CHAPTER 4: STRUCTURAL ANALYSIS OF RIGID CONDUITS, UNDERGROUND

Figure 4-1: Soil characteristics and bedding are critical to structural stability.

This chapter deals with the examination and evaluation of all those forces, which affect or influence the structural stability and useful life of vitrified clay pipe.

Methods are outlined by which trench loads may be considered and analyzed for the purpose of accomplishing required structural support.

Predetermining Loads Accurately

There is a tendency to think of sewer pipe from the hydraulic standpoint only and to neglect the importance of pipe as a structural element. It must, above all else, maintain structural stability.

Nearly all building codes impose legal standards upon designers to insure against the failure of building structures. Standard practice in highway work and railroad work also provides for predetermined structural safety.

Computer Design

The National Clay Pipe Institute has developed Trench Load, an online program, which can be used to determine backfill loads, safety factors and bedding classes. It is available at ncpi.org/toolbox/trenchload/.

Trench Load is available from any internet-connected device. The values provided by this program are based on the equations presented in this chapter and are conservative.

Loads Can Be Accurately Determined

Just as the safety of ordinary structural members involves the application of "mechanics" to cases of calculated live loadings, the safety in underground pipe work involves application of "soil mechanics" for determining the load on the pipe. The amount of load to be supported by the pipe can be computed and the result will be safe and accurate in the same sense that predetermination of strength is safe and accurate.

Complete reference tables are included in Chapter 5 to provide engineers with a convenient method of predetermining loads and strength requirements for clay pipe. These tables show the predicted load according to pipe size, trench depth and width and type of backfill. Chapter 6 provides data for determining the effect of the type of bedding or support given to the pipe.

Trench Load

To determine a reliable equation for computing the relationship between various kinds of loads and the required test strength of pipe, a series of studies were made at the Engineering Experiment Station of Iowa State College (now the Iowa State University). The result is the Marston Equation named for its originator, Anson Marston, who was the first Dean of Engineering at Iowa State and President of the American Society of Civil Engineers. First published in 1930 as part of The Iowa Engineering Experiment Station Bulletin 96, it is a widely recognized, conservative equation for computing trench loads on pipe.

Figure 4-2: *Pipe and bedding class are critical to support the backfill load.*

An understanding of the Marston Equation, and the factors involved, is helpful when using the trench load tables.

Essentially, any structure installed below the surface of the earth supports the weight of all the materials above it, depending upon certain characteristics of the trench backfill. These characteristics, (principally internal soil friction) tend to increase or diminish the backfill load on the pipe structure.

This is true for both trench and embankment loads. Considering a structure of circular cross-section such as a sewer pipe, the backfill material directly above the pipe is that material which lies between vertical planes tangent to the outside of the pipe barrel (Figure 4-3). The net load on the pipe exclusive of live load, is the actual weight of such backfill material plus or minus an amount which depends on whether internal soil friction assists in the support of the mass of backfill over the pipe or not.

Figure 4-3 illustrates the cross-section of a typical sewer trench showing the location of planes tangent to the sides of the pipe. These are called the primary planes. When the backfill in a trench is compacted uniformly, uniform settlement (further compaction) can be expected with the passage of time. The depth of the backfill between the primary tangent planes will be reduced through such settlement by a fairly definite amount, depending upon the nature and compaction of the original backfill.

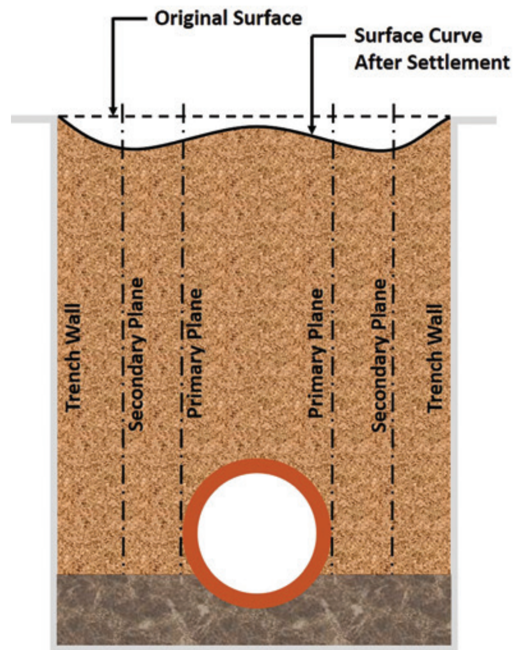

Figure 4-3: *Cross-section of a sewer trench illustrates expected pattern of settlement.*

The backfill between the trench walls and the primary planes on either side of the pipe will also settle in time.

Frictional Forces in the Backfill

Since the depth of the backfill between the pipe and the trench sidewalls is greater than the depth of the backfill directly over the pipe, it will settle or compact more than the material directly over the pipe. This movement will be restricted by friction between the backfill particles on each side of the primary tangent planes. The increased settlement of the backfill on both sides of the pipe tends to transfer load to that portion of the backfill located directly above the pipe, thereby transmitting additional load to the pipe.

Secondary vertical planes are assumed to be between the primary planes and the walls of the trench as shown in the drawing. As mentioned previously, the backfill between the primary and secondary planes is prevented from settling to a maximum amount by the action of frictional forces along the primary vertical planes. This increases the load supported by the pipe in the trench condition.

