*CSP sewers are designed for the deepest installations.*

# CHAPTER 7 Structural Design

**Introduction**

After the pipe diameter (or pipe arch size) has been determined for the expected hydraulic flow, the structural design must be considered. Specifically, the corrugation profile and the steel thickness must be determined, so that the final installation will have strength and stiffness to adequately resist the live and dead loads present. The tables subsequently presented in this chapter simplify this process of determination. The following discussion of loadings and design considerations provides a background for the tables.

**LOADINGS**

Underground conduits are subject to two principal kinds of loads:

(1) dead loads developed by the embankment of trench backfill, plus stationary superimposed surface loads, uniform or concentrated; and

(2) live loads - moving loads, including impact.

**Live Loads**

Live loads are greatest when the height of cover over the top of the pipe is small and decreased as the fill height increases. Standard highway loadings are referred to as CS-600 and AASHTO H-25 live loads, and standard railroad loadings are referred to as AREA E-80 live loads. Table 7.3 gives the pressure on the pipe for CS-600, H-25, and E-80 live loads.

It should be noted that the tire print and loading for CSA S-6, CS-600 is identical to AASHTO H-25. There are minor differences in the impact factor and method of pressure distribution thru the soil, however, these differences are only noticeable for heights of cover less than 1 metre.

**Dead Loads**

The dead load is considered to be the soil prism over the pipe. The unit pressure of this prism acting on the horizontal plane at the top of the pipe is equal to:

$$DL = wH \qquad (1)$$

Where w = Unit weight of soil, $kN/m^3$

H = Height of fill over pipe, m

DL = Dead load pressure, kPa

**Design Pressure**

When the height of cover is equal to or greater than the span or diameter of the structure, the total load (total load is the sum of the live and dead load) can be reduced by a factor of K which is a function of soil density.

For 85% Standard Density K = 0.86

For 90% Standard Density K = 0.75

For 95% Standard Density K = 0.65

The recommended K value is for a Standard Proctor Density (S.P.D.) of 85%. This value easily will apply to ordinary installations in which most specifications will call for compaction of 90%. However, for more important structures in high fill situations, select a higher quality backfill at a higher density and specify the same in construction. This will extend the allowable fill height or save on thickness.

If the height of cover is less than one pipe diameter, the total load (TL) is assumed to act on the pipe, and TL = $P_v$.

$P_v$ = K (DL + LL), when H ≥ S (2)

$P_v$ = (DL + LL), when H < S

where: $P_v$ = Design pressure, kPa

K = Load factor

DL = Dead load, kPa

LL = Live load, kPa

H = Height of cover, m

S = Span, m

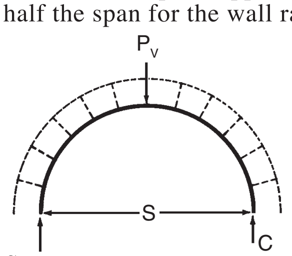
With the inherent flexibility of corrugated steel pipe, the vertically directed total load pushes the side of the pipe ring against the compacted fill material and mobilizes the passive earth pressure. Thus, the pipe ring is often assumed to be loaded by radial pressure. For round pipes, the pressure around the periphery tends to be approximately equal, particularly at deep fill heights.

For pipe-arch shapes, the pressure is approximately inversely proportional to the radius of curvature of the segments as shown in Figure 7.1. Since the pressures at the corners of the pipe-arch are greatest, the soil adjacent to them is subjected to the highest pressures. The soil in the corner areas must have sufficient bearing capacity to resist such pressure. Accordingly, the soil-bearing capacity may control the maxium allowable fill height for pipe arches.

**STRENGTH CONSIDERATIONS**

The radial pressures develop a compressive thrust in the pipe wall, and the pipe must have structural strength adequate for this purpose. Accordingly, the stress in the pipe wall may be determined and compared to recognized allowable values to prevent yielding, buckling, or seam failures. Such allowable values have been derived from destructive tests done in extensive research programs, applying a safety factor of about 2.0.

