STRUCTURAL DESIGN OF CSP

The structural design process consists of the following:

1. Select the backfill soil density to be required or expected.
2. Calculate the design pressure.
3. Compute the compression in the pipe wall.
4. Select the allowable compressive stress.
5. Determine the thickness required.
6. Check minimum handling stiffness.
7. Check seam requirements (when applicable).
8. Check pipe-arches.

1. Select Backfill Density

Select a percent compaction of pipe backfill for *design.* The value chosen should reflect the importance and size of the structure, and the quality that reasonably can be expected. The recommended value for routine use is 85%. This value easily will apply to ordinary installations in which most specifications will call for compaction to 90%. However, for more important structures in higher fill situations, select higher quality backfill and require the same in construction. This will extend the allowable fill height or save on thickness.

2. Calculate Design Pressure

When the height of cover is equal to or greater than the span or diameter of the structure, enter the load factor chart, Fig. 1, to determine the percentage of the total load acting on the steel. For routine use the 85% soil value will provide a factor of 0.86. The load factor, K, is applied to the total load to obtain the design pressure, Pv, acting on the steel. *If the height of coves is less than one pipe diameter, the total load is assumed to act on the pipe.*

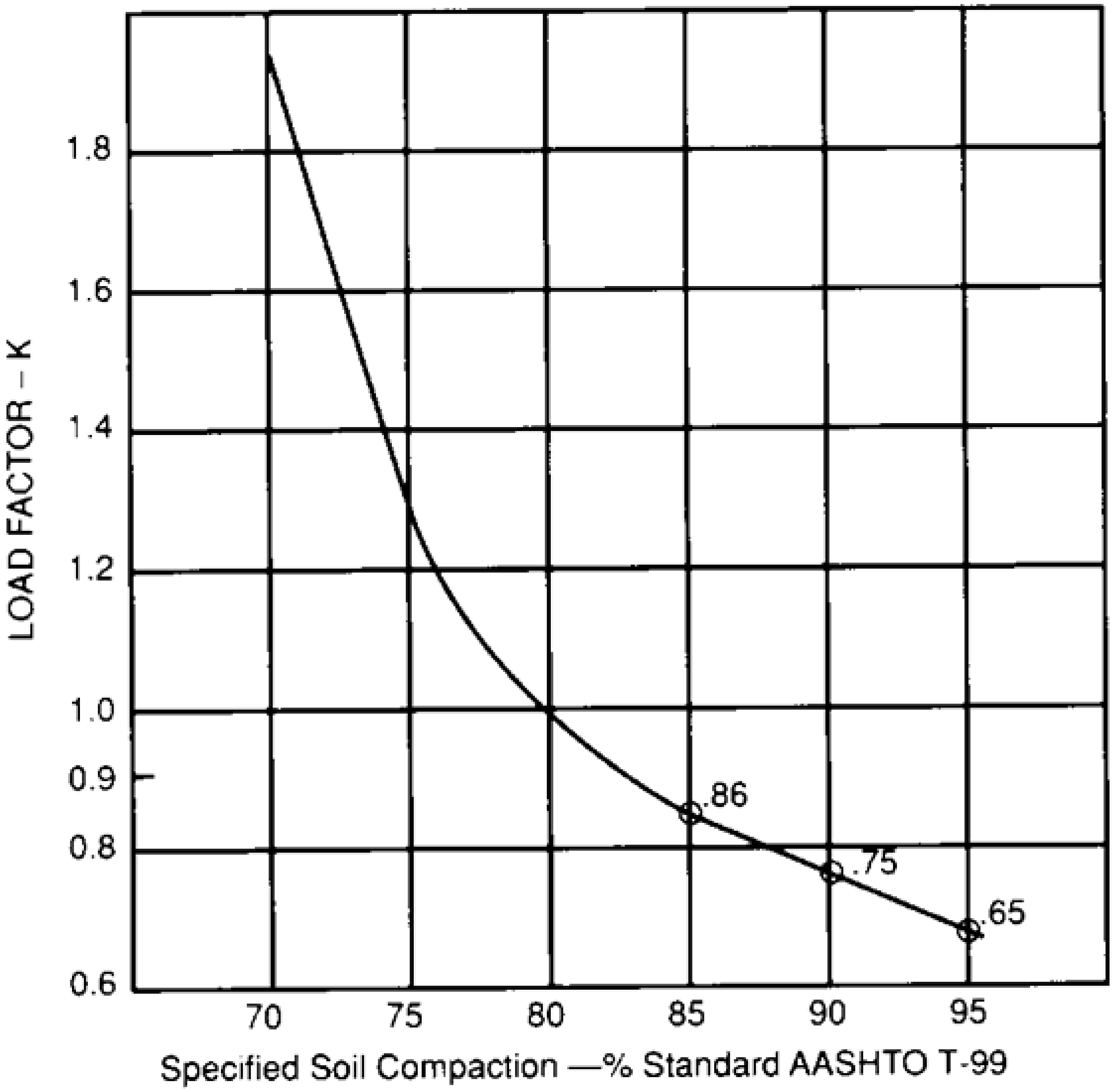

Figure 1 Load factors for corrugated steel pipe for backfill compacted to AASHTO T-99 density.

