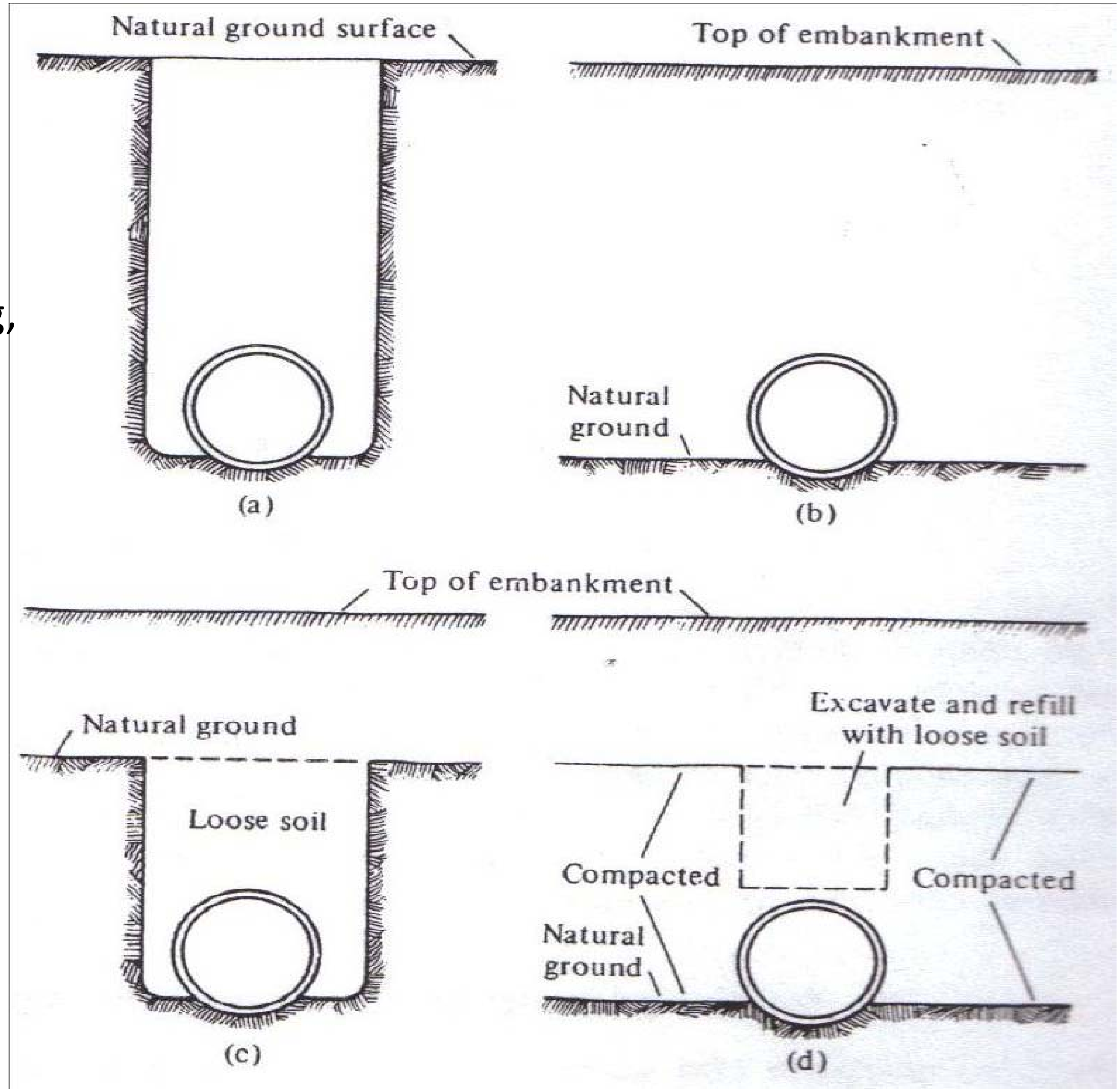
UNDERGROUND STRUCTURES

- Underground conduits are commonly used as sewers, drains, water mains, gas lines, culverts etc.
- Classification of Underground Conduits
- There are two basic types of buried conduits, classified according to their placement relative to the original ground surface.
- A ditch conduit is defined as one that is installed in a relatively narrow ditch and covered with earth backfill.
  - Examples are sewers, drains, and water and gas mains.
- A positive projecting conduit is installed in shallow bedding with its top projecting above the surface of the natural ground and then is covered with an embankment.
  - Railway and highway culverts generally are installed in this manner.

- In addition to the two major classes of conduit there are two subclasses:
- A negative projection condition results when a conduit is installed in a shallow trench of such depth that the top of the conduit is below the natural ground surface, but is then covered with earth fill to a higher ground level
- The imperfect ditch or induced trench conduit uses a concept that is similar to that of a negative projecting conduit, only in this case trenches are cut into the embankment over the conduit and backfilled with compressible material.
- This is effective for reducing the soil load on a pipe, but cannot be used in embankments that serve as water barriers because the loosely placed backfill will allow channeling of seepage water through the embankment

(a) ditch,
(b) Positive projecting,
(c) Negative projecting,
(d) Imperfect ditch.

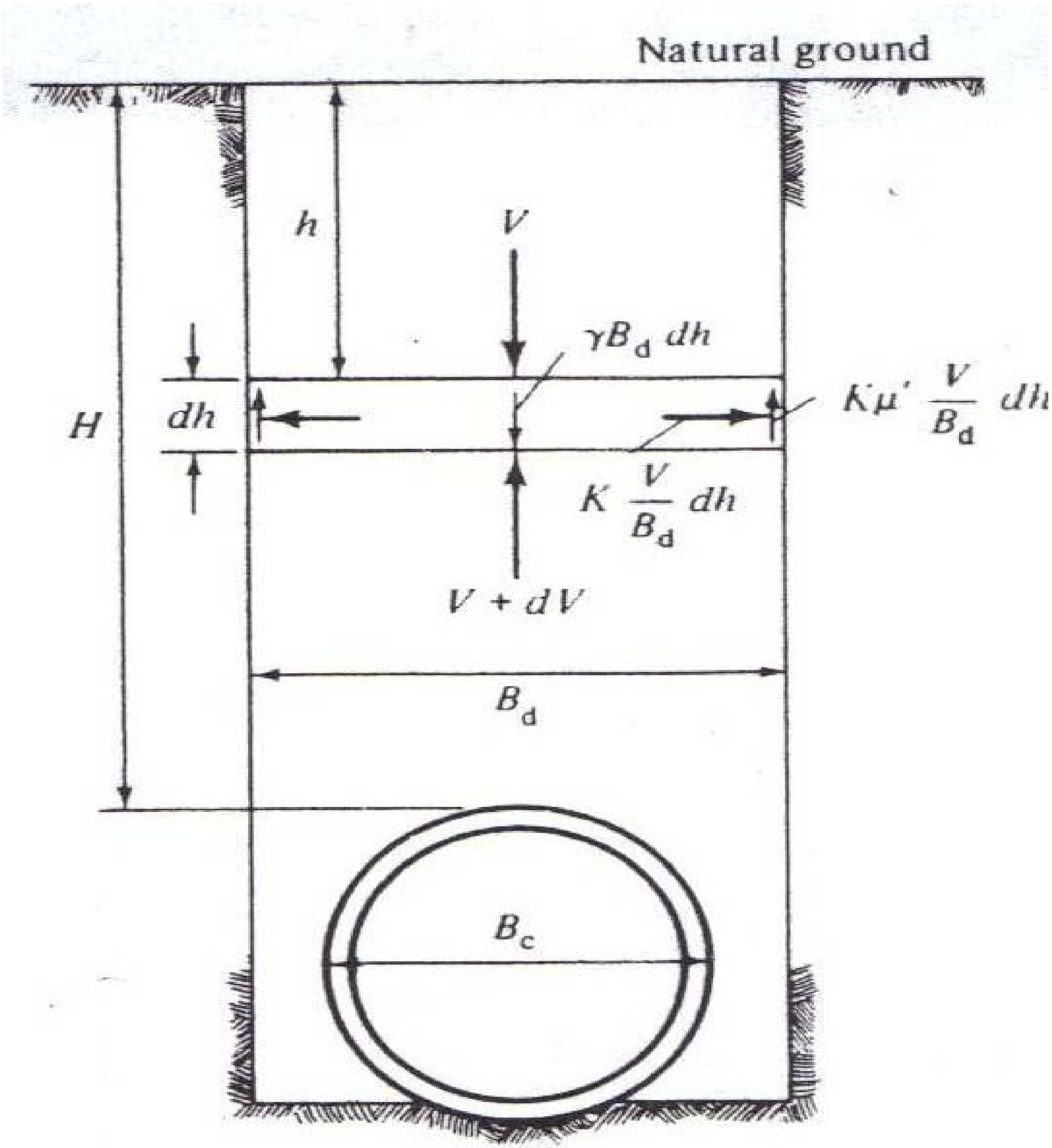


• Load on a Ditch Conduit

- A section of a ditch and ditch conduit 1 unit in length is shown in Fig. below. A thin horizontal element of fill material of thickness **dh** is located at a depth **h** below the ground surface.
- Loads acting on this element at equilibrium are: **V** on the top of the element; **V + dV** on the bottom of the element; the weight of the element, which equals $\gamma B_d\, dh$; and friction on the sides of the element which is equal to the lateral pressure times the thickness of the element times the coefficient of sliding friction, or $2K(V/B_d)\mu dh$.
- Equating the upward and downward vertical forces on the element gives

$$V + \gamma B_d\, dh = V + dV + 2K(V/B_d)\mu dh$$

- This is a linear differential equation, the solution for which is



Free Body Diagram for Ditch Conduit

$$V = \gamma B_d^2 \frac{1 - e^{-2K\mu(h/B_d)}}{2K\mu}$$

$$At \ the \ top \ of \ the \ conduit \ , h = H$$

$$V = \gamma B_d^2 \frac{1 - e^{-2K\mu(H/B_d)}}{2K\mu}$$

- If h is set equal to the height of soil over the top of the conduit, H, then V is the total load on a horizontal plane across the top of the conduit.
- The portion carried by the conduit depends on its rigidity compared with that of the fill material between the sides of the conduit and sides of the ditch.

