U. S. Department of Agriculture
Soil Conservation Service
Engineering Division
Design Branch

August 28, 1968

DESIGN NOTE NO. 4*

Subject: Cradle Modification Where a Rock Foundation Hiatus Exists

When a conduit is designed for a non-yielding foundation, it is sometimes discovered during construction that the actual profile of the rock foundation differs significantly from that assumed in design. If the actual profile differs from the assumed profile, the loading on the conduit will be affected unless some modification is made. Where the rock profile lies below the assumed rock profile, the load on the conduit will be increased due to the increase in the distance between the top of the conduit and the rock foundation. In this case the designed conduit should be used only if the load on the conduit can be reduced to that assumed in design.

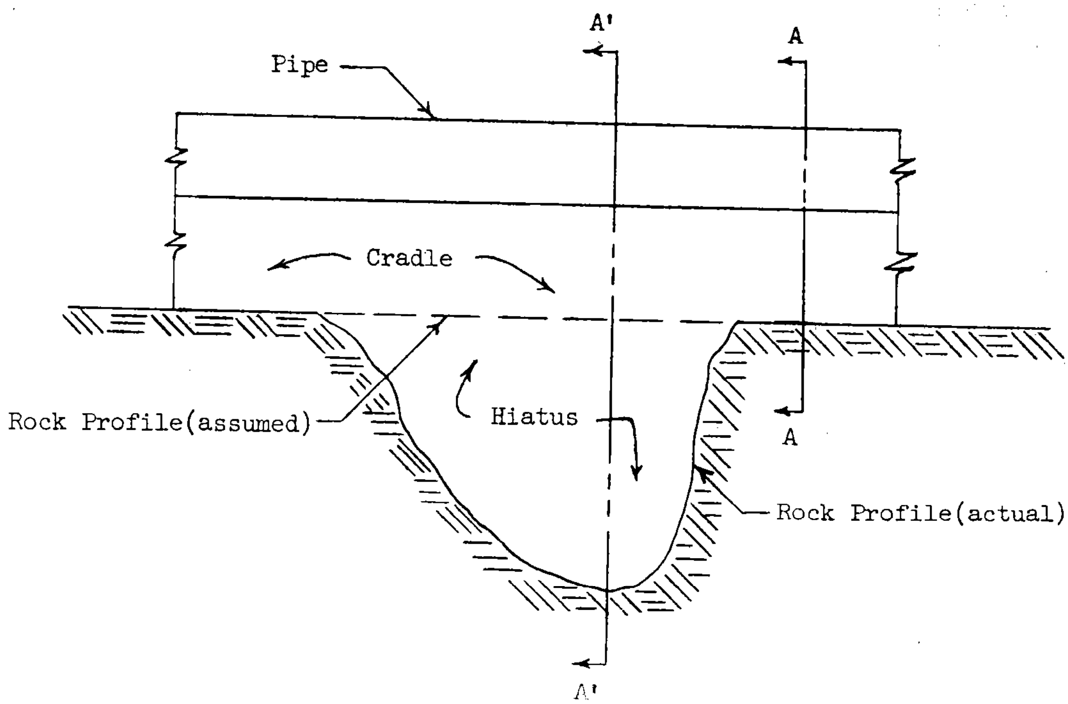


Figure 1. Definition sketch

*Prepared by the personnel of the Design Unit, Design Branch, Hyattsville, Maryland.

The purpose of this design note is to present a method for maintaining the load on a conduit at a hiatus in the rock foundation equal to the load determined in design. This method is intended for use where the deviation between the assumed and actual rock profiles occurs over a relatively short length. The method presented involves a modification of the dimensions of the cradle for the pipe conduit.

In determining the cradle modification required, the theory contained in Technical Release No. 5 is used along with the following assumptions:

1. The conduit is a positive projecting conduit on a non-yielding foundation.
2. The average unit load on the designed conduit and the modified cradle obtained by using an interior prism width equal to the top width of the modified cradle may be conservatively taken equal to the average unit load on the designed conduit and cradle obtained by using an interior prism width equal to the top width of the designed cradle.