Total load on pipe becomes:

P_v = K x (DL + LL), when H $\geq$ S
P_v =(DL + LL), when H < S

where:

Pv = Design pressure, (lb/ft^2)
K = Load factor
DL = Dead load, (lb/ft^2)
LL = Live load, (lb/ft^2)
H = Height of cover, (ft)
S = Span, (ft)

3. Compute Ring Compression

The compressive thrust in the conduit wall is equal to the radial pressure acting on the wall multiplied by the wall radius or: $C = P \times R$. This thrust, called ring compression, is the force carried by the steel. The ring compression force acts tangentially to the conduit wall. For conventional structures in which the top arc approaches a semicircle, it is convenient to substitute half the span for the wall radius.

Then:

$$C=P_v \times S/2$$

where:

C=Ring compression (lb/ft)
P_v=Design pressure, (lb/ft^2)
S =Span, (ft)

4. Select Allowable Wall Stress

The ultimate compressive stresses, f_b, for corrugated steel structures with backfill compacted to 85% standard AASHTO density and a minimum yield point of 33,000 psi, are shown in Fig. 4.7. The ultimate compression in the pipe wall is expressed by the equations below. The first is the specified minimum yield point of the steel which represents the *zone of wall crushing* or yielding, the second represents the *interaction zone of yielding* and ring buckling, and the third represents the *ring buckling zone.*

$f_b=f_y = 33{,}000$ lb/in.^{2}, when $D/r \leq 294$
$f_b=40{,}000 - 0.081\,(D/r)^2$, when $294 < D/r \leq 500$

$$f_b=\frac{4.93 \times 10^9}{(D/r)^2}, \text{when } D/r > 500$$

where:

D = Dia. or span, (in.)
r = Radius of gyration, (in.)

A factor of safety of 2 is applied to the ultimate wall stress to obtain the design stress, f_c