- In the case of a rigid pipe, the side fills typically are compressible so the pipe will carry practically all of the load.
- On the other hand, if the pipe is flexible and soil is thoroughly tamped along the sides, the stiffness of the side fills may approach that of the conduit, so the load is spread over the entire width of the ditch.

Maximum Loads on Ditch Conduits

- If we assume relatively compressible side fills alongside the pipe, the load on the conduit can be described by

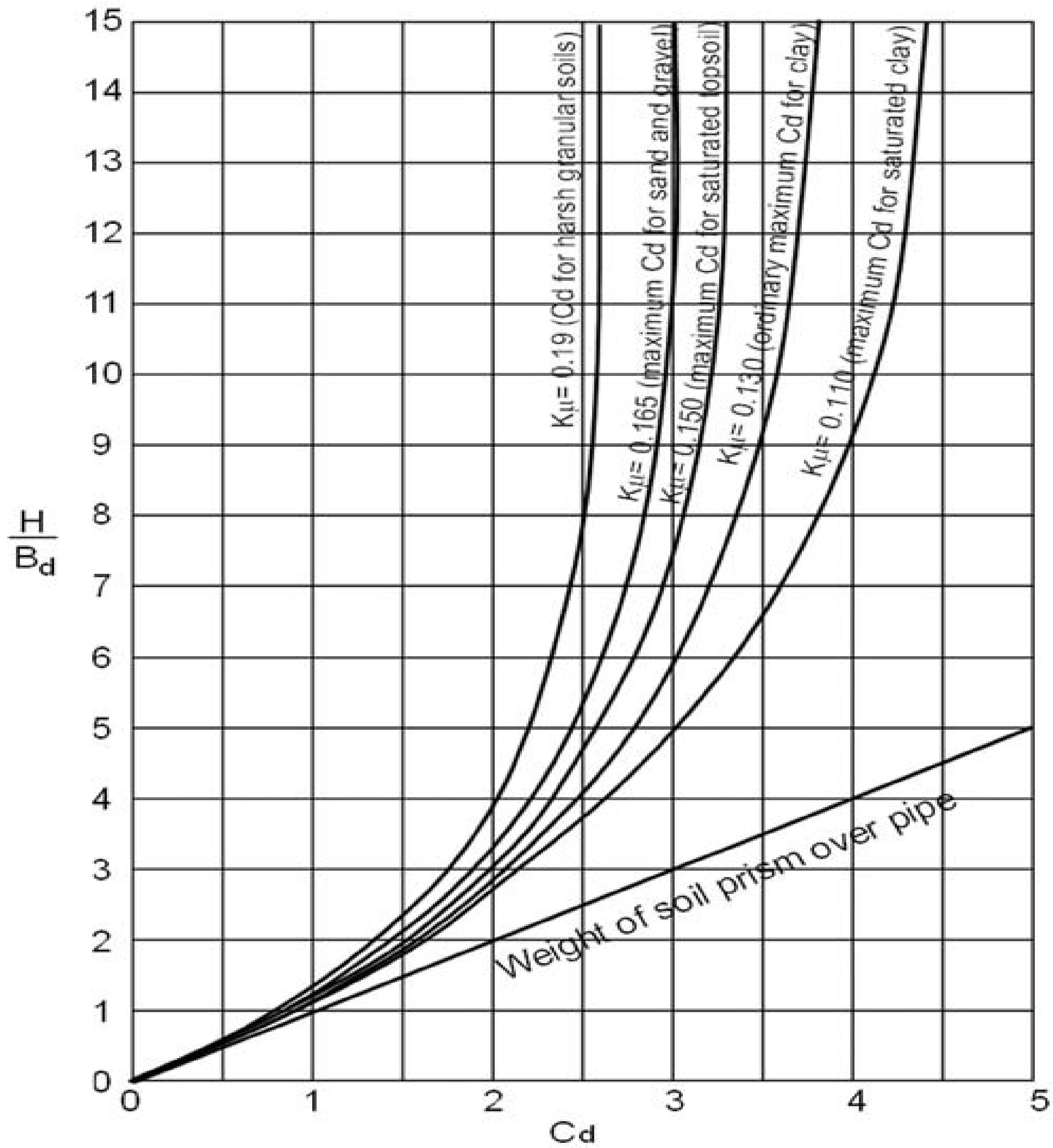
$$Wc = Cd \gamma B_d^2$$

$$\text{where} \quad C_d = \frac{1 - e^{-2K\mu(H/B_d)}}{2K\mu}$$

- W_c = load on conduit in N per linear m
- C_d = load coefficient for ditch conditions based on ratio of height of fill to width of trench and friction coefficient (type of backfill material)
- γ = unit weight of fill material, lbs/ft^3
- B_d = horizontal width of ditch at top of conduit, m
- B_c = horizontal width of conduit, m

- The values of C_d for different values of H/B_d and $K\,\mu$ can be obtained from the following Figure

C_d Coefficient for Ditch Conduits



• Flexible Conduits in Ditches

- If soil alongside a flexible pipe is thoroughly tamped it may have essentially the same degree of stiffness as the pipe itself. In this case the load on flexible pipe becomes

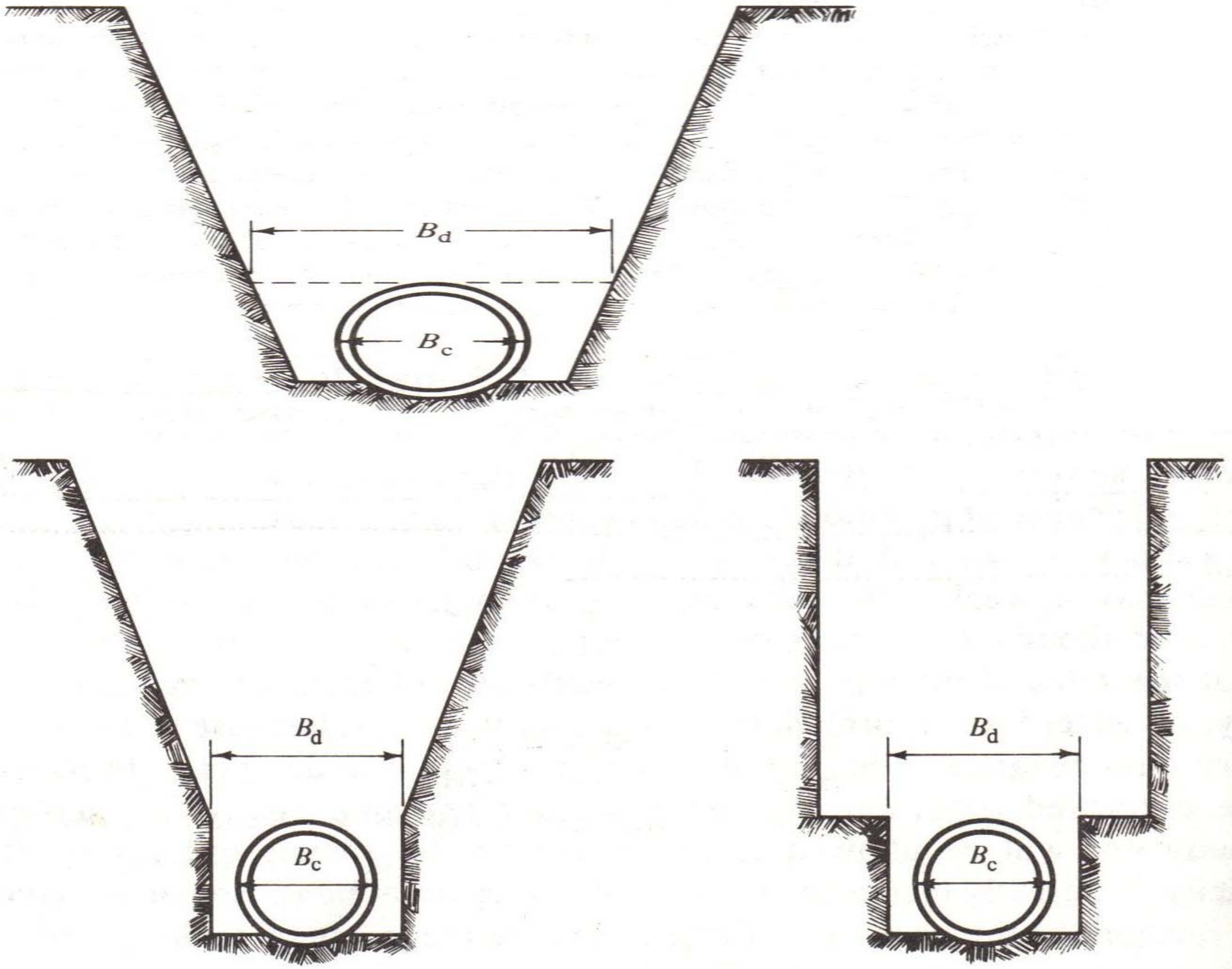
$$Wc = C_d \gamma B_d B_c$$

- Since $B_c < B_d$, a consequence of the pipe deflection is to divert part of the load to the soil and therefore decrease the load on the pipe

