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 (l) 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 kilograms per lineal meter (pounds per lineal foot)
C_t = trench load coefficient for buried conduits
w = unit weight of trench fill materials in kilograms per cubic meter (pounds per cubic foot), and
B_t = horizontal width of trench at top of pipe in meters (feet)

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

$$W_t = H w B_c$$

where:

H = height of fill from top of pipe to ground surface in meters (feet), and
B_c = horizontal width or outside diameter of pipe in meters (feet).

The unit weight of soil backfill normally varies from a minimum of 1600 to a maximum of 2160 kilograms per cubic meter (100 to 135 pounds per cubic foot). In the absence of soil density measurements, the weight per cubic meter (cubic foot) of various materials may be taken as

1920 kilograms (120 pounds) for mixed sand and gravel, 1760 kilograms (110 pounds) for saturated top soil (loam and silt), 1920 kilograms (120 pounds) for ordinary damp clay, and 2080 kilograms (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. 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.

$$W_d = C_s p F B_c$$

where:

W_d = vertical load on the conduit in kilograms per lineal meter (pounds per lineal foot)
C_s = surface load coefficient for buried conduits
p = intensity of distributed load in kilograms per square meter (pounds per square foot)
F = impact factor, and
B_c = horizontal width or outside diameter of pipe in meters (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.

Table 5-1. Surface load coefficient
Values of load coefficients, C_s, for concentrated and distributed
Superimposed loads vertically centered over conduit

D/2H or B_c/2H	M/2H or 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	0.0890	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	.174	0.189	0.2020	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	.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

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 kilograms per lineal meter (pounds per lineal foot)
C_s = surface load coefficient for buried conduits
P = concentrated load in kilograms (pounds)
F = impact factor, and
L = effective length of conduit in meters (feet).

An effective length of 0.914 meters (3 feet) will be used in all cases, except where pipe lengths are less than 0.914 meters (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.

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

Height of Cover, m. (ft.)	Installation Surface Condition			
	Highways	Railways	Runways	Taxiways, Aprons Hardstands, Run-up Pads
0 to 0.35 (0 to 1)	1.50	1.75	1.00	1.50
0.35 to 0.65 (1 to 2)	1.35	*	1.00	**
0.65 to 1.00 (2 to 3)	1.15	*	1.00	**
Over 1.00 m (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 PVC Pipe Association, Dallas, Texas, Copyright 1977,1979, p. 133.

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 kilograms per lineal meter (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 must not exceed the safe supporting strength.

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

- The load factor is the ratio of the field support strength to the TEBT, and will be selected from figure 5-1 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 0.25-mm (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 8-1 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.

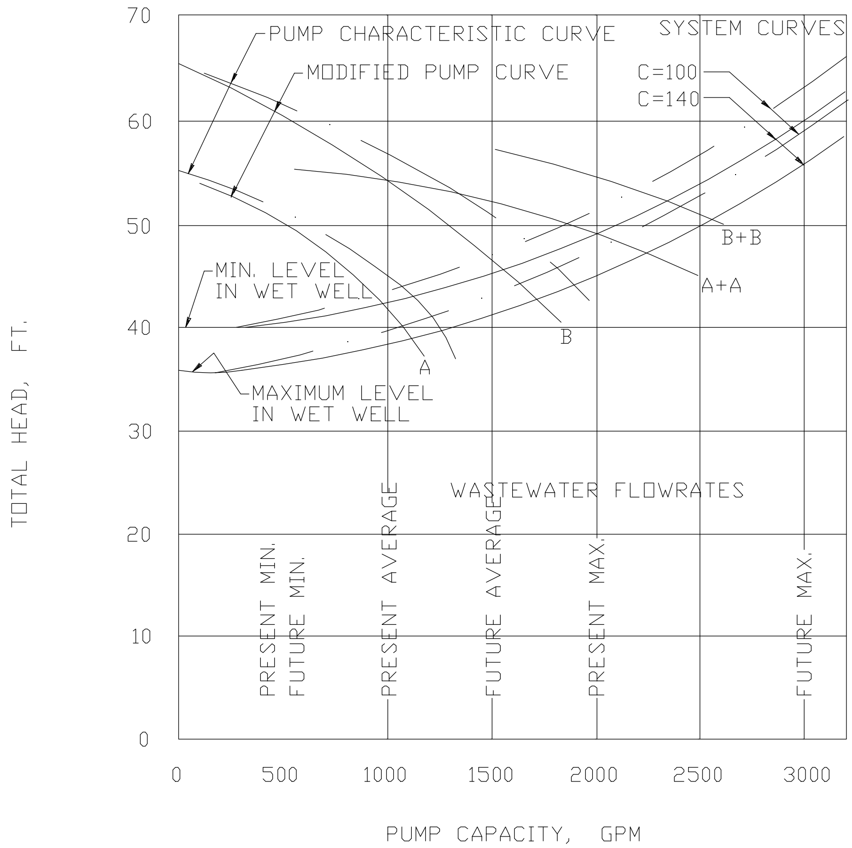

Figure 5-1. Load factors and class of bedding

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 same is true with less flexible plastic pipes such as acrylinitrile butadiene-styrene and profile wall PVC (ribbed or corrugated). The methods and procedures adopted in the Handbook of PVC Pipe Design and Construction by the Uni-Bell PVC Pipe Association, and WEF Manual of Practice FD-5 will be used in design. The project specifications will be prepared to reflect the stringent installation and construction requirements