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design data 22

american Concrete Pipe association

SURCHARGE LOADS

Changes in land use may necessitate the placement of surcharge loads over existing pipe installations. The most common type of surcharge load is additional earth fill. If the surcharge load is a building or other surface load, the resultant uniformly distributed load can be converted to an equivalent frictionless height of fill, and therefore, evaluated as additional earth fill.

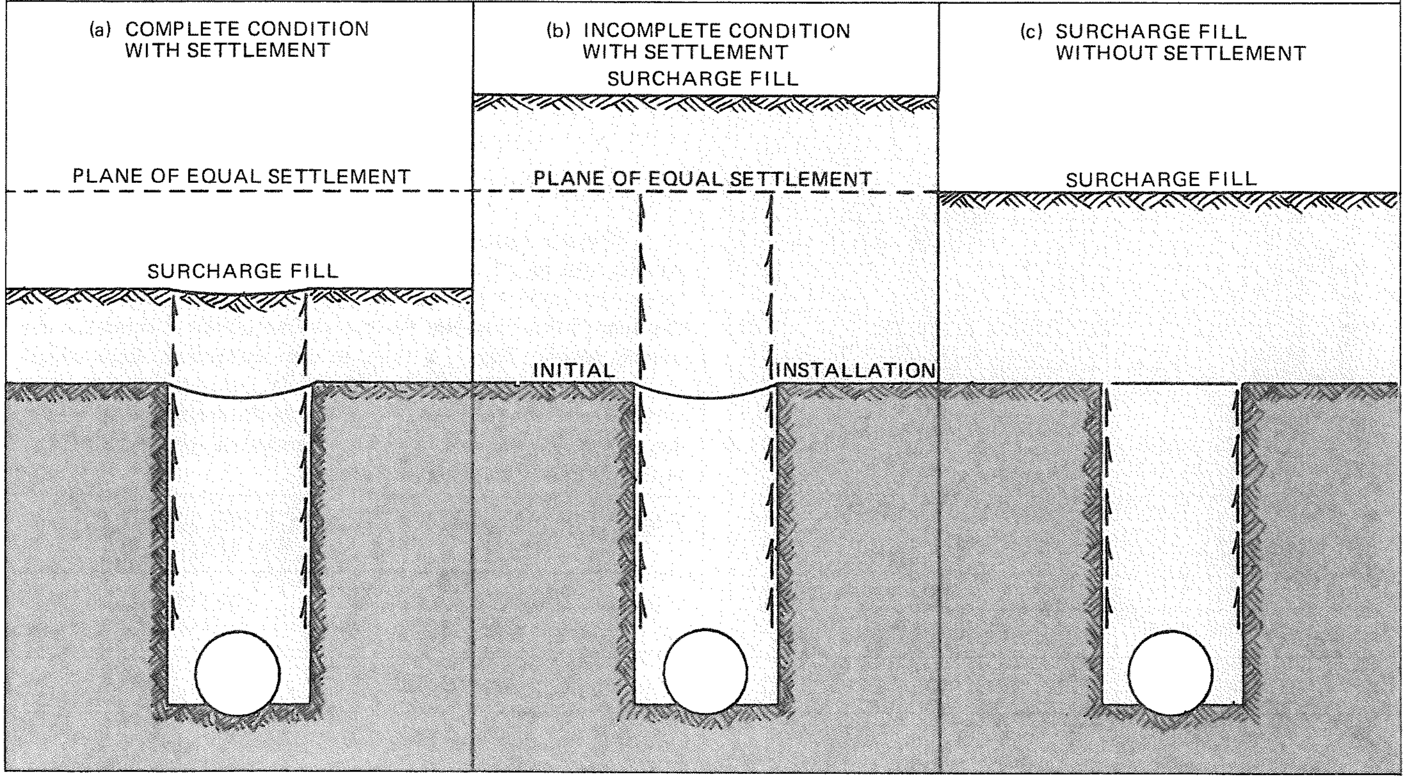
When concrete pipe has been installed underground for any period of time an ideal soil-structure stability is realized. In addition, the load carrying capacity of the pipe increases, because of increased concrete strength and favorable load distribution around the periphery of the pipe. The possibility of cohesion developing within the soil mass may result in negligible, surcharge load transmitted to the pipe. All of these time related factors contribute to the adequacy of an installed concrete pipe to withstand greater loads than the initial design loads. Through site investigations, soils analysis, tests and information on the design and construction of the initial installation, it should be possible to quantitatively evaluate these factors. Test data on concrete pipe which have been removed from service and three-edge bearing tested, indicate an increase in load carrying capacity of 10 percent to 40 percent.

Data required for the proper evaluation of surcharge loads are:

a. historical data regarding pipe size and strength class.
b. installation data regarding type of installation, type of bedding and, if applicable, type of backfill material and trench width.
c. soils analysis to determine whether or not differential settlements will occur between the backfill or fill material over the pipe and the soil adjacent to the sides of the pipe, after the surcharge is placed.

Assuming that the time related factors have been determined, the proper evaluation of surcharge loads is primarily dependent on the initial installation and the two most common types are trench and positive projecting embankment.

FIGURE 1: TRENCH INSTALLATIONS WITH SURCHARGE FILL LOAD



TRENCH

Trench installations are normally used in the construction of sewers. The pipe is installed in a relatively narrow trench excavated in undisturbed soil and then covered with backfill extending to the original ground surface. When pipe is installed in a narrow trench and backfilled, the backfill material will tend to settle. This downward movement generates frictional forces along the trench walls, which act upward to help support the weight of the backfill material. The magnitude of the frictional forces depends on the unit weight of the backfill material w, the value of Rankine's lateral pressure ratio K, and the coefficient of sliding friction μ', between the backfill material and the trench walls.