The compressive thrust in the conduit wall is equal to the radial pressure acting on the wall multiplied by the pipe radius or C = P x R. This thrust, called the "ring compression" is the force carried by the steel. The ring compression is an axial force acting 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: $C = P_V \times \frac{S}{2}$ .................................................................. (3)

where: C = Ring compression, kN/m

$P_V$ = Design pressure, kPa, S = Span, m

The ultimate compressive stresses, $f_b$, for corrugated steel structures with backfill compacted to 90% S.P.D. (Standard Proctor Density) and a minimum yield point of 230 MPa is expressed by equations (4), (5) and (6). 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 third, the ring buckling zone.

$$f_b = f_y = 230 \text{ MPa, when } \frac{D}{r} \leq 294 \qquad (4)$$

$$f_b = 275 - 558 \times 10^{-6} \left(\frac{D}{r}\right)^2, \text{ when } 294 < \frac{D}{r} \leq 500 \qquad (5)$$

$$f_b = \frac{3.4 \times 10^7}{\left(\frac{D}{r}\right)^2}, \text{ when } \frac{D}{r} > 500 \qquad (6)$$

where: D = Diameter or span, mm
r = Radius of gyration = $\sqrt{I/A}$ (calculate using r min. for an assumed corrugation profile) from Table 7.4., mm
I = Moment of inertia of pipe wall, $mm^4/m$
A = Area of pipe wall, $mm^2$ / m

A factor of safety of 2 is applied to the ultimate compressive stress to obtain the design stress, $f_c$.

$$f_c = \frac{f_b}{2} \qquad (7)$$

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

$$A = \frac{C}{f_c} \qquad (8)$$

Values of A and I for the various corrugations are given in Table 7.4

**HANDLING STIFFNESS**

Minimum pipe stiffness requirements for practical handling and installations 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.

$$FF = \frac{D^2}{EI} \qquad (9)$$

where: $E$ = Modulus of elasticity = 200 x $(10)^3$, MPa
$D$ = Diameter or span, mm
$I$ = Moment of inertia of wall, $mm^4/mm$

Recommended maximum values of *FF* for ordinary installation:

| | | | |
|---|---|---|---|
| 68 x 13 mm corrugation, | *FF* | = | 0.245 mm/N |
| 125 x 26 mm corrugation, | *FF* | = | 0.188 mm/N |
| 76 x 25 mm corrugation, | *FF* | = | 0.188 mm/N |
| 152 x 5l mm corrugation, | *FF* | = | 0.114 mm/N |

Increase the maximum values of *FF* for pipe arch and arch shapes as follows:

Pipe-Arch *FF* = 1.5 x *FF* shown for round pipe

Arch *FF* = 1.3 x *FF* shown for round pipe

Higher values can be used with special care or where experience has so been proven. 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 is approximately one-third the stiffness of steel; the modulus for aluminum is approximately 67 x $10^3$ MPa vs. 200 x $10^3$ MPa 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 below. The details of the installation requirements are given subsequently with the allowable fill heights in Table 7.12.

| Installation Type | Flexibility Factor mm / N 19 x19 x 190 Corr. | | |
|---|---|---|---|
| | Thickness, mm | | |
| | 1.6 | 2.0 | 2.8 |
| I | 0.151 | 0.166 | 0.190 |
| II | 0.175 | 0.192 | 0.220 |
| III | 0.232 | 0.254 | 0.292 |

**DEFLECTION**

Although ring deflection does occur, it is not usually a consideration in the theoretical design of the pipe structure. It has been shown in both test and field applications that, if granular backfill soil is compacted to a specified S. P. D. of 90%, the pipe deflection under total load will not influence the overall strength of the pipe.

**Table 7.1** Riveted CSP – Minimum longitudinal seam strength[b] (kN/m)

| Design base metal thickness, mm | 8mm RIVETS | | 10mm RIVETS | | | 12mm RIVETS |
|---|---|---|---|---|---|---|
| | 68 x 13mm | | 68 x 13mm | | 76 x 25mm | 76 x 25mm |
| | SINGLE | DOUBLE | SINGLE | DOUBLE | DOUBLE | DOUBLE |
| 1.0 | 93[a] | | | | | |
| 1.3 | 148[a] | | | | | |
| 1.6 | 236 | 274 | | | 387 | |
| 2.0 | 261 | 401 | | | 499 | |
| 2.8 | | | 341 | 682 | | 769 |
| 3.5 | | | 356 | 712 | | 921 |
| 4.2 | | | 372 | 746 | | 1023 |

[a] Interpolated from independent test data on riveted connections (United States Steel Inc.)