The remainder of the backfill, which lies between the secondary planes and the trench walls is supported in part by friction along the trench walls. This reduces the load on the pipe.

The Effect of Trench Width

It will be seen that, as the secondary plane is moved away from the pipe, the differential settlement on opposite sides of the plane will become less. It is therefore possible to locate a definite position where the differential settlement on opposite sides of the secondary plane is so small that no frictional forces are transmitted across it. When this location is within the cross section of the trench, the weight of backfill between the secondary plane and trench wall can add nothing to the load on the pipe. In other words, the trench width may be increased beyond this point without adding to the load on the pipe.

The minimum distance, which meets the above qualifications, is called the **transition width** of the trench. It is the trench width at which further widening will have no effect on the load on the pipe.

When the actual width is less than the **transition width**, friction in the plane of the trench wall tends to support part of the load and to lessen the load on the pipe. This phenomenon is illustrated by the curve marked surface curve after settlement as shown in Figure 4-3. Wherever this curve deflects downward from its origin directly over the center of the pipe, internal friction in the backfill transmits weight to the pipe. Where the curve deflects upward (as alongside the trench wall) backfill weight is transmitted to the sidewall of the trench.

Marston Equation

The Marston Equation applies the preceding reasoning to the calculation of loads on pipes. Actual tests have been performed on many types of soil to determine the weight, frictional characteristics and the relative settlement of each type. These measurable quantities have been combined into a single expression to produce for each case a computation of the total load supported by the pipe.

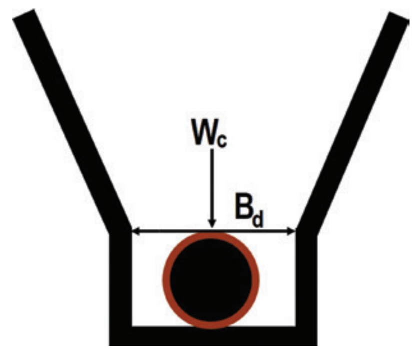

Figure 4-4: *The Marston Equation for pipe in narrow trenches.*

The factors taken into consideration in the following Marston Equation are:

- Depth of backfill cover over the top of the pipe.
- Width of trench measured at the level of the top of the pipe.
- Unit weight of backfill.
- Values for frictional characteristics of the backfill material.

The Marston Equation for pipe in narrow trenches is:

$$W_c = C_d \omega B_d{}^2$$

Where:

W_c = The vertical external load on a closed conduit due to fill materials (lb/ ft. of length),

C_d = Load calculation coefficient for conduits completely buried in ditches, abstract number (see Computation Diagram – Figure 4-5 on page 4-6),

ω = The unit weight of fill materials, (lb/ ft.^{3}) and

B_d = Breadth of Ditch (trench width measured at top of pipe barrel, ft.).

By substitution of available data in the Marston equation, a direct result is obtained for the load on the pipe in terms of pounds per linear foot. The computation of loads is simplified by the use of this equation and the Computation Diagram (Figure 4-5 on page 4-6), which represents the plotted solution of the "Load Calculation Coefficient" equation shown below:

$$C_d = \frac{1 - e^{-2K\mu'\left\{\frac{H}{B_d}\right\}}}{2K\mu'}$$

Where:

C_d = Load calculation coefficient for conduits completely buried in ditches, abstract number (see Computation Diagram – Figure 4-5 on page 4-6),

e = 2.7182818 which equals base of natural logarithms, an abstract number,

K = Ratio of active horizontal pressure at any point in the fill to the vertical pressure which caused the active horizontal pressure, an abstract number,

μ' = The "coefficient of sliding friction" between the fill material and sides of the trench, an abstract number,

H = Vertical height from top of conduit to the upper surface of fill in feet, and

B_d = Breadth of Ditch (trench width measured at top of pipe barrel, ft.).

The Computation Diagram is based on various types of soil conditions, and may be used to obtain the values of the load calculation coefficient C_d.

The Trench Load Tables in Chapter 5 have been compiled using the Marston Equation previously described. The soil weights are based upon an arbitrary value of 100 lbs/ ft^3. When the actual soil weight is known to vary from 100 lbs/ ft^3, the tabulated loads may be adjusted up or down by direct ratio.