The nomenclature used in this design note is the same as that of Technical Release No. 5 with these additions:

B $\equiv$ top width of the designed cradle, ft

B' $\equiv$ top width of the modified cradle, ft

C_{cp} $\equiv$ load coefficient for positive projecting conduits – designed cradle

C'_{cp} $\equiv$ load coefficient for positive projecting conduits – modified cradle

w_{cp} $\equiv$ average unit load at the top of the conduit – designed cradle, lbs/ft^2 (See Equation (2))

w'_{cp} $\equiv$ average unit load at the top of the conduit – modified cradle, lbs/ft^2 (See Equation (4))

W_{cp} $\equiv$ total vertical load at the top of the conduit over the designed cradle width, lbs/ft length of conduit

W'_{cp} $\equiv$ total vertical load at the top of the conduit over the modified cradle width, lbs/ft length of conduit

η $\equiv$ projection ratio – designed cradle (See Figure 2)

η' $\equiv$ projection ratio – modified cradle (See Figure 3)

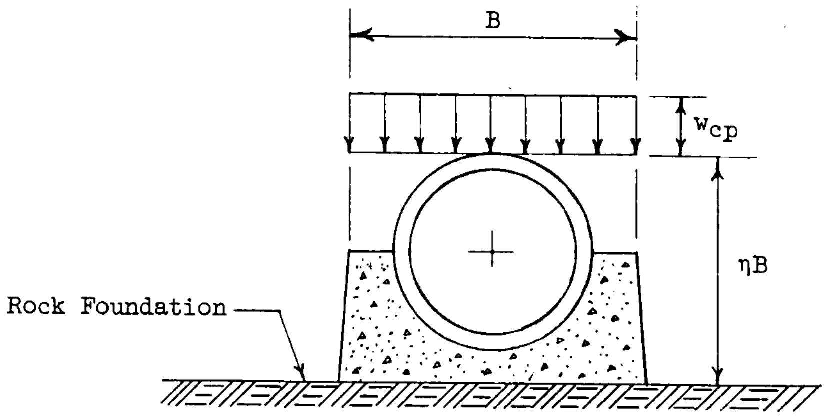


Figure 2. Section A-A

The derivations of load formulas for positive projecting conduits are given in Technical Release No. 5, Appendix A.

The load on the designed conduit and cradle is

$$W_{cp} = C_{cp}\gamma B^2 \tag{1}$$

The average unit load is

$$w_{cp} = \frac{W_{cp}}{B} = C_{cp}\gamma B \tag{2}$$

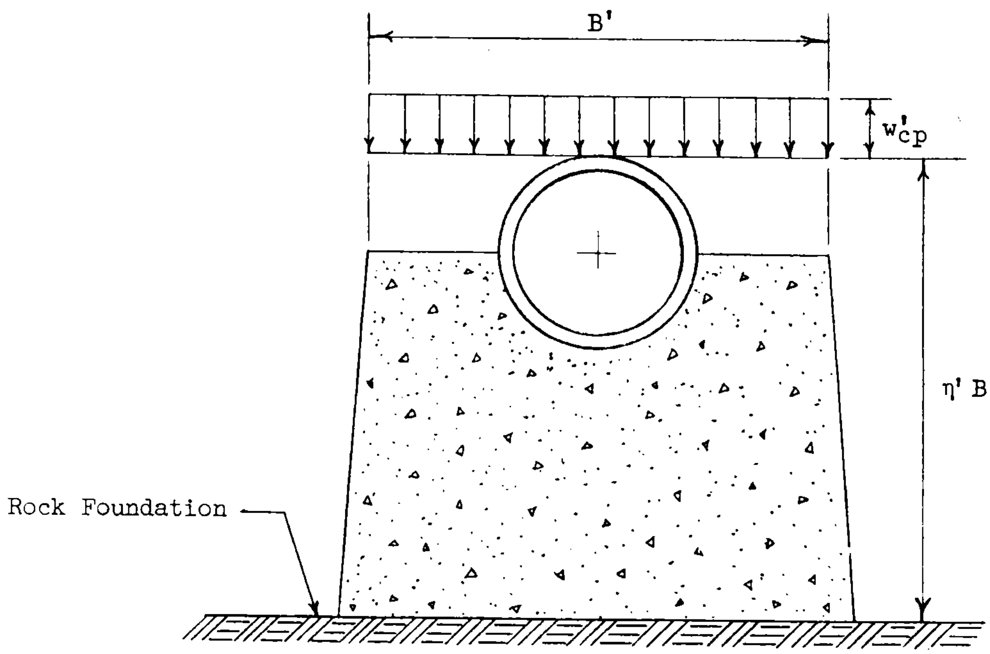


Figure 3. Section A'-A'