- It must be emphasized that the above equation to be applicable, side fills must be compacted sufficiently to have the same resistance to vertical deformation as the conduits itself. This equation should not be used simply because the conduits is a flexible type.

• Ditches with Sloping Sides

- Worker safety is of paramount importance because of ever-present dangers of trench cave-ins. Many trenches therefore are now cut with sloping sides if the ditches are not too deep and space is available.
- Experimental evidence indicates that in this case B_d should be the width of the ditch at or slightly below the top of the conduit, not at the bottom.
- In order to reduce the effective width, the conduit can be laid in a relatively narrow sub-ditch at the bottom of the wider ditch, which will cause a considerable reduction in the load that must be carried by the conduit



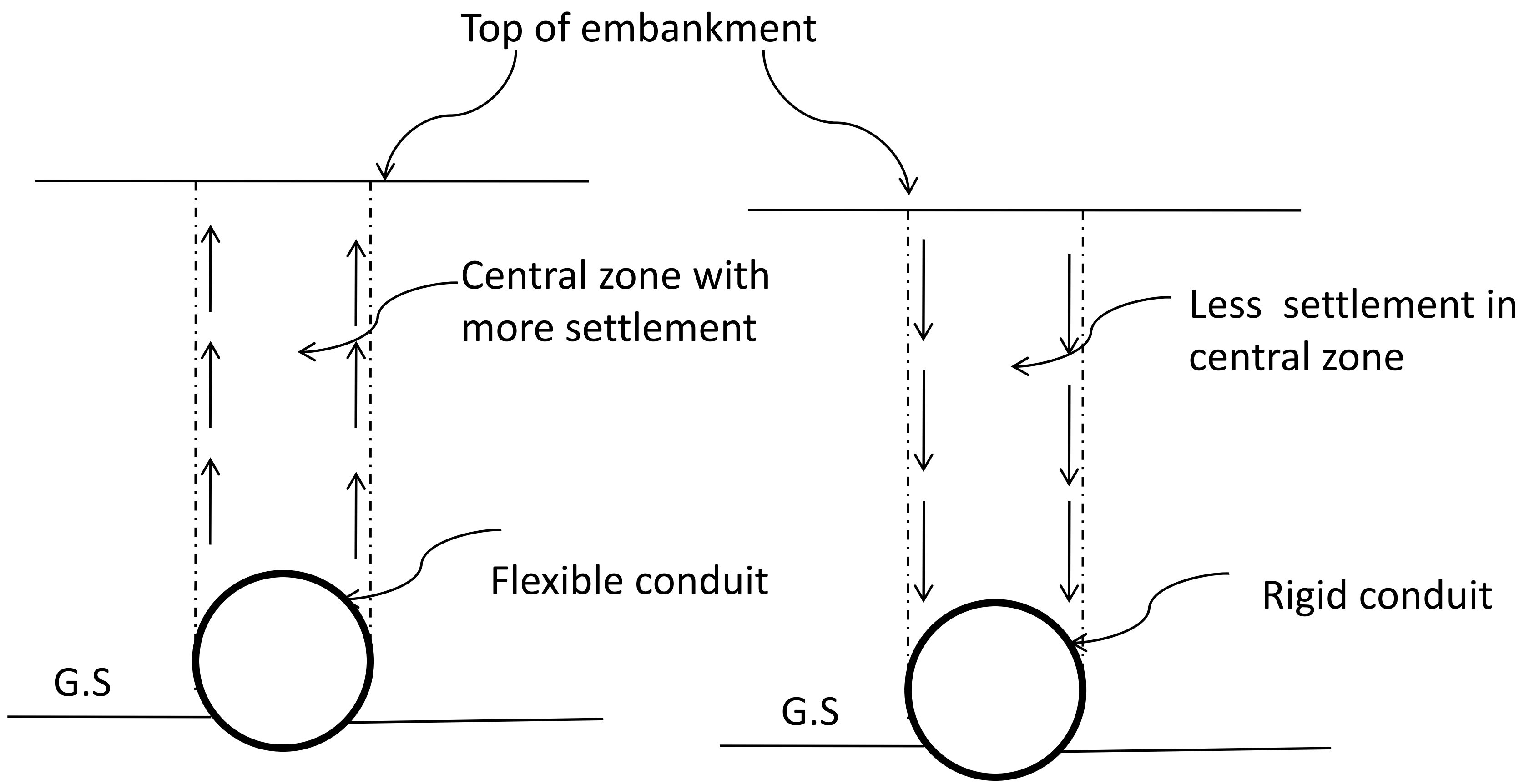
(a) (b)

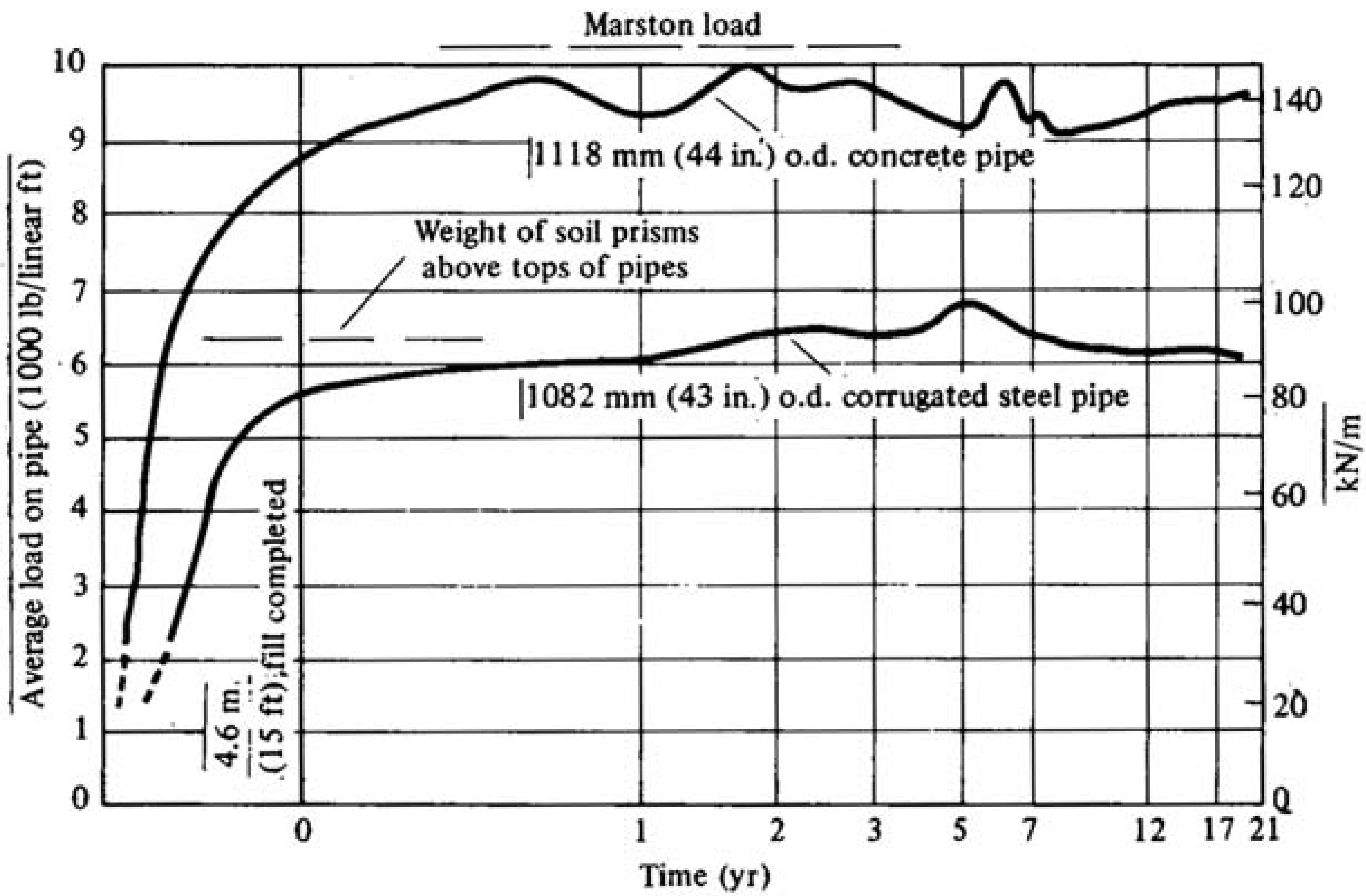
Figure 26.9 Use of a subditch.