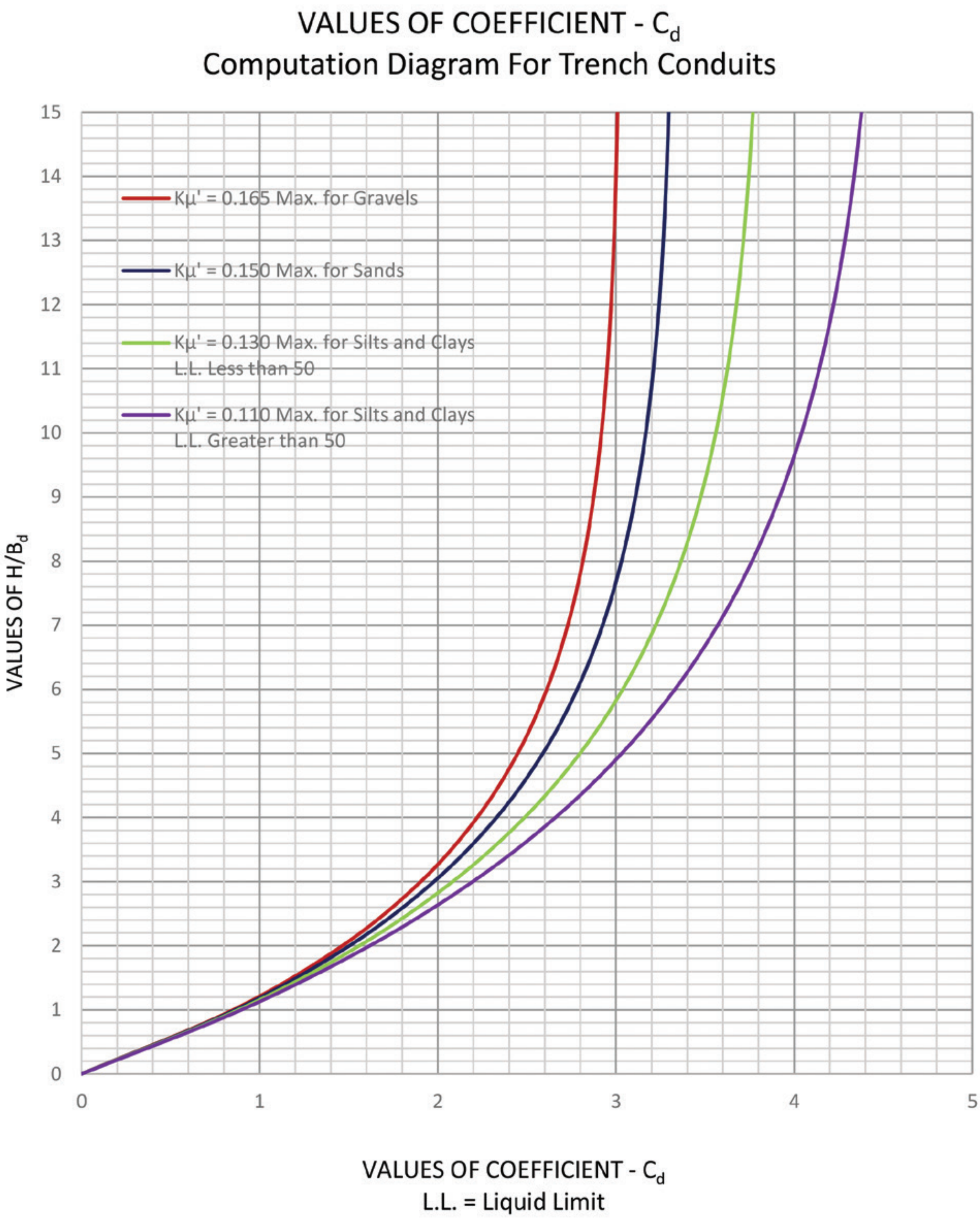

Figure 4-5: *Computation Diagram for Trench Conduits (completely buried in trenches).*

Backfill Soils Classification Chart

	Criteria For Assigning Group Symbols And Group Names		Soil Classification*		Weight (lbs.ft^3)	
			Group Symbol	Group Name	Approximate Soil Weight	Average
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve	**GRAVELS** More than 50% of coarse fraction retained on No. 4 sieve Kμ’ 0.165	**CLEAN GRAVELS** Less than 5% fines	GW	Well-graded gravel	119 - 128	124
			GP	Poorly graded gravel	104 – 128	122
		GRAVELS WITH FINES More than 12% fines	GM	Silty gravel	87 – 133	113
			GC	Clayey gravel	96 – 129	117
	SANDS 50% or more of coarse fraction passes No. 4 sieve Kμ’ 0.150	**CLEAN SANDS** Less than 5% fines	SW	Well-graded sand	93 – 133	117
			SP	Poorly graded sand	104 – 132	119
		SANDS WITH FINES More than 12% fines	SM	Silty sand	93 – 133	117
			SC	Clayey sand	104 – 132	119
FINE-GRAINED SOILS 50% or more passes the No. 200 sieve	**SILTS AND CLAYS** Liquid limit less than 50 Kμ’ 0.130	**INORGANIC**	CL	Lean clay	90 – 121	109
			ML	Silt	82 - 126	103
	SILTS AND CLAYS Liquid limit 50 or more Kμ’ 0.110	**INORGANIC**	CH	Fat clay	82 – 107	95
			MH	Elastic silt	83 – 89	85
HIGHLY ORGANIC SOILS		Primarily organic matter, including landfill waste, organic clays and silts, peat, etc.			Soil weight will vary – use appropriate geotechnical soils data	

* Reference – ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes* (Unified Soil Classification System)

Table 4-1: *Backfill Soils Classification Chart*

Embankment Loads

Although the Trench Load Tables (Chapter 5) show loads on pipe in trenches, they are equally applicable for pipe installed under embankment or "wide trench" conditions. As the width of the trench increases, other factors remaining constant, the load on the pipe increases until it reaches a limiting value equal to the embankment load on the pipe. This limiting value is called the load at transition width. The transition widths shown in the Trench Load Tables have been calculated using the equation for positive projecting conduits in wide trenches.

