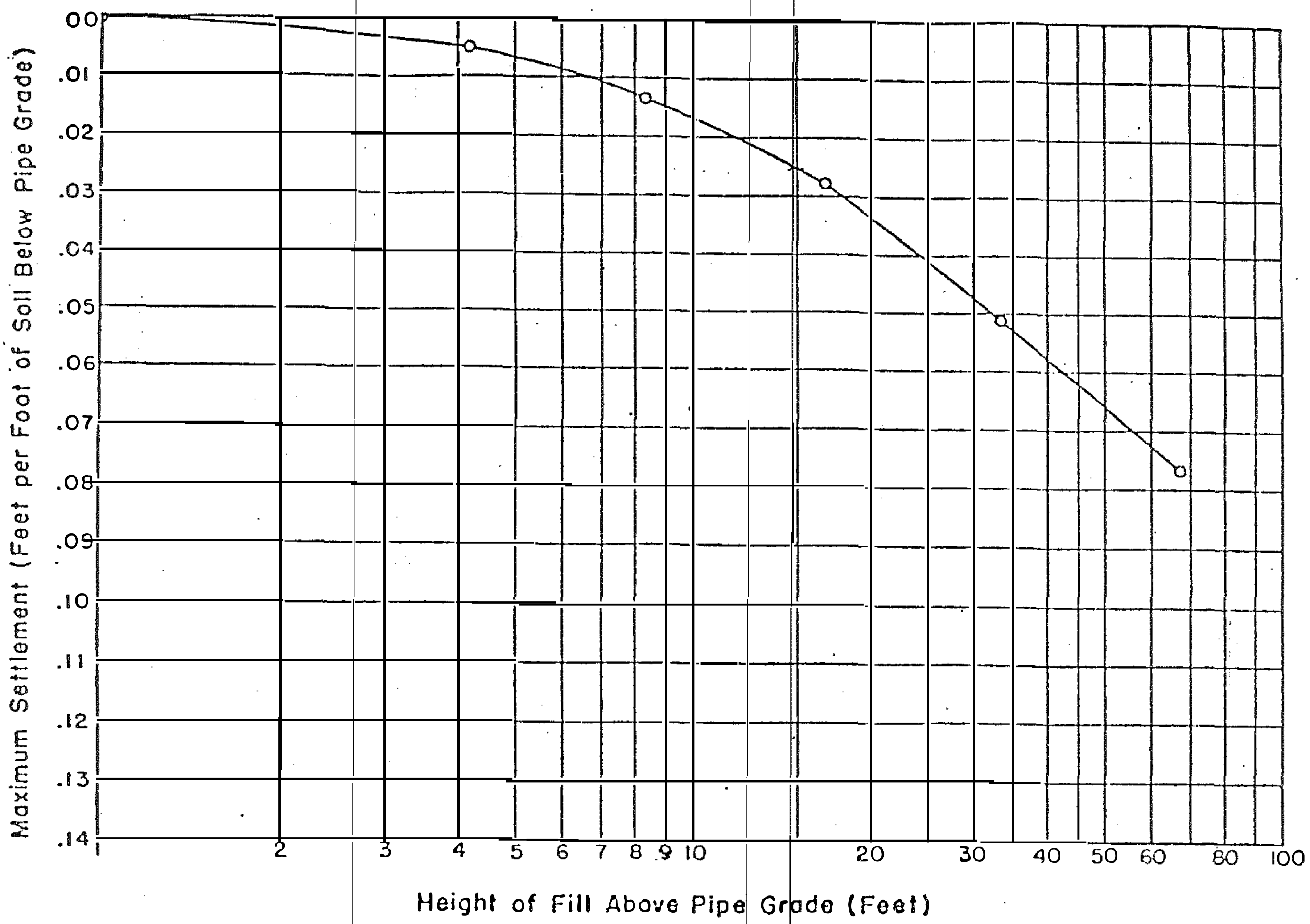
Example



Step 2 →	0	1	2	3	4	5	6	7	8	9	10 ← Step 2
	×10	×9	×8	×7	×6	×5	×4	×3	×2	×1	×0
Step 3 →	0	9	16	21	24	25	24	21	16	9	0

Point 5 Step no. 4: $\frac{25}{25} = 1$ Step no. 5: 1 × .84' = .84' Camber
Points 4 & 6 Step no. 4: $\frac{24}{25} = .96$ Step no. 5: .96 × .84' = .81' "
Points 3 & 7 Step no. 4: $\frac{21}{25} = .84$ Step no. 5: .84 × .84' = .71' "
Points 2 & 8 Step no. 4: $\frac{16}{25} = .64$ Step no. 5: .64 × .84' = .54' "
Points 1 & 9 Step no. 4: $9/25 = .36$ Step no. 5: .36 × .84' = .30' "
Points 0 & 10 Step no. 4: $\frac{0}{25} = 0$ Step no. 5: 0 × .84' = 0' "

Add the amount of camber thus calculated for each point to the straight line grade of the pipe


Maximum Settlement (Feet per Foot of Soil Below Pipe Grade)
.00
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
.11
.12
.13
.14
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
80
100
Height of Fill Above Pipe Grade (Feet)