POSITIVE PROJECTING CONDUIT

- Positive projecting conduits commonly are called ‘‘culverts,’’ and are installed underneath soil embankments.
- Culverts have a wide variety of shapes including circular, rectangular, elliptical, etc., and are composed of concrete, corrugated metal, or plastic.
- In positive projecting conduits, there is a differential settlement between the central zone directly overlying the conduit and the side zones. Depending upon the relative settlement, the load on the conduit will vary.
- For rigid conduit, the total compression of the earth fill in the side zones will be greater than the total compression of the central zone of the earth fill directly over the conduit. This is because greater height of fill in side zones.

- On the other hand, if the conduit is flexible and deflects considerably under the weight of the fill, the settlement of the fill in the central zone will be greater than the settlement in the side zones.
- The differential settlement between the two zones results in the development of shearing stresses on vertical plane passing through the sides of the conduit.
- If the culvert is more rigid than the soil, friction on the soil column over the culvert acts downward and adds to pressure, instead of acting upward and subtracting from pressure.
- Rigid culverts therefore must be made strong enough to resist this additional force.
- Another option is to use a flexible metal culvert that can yield as the soil load is applied, in which load on the conduit is less than the weight of the column of overburden

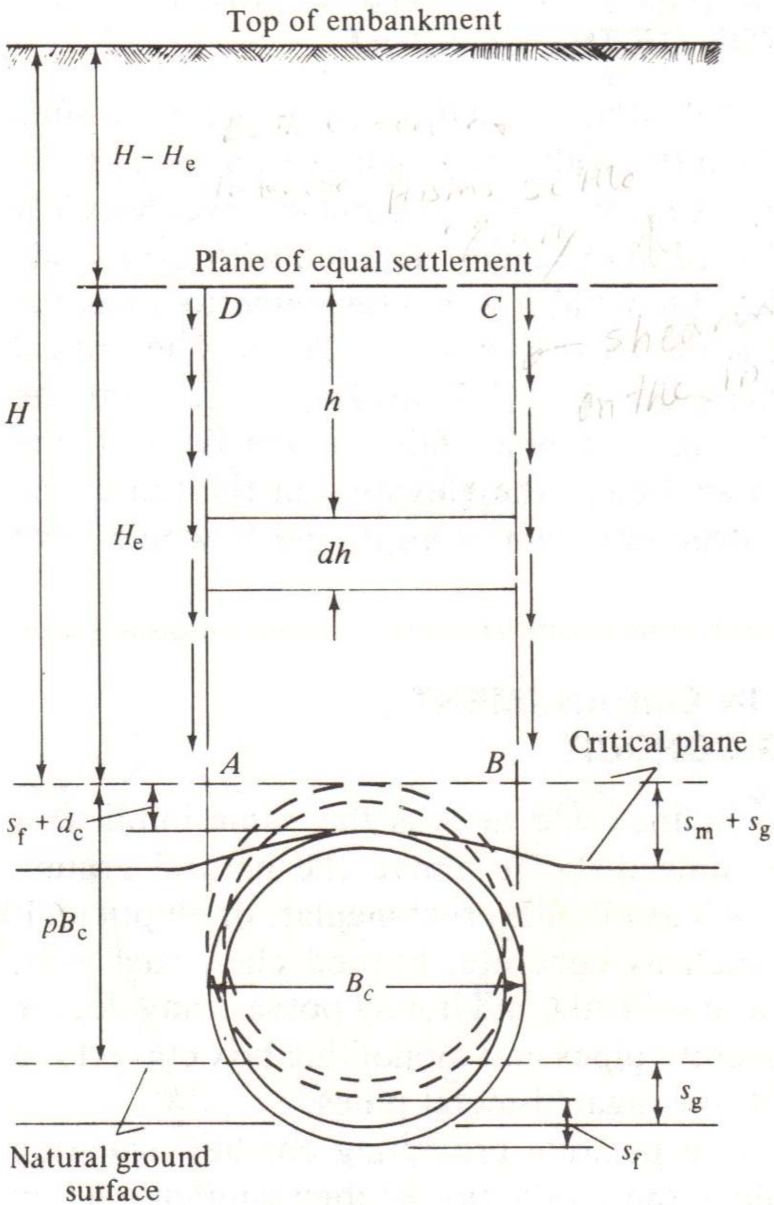

Top of embankment
Central zone with more settlement
Flexible conduit
G.S
Less settlement in central zone
Rigid conduit
G.S

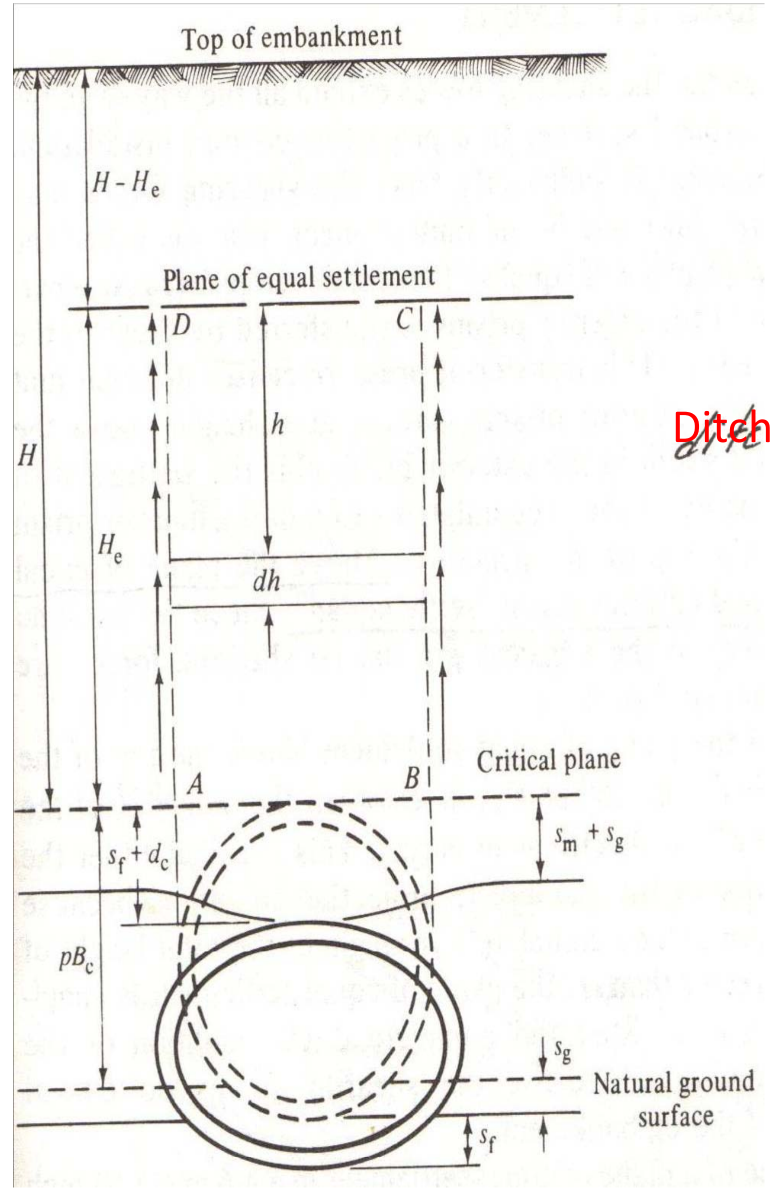


Loads measured over two decades on rigid and flexible pipes under an embankment

- The direction of the shearing stresses can be determined from the settlement of a plane, known as critical plane.
- It is a horizontal plane in the fill material at the level of the top of the conduit at the time when the embankment is construction begun.
- If the critical plane, after the construction, settles less than the top of the conduit, the direction of shearing stresses is upward.
- However, if the critical plane settles more than the top of the conduit, the direction is downward.
- A ratio, known as settlement ratio, is used to determine the settlement of critical plane.

$$r_p = \frac{(s_m + s_g) - (s_f + d_c)}{s_m}$$


Top of embankment
$H - H_e$
Plane of equal settlement
D
C
h
H
H_e
dh
Critical plane
A
B
$s_f + d_c$
$s_m + s_g$
pB_c
B_c
s_g
s_f
Natural ground surface


Top of embankment
$H - H_e$
Plane of equal settlement
D
C
h
H
H_e
dh
Critical plane
A
B
$s_f + d_c$
$s_m + s_g$
pB_c
s_g
Natural ground surface
s_f
Ditch

- where r_p= settlement ratio,

  s_m= compression strain of the side columns of soil of height PB_c,

  s_g= settlement of the natural ground surface adjacent to the conduit,

  s_f= settlement of the conduit into its foundation,

  d_c= shortening of the vertical height of the conduit,

  p =H/ B_c = projection ratio. It is the ratio of the distance from the natural ground surface to the top of the conduit to its width Bc,

  B_c= diameter or width of conduit

- Negative settlement ratio
- the settlement ratio negative when the conduit settles more than the critical plane .
- The load on the conduit is less than the weight of the overlying fill.
- It is similar to the conditions in the ditch conduit and is known as *ditch condition*

- Positive settlement ratio
- The load on the conduit is greater than the weight of the overlying fill.
- It is known as *projection condition*

- If the settlement ratio is zero, the load on the pipe exactly equals the weight of the soil column.
- It is extremely difficult to determine the individual terms in the settlement ratio. However, empirically determined values given by Spangler are generally used for design purposes.

