CHAPTER 5

STRUCTURAL DESIGN OF SEWERS

5-1. General.

The structural design of a sewer requires that the supporting strength of the pipe as installed, must equal or exceed the external loading multiplied by a factor of safety. The following criteria for structural design of sewers are based on the assumption that sewers will be laid in open trenches entirely below natural ground surface and backfilled with suitable materials, that the sides of the trench will be nearly vertical below the top of the pipe and will have slopes no flatter than one horizontal to two vertical above the pipe, and that the trench width at the top of the pipe will be relatively narrow. In general, the trench width will be limited to the maximum allowed or recommended by the pipe manufacturer. Special cases involving sewer installation in unsatisfactory soil, rock, embankments or fills, sewers requiring jacking, boring or tunneling, and pipe placed above ground, are too rare to warrant lengthy consideration in this manual. Paragraph 5-4 contains a general discussion of such situations. Sewers installed in cold regions or in seismic zones will require special design considerations.

5-2. Loads on sewers.

There are three kinds of external loads to which a sewer laid in a trench may be subjected. They are (1) loads due to trench filling materials, (2) uniformly distributed surface loads, such as stockpiled materials or loose fill, and (3) concentrated surface loads, such as those from truck wheels.

a. Trench fill loads. The Marston formula will be used for calculating loads on rigid conduits as follows:

$$W_t = C_t w B_t^2$$

where:

W_t = vertical load on conduit in pounds per lineal foot

C_t = trench load coefficient for buried conduits

w = unit weight of trench fill materials in pounds per cubic foot, and

B_t = horizontal width of trench at top of pipe in feet

For calculation of loads on flexible conduits the prism formula will be used as follows:

$$W_t = Hw B_c$$

where:

H = height of fill from top of pipe to ground surface in feet, and

B_c = horizontal width or outside diameter of pipe in feet

The unit weight of soil backfill normally varies from a minimum of 100 to a maximum of 135 pounds per cubic foot. In the absence of soil density measurements, the weight per cubic foot of various materials may be taken as 120 pounds for mixed sand and gravel, 110 pounds for saturated top soil (loam and silt), 120 pounds for ordinary damp clay, and 130 pounds for saturated clay. The load coefficient C_t is a function of the fill height H divided by the width of trench B_t, and will be determined from figure 5-1. An examination of the Marston formula will show the importance of the trench being as narrow as practicable at and below the top of the pipe.

b. Uniformly distributed loads. Newmark's modification to the classical Boussinesq equation results in the following formula to be used for calculating distributed loads on rigid and flexible conduits.

$$W_d = C_s pFB_c$$

where:

W_d = vertical load on the conduit in pounds per lineal foot

C_s = surface load coefficient for buried conduits

p = intensity of distributed load in pounds per square foot

F = impact factor, and

B_c = horizontal width or outside diameter of pipe in feet

The load coefficient C_s is dependent upon the area over which the load p acts. It will be selected from table 5-1 as a function of the area width D and length M, each divided by twice the height of fill H. The impact factor F will be determined with the use of the table 5-2.

c. Concentrated loads. The formula to be used for calculating concentrated loads on rigid and flexible conduits is a modified form of the Boussinesq equation developed by Holl, and is as follows:

$$W_c = C_s PF/L$$

where:

W_c = vertical load on the conduit in pounds per lineal foot

C_s = surface load coefficient for buried conduits

p = concentrated load in pounds

F = impact factor, and

L = effective length of conduit in feet

An effective length of 3 feet will be used in all cases, except where pipe lengths are less than 3 feet, in which case the actual length of pipe will be used. The load coefficient C_s is a function of conduit width B_c and effective length L, each divided by twice the height of fill H. Determination of the load coefficient will be by the use of table 5-1, and impact factor F will be selected from table 5-2. It will be noted from table 5-1 that the effect of a concentrated or distributed load diminishes rapidly as the amount of cover over the sewer increases.