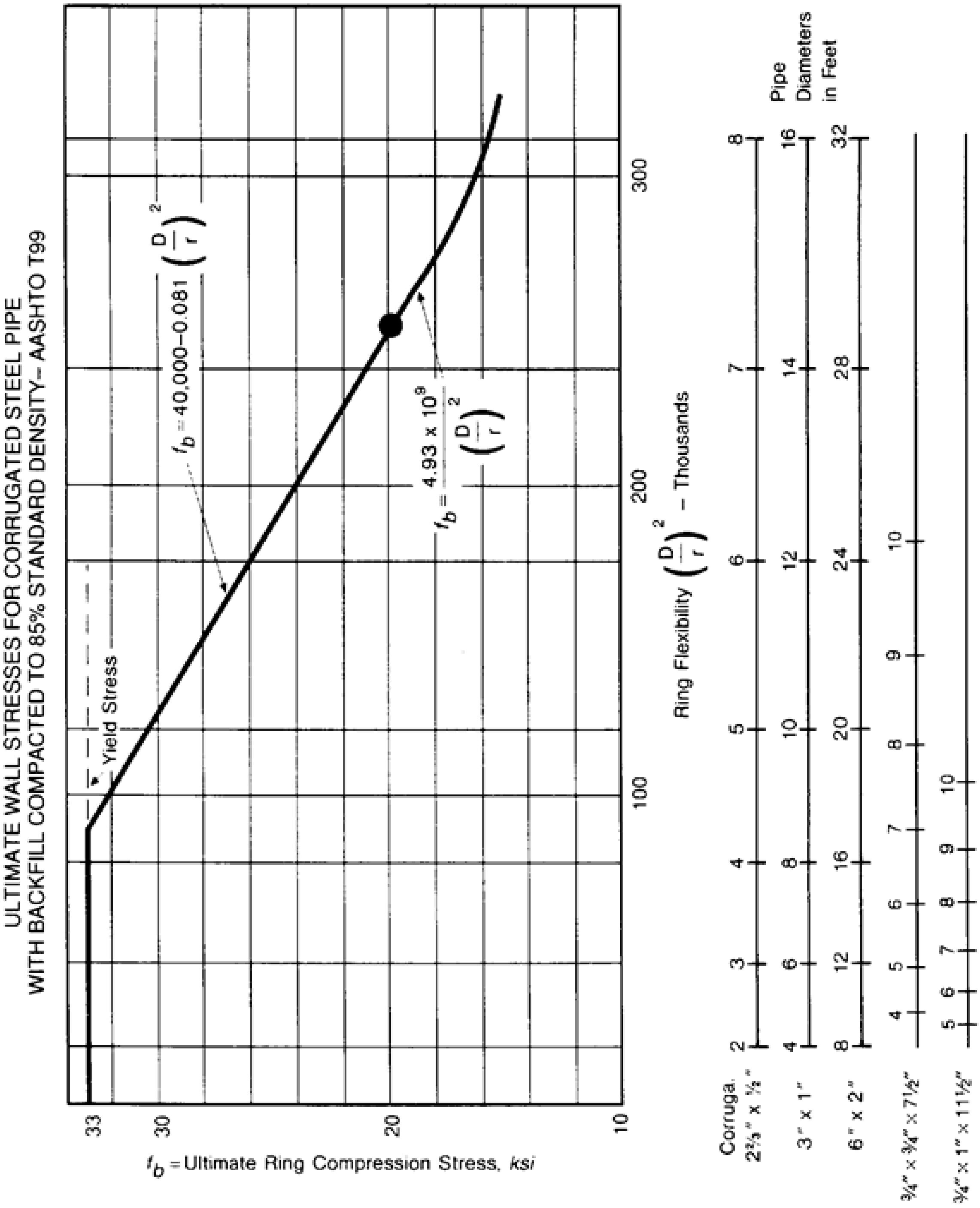

Figure Ultimate wall or bucking stresses for corrugated steel pipe of variuos diameters and corrugations. The allowable stress is taken as one-half the ultimate.

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5. Determine Wall Thickness

Required wall area, A, is computed from calculated compression in the pipe wall, C, and the allowable stress, f_c.

$A = C/f_c$

From Table 2 select the wall thickness providing the required area in the same corrugation used to select the allowable stress.

6. Check Handling Stiffness

Minimum pipe stiffness requirements for practical handling and installation without undue care or bracing have been established through experience and formulated. The resultant flexibility factor, FF, limits the size of each combination of corrugation and metal thickness.

$FF = D^2/EI$

where:

E = Modulus of elasticity = 30 x 106 lb/in^2
D = Diameter or span, (in.)
I = Moment of inertia of wall, $in.^4/in.$

Recommended maximum values of FF for ordinary installations:

FF = 0.0433 for factory-made pipe with riveted, welded, or helical seams
FF = 0.0200 for field-assembled pipe with bolted seams

Increase the maximum values of FF for pipe-arch, arch and underpass shapes as follows:

Pipe-Arch FF = 1.5 xFF shown for round pipe
Arch FF = 1.5 x FF shown for round pipe
Underpass FF = same as shown for roundpipe

Higher values can be used with special care or where experience has so proved. Trench condition, as in sewer design, is one example. Aluminum pipe experiences are another. For example, the flexibility factor permitted for aluminum pipe in some national specifications is more than twice that recommended above for steel. This has come about because aluminum has only one-third the stiffness of steel, the modulus for aluminum being approximately 10 x 10^6 psi vs 30 x 10^6 for steel. Where this degree of flexibility is acceptable in aluminum, it will be equally acceptable in steel.

For spiral rib pipe, a somewhat different approach is used. To obtain better control, the flexibility factors are varied with corrugation profile, sheet thickness, and type of installation, as shown in Table 1. The details of the installation requirements are given subsequently with the allowable fill heights in Table HC-2.

Table 1 - Flexibility Factors for Spiral Rib Pipe

Installation Type	Flexibilitv Factor in./lb.						
	3/4 x 1 x 11-1/2 Corr.			3/4 x 3/4 x 71/2 Corr.			
	Specified Thickness, Inches			Specified Thickness, Inches			
	0.064	0.079	0.109	0.064	0.079	0.109	0.138
I	0.022	0.025	0.026	0.022	0.026	0.028	0.0368
II	0.027	0.030	0.033	0.028	0.032	0.038	0.0426
III	0.033	0.040	0.044	0.035	0.044	0.050	0.0564

Table 2 - Moment of Inertia (I) and Cross-Sectional Area (A) of Corrugated Steel Pipe for Underground Conduits