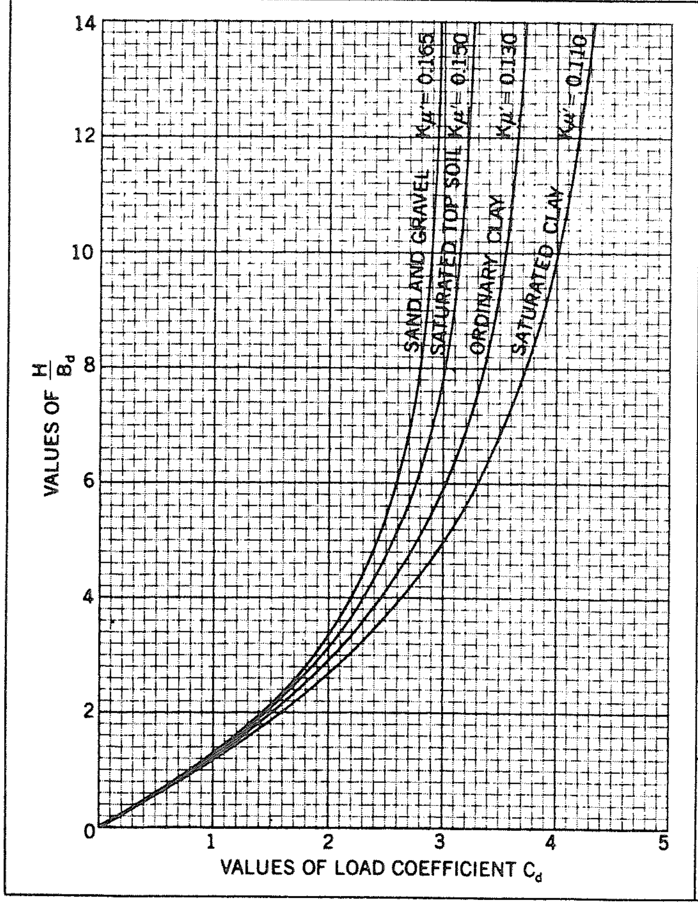
After placement of the surcharge load these frictional forces may or may not occur in the additional fill, depending on the relative compressibility of the initial backfill material and the adjacent soil in which the trench was excavated.

As illustrated in Figure 1, three possible conditions could develop when a surcharge fill is placed over an existing trench installation. The proper method of analysis depends on the height of the additional fill and relative settlements. The three conditions are:

1. complete condition with settlement
2. incomplete condition with settlement
3. surcharge fill without settlement

When a surcharge fill is placed over an existing trench installation and differential settlements are expected between the initial backfill material and the surrounding soil in which the trench was excavated, upward friction forces will be generated in the additional fill. The terminology *complete condition* indicates that differential settlements and friction forces act throughout the entire height of fill, and *incomplete condition* indicates that differential settlements and friction forces are dissipated within the fill with a plane of equal settlement being developed.

FIGURE 2: LOAD COEFFICIENT DIAGRAM FOR TRENCH INSTALLATIONS



As illustrated in Figure 1(a), when the height of the surcharge fill is relatively shallow as compared to the depth of the initial trench, upward friction forces will be generated throughout the entire height of the additional fill. This simulates a trench condition and the total load is computed by the equation:

$$W_d = C_d w B_d^2 \quad (1)$$

where

W_d = total load including initial backfill load and surcharge load, pounds per linear foot.

C_d = load coefficient for trench installations with a relatively shallow surcharge fill.

w = unit weight of initial backfill material and/or additional fill material, pounds per cubic foot.

B_d = trench width of the initial installation, feet

Figure 2 presents values of the load coefficient, C_d, for various types of soils and H/B_d ratios. The H value to be used in Figure 2 is the total height of cover over the pipe; the height of the initial backfill plus the height of the surcharge fill.

As illustrated in Figure 1 (b), the surcharge fill is of sufficient height that a plane of equal settlement is developed within the soil mass. This simulates a negative projecting embankment installation and the total load is computed by the equation:

$$W_n = C_n \, w \, B_d^2 \quad (2)$$

where

W_n = total load including initial backfill load and surcharge load, pounds per linear foot.

C_n = load coefficient for trench installations with a relatively high surcharge fill.

w = unit weight of initial backfill material and/or additional fill material, pounds per cubic foot.

B_d = trench width of the initial installation, feet.

Figure 3 presents values of the load coefficient, C_n, for various values of p' and r_{sd}. The p' term is the negative projection ratio and is defined as the vertical distance between the top of the pipe and the top of the trench divided by the trench width. The r_{sd} term is the settlement ratio which evaluates the differential settlements between the backfill material within the trench and the surrounding soil in which the trench was excavated. Recommended design values for the settlement ratio are listed in Table I.