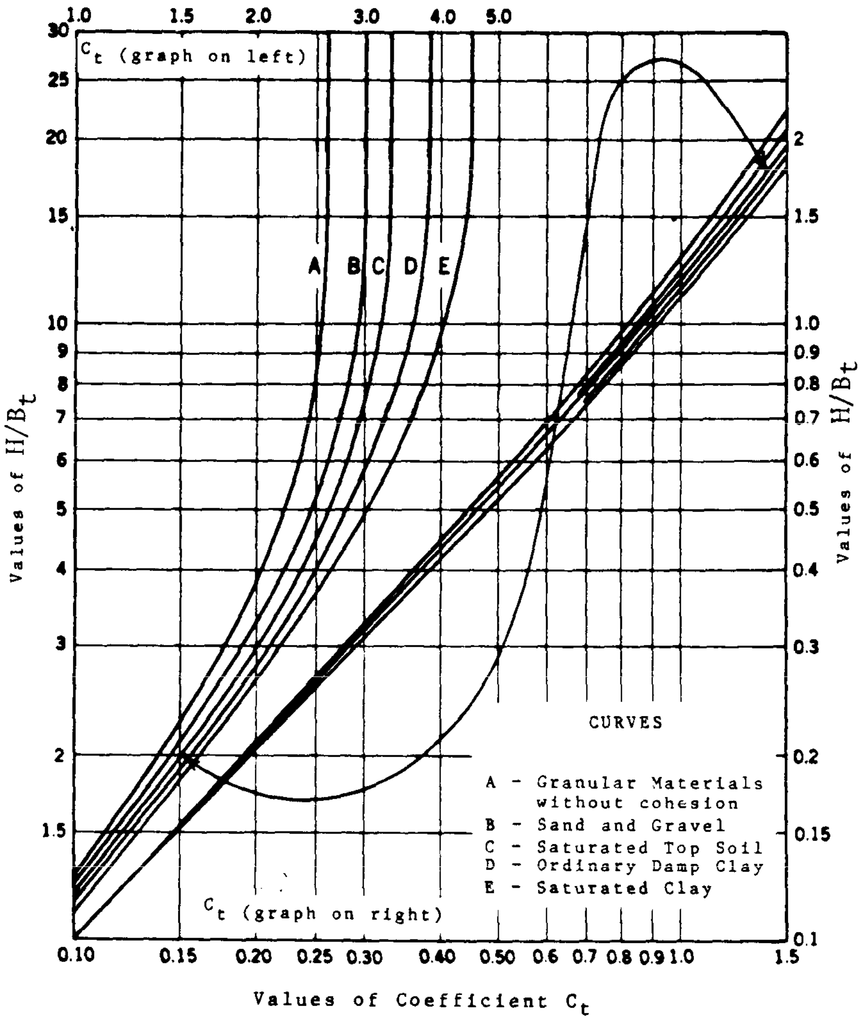
5-3. Supporting strength of sewers.

A sewer's ability to resist external earth and superimposed loads depends not only on the pipe's inherent structural capability, but also on the method of installing the pipe in the trench, i.e., class of bedding, type of backfill materials and soil compaction effort, etc.

a. Rigid conduit. Pipe strength in general will be determined by the three-edge bearing test or TEBT (termed crushing strength in various pipe specifications) and is expressed in pounds per lineal foot. However, since this does not represent the actual field loading conditions, a relationship must be established between calculated load, laboratory test strength and field support strength. The definitions and terminology listed below will be used to develop this relationship. The total load calculated in paragraph 5-2 must not exceed the safe supporting strength.

—Field support strength is the maximum load in pounds per lineal foot which the pipe will support when installed under specified trench bedding and backfill conditions.

—The load factor in the ratio of the field support



Source: Design and Construction of Sanitary and Storm Sewers - WPCF Manual of Practice No. 9 by Water Pollution Control Federation, 1970, p. 189.

Figure 5-1. Trench load coefficient.

Table 5-1. Surface load coefficient
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 Holl's and Newmark's integration of the Boussinesq equation for vertical stress.*

Source: Design and Construction of Sanitary and Storm Sewers—WPCF Manual of Practice No. 9 by Water Pollution Control Federation, 1970, p. 206.

strength to the three-edge bearing test, and will be selected from figure 5-2 depending on the class of bedding used.

—Safe supporting strength is the field support strength divided by a factor of safety, equal to 1.5 for rigid conduits.

—An additional parameter is the working strength, which is the three-edge bearing strength divided by the factor of safety.

For piping not tested and rated by the TEBT method, other strength criteria will be applied as follows. Reinforced concrete pipe strength will be based on D-loads at the 0.01-inch crack load and/or ultimate load as described in the Concrete Pipe Handbook published by the American Concrete Pipe Association. For ductile iron pipe, ANSI A21.50 will be used to calculate the required pipe thickness classification in relation to field loadings. See paragraph 6-2b for additional information. The strength of cast iron soil pipe, which normally will be used for building connections only, should be evaluated as outlined in the Cast Iron Soil Pipe & Fittings Handbook published by the Cast Iron Soil Pipe Institute.

b. Flexible conduit. The capability to resist pipe deflection and buckling under loads is the primary criterion used in the structural design of flexible conduit. When loaded the pipe walls will deflect, thereby creating a passive soil support at the sides of the conduit. This pipe-soil system is essential in providing a high effective strength, often enabling it to out perform rigid pipe under identical loading and soil conditions. While the three-edge bearing strength is an appropriate measure of load carrying capacity for rigid conduits, it is not applicable for describing flexible pipe stiffness. Because a flexible conduit must successfully interact with the surrounding soil to support its load, the method of backfill placement, types of materials used, soil compaction, etc., are more critical than trench width or bedding. Since the theories describing flexible pipe behavior, stiffness and deflections under load are lengthy, and the formulas cumbersome to use, they will not be presented in this manual. The methods and procedures adopted in the Handbook of PVC Pipe-Design and Construction by the UniBell Plastic Pipe Association, and WPCF Manual of Practice No. 9 will be used in design. The project specifications will be prepared to reflect the stringent installation and construction requirements for flexible pipe.

c. Pipe installation.