Modified Marston Equation When Designing with CLSM

Marston factored the consolidation of the soil prism along both sides of the pipe as inducing load on the rigid pipe dependent upon the soil type, soil weight and trench width. Arching or inverted arching of the prism of soil directly above the pipe via shear of the exterior soil prisms above the sidefills is an inherent principle in the Marston Theory.

He theorized that the material at the sides of rigid pipe was so loose compared to the rigidity of the pipe that the support of any backfill load by the sidefill would be negligible. The presumed inability of the sidefills to carry a significant share of the backfill load is not applicable when Controlled Low Strength Material (CLSM) bedding is used since it neither settles nor compacts or shrinks significantly.

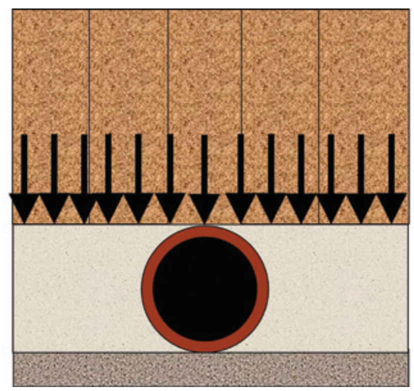

Figure 4-6: *CLSM sidefills support a portion of the load from the soil prism directly above the rigid pipe as well as the adjacent prisms.*

With the experience gained by testing flexible corrugated metal pipe at Iowa State, Professor Spangler realized that the full trench backfill load was not actually applied to flexible pipe with compacted sidefills. Since it was common practice to compact the material at the sides of the corrugated steel pipe to keep it in shape, he reasoned that this compacted material not only reduced deflection of the pipe but it also must be supporting some of the backfill load.

Professor Spangler made the following statement in his classic 1951 textbook, Soil Engineering: "For the case of a flexible pipe conduit and thoroughly tamped sidefills having essentially the same degree of stiffness as the pipe itself, the value of given by equation (25-3)(rigid pipe equation) might be multiplied by the ratio $\frac{B_c}{B_d}$ [Breadth of conduit / Breadth of ditch]." As a result, the flexible pipe load equation was generated.

This flexible pipe load equation takes the form:

$$W_c = C_d \omega B_c B_d$$

Where:

- W_c = The vertical external load on a closed conduit due to fill materials (lbs/ LF)
- C_d = Load calculation coefficient for conduits completely buried in ditches, abstract number (see Computation Diagram – Figure 4-5 on page 4-6),
- ω = The unit weight of backfill (lbs/ ft^3)
- B_c = The width of conduit (O.D.), (ft.)
- B_d = Breadth of Ditch (trench width measured at top of pipe barrel, ft)

Where clay pipe is installed with CLSM sidefills from the bottom of the pipe to the top of the pipe barrel; the clay pipe is rigid and, when set sufficiently prior to backfill, CLSM is also rigid. The backfill load is distributed with reasonable uniformity across the top of the pipe and the sidefills.

Applying the Spangler principal, the load on a clay pipe can be reduced by the ratio $\frac{B_c}{B_d}$. The standard Marston rigid pipe trench load equation becomes:

$$W_c = C_d \omega B_d^{\,2} \left(\frac{B_c}{B_d}\right)$$

which can be simplified to:

$$W_c = C_d \omega B_c B_d$$

resulting in a modification to the standard Marston Equation.

The main reason for the high computed loads on rigid pipe is the presumed inability of the sidefills to carry any significant share of the backfill load. In CLSM installations, the CLSM neither settles nor compacts or shrinks significantly. It will support a large portion of the load that would otherwise be carried by the pipe. It only requires sufficient strength so that it does not move downward any distance greater than the top of the pipe when loaded.

For additional information, see *CLSM as a Pipe Bedding: Computing Predicted Load using the Modified Marston Equation* paper presented at 2013 ASCE Pipelines Conference.

Example 4-1: Modified Marston CLSM Design Computation

A 24-inch sewer is to be installed in an area of CL lean clay $K\mu' = 0.130$ with an average weight of 120 lbs/ ft^3. The top of the pipe is 40 ft. below ground surface and the trench width is 84 in. At this cover depth and trench width; CLSM side fills will be utilized. Determine the factor of safety.

Pipe diameter =	24-inch
t (wall thickness) =	3 in.
B_c =	24 + 2t = 24 + 6 = 30 in. or 2.5 ft
H =	40 ft
B_d =	84 in. or 7 ft
ω =	120 lbs. / ft^3 ($K\mu'$ = 0.130)
24 in. pipe bearing strength	4,400 lbs/ LF
H/B_d	40 ft./ (84/12) = 5.71
C_d*	$[1- e^{-2(0.130)(5.71)}] / 2(0.130) = 2.97$
* For C_d Equation, see page 4-5	

Example 4-1 (Continued): Modified Marston CLSM Design Computation

$$W_c = C_d \omega B_c B_d$$

W_c = (2.97)(120 lbs / ft^3)(2.5 ft.)(7 ft.)

W_c = 6237 lbs/ LF.

Safety Factor = [Bearing strength of pipe X Load Factor] / [Backfill Load]

Safety Factor = [4,400 lbs/ LF. X 2.8] / [6,237 lbs/ LF.]