[b] Interpolated from tests on straight unsupported columns (Utah Highway Dept., 1964).
Values are calculated from design base metal thicknesses and increases in rivet diameter are not included.

**SEAM STRENGTH**

Most pipe seams develop the full yield strength of the pipe wall. However, there are exceptions in standard pipe manufacture. Shown underlined in Tables 7.1 and 7.2 are those standard riveted and bolted seams which do not develop a strength equivalent to $f_y$ = 230 MPa. To maintain a consistent factor of safety of 2 and to account for change in soil density, the maximum ring compression should not exceed the ultimate longitudinal seam strength divided by a factor of 2.

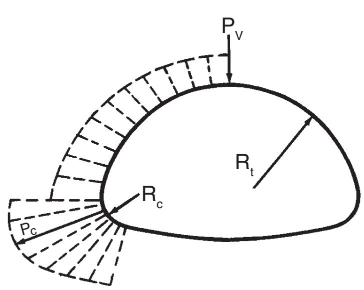
**Table 7.2** Minimum ultimate longitudinal seam strength for SPCSP structures (kN/m)

| Specified wall thickness, mm | Bolts per corrugation | | |
|---|---|---|---|
| | 2 | 3 | 4 |
| 3.0 | <u>745</u> | – | – |
| 4.0 | 1120 | – | – |
| 5.0 | 1470 | 1650 | – |
| 6.0 | 1840 | 2135 | – |
| 7.0 | 2100 | 2660 | 3200 |

**PIPE-ARCHES**

The pipe-arch shape 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 pipe-arch, and C = *P x R* at any point on the periphery. This means the pressure normal to the pipe-arch wall is inversely proportional to the wall radius.




Corner Pressure, $P_c = P_v \times \frac{R_t}{R_c}$

$P_c$ = Pressure acting on soil at corners (kPa)

$R_t$ = Radius at crown (mm)

$R_c$ = Radius of corner (mm)

$P_v$ = Design pressure (kPa)

**Figure 7.1.** The pressure on a pipe-arch varies with location and radius being greatest at the corners.

*Installation of SPCSP.*

**ASTM STANDARD PRACTICES**

A procedure for the structural design of pipe is provided by ASTM A796, "Standard Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications." The Practice applies to structures installed in accordance with A798, "Standard Practice for Installing Factory-Made Corrugated Steel Pipe for Sewers and Other Applications," or A807, "Standard Practice for Installing Corrugated Steel Structural Plate Pipe for Sewers and Other Applications." These Practices are frequently referenced in project specifications.

The design procedure in A796 is similar to that described in this chapter but differs in several respects. First, for the dead load, ASTM uses the weight of the entire prism of soil over the pipe and does not recognize the load reduction factor. It uses a more conservative form of the buckling equation. It provides flexibility factors for both trench and embankment conditions, some of which are more conservative than those listed here. It includes more specific information on acceptable soil types. In spite of all these differences, the resulting designs for typical projects will usually not differ greatly from those provided in this chapter.

**CANADIAN STANDARD PRACTICES**

The upcoming Canadian Highway Bridge Design Code (CHBDC) will be the first code that will be used across the country. The design practice is based on the current code used in Ontario. A commentary containing recommendations for installation will also be published. This code is only appropriate for structural plate installations.

Practices for CSP installation are generally set out by provincial highway authorities, or major municipalities. While some provinces have developed their own design practices, most refer to AASHTO or ASTM.

**Table 7.3** Highway and railway live loads (LL)

| Highway loading[1] | | | Railway E-80 loading[1] | |
|---|---|---|---|---|
| Depth of cover, metres | Load, kPa CS-600[2] | Load, kPa H-25[3] | Depth of cover, metres | Load, kPa |
| 0.75 | 45 | 44 | | |
| 1.00 | 31 | 31 | 1 | 147 |
| 1.25 | 22 | 22 | 1.2 | 133 |
| 1.50 | 16 | 16 | 1.5 | 115 |
| 1.75 | 12 | 12 | 2 | 91 |
| 2.00 | 10 | 10 | 3 | 53 |
| 2.25 | 8 | 8 | 4 | 34 |
| 2.50 | 6 | 6 | 6 | 15 |
| 2.75 | 5 | 5 | 8 | 7 |
| 3.00 | – | – | 9 | 5 |

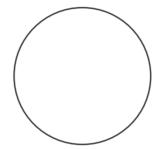
Notes:
1. Neglect live load when less than 5 kPa; use dead load only.
2. Load distribution through soil according to CSA-S6-88.
3. Load distribution through soil according to ASTM traditional method.