The load on the designed conduit and modified cradle is

$$W'_{cp} = C'_{cp}\gamma(B')^2 \tag{3}$$

The average unit load is

$$w'_{cp} = \frac{W'_{cp}}{B'} = C'_{cp}\gamma B' \tag{4}$$

If the average unit load on the designed conduit and modified cradle is made the same as that on the designed conduit and cradle, then

$$w_{cp} = w'_{cp} \tag{5}$$

or

$$C_{cp}\gamma B = C'_{cp}\gamma B' \tag{6}$$

$$C_{cp}B = C'_{cp}B' \tag{7}$$

It should be observed that this method involves a modification of the cradle in which the top of the cradle, for the width, B', is at the elevation of the center of the conduit. Cursory investigation might suggest that the average unit load on the designed conduit and cradle could be duplicated merely by increasing the cradle width at and below the elevation of the assumed rock profile. In order that this approach duplicate the original design conditions, the cradle would of necessity have to be made quite wide. Hence this approach is not economical.

Using Equation (7) and Technical Release No. 5, a trial and error solution could be made for B'. The attached drawing, ES-181, can be used to explicitly determine B', thus simplifying the procedure for obtaining the necessary cradle modification.

ES-181 is a plot having an abscissa of $\frac{H_c}{\eta B}$ (or $\frac{H_c}{\eta' B'}$) and curves of $2K\mu\eta$ (or $2K\mu\eta'$). Sheet 1 of ES-181 encompasses values of $\frac{H_c}{\eta B}$ from 0 to 20 and $2K\mu\eta$ from 0.2 to 2.0. Sheet 1 is an enlargement of a portion of sheet 2. Sheet 2 has values of $\frac{H_c}{\eta B}$ from 0 to 60 and values of $2K\mu\eta$ from 0.2 to 2.0.

For the normal situation the value of B' can be obtained from ES-181. Knowing H_c, η, B, $(\eta' B')$, and $K\mu$,

1. Draw a straight line from the intersection of the known values of $\frac{H_c}{\eta B}$ and $2K\mu\eta$ to the origin of the chart. This line is the Solution Line.

2. Read the value of $2K\mu\eta'$ at the intersection of the Solution

Line and the value of $\frac{H_c}{(\eta' B')}$.

3. Calculate the value of η' by

$$\eta' = \frac{2K\mu\eta'}{2K\mu}$$

4. Determine the value of B' by

$$B' = \frac{(\eta' B')}{\eta'}$$

Normally ES-181, sheet 1 will be used in determining B'. However, if $\frac{H_c}{\eta B}$ is greater than 20, sheet 2 will be used. Where this is the case and $\frac{H_c}{\eta' B'}$ is less than 20, the direction of the Solution Line will be obtained from sheet 2; but the value of $2K\mu\eta'$ can be obtained from either sheet 1 or 2. Sheet 1 gives better accuracy than sheet 2. To obtain from sheet 1 the value of $2K\mu\eta'$, where $\frac{H_c}{\eta B}$ is greater than 20 and $\frac{H_c}{\eta' B'}$ is less than 20,