Safety Factor = 1.98

Earth Load on Jacked Pipe

When modified to include soil cohesion, the Marston Equation is used to compute earth load on a jacked pipe through undisturbed soil. In the case of Vitrified Clay Jacking Pipe (VCP-J), the applicable trenchless methods are pilot tube and slurry microtunneling installations (See Chapter 8). Typically, the greatest load on these pipes is the axial compressive force exerted during installation. When computing earth load for pipe in a tunnel, the Marston Equation takes the form:

$$W_t = C_t B_t (\omega B_t - 2c)$$

Where:

W_t = earth load on the tunneled pipe (lbs/ LF.)
C_t = coefficient for tunnels (see Figure 4-8)
B_t = tunnel diameter (Pipe OD + overcut) (ft.)
ω = weight of backfill (lbs/ ft^3)
c = "safe values" for soil cohesion (psf)

Recommended Safe Values for Soil Cohesion	
Material	**Values of c (psf)**
Clay, very soft	40
Clay, medium	250
Clay, hard	1,000
Sand, loose dry	0
Sand, silty	100
Sand, dense	300
Top soil, saturated	100

Table 4-2: *Safe Values for Soil Cohesion*

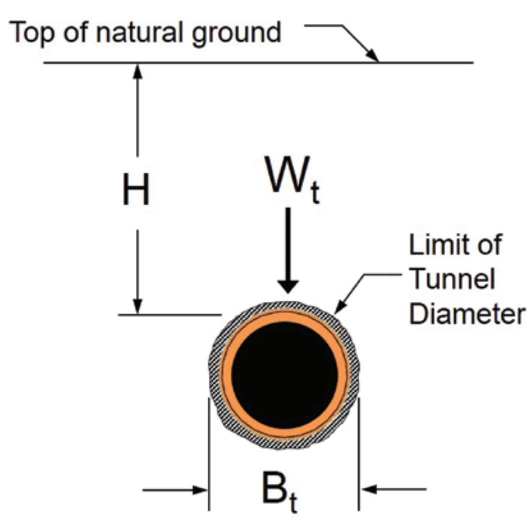

Figure 4-7: *Jacked pipe in tunnel*

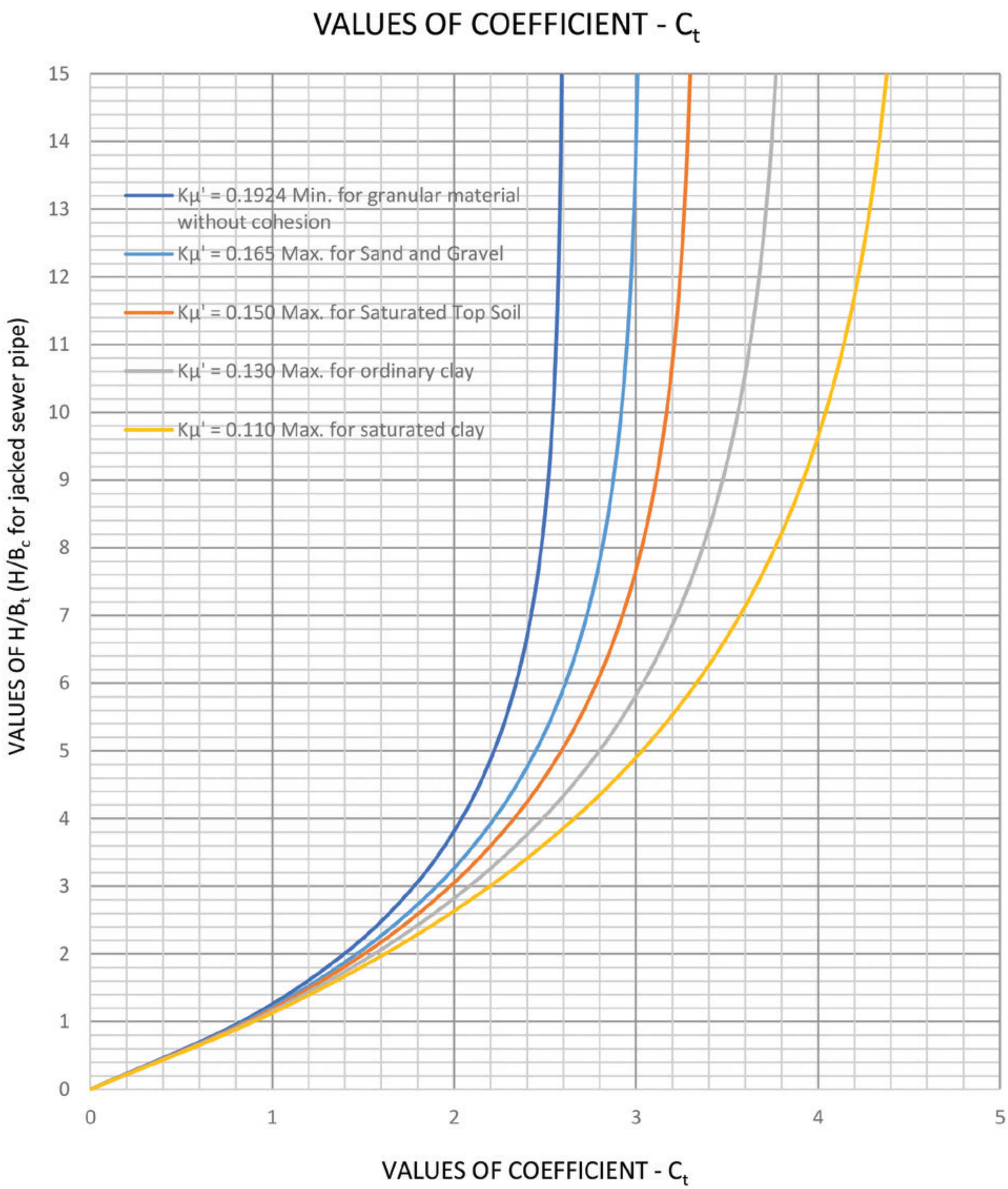

Figure 4-8: *Jacked sewer pipe or tunnels in undisturbed soil.*

Example 4-2: Computing Earth Load On A Jacked Pipe

A 12-inch Vitrified Clay Jacking Pipe installed via Pilot Tube Method. It is to be installed in an area with 25 ft. of cover. The soils are lean clay, native soils at 120 lbs/ ft^3.

B_t = (Pipe O.D. + overcut)/12 =	(15.8 in. + 1 in.)/12 = 1.4 ft.
$K\mu'$ =	0.130
H/B_t =	25.0 ft./ 1.40 ft. = 17.86

Using computation diagram (Figure 4-8 on page 4-11) with H/B_t = 17.86 and $K\mu'$ = 0.130, therefore, C_t = the limiting value of 1/(2 $K\mu'$) = 3.85

Using Table 4-2 (on page 4-10) find the value of c: c = 40 psf (clay, very soft)

Inserting the above values into the Marston Equation modified for soil cohesion:

$$W_t = C_t B_t(\omega B_t - 2c)$$

W_t = (3.85)(1.40 ft.)[(120 lbs/ ft^3)(1.40 ft.) – (2)(40 lbs/ ft^2)]

W_t = (3.85)(1.40 ft.)[168.0 lbs/ ft^2 – 80 lbs/ ft^2]

W_t= 474 lbs/ LF

Superimposed Loads

Concentrated and distributed superimposed loads should be considered in the structural design of sewers, especially where the depth of earth cover is less than 8 ft. Where these loads are anticipated, they are added to the predetermined trench load. Superimposed loads are calculated by use of Holl's and Newmark's modifications to Boussinesq's equation.