TABLE 26.2. Design Values of Settlement Ratio

Conditions	Settlement Ratio
Rigid culvert on foundation of rock or unyielding soil	+1.0
Rigid culvert on foundation of ordinary soil	+0.5–+0.8
Rigid culvert on foundation of material that yields with respect to adjacent natural ground	0–+0.5
Flexible culvert with poorly compacted side fills	−0.4–0
Flexible culvert with well-compacted side fills	−0.2–+0.2

- Plane of equal settlement
- The shearing stresses acting on the vertical planes do not necessarily extend to the top of the embankment, especially where a high fill exists over the conduit.
- Differential settlements are greatest at the top surface of the conduit and progressively decrease towards the top of the embankment.
- At certain height H_e above the conduit, a horizontal plane exist at which the differential settlements are zero. This plane is called the plane of equal settlement.
- Thus no differential settlement occurs within the embankment soil above the plane of equal settlement.
- An expression for the height H_e can be obtained by equating the total vertical settlements in the central zone and the side zone as under

$$\left[\frac{1}{2K\mu'} \pm \left(\frac{H}{B_c} - \frac{H_e}{B_c} \pm \frac{r_p xp}{3}\right)\right] \frac{e^{\pm 2K\mu'\left(H_e/B_c\right)} - 1}{\pm 2K\mu'} + \frac{1}{2}\left(\frac{H_e}{B_c}\right)^2$$

$$+ \frac{r_p xp}{3}\left(\frac{H - H_e}{B_c}\right) e^{\pm 2K\mu'\left(H_e/B_c\right)} - \frac{1}{2K\mu'}\left(\frac{H_e}{B_c}\right) \mp \left(\frac{H}{B_c}\right)\left(\frac{H_e}{B_c}\right) = \pm r_p p \left(H/Bc\right)$$

- The upper (plus or minus) signs apply when settlement ratio(r_p) is positive, whereas the lower signs apply when r_p is negative .

- Types of positive projecting conduits

- The positive projecting conduits can be classified in to 4 types, depending upon

1. Magnitudes of actual embankment height(H) and the height of plane of equal settlement (H_e) and
2. The sign of the settlement ratio (r_p) as given below.

Complete ditch conditions	$H < H_e$	r_p = negative
Complete projection conditions	$H < H_e$	r_p = positive
Incomplete ditch conditions	$H > H_e$	r_p = negative
Incomplete projection conditions	$H > H_e$	r_p = positive

- It may be noted that for complete ditch or complete projection conditions, the shearing stresses extend up to the top of the embankment; whereas for incomplete ditch or incomplete projection conditions, the shearing stresses extend up to the plane of equal settlement, which is lower than the top of the embankment.

- Marston's Formula for load on positive projecting conduit
- The vertical load on a positive projecting conduit can be expressed by a formula that is similar to that for the ditch condition:

$$Wc = C_c \gamma B_c^2$$

- where the coefficient C_c *for the complete projection or ditch condition is given by*

$$C_c = \frac{e^{\pm 2K\mu'\left(H_e / B_c\right)} - 1}{\pm 2K\mu'}$$

- *and that for incomplete projection or ditch condition as*

$$C_c = \frac{e^{\pm 2K\mu'\left(H_e / B_c\right)} - 1}{\pm 2K\mu'} + \left(\frac{H}{B_c} - \frac{H_e}{B_c}\right) e^{\pm 2K\mu'\left(H_e / B_c\right)}$$

- *The positive signs apply when r_p is positive (projection conduits), whereas the negative signs apply when r_p is negative (ditch conditions)*

- where W_c= load on conduit, in Newton's per meter);

  γ= unit weight of embankment soil, (kN/m^3);

  B_c= outside width of conduit, in m;

  H= height of fill above the top of the conduit, in m;

  He= height of the plane of equal settlement above the top of the conduit, in m;

  K= lateral stress ratio

  μ= tanϕ, ϕ where is the angle of internal friction of the embankment material;

  e= base of natural logarithms

- Values of C_c for different H/B_c ratios and the products (r_p x p) can be obtained from the next figure. The position of the curves is not sensitive to the variation of $K\mu'$ values expected in the field. The curves are for $K\mu' = 0.13$ and $K\mu' = 0.19$

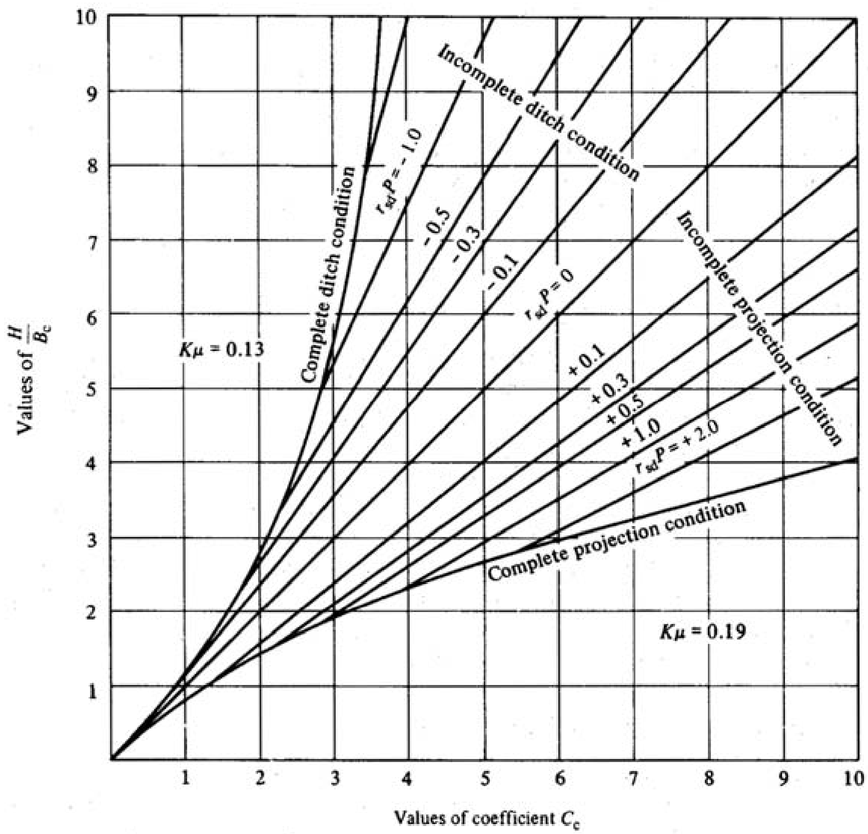


TABLE 26.1 Values[a] of C_c in Terms of H/B_c

Incomplete Projection Condition $K\mu = 0.19$ $r_{sd}p$	Equation	Incomplete Ditch Condition $K\mu = 0.13$ $r_{sd}p$	Equation
+0.1	$C_c = 1.23H/B_c - 0.02$	−0.1	$C_c = 0.82H/B_c + 0.05$
+0.3	$C_c = 1.39H/B_c - 0.05$	−0.3	$C_c = 0.69H/B_c + 0.11$
+0.5	$C_c = 1.50H/B_c - 0.07$	−0.5	$C_c = 0.61H/B_c + 0.20$
+0.7	$C_c = 1.59H/B_c - 0.09$	−0.7	$C_c = 0.55H/B_c + 0.25$
+1.0	$C_c = 1.69H/B_c - 0.12$	−1.0	$C_c = 0.47H/B_c + 0.40$
+2.0	$C_c = 1.93H/B_c - 0.17$		

[a] From Ref. 1.