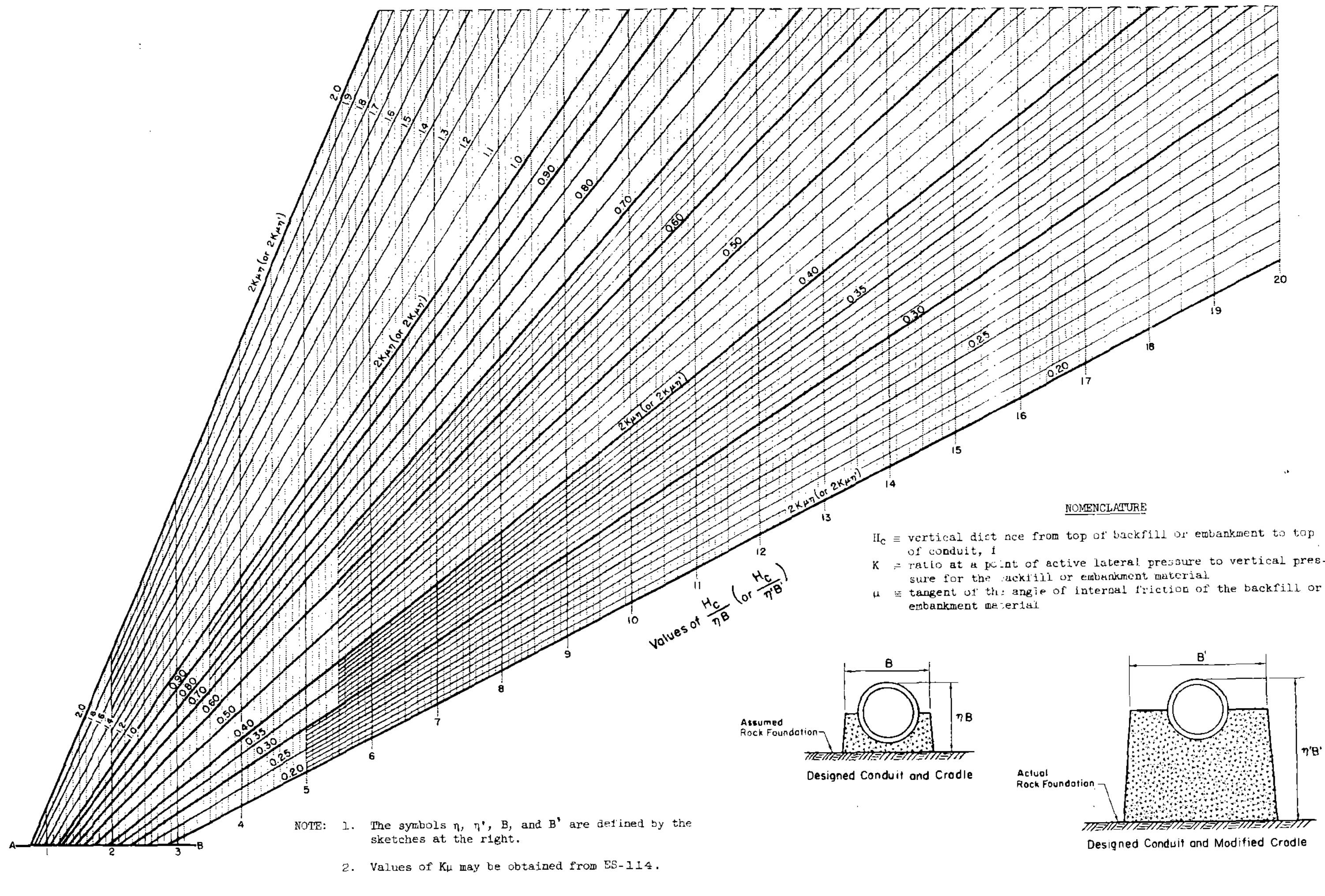
1. Determine from sheet 2 the $2K\mu\eta$ value at the intersection of the Solution Line and the dashed line designating the limits of sheet 1.

2. Locate this same point on sheet 1 and draw from this point the Solution Line.

3. Read the value of $2K\mu\eta'$ at the intersection of the Solution Line and $\frac{H_c}{\eta' B'}$.

The presence of a rock foundation hiatus will increase the tendency for failure in the soil because of the increased differential settlement at the hiatus. Where the soil used in the embankment is "brittle," consideration should be given to flattening the cradle side slopes, to perhaps 1 to 1, to decrease this possibility of failure.

UNDERGROUND CONDUITS: Cradle Modification for a Rock Foundation Hiatus— Determination of $2K\mu\eta'$



NOTE: 1. The symbols η, η', B, and B' are defined by the sketches at the right.

2. Values of Kμ may be obtained from ES-114.

NOMENCLATURE

H_c ≡ vertical distance from top of backfill or embankment to top of conduit, ft

K ≡ ratio at a point of active lateral pressure to vertical pressure for the backfill or embankment material

μ ≡ tangent of the angle of internal friction of the backfill or embankment material