(1) *Bedding.* Figure 5-2 depicts various classes of bedding generally used when installing sewers. A complete discussion of each class is contained in several engineering publications, including WPCF Manual of Practice No. 9 and the Clay Pipe Engineering Manual by NCPI. The designer should refer to these when selecting a pipe bedding system. When the class and type of bedding have been chosen, the bedding materials will be coordinated with and identified in the specifications, and the types and sizes will be shown on the drawings.

(2) *Backfill and compaction.* Backfill materials and compaction requirements will be included in the

Table 5-2. Impact factor (F) vs. height of cover

Height of Cover, ft.	Installation Surface Condition: Highways	Railways	Runways	Taxiways, Aprons, Hardstands, Run-up Pads
0 to 1	1.50	1.75	1.00	1.50
1 to 2	1.35	*	1.00	**
2 to 3	1.15	*	1.00	**
Over 3′	1.00	*	1.00	**

**Refer to data available from American Railway Engineering Association (AREA)*

***Refer to data available from Federal Aviation Administration (FAA)*

Note that for a static load, F = 1.0

Source: Handbook of PVC Pipe-Design and Construction by Uni-Bell Plastic Pipe Association, Dallas, Texas, Copyright 1977, 1979, p. 133.

specifications. The possible use of locally available materials for backfill will be investigated. Compaction requirements will be designated for the particular soil and moisture content at the site.

(3) Installation manuals for the particular types of pipe to be specified will be reviewed to ascertain that bedding, backfill and compaction are adequate for the existing subsurface conditions at the site.

5-4. Special designs.

a. Unsatisfactory soil conditions. Information on subsurface conditions must be obtained from borings, drill holes, or test pits prior to design of the sewer system. Soil considered too unstable for use as pipe bedding or backfill consists of silt, quicksand, peat bog, muck and other organic materials. Where these materials exist, the following procedures will be used to provide a suitable pipe bedding.

(1) In situations where unstable materials occur at shallow depths, it will generally be acceptable to over-excavate native soil to just below the trench bottom, and replace with a layer of crushed stone, gravel or other coarse aggregate. Concrete or wooden cradles can be used in lieu of aggregates.

(2) Where unstable soil extends to considerable depths, more stringent measures must be taken. The sewer will be fully encased in concrete and supported on piles at each end. The pipe and encasement will be designed to act as a beam when the span distance is relatively short.

(3) For extremely severe cases, where unsatisfactory material covers a large area, and extends well below the trench bottom, a row of piling capped with concrete or wood cradles will be required to support the sewer. Dwarf piling may be suitable substitute for conventional piling in certain situations.

b. Installation in rock. Where sewers must be constructed in rocky terrain, trenches will be sufficiently wide to provide clearance between the sides and bottom of the pipe, and any rock in the trench. Pipe must be installed to avoid all contact with rock, or any other unyielding material in the trench. A granular type bedding or concrete cradle will normally be provided along the pipe bottom, and trenches will be backfilled with satisfactory materials.

c. Sewers in embankments. The need to install sewers above original ground surface in an embankment or fill does not arise frequently at military installations. Occasionally, an embankment will be required in low lying areas to raise the grade, or will be provided to avoid placing sewers aboveground, as discussed below.

d. Aboveground sewers. Sewers are normally laid underground, and at sufficient depths to be protected from impact and freezing. However, in cases where valleys, watercourses, structures, or other obstacles must be crossed, it is sometimes more advantageous to install sewers aboveground. Sewers supported from bridges, piers, suspension cables, or pipe beams, ec., will be designed with adequate structural capability. Protection against freezing and prevention of leakage are important design considerations. Expansion jointing may also be required.

e. Jacking, boring and tunneling. In situations where sewers must be constructed more than 15 to 20 feet below ground surface, through embankments, under railroads, primary access roads, or airfield pavements, or where the facility Engineer determines that surface conditions make it difficult or impractical to excavate open trenches, it will be necessary to install the pipe by other methods. In these cases, pipe may be pushed, jacked, bored or tunneled into place. A casing pipe will normally be required for sewers installed using these methods, and will always be required to protect sewers under railroads, primary access roads and airfield pavements. The void space between the sewer pipe and casing will be filled with special aggregates capable of being blown into place, or with commercially available polyethlene or other type spacers, saddles and seals. Depending on soil resistance, rigid extra strength pipe can be forced underground by machine for distances of 50 to 150 feet. Commercially available machines used hydraulic power to produce forces ranging from 6500 to 150,000 pounds. Horizontal boring (augering) and reaming machines placed in excavated pits simultaneously remove material and hydraulically jack extra strength pipe through the ground in sizes up to 3 feet in diameter.