TABLE I: NEGATIVE PROJECTING SETTLEMENT RATIO DESIGN VALUES

NEGATIVE PROJECTION RATIO p'	SETTLEMENT RATIO r_{sd}
0.5	-0.1
1.0	-0.3
1.5	-0.5
2.0	-1.0
3.0	-2.0

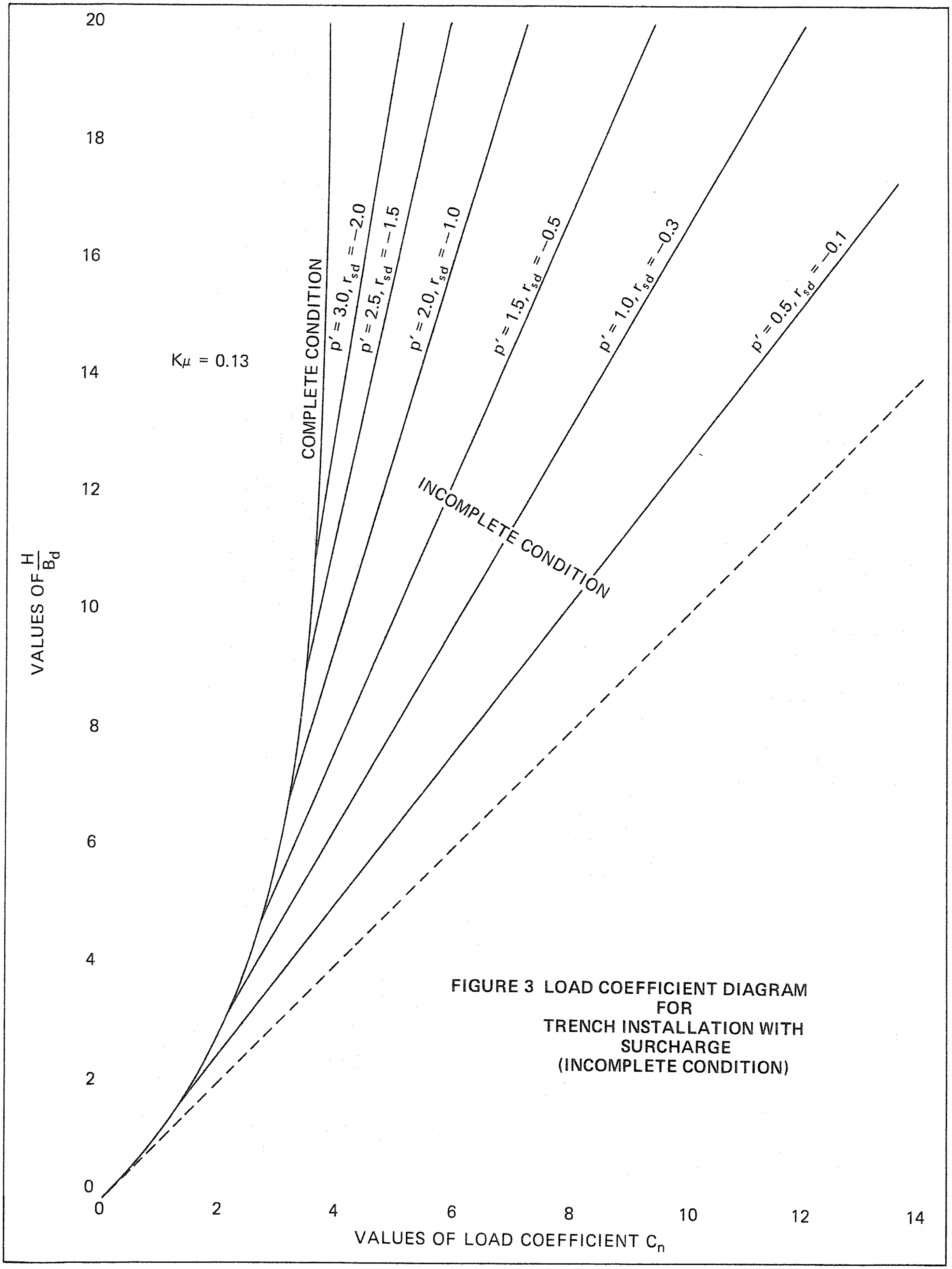


FIGURE 3 LOAD COEFFICIENT DIAGRAM FOR TRENCH INSTALLATION WITH SURCHARGE (INCOMPLETE CONDITION)

To determine if equation (1) or (2) is applicable, it is necessary to evaluate the height of surcharge fill required to develop a plane of equal settlement. This can be determined from Figure 3 at the points of intersections between the straight p′, r_{sd} lines representing the INCOMPLETE CONDITION and the curved line representing the COMPLETE CONDITION. Once the incomplete condition is realized, the fill load varies linearly for any given trench width, negative projection ratio and settlement ratio.

As illustrated in Figure 1 (c), if the backfill material and adjacent soil have developed sufficient stability over a period of time so that all material will compress equally, then differential settlements and frictional forces will not develop within the surcharge fill. For this condition the total load is computed by the equation:

$$W_d = C_d\, w\, B_d^2 + C_s\, w\, H\, B_d \qquad (3)^*$$

where

W_d = total load including initial backfill load and surcharge load, pounds per linear foot

C_d = load coefficient for trench installations

w = unit weight of initial backfill material, pounds per cubic foot

B_d = trench width of the initial installation, feet

C_s = load coefficient for surcharge loads

H = height of surcharge fill, feet

The first term in equation (3), $C_d\, w\, B_d^2$, accounts for the backfill load of the initial installation and the second term, $C_s\, w\, H\, B_d$, accounts for the surcharge load.

Figure 2 presents values of the backfill load coefficient, C_d, and Figure 4 presents values of the surcharge load coefficient, C_s. Load coefficient values are presented for various types of soils and H/B_d ratios. The height of backfill, H, is measured from the top of the pipe to the original ground surface for both Figures.

POSITIVE PROJECTING EMBANKMENT

Positive projecting embankment installations are normally used in the construction of culverts. The pipe is installed on the original ground or compacted fill and then covered by an earth fill or embankment.

In considering fill loads on concrete pipe installed in a positive projecting embankment condition, it is convenient to designate the prism of fill directly above the pipe and bounded by vertical planes tangent to the sides of the pipe as the interior prism. The exterior prisms are the prisms of fill adjacent to the vertical planes on both sides of the pipe. Since the length of the exterior prisms are greater than the interior prism, the exterior prisms of fill will compress more than the interior prism as the embankment is built up. The relative settlements between the interior prism and the exterior prisms generate downward frictional forces along the vertical planes adjacent to the sides of the pipe, which increases the fill load over the pipe.

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* For uniform surcharge loads resulting from buildings or other surface loads, the second term in equation (3) is expressed as $C_s\, U_s\, B_d$; where U_s is the uniform pressure at the ground surface, pounds per square foot.