- Load on negative projecting conduit due to earth fill
- A conduit installed in a trench such that its top is below the original ground surface and then covered with earth embankment is known as the negative projecting conduit.
- In this case, the critical plane lies below the original ground surface (GS), and the settlement ratio (r_n) is given by

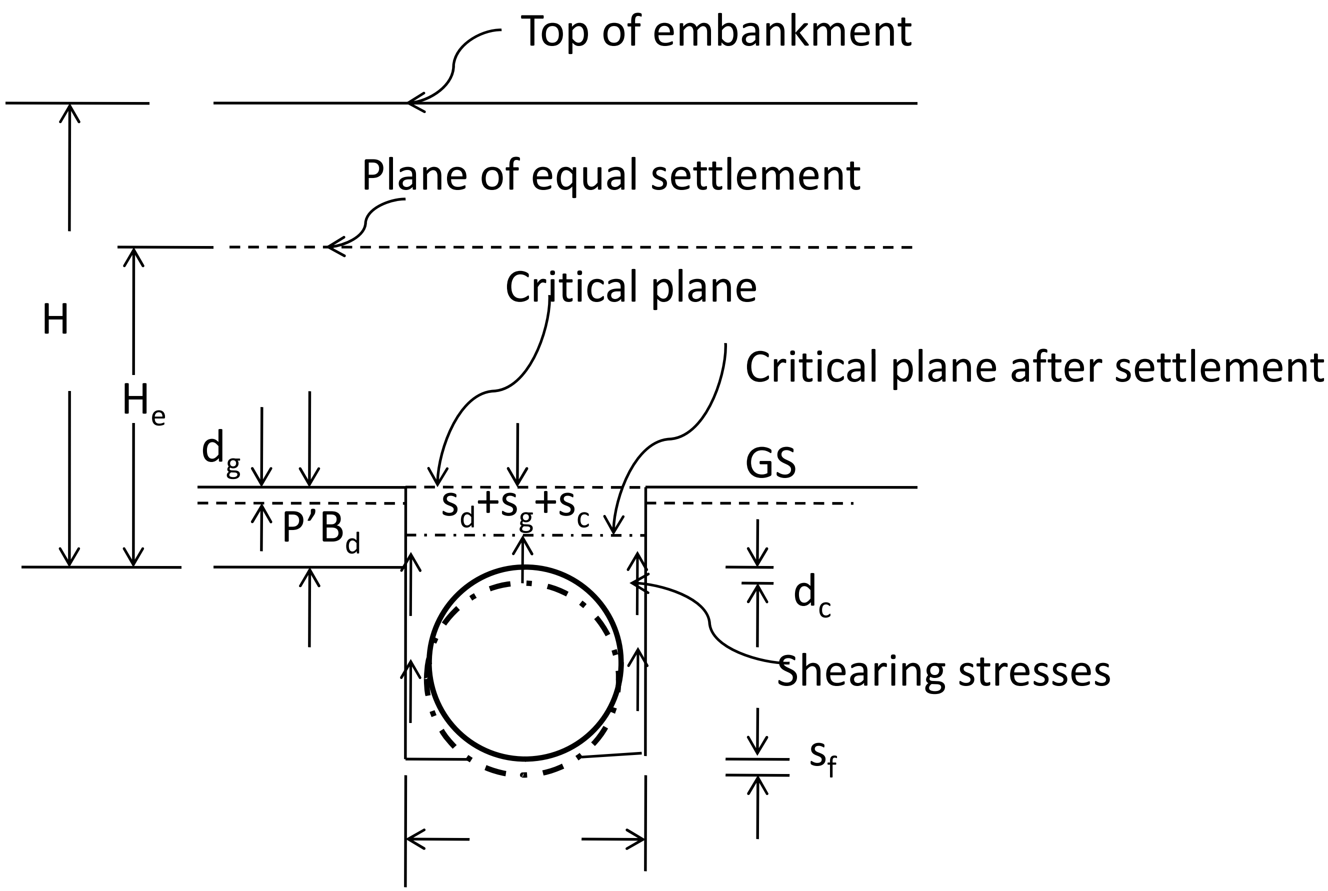
$$r_n = \frac{s_g - (s_d + s_f + d_c)}{s_d}$$

where s_g = settlement of ground surface,

S_d = settlement of backfill in the trench,

S_f settlement of the conduit foundation,

d_c = vertical deflection of the conduit.



- The critical plane is taken as the horizontal plane at the ground surface. Generally, the settlement of the critical plane in the fill over the conduit is greater than the settlement of the ground surface adjacent to the trench.

- The load on the conduit is given by

$$Wc = C_n \gamma B_d^2$$

where C_n is the coefficient for negative projecting conduit, given by

- when $H<H_e$

$$Cn = \frac{e^{\pm 2K\mu'\left(H_e / Bd \right)} - 1}{-2K\mu'}$$

- When H>He

$$Cn = \frac{e^{\pm 2K\mu'\left(H_e / B_d \right)} - 1}{-2K\mu'} + \left(\frac{H}{B_d} - \frac{H_e}{B_d} \right) e^{-2K\mu'\left(H_e / B_d \right)}$$

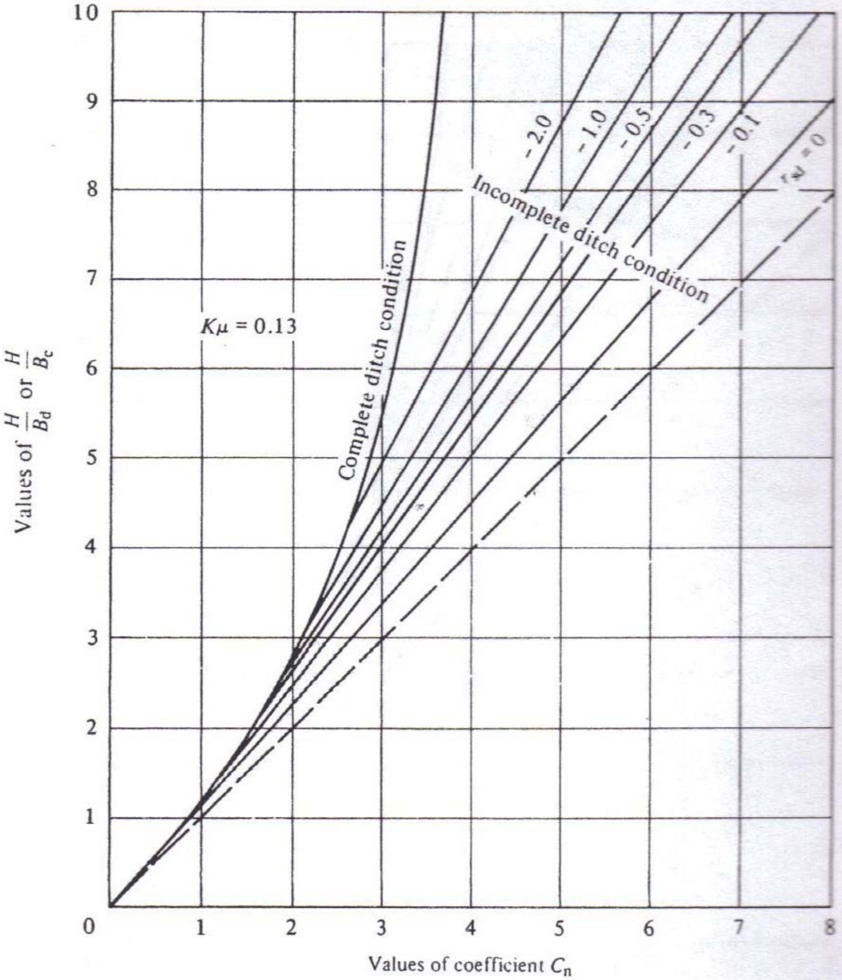


Figure 26.19 Diagram for coefficient C_n for negative projecting conduits and imperfect ditch conditions when $p' = 0.5$. For higher values of H/B use equations in Table 26.3

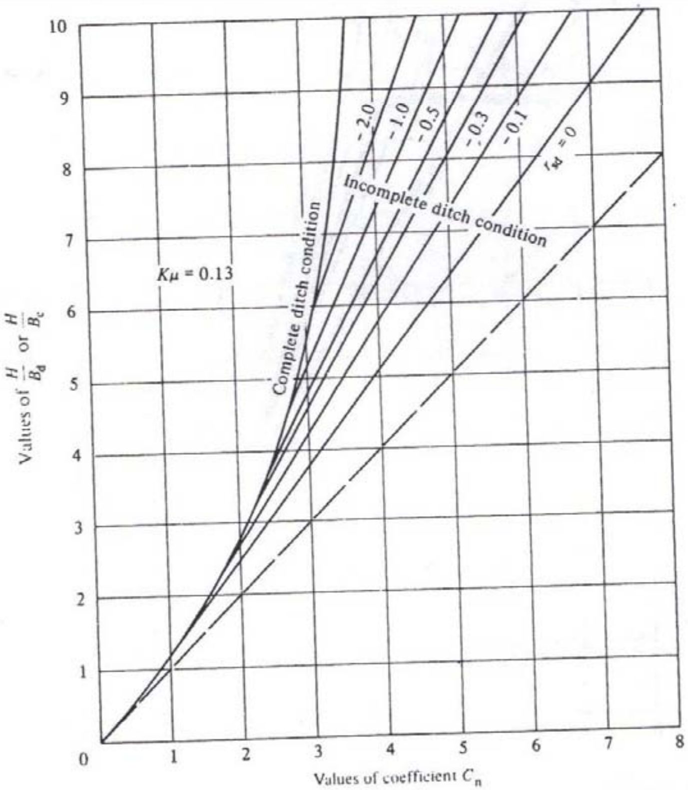


Figure 26.20 Diagram of coefficient C_n for negative projecting conduits and imperfect ditch conduits when $p' = 1.0$. For higher values of H/B use equations in Table 26.4.