Concentrated Loads

Holl's integration of Boussinesq's solution leads to the following equation for determining loads due to superimposed concentrated load, such as a truck wheel load (Figure 4-9):

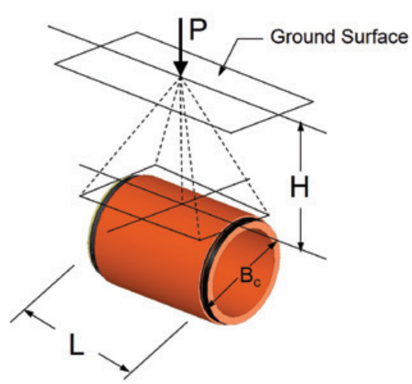

Figure 4-9: *Concentrated superimposed load vertically centered over sewer pipe.*

$$W_{sc} = C_s \frac{PF}{L}$$

Where:

W_{sc} = The load on the conduit (lbs/ LF)
P = The concentrated load (lbs)
F = The impact factor
C_s = The load coefficient, a function of $\frac{B_c}{(2H)}$ and $\frac{L}{(2H)}$

Where:

H = The height of fill from the top of conduit to ground surface in ft.
B_c = The width of conduit (O.D.), (ft.)
L = The effective length of conduit (ft.)

For values of C_s see Table 4-3 on page 4-15. For values of *F*, see Table 4-5 on page 4-17.

An effective length, *L*, equal to 3 ft. for pipe greater than 3 ft. long, and the actual length for pipe shorter than 3 ft. is recommended. H-20, H-25 wheel loadings are standard for highway and bridge design and are applicable for estimating traffic loads on sewers. However, engineers and contractors must also consider construction loads imposed upon sewers subsequent to their installation. Large earthmoving equipment traveling over sewers and construction activities from subsequent installation of nearby structures should be reviewed for additional imposed loads on installed pipes. Wheel loads from large construction equipment may exceed 50,000 lbs.

Notes: *H-20 (as defined by the American Association of State Highway and Transportation Officials, or AASHTO) refers to wheel loading resulting from the passage of trucks having a gross weight of 40,000 lbs., 32,000 lbs. (80%) of which is on the rear axle; each rear wheel carrying one half this load or 8 tons (16,000 lbs.) without impact.*

H-25 (as defined by the American Association of State Highway and Transportation Officials, or AASHTO) refers to wheel loading resulting from the passage of trucks having a gross weight of 50,000 lbs., 40,000 lbs. (80%) of which is on the rear axle; each rear wheel carrying one half this load or 10 tons (20,000 lbs.) without impact.

Example 4-3: Calculating Load

Determine the load on a 15-inch, 6 ft. length of pipe with 5 ft. of cover caused by a concentrated H-20 wheel load. For pipe greater than 3 ft. long, use 3 ft. as the effective length, *L*.