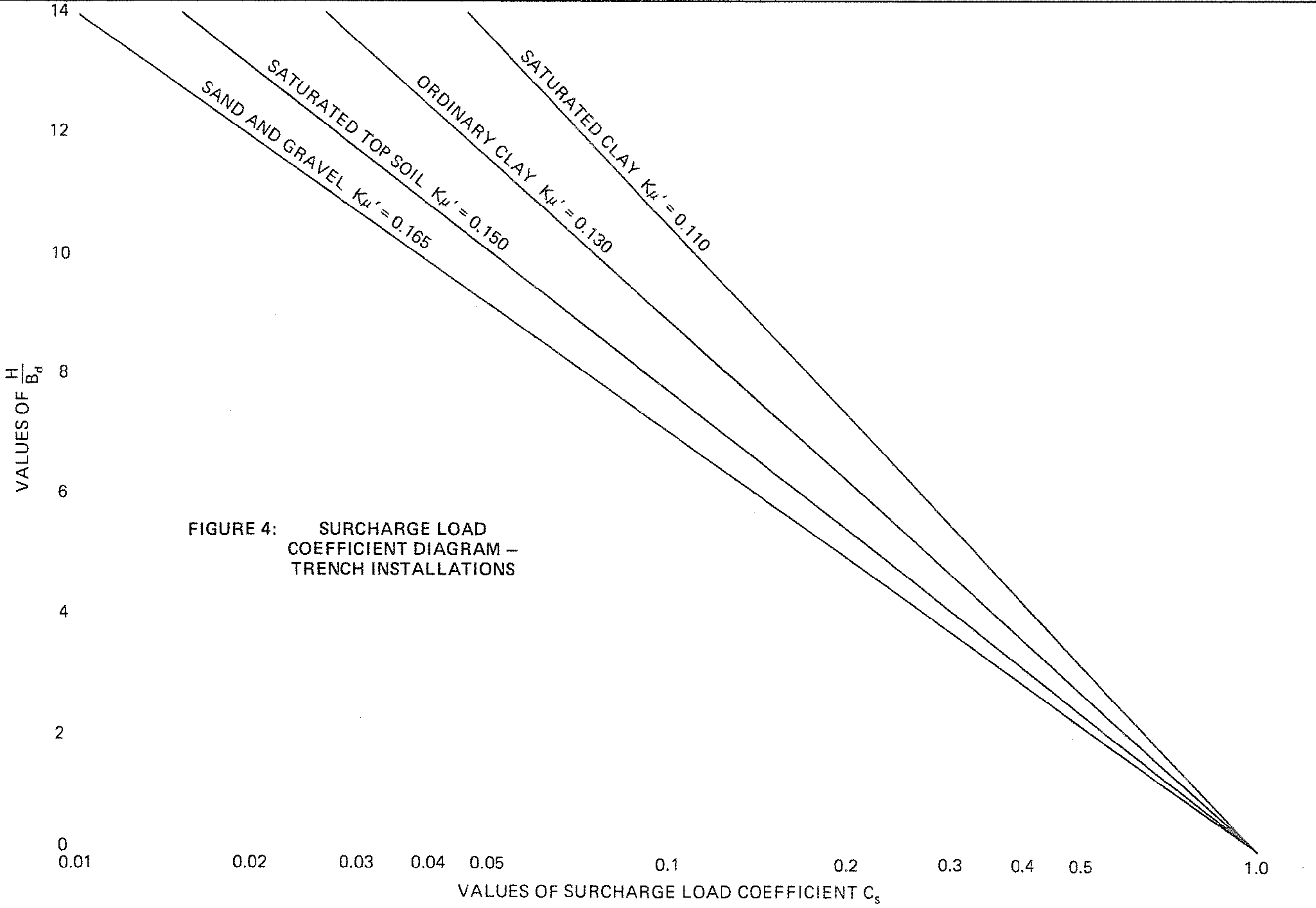

FIGURE 4: SURCHARGE LOAD COEFFICIENT DIAGRAM – TRENCH INSTALLATIONS

As illustrated in Figure 5, three possible conditions could develop when a surcharge fill is placed over an existing embankment installation and these conditions are:

1. complete condition with settlement
2. incomplete condition with settlement
3. surcharge fill without settlement

When a surcharge fill is placed over an existing embankment installation and differential settlements are expected between the interior and exterior prisms, downward frictional forces will be generated through the additional fill. Under shallow fills, differential settlements and downward frictional forces will act throughout the entire fill height and this condition is defined as the *complete condition.* If the fill is of sufficient height, a plane of equal settlement will develop within the soil mass and this condition is defined as the *incomplete condition.* If the initial installation is a complete condition, the additional fill may be of sufficient height to enable development of a plane of equal settlement and change the complete into the incomplete condition. Once the incomplete condition is realized the fill load varies linearly for any given size of pipe, projection ratio, p, and settlement ratio, r_{sd}. The projection ratio, p, is defined as the vertical distance the pipe projects above the original ground for the initial installation divided by the outside vertical height of the pipe. The settlement ratio evaluates the relative settlements between the interior and exterior prisms of fill, including the settlement of the original ground and deflection of the pipe.

Recommended design values for the settlement ratio are:

TABLE II: POSITIVE PROJECTING SETTLEMENT RATIO DESIGN VALUES

TYPE OF FOUNDATION	USUAL RANGE	DESIGN* VALUE r_{sd}
ROCK OR UNYIELDING SOIL	1.0	1.0
ORDINARY SOIL	0.5 to 0.8	0.5
YIELDING SOIL	0.0 to 0.5	0.3

For both the complete and incomplete conditions the total load is computed by the equation:

$$W_c = C_c w B_c^2 \qquad (3)$$

where

W_c = total load including initial fill load and surcharge fill load, pounds per linear foot

C_c = load coefficient for positive projecting embankment installations

w = unit weight of fill material, pounds per cubic foot

B_c = outside horizontal span of the pipe, feet

Figures 6 through 8 present values of the load coefficient for various H/B_c ratios and $r_{sd}p$ products. The H value to be used in the Figures is the total cover over the pipe; the height of the initial fill plus the height of the surcharge fill. The height of fill required to change from the complete to the incomplete condition can also be determined from Figures 6 through 8. For any given pipe size and $r_{sd}p$ product, this change occurs at the intersection of the straight $r_{sd}p$ lines indicated as INCOMPLETE CONDITION and the curved line indicated as COMPLETE CONDITION.

The complete condition usually exists for pipe installed with shallow cover and, over a period of time, sufficient stability of the surrounding fill may be realized such that placement of a surcharge load will not cause differential settlements between the fill over the pipe and the adjacent fill.