Designed Conduit and Cradle

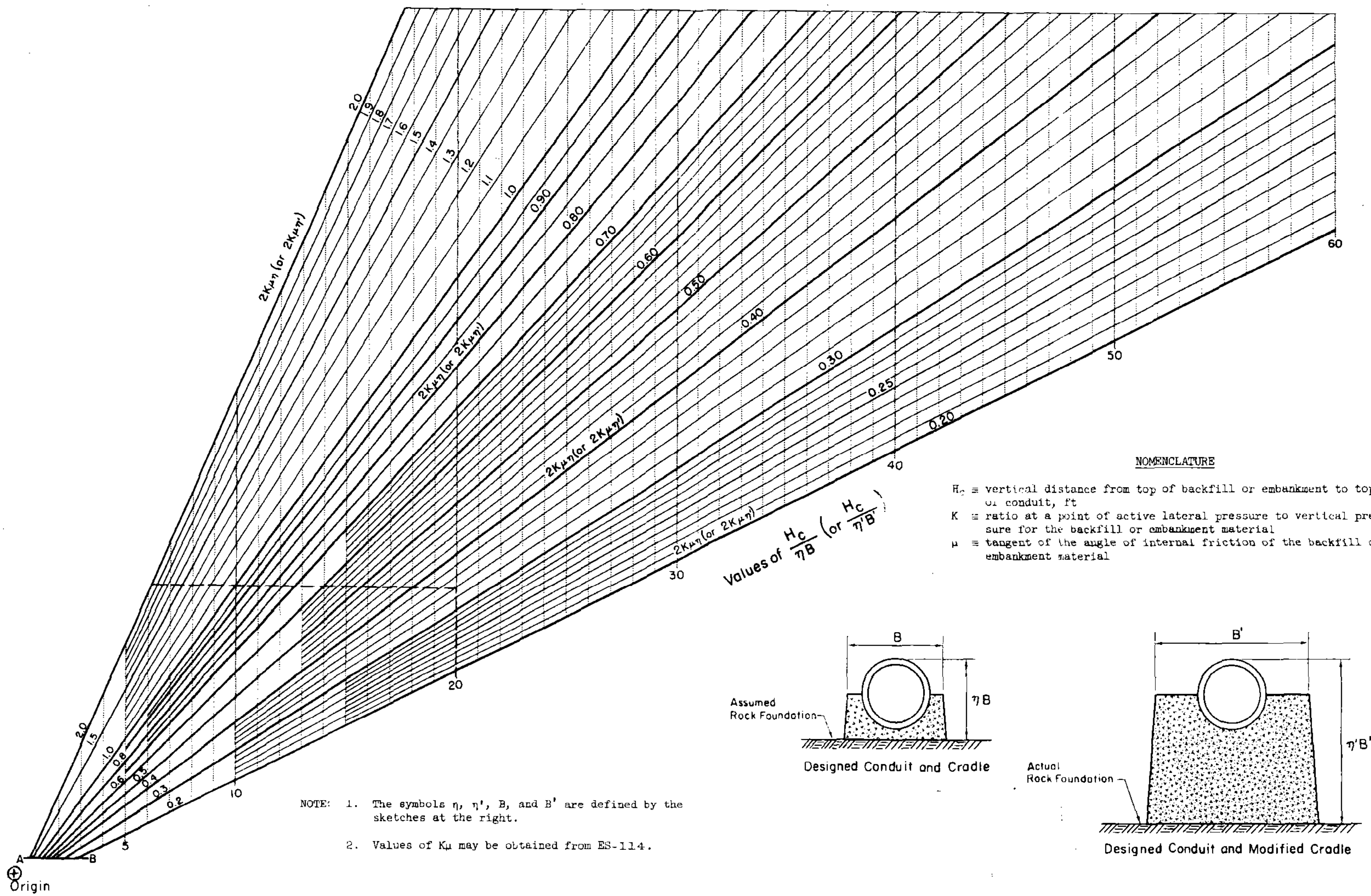
Designed Conduit and Modified Cradle

REFERENCE
Technical Release No. 5

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN UNIT

STANDARD DWG. NO.
ES-181
SHEET 1 OF 3
DATE 8-68

UNDERGROUND CONDUITS: Cradle Modification for a Rock Foundation Hiatus — Determination of $2K\mu\eta'$



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U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION · DESIGN UNIT

STANDARD DWG. NO.
ES - 181
SHEET 2 OF 3
DATE 8-68

UNDERGROUND CONDUITS: Cradle Modification for a Rock Foundation Hiatus—Determination of $2K\mu\eta'$

EXAMPLE 1

Given: 36" I.D. pipe; $H_c = 40$ ft; $K\mu = 0.19$; $b_c = 3.813$ ft; $B = 5.15$ ft; $\eta B = \rho b_c = 4.5$ ft

Determine: The cradle modification required if $\eta' B' = 8$ ft.

Solution:

1. Compute

$$\frac{H_c}{\eta B} = \frac{40}{4.5} = 8.89$$

$$\eta = \frac{\eta B}{B} = \frac{4.5}{5.15} = 0.874$$

$$2K\mu\eta = 2(0.19)(0.874) = 0.332$$

2. Use ES-181, sheet 1.

For $\frac{H_c}{\eta B} = 8.89$ and $2K\mu\eta = 0.332$, draw the Solution Line.