P =	16,000 lbs
F =	1.5 (Highway)
L =	3.0 ft.
d (pipe I.D.) =	15 in.
t (wall thickness)=	1.5 in.
Therefore B_c = 15 + 3 = 18 inches = 1.5 ft.	
H =	5.0 ft.
$\frac{B_c}{2H}$ =	1.5/10 = 0.15
$\frac{L}{2H}$ =	3/10 = 0.30
C_s =	0.078
(C_s found by interpolation of the values in Table 4-3)	

$$W_{sc} = C_s \frac{PF}{L}$$

Inserting the known values in the equation:

$$W_{sc} = \frac{(0.078)(16{,}000 \text{ lbs})(1.5)}{3.0 \text{ ft.}}$$

$$W_{sc} = 624 \text{ lbs/ LF}$$

If the concentrated load is not centered vertically over the pipe, but is displaced laterally and longitudinally, the load on the pipe can be computed by adding the effect of the concentrated load. Dividing the tabular values of C_s by 4 will give the result for this condition.

An alternative method of determining concentrated or superimposed loads on a buried conduit is to use the Percentages of Wheel Loads shown in Table 4-4 (on page 4-16). These percentages have been determined directly from data contained in “Theory of External Loads on Closed Conduits,” Bulletin 96, published by the Engineering Experiment Station at Iowa State College. Note that an allowance for impact must be added to the percentage figures shown in the table. The table does not apply to distributed superimposed loads.

Example 4-4: Calculating Load Using the Simplified Equation

Using the same case as Example 4-3,

P =	16,000 lbs
F =	1.5 (Highway)
Percentage of load 15-in. pipe with 5 ft. depth of cover =	2.6% (0.026)
(from the Percentage of Wheel Load Table (Table 4-4))	

Inserting the known values in the equation:

$$W_{sc} = PF(\%) = 16{,}000 \text{ lbs } (1.5)(0.026)$$

$$W_{sc} = 624 \text{ lbs/ LF}$$

Values of Load Coefficients, C_s
for Concentrated and Distributed Superimposed Loads Vertically Centered Over Conduit*

$\frac{D}{2H}$ OR $\frac{B_c}{2H}$	$\frac{M}{2H}$ or $\frac{L}{2H}$													
	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**1.2**	**1.5**	**2.0**	**5.0**
0.1	0.019	0.037	0.053	0.067	0.079	0.089	0.097	0.103	0.108	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0.072	0.103	0.131	0.155	0.174	0.189	0.202	0.211	0.219	0.229	0.238	0.244	0.248
0.3	0.053	0.103	0.149	0.190	0.224	0.252	0.274	0.292	0.306	0.318	0.333	0.345	0.355	0.360
0.4	0.067	0.131	0.190	0.241	0.284	0.320	0.349	0.373	0.391	0.405	0.425	0.440	0.454	0.460
0.5	0.079	0.155	0.224	0.284	0.336	0.379	0.414	0.441	0.463	0.481	0.505	0.525	0.540	0.548
0.6	0.089	0.174	0.252	0.320	0.379	0.428	0.467	0.499	0.524	0.544	0.572	0.596	0.613	0.624
0.7	0.097	0.189	0.274	0.349	0.414	0.467	0.511	0.546	0.584	0.597	0.628	0.650	0.674	0.688
0.8	0.103	0.202	0.292	0.373	0.441	0.499	0.546	0.584	0.615	0.639	0.674	0.703	0.725	0.740
0.9	0.108	0.211	0.306	0.391	0.463	0.524	0.574	0.615	0.647	0.673	0.711	0.742	0.766	0.784
1.0	0.112	0.219	0.318	0.405	0.481	0.544	0.597	0.639	0.673	0.701	0.740	0.774	0.800	0.816
1.2	0.117	0.229	0.333	0.425	0.505	0.572	0.628	0.674	0.711	0.740	0.783	0.820	0.849	0.868
1.5	0.121	0.238	0.345	0.440	0.525	0.596	0.650	0.703	0.742	0.774	0.820	0.861	0.894	0.916
2.0	0.124	0.244	0.355	0.454	0.540	0.613	0.674	0.725	0.766	0.800	0.849	0.894	0.930	0.956

*Influence coefficients for solution of Holls' and Newmark's Integration of the Boussinesq Equation for vertical stress.

Table 4-3: *C_s values for Concentrated and Distributed Superimposed Loads Vertically Centered Over Conduit*

Percentage of Wheel Loads Transmitted to Underground Pipes*														
Depth of Backfill Over Top of Pipe in Feet	Pipe Size in Inches													
	6	8	10	12	15	18	21	24	27	30	33	36	39	42
	Outside Diameter of Pipe in Feet (Approx.)													
	.64	.81	1.0	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.5	3.9	4.2
1	12.8	15.0	17.3	20.0	22.6	24.8	26.4	27.2	28.0	28.6	29.0	29.4	29.8	29.9
2	5.7	7.0	8.3	9.6	11.5	13.2	15.0	15.6	16.8	17.8	18.7	19.5	20.0	20.5
3	2.9	3.6	4.3	5.2	6.4	7.5	8.6	9.3	10.2	11.1	11.8	12.5	12.9	13.5
4	1.7	2.1	2.5	3.1	3.9	4.6	5.3	5.8	6.5	7.2	7.9	8.5	8.8	9.2
5	1.2	1.4	1.7	2.1	2.6	3.1	3.6	3.9	4.4	4.9	5.3	5.8	6.1	6.4
6	0.8	1.0	1.1	1.4	1.8	2.1	2.5	2.8	3.1	3.5	3.8	4.2	4.3	4.4
7	0.5	0.7	0.8	1.0	1.3	1.6	1.9	2.1	2.3	2.6	2.9	3.2	3.3	3.5
8	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.3	2.5	2.6
*These figures make no allowance for impact. See Impact Factor values in Table 4-5.														