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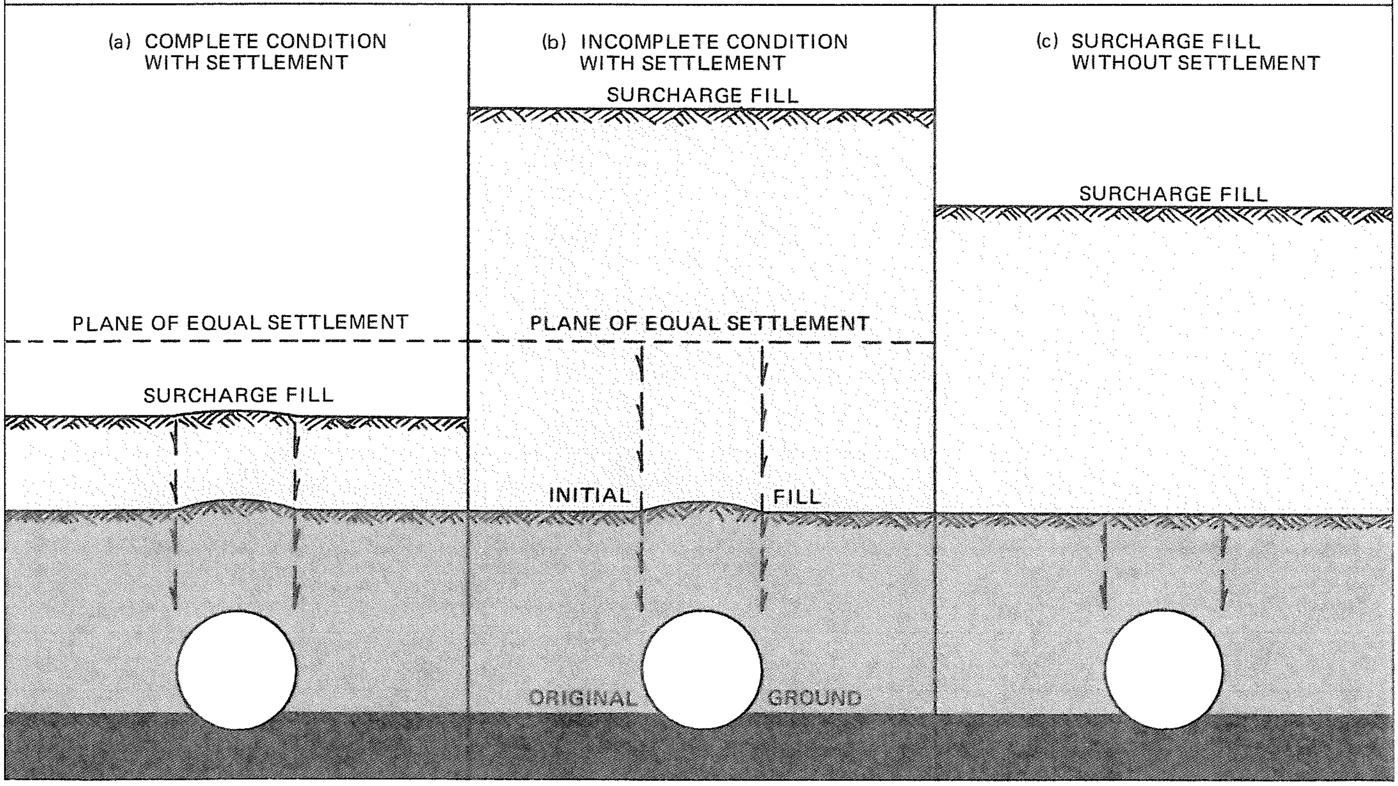
* The value of the settlement ratio depends on the degree of compaction of the fill material adjacent to the sides of the pipe. With good construction methods resulting in proper compaction of bedding and sidefill materials, lower design values of the settlement ratio may be used.