TABLE 26.4 Values[a] of C_n in Terms of H/B_d or H/B_c

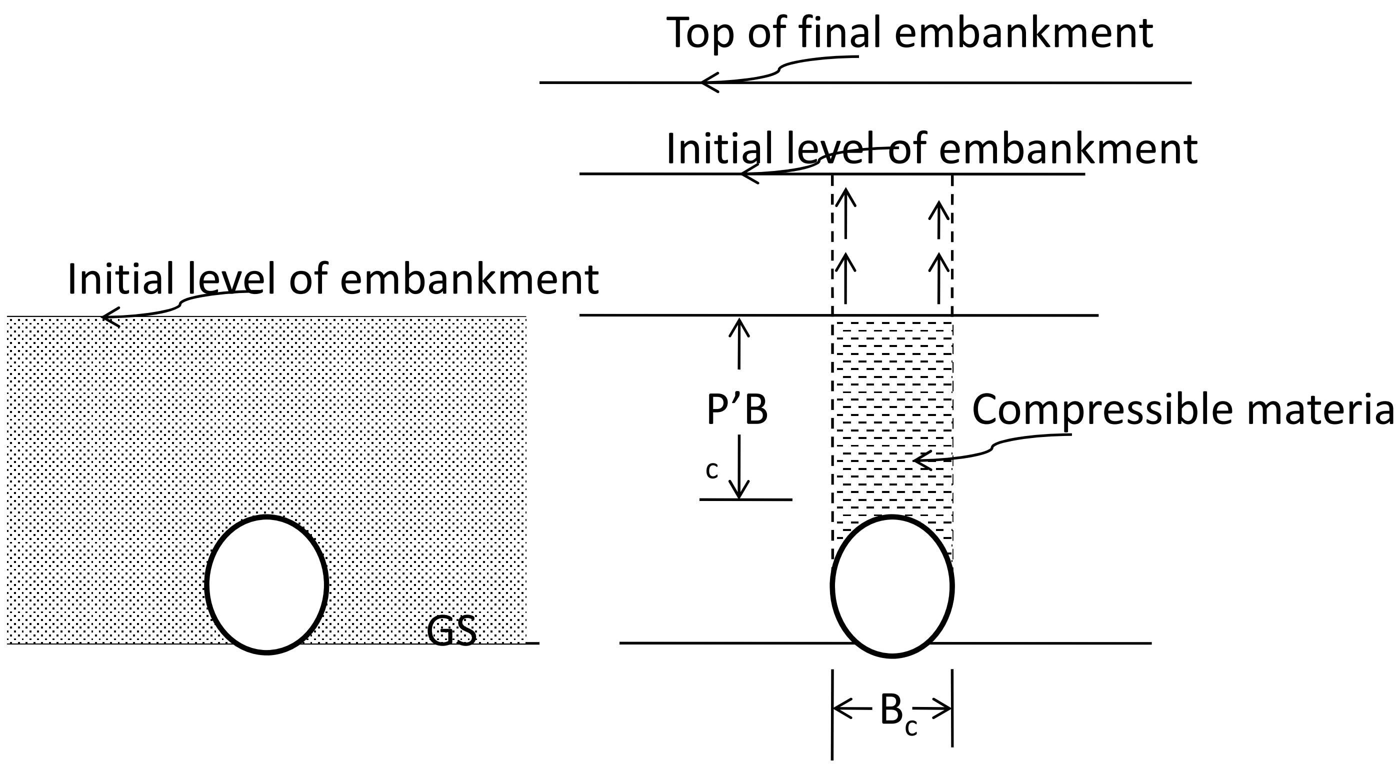
r_{sd}	Equation
0	$C_n = 0.77H/B + 0.11$
−0.1	$C_n = 0.65H/B + 0.25$
−0.3	$C_n = 0.58H/B + 0.34$
−0.5	$C_n = 0.53H/B + 0.41$
−1.0	$C_n = 0.47H/B + 0.52$
−2.0	$C_n = 0.40H/B + 0.69$

[a] Negative projecting conduits and imperfect ditch conduits (l). $p' = 1.0$.

- Imperfect Ditch Conduit
- Imperfect ditch conduit (or induced trench) is special type of conduit which is constructed to reduce the load on a conduit under a high embankment.
- The construction of imperfect ditch conduits is done in two stages:

i. The conduit is first installed as a positive projecting conduit above the ground surface and it is covered with earth fill up to a height $p'B_c$ where p' =1.0 to 2.0. The fill is well compacted.

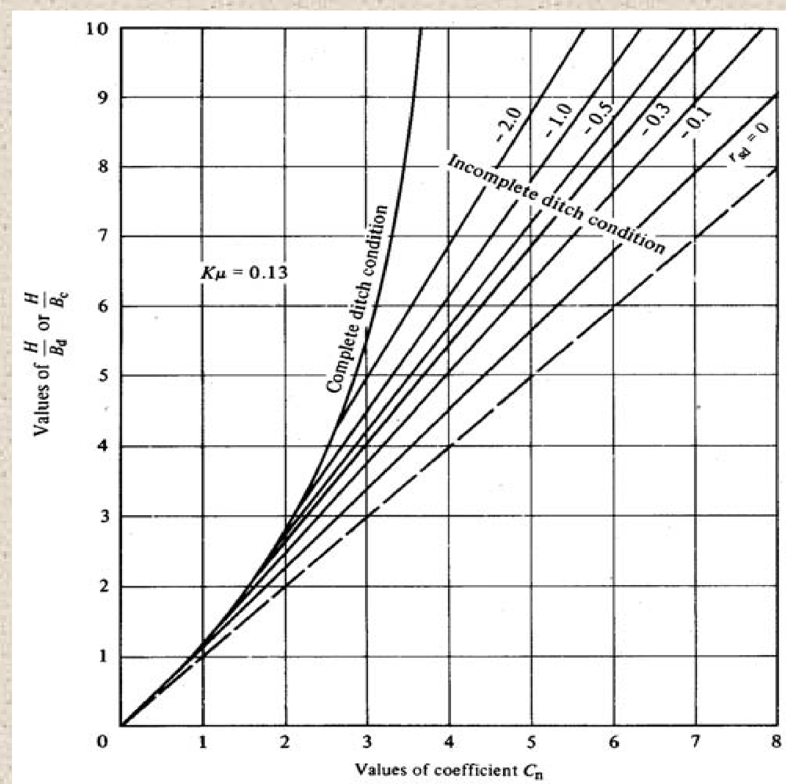
ii. In the second stage, a trench is excavated directly above the conduit from the initial level of embankment to the top of the conduit. The trench is backfilled with some compressible material such as hay, straw , leaves. The rest of the embankment is completed as usual up to the final level. Thus this construction procedure creates the situation like a negative projection condition



- As the compressible material settles, arching action develops in the overlying embankments and the shearing stresses act in upward direction. Thus the load on the conduit is reduced.

- Loads on the Imperfect Ditch
- The equations developed for the negative projecting conduits can be used for the imperfect ditch conduit by substituting B_c for B_d.

$$Wc = C_n \gamma B_c^2$$



Theoretical values of C_n for the imperfect ditch condition with a compressible fill thickness equal to Bc. The line for $r_p = 0.5$ is suggested for general use.

- Loads on conduits due to surface loads.
- Marston proposed the following equation for computing the load on the conduit due to loads applied on the surface of the fill.

$$W_t = \frac{1}{L_e} I_c C_l P$$

- where W_t = average load per unit length of conduit due to wheel loads.