At the intersection of the Solution Line and $\frac{H_c}{\eta' B'} = \frac{40}{8} = 5.0$, read $2K\mu\eta' = 0.393$.

3. Compute

$$\eta' = \frac{2K\mu\eta'}{2K\mu} = \frac{0.393}{0.38} = 1.03$$

$$B' = \frac{\eta' B'}{\eta'} = \frac{8.0}{1.03} = 7.77 \text{ ft}$$

EXAMPLE 2

Given: 30" I.D. pipe; $H_c = 20$ ft; $K\mu = 0.18$; $b_c = 2.958$ ft; $B = 4.29$ ft; $\eta B = 3.6$ ft

Determine: The cradle modification required where $\eta' B' = 19$ ft.

Solution:

1. Compute

$$\frac{H_c}{\eta B} = \frac{20}{3.6} = 5.56$$

$$\eta = \frac{\eta B}{B} = \frac{3.6}{4.29} = 0.839$$

$$2K\mu\eta = 2(0.18)(0.839) = 0.302$$

2. Use ES-181, sheet 1.

Determine the intersection for $\frac{H_c}{\eta B} = 5.56$ and $2K\mu\eta = 0.302$ and draw the Solution Line. Normally the $2K\mu\eta'$ value to be determined would be located at the intersection of the Solution Line and the $\frac{H_c}{\eta' B'}$ value, but notice that this intersection, where $\frac{H_c}{\eta' B'} = \frac{20}{19} = 1.05$, is below the line AB. Since this is the case, read the values of $2K\mu\eta' = 0.80$ and $\frac{H_c}{\eta' B'} = 1.31$ at the intersection of the Solution Line and the line AB.

3. Compute

$$\eta' = \frac{2K\mu\eta'}{2K\mu} = \frac{0.80}{0.36} = 2.22$$

$$\eta' B' = \frac{H_c}{\frac{H_c}{\eta' B'}} = \frac{20}{1.31} = 15.27$$

$$B' = \frac{\eta' B'}{\eta'} = \frac{15.27}{2.22} = 6.88 \text{ ft}$$

NOTE: If the intersection of the values of $\frac{H_c}{\eta B}$ and $2K\mu\eta$ occurs below the line AB, no modification of the cradle width is required.

EXAMPLE 3

Given: 24" I.D. pipe; $H_c = 80$ ft; $K\mu = 0.19$; $b_c = 2.5$ ft; $B = 3.833$ ft; $\eta B = \rho b_c = 2.5$ ft

Determine: The cradle modification required where $\eta' B' = 7$ ft

I. Using ES-181, sheet 2.
II. Using ES-181, sheets 1 and 2.

Solution:

I. Using ES-181, sheet 2.

A. Compute

$$\frac{H_c}{\eta B} = \frac{80}{2.5} = 32.0$$

$$\eta = \frac{\eta B}{B} = \frac{2.5}{3.833} = 0.652$$

$$2K\mu\eta = 2(0.19)(0.652) = 0.248$$

B. Determine the intersection for $\frac{H_c}{\eta B} = 32.0$ and $2K\mu\eta = 0.248$ and draw the Solution Line.

Then, at the intersection of the Solution Line and $\frac{H_c}{\eta' B'} = \frac{80}{7.0} = 11.43$, read $2K\mu\eta' = 0.28$.

C. Compute

$$\eta' = \frac{2K\mu\eta'}{2K\mu} = \frac{0.28}{0.38} = 0.737$$

$$B' = \frac{\eta' B'}{\eta'} = \frac{7.0}{0.737} = 9.5 \text{ ft}$$

II. Using ES-181, sheets 1 and 2.

A. From sheet 2

At the intersection of the Solution Line and $\frac{H_c}{\eta B} = 20$, read $2K\mu\eta = 0.26$.

B. From sheet 1

From the intersection of $\frac{H_c}{\eta B} = 20$ and $2K\mu\eta = 0.26$, draw the Solution Line.

Then at the intersection of the Solution Line and $\frac{H_c}{\eta' B'} = 11.43$, read $2K\mu\eta' = 0.284$.

C. Compute

$$\eta' = \frac{2K\mu\eta'}{2K\mu} = \frac{0.284}{0.38} = 0.747$$

$$B' = \frac{\eta' B'}{\eta'} = \frac{7.0}{0.747} = 9.37 \text{ ft}$$

REFERENCE