FIGURE 5: POSITIVE PROJECTING EMBANKMENT INSTALLATIONS WITH SURCHARGE FILL LOAD



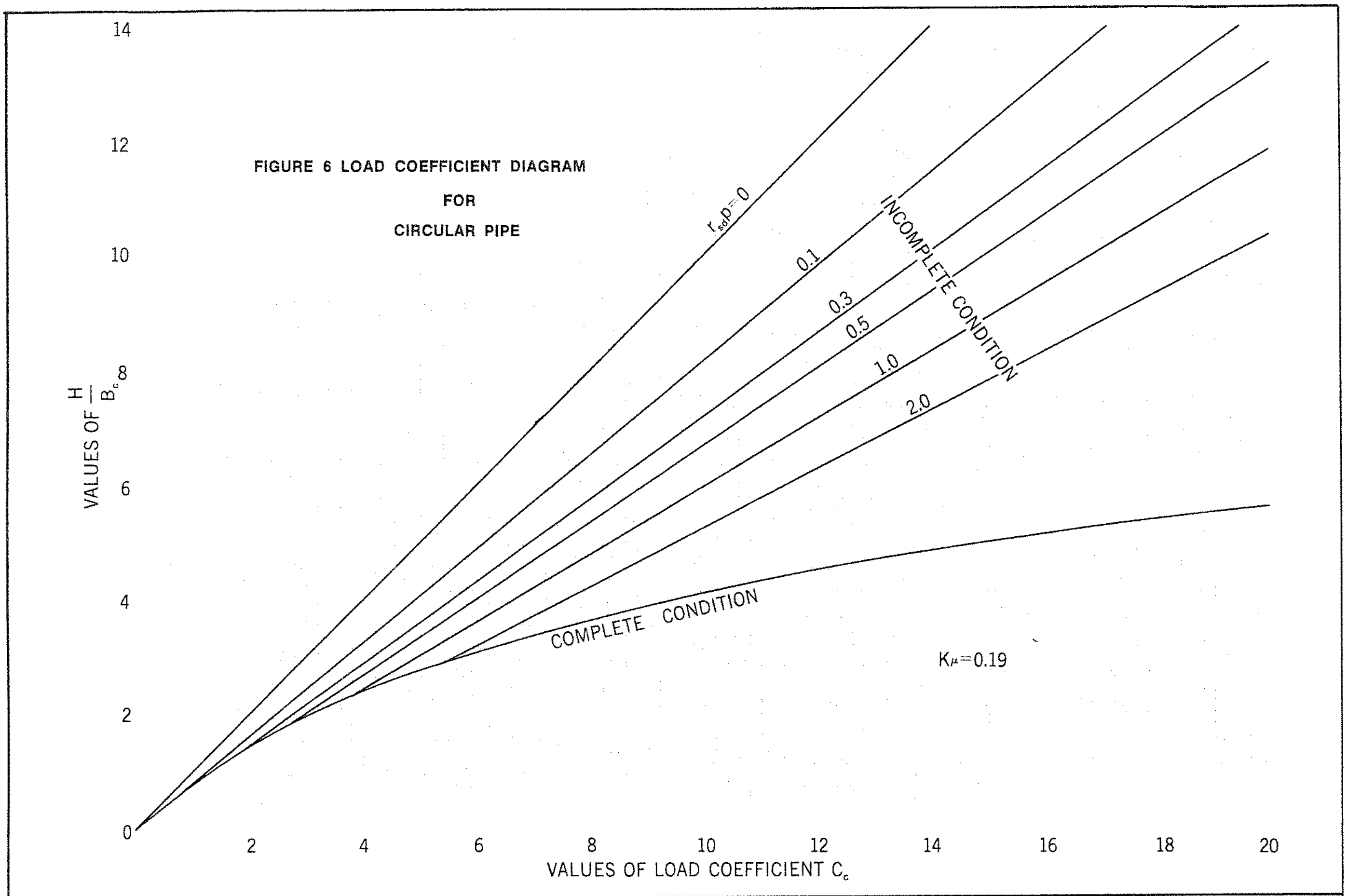


FIGURE 6 LOAD COEFFICIENT DIAGRAM
FOR
CIRCULAR PIPE

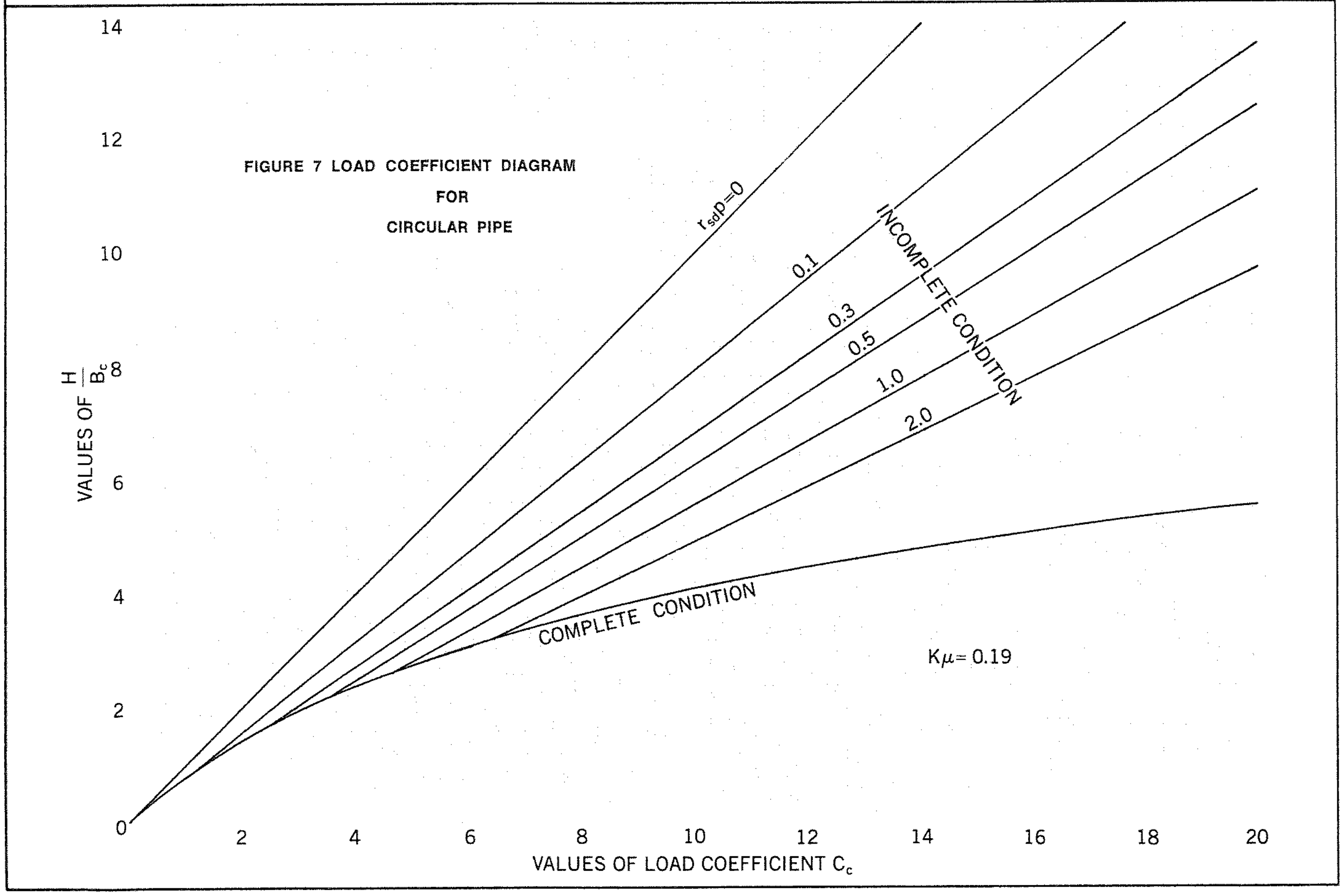


FIGURE 7 LOAD COEFFICIENT DIAGRAM
FOR
CIRCULAR PIPE

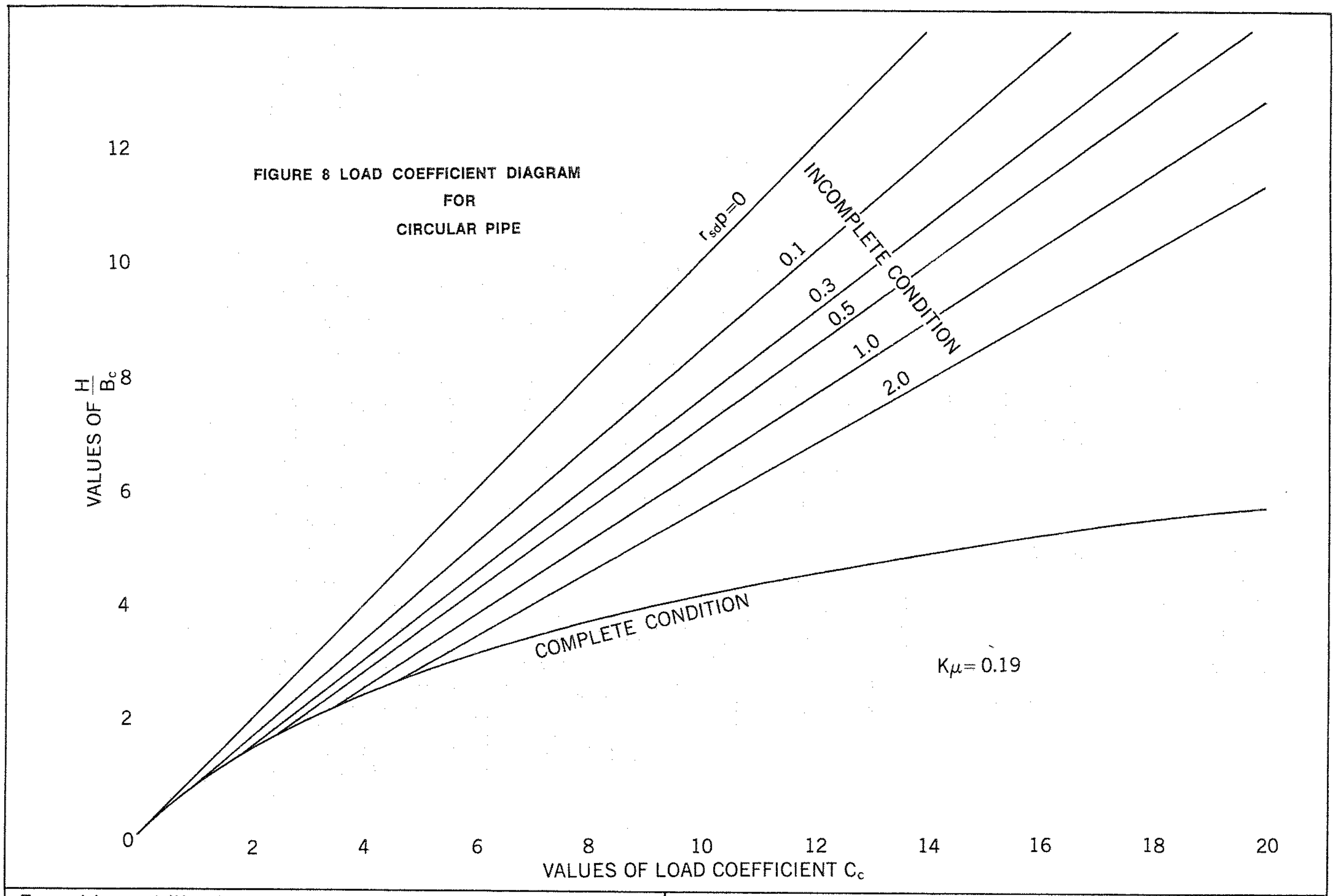


FIGURE 8 LOAD COEFFICIENT DIAGRAM FOR CIRCULAR PIPE

For this stabilized complete condition the total load is computed by the equation:

$$W_c = C_c \, w \, B_c^2 + C_s \, w \, H \, B_c \qquad (5)^*$$

where

W_c = total load including initial fill load and surcharge load, pounds per linear foot

C_c = load coefficient for positive projecting embankment installations without surcharge fill

w = unit weight of initial fill material and/or surcharge fill material, pounds per cubic foot

B_c = outside horizontal span of the pipe, feet

C_s = load coefficient for surcharge loads