  L_e = length of conduit section

  I_c = impact factor,

  C_l = load factor,

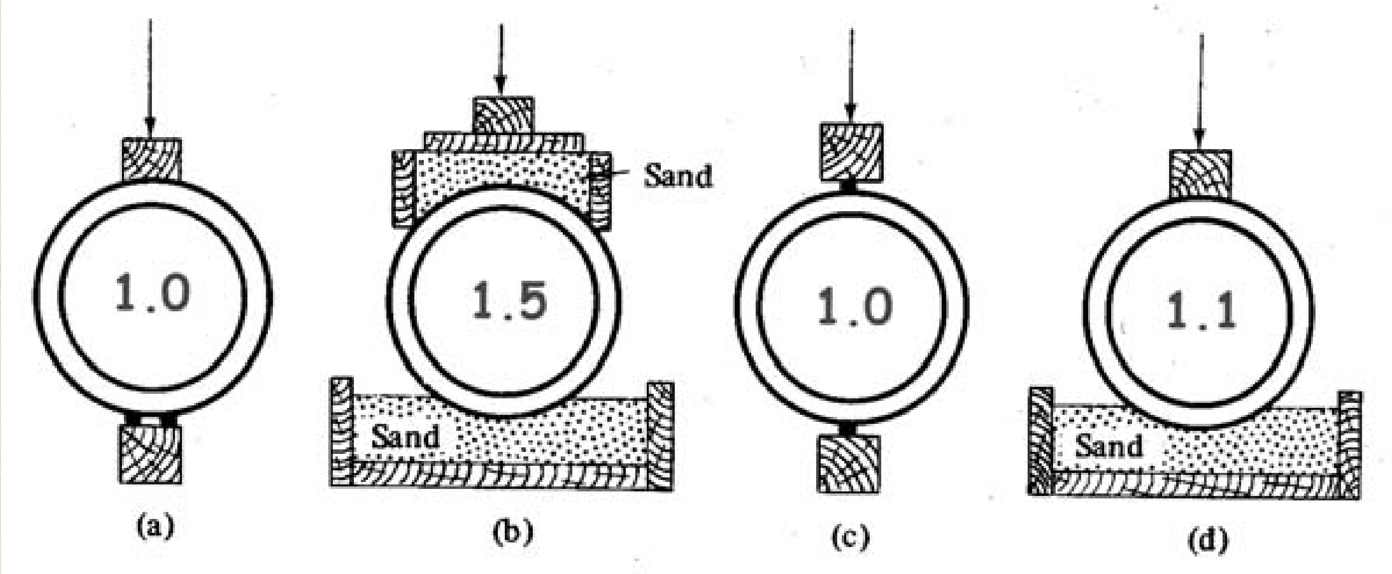
  P= concentrated wheel load on the surface of fill

- I_c =1 when the surface load is static
- Moving loads cause impact. Therefore, the effect of moving loads is greater than equivalent static loads.
- The effect of impact is more in the case of unpaved formation compared with that of a paved surface.
- Generally, an impact factor of 1.5-2.0 is taken for unpaved formation and unity for a paved highway .
- C_l is dependent on the length and width of conduit and on the depth of cover over the conduit. It is based on Boussinesq's law of stress distribution.

• SUPPORTING STRENGTH OF CONDUIT

- The supporting strength of conduits mainly depending on shape, kind and quality of material of which it is made.
- Tests for supporting strength of pipes
    - Plain concrete
    - Reinforced concrete
    - Cast iron pipes

- The following laboratory compression testing machines are used to measure the supporting strength of rigid circular or elliptical pipes.
    - three-edged bearing test;
    - sand bearing;
    - two-edged bearing;
    - Minnesota bearing.



a) three-edged bearing test; (b) sand bearing; (c) two-edged bearing; (d) Minnesota bearing.
Numbers indicate load factors for each type of test

- Of the stated tests, the three edge bearing has been standardized and is the simplest and easiest to perform.
- In each of the type of tests, the test load and the reaction on the pipe are distributed differently and the breaking or supporting strength is like wise different.

- For convenience the supporting strength of a pipe is expressed in-terms of its strength when tested by the three-edge bearing method.
- The ratio of the strength of pipe under any stated condition of loading to its strength by the three-edge bearing test is called the load factor or the strength ratio for the stated condition

$$Load\ Factor = \frac{strength\ of\ pipe\ under\ any\ condition}{Three-edge\ Bearing\ Strength}$$

- Numerous tests of rigid pipes have indicated the following load factor
  - sand bearing………. 1.5
  - two-edged bearing…….. 1.0
  - Minnesota bearing…………..1.1

• Bedding

- The different load factors listed above illustrate the significance of bedding, which functions to spread the load over larger sectors of the pipe.
- Bedding is one of the most important factors governing pipe strength in field installations, as a lateral distribution of the bottom reaction decreases the bending moment in the pipe walls
- In the field a distribution of the bottom contact stress is achieved by shaping a bedding material such as a layer of sand by use of a template cut to fit the contour of the pipe.

• Classification of Pipe Bedding

- Several classes of pipe bedding have been defined to represent construction practices used in the field. Both the distribution of the bottom pressure and the influence of lateral pressure are taken into account in the bedding class.

- Bedding classes and corresponding load factors are shown in Fig. below; the better the bedding, the higher the load factor and the larger the load that can be sustained by the pipe.

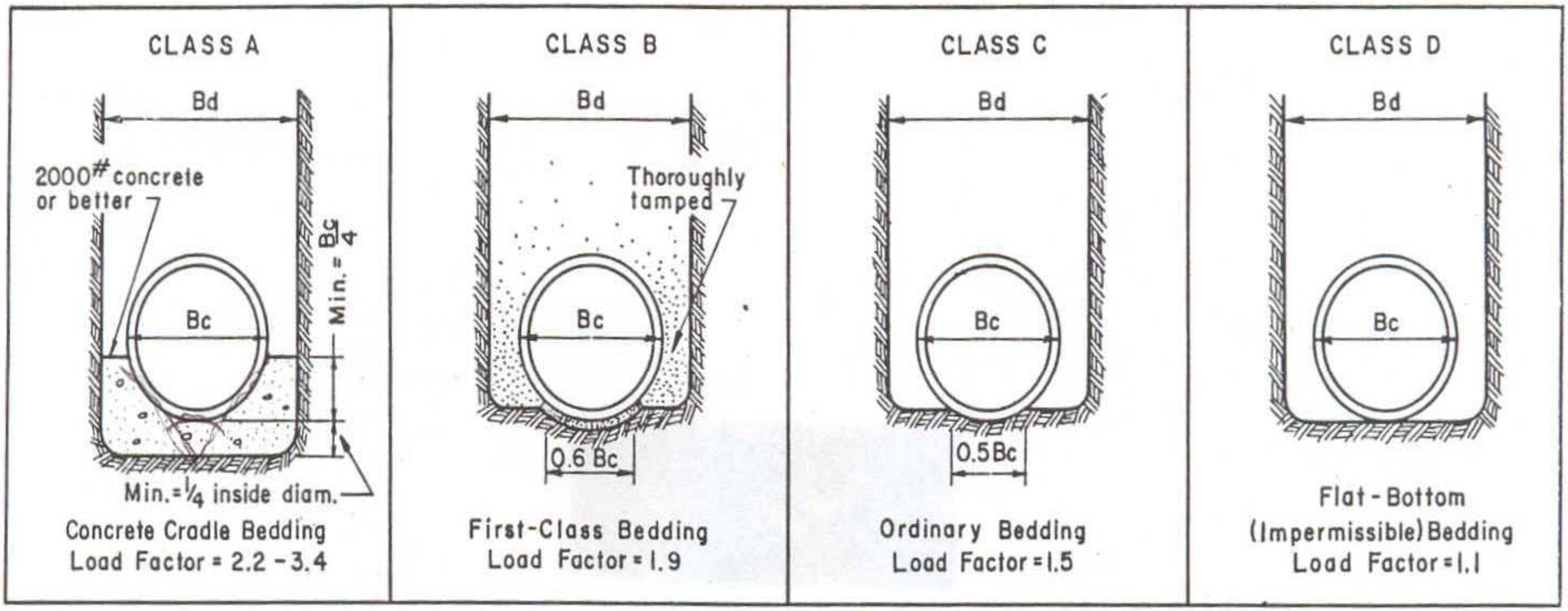


Fig. 14. Bedding methods for trench conduits.

- Class A – concrete cradle/arch
- This bedding involves setting the lower part of a conduit in plain or reinforced concrete of suitable thickness and extending upward on each side of the conduit for a distance that is not greater than one-fourth of the outside diameter of the conduit.

  Load factor
  - Concrete Cradle 2.4 - 3.4
  - Concrete Arch 2.8 – 3.4
- First-Class or Class B Bedding: Load Factor=1.9
- In this class a conduit is carefully laid on fine granular materials that have been carefully pre-shaped by means of a template to fit the lower part of the conduit exterior for a width of at least 60 percent of the conduit breadth, and the remainder of the conduit is entirely surrounded to a height of at least 0.3m above its top by granular materials that must fill all spaces under and adjacent to the conduit, and are thoroughly tamped on each side and under the conduit in layers not exceeding 0.15m in thickness

- Ordinary or Class C Bedding: Load Factor=1.5
- This class is used to indicate ''ordinary care'' in pre-shaping the earth foundation to fit the lower part of the conduit exterior for a width of at least 50 percent of the conduit breadth, and in which the remainder of the conduit is surrounded to a height of at least 0.15m above its top by granular materials that are shovel placed and shovel-tamped to completely fill all spaces under and adjacent to the conduit

- Impermissible, or Class D Bedding: Load Factor= 1.1
- This bedding class describes a situation where no effort has been made to shape the foundation to fit the lower part of the conduit and no attempt has been made to fill the spaces under and around the conduit

- Structural design of underground conduits

$$Design\ supporting\ strength = \frac{Three-edge\ Bearing\ Strength * Load\ Factor}{FS}$$

- FS = Factor of safety,
  - 1.0 for reinforced concrete pipe
  - 1.2 to 1.5 non-reinforced concrete pipe