Table 4-4: *Percentage of Wheel Loads Transmitted to Underground Pipes*

Distributed Loads

For determining loads on pipe due to superimposed loads distributed over a surface area (Figure 4-10) the following equation was developed:

$$W_{sd} = C_s P F B_c$$

Where:

- W_{sd} = The load on the conduit in lbs/ ft. of length
- P = The intensity of distributed load in psf.
- F = The impact factor
- B_c = The width of the conduit (ft.)
- C_s = The load coefficient, a function of $\frac{D}{(2H)}$ and $\frac{M}{(2H)}$

Where:

- H = The height from the top of the conduit to the ground surface (ft.)
- D = The width of the area over which the distributed load acts (ft.)
- M = The length of the area over which the distributed load acts (ft.)

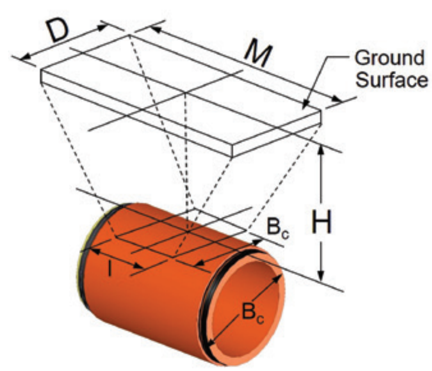

Figure 4-10: *Superimposed distributed load vertically centered over pipe.*

For values of C_s see Table 4-3 on page 4-15. For values of F, see Table 4-5 on page 4-17.

If the area of the distributed superimposed load is not centered vertically over the pipe, but is displaced laterally and longitudinally, the load on the pipe can be computed by adding algebraically the effect of various rectangles of loaded area. It is more convenient to work in terms of load under one corner of a rectangular loaded area rather than at the center. Dividing the tabular values of C_S by 4 will give the effect for this condition.

Impact Loads

Impact factors must be considered to account for the influence of impact loading due to traffic and construction activities after sewer installation.

Extremely high impact loads can be transmitted to the pipe especially when wheeled construction equipment travels over the trench. The engineer and contractor need to consider construction impact loads during the initial project and any subsequent construction.

Suggested Impact Factor (F) Values	
Traffic	**Impact Factor**
Highway	1.50
Railway	1.75
Runways/Airfield	1.00
Taxiways, aprons, hardstands	1.50

Table 4-5: *Suggested values of Impact Factors (F)*

Trench Width, Depth of Fill and Soil Characteristics

To properly approach the analysis of loads imposed on the pipe, it is necessary to decide, for each size of pipe, what the minimum practicable design trench width at the top of the pipe is to be and still permit good workmanship. The design trench width, the depth of fill over the pipe, and the soil characteristics of the fill, will produce the load which must be supported by the pipe and its bedding. This load is readily available from either the Trench Load Tables in Chapter 5 or the NCPI trench load online program when the above factors are known.

Using Trench Load Tables

The correct use of the Trench Load Tables, which are given in Chapter 5, is demonstrated by the following hypothetical case where a designer wants to calculate the trench load imposed.

Example 4-5: Using Trench Load Tables

A 12-inch sewer is to be installed in an area of gravel $K\mu' = 0.165$ with an average weight of 120 lbs/ ft^3. The top of the pipe is 8 ft. below ground surface and the trench width is 30 in. To determine the trench load use the Trench Load Tables for 12-inch pipe in Chapter 5 on page 5-5.

Pipe diameter =	12-inch
$K\mu'$=	0.165 Backfill gravel
B_d =	30 in.
H =	8 ft.
ω =	120 lbs / ft^3

W_c = 1,240 lbs/ LF x 120/100 = 1,488 lbs/ LF

Example 4-6: Using Calculated Live Load

Plans call for the installation of a 15-inch sewer line with 5 ft. of cover in a 3 ft. wide trench of silt and clay $K\mu'$= 0.110 weighing 95 lbs/ ft^3 and that construction equipment wheel loads of 16,000 lbs. each will pass over the backfilled trench before the pavement is placed. This is the maximum loading condition. What is the total load on the pipe? To determine the trench load use the Trench Load Tables for 15-inch pipe in Chapter 5 on page 5-6.

Pipe size	15 in.
Backfill – silt and clay	$K\mu'$= 0.110
Trench width	36 in.
Backfill weight	95 lbs/ ft^3
Backfill load	(1,170 lbs / LF x 95/100) = 1,112 lbs/ LF
(The live load has been calculated. See Examples 4-3 and 4-4 on page 4-14)	
Live load	624 lbs/ LF
Total trench load	1,736 lbs/ LF