H = height of surcharge fill, feet

The first term in equation (5), $C_c \, w \, B_c^2$, accounts for the initial fill load and the second term, $C_s \, w \, H \, B_c$, accounts for the surcharge fill load. The initial fill load coefficient is determined from Figures 6 through 8 with the H/B_c ratio corresponding to the initial height of fill. Figure 9 presents values of the surcharge load coefficient, C_s, for various H/B_c ratios. The H value to be used in Figure 9 is the initial height of fill.

The examples on page 8 illustrate the proper use of the Figures.

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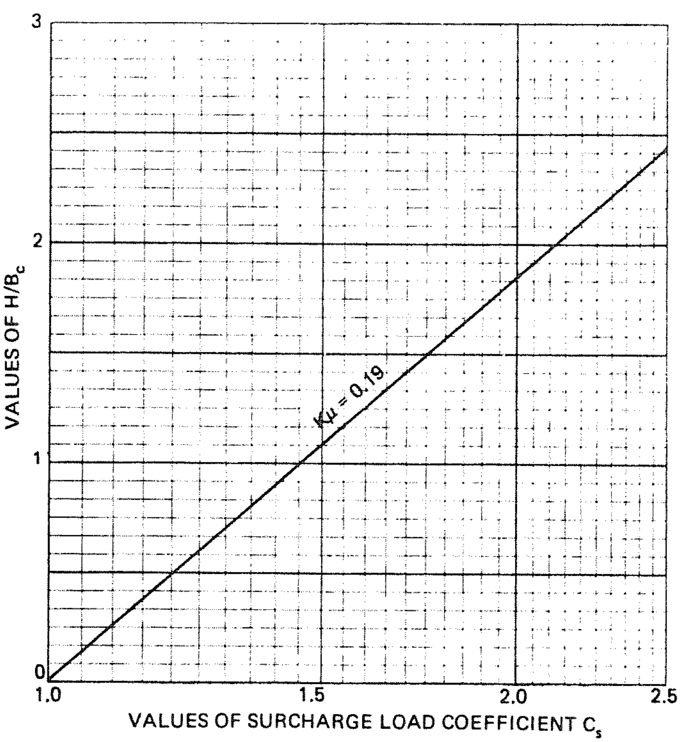
* For uniform surcharge loads resulting from buildings or other surface loads, the second term of equation (5) is expressed as $C_s \, U_s \, B_c$; where U_s is the uniform load at the original fill surface in pounds per square foot.