Corrugation Pitch x Depth, inches	Specified Thickness, Inches*									
	0.052	0.064	0.079	0.109	0.138	0.168	0.188	0.218	0.249	0.280
				0.111	0.140	0.170				

	Moment of Inertia, I, Inches^4 per Foot of Width									
1-1/2 x 1/4	.0041	.0053	.0068	.0103	.0145	0.0196				
2 x 1/2	.0184	.0233	.0295	.0425	.0586	0.0719				
2-2/3 x 1/2	.0180	.0227	.0287	.0411	.0544	0.0687				
3 x 1	.0827	.1039	.1306	.1855	.2421	0.3010				
5 x 1		.1062	.1331	.1878	.2438	0.3011				
6 x 2				.725	.938	1.154	1.296	1.523	1.754	1.990
3/4 x 3/4 x 7-1/2**		.0431	.0569	.0858	.1157					
3/4 x 1 x 11-1/2		.0550	.0730	.1111						
	Cross-Sectional Wall Area, Inches^2 per Foot of Width									
1-1/2 x 1/4	.608	.761	.950	1.331	1.712	2.093				
2 x 1/2	.652	.815	1.019	1.428	1.838	2.249				
2-2/3 x 1/2	.619	.775	.968	1.356	1.744	2.133				
3 x 1	.711	.890	1.113	1.560	2.008	2.458				
5 x 1		.794	.992	1.390	1.788	2.196				
6 x 2				1.556	2.003	2.449	2.739	3.199	3.658	4.119
3/4 x 3/4 x 71/2**		.511	.715	1.192	1.729					
3/4 x 1 x 11-1/2		.374	.524	.883						

* Where two thicknesses are shown top is corrugated steel pipe and bottom is structural plate.
** Ribbed pipe. Properties are effective values.

7. Check Longitudinal Seams

Most pipe seams develop the full yield strength of the pipe wall. However, there are exceptions in standard pipe manufacture and these are identified here. Shown below are those standard riveted and bolted seams which do not develop a strength equivalent to f_y = 33,000 psi. To maintain a consistent factor of safety of 2.0 for these pipes, it is necessary to reduce the maximum ring compression to one half the indicated seam strength. Nonstandard, or new longitudinal seam details should be checked for this same possible condition. Since helical lockseam and continuously-welded-seam pipe have no longitudinal seams, there is no seam strength check for these types of pipe.

Table 3 - Ultimate Longitudinal Seam* Strengths (lb/ft)

Thickness, in.		6 x 2 in. 4 Bolts Per Ft	3 x 1 in.	2-2/3 x 1/2 in. Rivet Seams		
Corrugated Steel Pipe	Structural Plate			5/16 in SIngle Rivet	3/8 in. Single Rivet	3/8 in. Double Rivet
0.064			28,700[1]	16,700		
0.079			35,700[1]	18,200		
0.109	0.111	42,000			23,400	
0.138	0.140	62,000	63,700[2]		24,500	49,000
0.168			70,700[2]		25,600	51,300

*See Chapter 2 in *Handbook of Steel Drainage and Highway Construction Products* for seam details.
Standard seams not shown develop full yield strength of pipe wall.
[1] Double 3/8-in rivets.
2Double 7/15-in. rivets.

8. Check Pipe-Arches

The pipe-arch shapes poses special design problems not found in round or vertically-elongated pipe. Pipe-arches generate corner pressures greater than the pressure in the fill. This often becomes the practical limiting design factor rather than stress in the pipe wall.

To calculate the corner pressure, ignore the bending strength of the corrugated steel and establish allowable loads based on the allowable pressure on the soil at the corners. Assuming zero moment strength of the pipe wall, ring compression, C, is the same at any point around the pip-arch, and C = P x R at any point on the periphery. This means the normal pressure to the pipe-arch wall is inversely proportional to the wall radius.

However, this relationship is overly conservative for live loads, such as wheel loads that are not uniformly distributed over the full pipe length. As the ring compression force generated at the top of the pipe-arch by live loads is transmitted circumferentially down toward the corner region, it is also distributed along the length of the pipe. Thus, the length of the corner region that transmits the live load pressures into the soil is much greater than the length of pipe-arch over which they were initially applied.

This is the procedure that was used to calculate the height-of-cover limits for pipe-arches in this Handbook. Furthermore, the live load was used without impact because (1) the distance from the point of pressure application to the corner region is much greater than the distance from that point to the crown of the structure, and (2) bearing failures are progressive failures over a significant time period as opposed to the brief time of an impact loading. However, the full live load pressure (including impact and unmodified by the C, factor) should continue to be used to design the pipe wall.