FIGURE 9: SURCHARGE LOAD COEFFICIENT DIAGRAM COMPLETE EMBANKMENT INSTALLATIONS



Example 1a: Trench Installation

Given: A 10-foot high surcharge fill, weighing 120 pounds per cubic foot, is to be placed over an existing 36-inch diameter concrete pipe storm sewer. Based on historical and installation data, the existing pipe was installed in a 5-foot wide trench and backfilled with 5 feet of ordinary clay material. Differential settlements will be expected.

Find: The total earth load on the pipe with the surcharge fill in place.

Solution: It is first necessary to determine if the initial installation, with the surcharge fill, is in the complete or incomplete condition.

For the initial installation $H/B_d = p' = 1.0$ and for the surcharge condition $H/B_d = 3$. From Figure 3, the straight $p' = 1.0$, $r_{sd} = -0.3$ line representing the incomplete condition intersects the curved line representing the complete condition at a H/B_d value of 3.2. Since the H/B_d value of 3.2 is larger than the surcharge H/B_d value of 3.0, the surcharge fill is not of sufficient height to develop a plane of equal settlement and the installation is in a complete condition. For this condition, equation (1) and Figure 2 is applicable.

From Figure 2, for $H/B_d = 3$ and $K\mu' = 0.13$, $C_d = 2.1$

Answer:

$$W = C_d\ w\ B_d^2$$

$$W = (2.1)\ (120)\ (5)^2$$

$$W = 6{,}300 \text{ pounds per linear foot}$$

Example 1b:

Given: All data the same as Example 1a, except that the height of the surcharge fill will be increased to 25 feet.

Find: The total earth load on the pipe with the surcharge fill in place.

Solution: The surcharge H/B_d value = 30/5 = 6, which is larger than the 3.2 H/B_d value required to change the complete to the incomplete condition. Since the installation is in the incomplete condition, equation (2) and Figure 3 is applicable.

From Figure 3, for $H/B_d = 6$ and $p' = 1$, $r_{sd} = -0.3$, $C_n = 3.8$

Answer:

$$W = C_n\ w\ B_d^2$$

$$W = (3.8)\ (120)\ (5)^2$$

$$W = 11{,}400 \text{ pounds per linear foot}$$

Example 1c:

Given: All data the same as Example 1a, except that differential settlements are not expected.

Find: The total earth load on the pipe with the surcharge fill in place.

Solution: When differential settlements are not expected, the total load can be evaluated in two parts; the initial backfill load and the surcharge fill load. From Figure 2, for $H/B_d = 5/5 = 1$ and $K\mu' = 0.13$, the initial backfill load coefficient $C_d = 0.88$. From Figure 4, for $H/B_d = 1$ and $K\mu' = 0.13$, the surcharge load coefficient $C_s = 0.77$.

Answer: The total load is computed by equation (3).

$$W = C_d\ w\ B_d^2 + C_s\ w\ HB_d$$

$$W = (0.88)\ (120)\ (5)^2 + (0.77)\ (120)\ (10)\ (5)$$

$$W = 7{,}260 \text{ pounds per linear foot.}$$

Example 2a: Embankment Installation

Given: A 6-foot high surcharge fill, weighing 120 pounds per cubic foot, is to be placed over an existing 60-inch diameter concrete pipe culvert (6-foot outside diameter). Based on historical and installation data the existing pipe was installed in a positive projecting condition on an unyielding foundation with a 1.0 projection ratio and 6 feet of cover. Differential settlements are expected.

Find: The total earth load on the pipe with the surcharge fill in place.

Solution: From Table II, for pipe installed on an unyielding foundation, a settlement ratio value of 1.0 is recommended. Therefore the $r_{sd}\ p$ product will be 1.0. From Figure 6, the straight $r_{sd}\ p$ line representing the incomplete condition intersects the curved line representing the complete condition at a H/B_c value of 2.4. The initial height of fill plus the height of the surcharge fill results in a H/B_c value of 2.0. Since the H/B_c value of 2.4 is larger than the surcharge H/B_c value of 2.0, the surcharge fill is not of sufficient height to develop a plane of equal settlement and the installation is in a complete condition. From Figure 6, for $H/B_c = 2$ and $r_{sd}\ p = 1.0$, $C_c = 3$.

Answer:

$$W = C_c\ w\ B_c^2$$

$$W = (3)\ (120)\ (6)^2$$

$$W = 12{,}960 \text{ pounds per linear foot}$$

Example 2b:

Given: All data the same as Example 2a, except that the height of the surcharge fill will be increased to 24 feet.

Find: The total earth load on the pipe with the surcharge fill in place.

Solution: The surcharge H/B_c = 30/6 = 5, which is larger than the 2.4 H/B_c value required to change the complete to the incomplete condition. From Figure 6, for $H/B_c = 5$ and $r_{sd}\ p = 1.0$, $C_c = 8.4$.

Answer:

$$W = C_c\ w\ B_c^2$$

$$W = (8.4)\ (120)\ (6)^2$$

$$W = 36{,}300 \text{ pounds per linear foot}$$

Example 2c:

Given: All data the same as Example 2a, except that differential settlements are not expected.

Find: The total earth load on the pipe with the surcharge fill in place.

Solution: When differential settlements are not expected and the initial installation is in a complete condition, the total load can be evaluated in two parts; the initial fill load and the surcharge fill load. From Figure 6, for $H/B_c = 6/6 = 1.0$, the initial fill load coefficient $C_c = 1.22$. From Figure 9, for $H/B_c = 1.0$, the surcharge load coefficient $C_s = 1.46$

Answer: The total load is computed by equation (5).

$$W = C_c\ w\ B_c^2 + C_s\ w\ HB_c$$

$$W = (1.22)\ (120)\ (6)^2 + (1.46)\ (120)\ (6)\ (6)$$

$$W = 11{,}580 \text{ pounds per linear foot}$$