**Table 7.4** Moment of inertia (I) and cross-sectional area (A) of corrugated steel for underground conduits

| Corrugation profile, mm | Specified thickness, mm 1.0 | 1.3 | 1.6 | 2.0 | 2.8 | 3.0 | 3.5 | 4.0 | 4.2 | 5.0 | 6.0 | 7.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Moment of inertia, I, $mm^4/mm$ | | | | | | | | | | | |
| 38 x 6.5 | 3.70 | 5.11 | 6.46 | 8.58 | | | | | | | | |
| 68 x 13 | 16.49 | 22.61 | 28.37 | 37.11 | 54.57 | | 70.16 | | 86.71 | | | |
| 76 x 25 | 75.84 | 103.96 | 130.40 | 170.40 | 249.73 | | 319.77 | | 393.12 | | | |
| 125 x 26 | | | 133.30 | 173.72 | 253.24 | | 322.74 | | 394.84 | | | |
| 152 x 51 | | | | | | 1057.25 | | 1457.56 | | 1867.12 | 2278.31 | 2675.11 |
| 19 x 19 x 190 | | | 58.83 | 77.67 | 117.17 | | | | | | | |
| | Cross-sectional wall area, $mm^2/mm$ | | | | | | | | | | | |
| 38 x 6.5 | 0.896 | 1.187 | 1.484 | 1.929 | | | | | | | | |
| 68 x 13 | 0.885 | 1.209 | 1.512 | 1.966 | 2.852 | | 3.621 | | 4.411 | | | |
| 76 x 25 | 1.016 | 1.389 | 1.736 | 2.259 | 3.281 | | 4.169 | | 5.084 | | | |
| 125 x 26 | | | 1.549 | 2.014 | 2.923 | | 3.711 | | 4.521 | | | |
| 152 x 51 | | | | | | 3.522 | | 4.828 | | 6.149 | 7.461 | 8.712 |
| 19 x 19 x 190 | | | 1.082 | 1.513 | 2.523 | | | | | | | |

**DESIGN EXAMPLE**

The following example illustrates the application of design procedures developed.



| | | | |
|---|---|---|---|
| **Given:** | Pipe diameter required | = | 1200 mm |
| | Depth of cover, H | = | 18 m |
| | Live Load, LL | = | H-25 |
| | Weight of Soil, w | = | 19 kN/$m^3$ |

**Find:** Wall thickness and type of corrugation.

**Solution:**

**Loadings**

90% S.P.D. is specified. Assume a minimum of 85% for design.

∴ K = 0.86

Design Pressure, $P_v$ = 0.86 (DL + LL),

where DL = dead load = H x 19 = 18 x 19 = 342 kPa

LL = live load = negligible for cover greater than 3.0 m. (from Table 7.3)

∴ $P_v$ = 0.86 (342 + O) = 294 kPa

Ring Compression, C = $P_v$ x S/2,

where S = Span, m

∴ C = 294 x 1.2/2 = 176 kN/m

Design Stress, $f_c = f_b/2$ = 0.194

Assume 68 mm x 13 mm corrugation.

Then, $D/r_{min}$ = 1200/4.32 = 278 < 294

∴ $f_b = f_y$ = 230 MPa

∴ $f_c$ = 115 MPa

Wall Area, $A = C/f_c$ = 176/115 = 1.53 $mm^2$/mm

From Table 7.4, a specified thickness of 2 mm provides an uncoated wall area of 1.966 $mm^2$/mm.

**Handling Stiffness**

$$FF = \frac{D^2}{EI} \quad = \text{flexibility factor} = 0.245 \text{ max}$$

where: D = diameter, 1200 mm

E = modulus of elasticity = 200 x $10^3$ MPa

I = moment of inertia, $mm^4$/mm

From table 7.4, for 2 mm specified thickness,

I = 37.11 $mm^4$/mm

$$\therefore FF = \frac{1200^2}{200 \times 10^3 \times 37.11}$$

0.194 < 0.245; Therefore flexibility factor is OK.

**Seam Strength**

From Table 7.1, 2 mm thickness and double 8 mm rivets

Seam strength = 401/2 = 200 kN/m > 176 kN/m

**Answer:** A specified wall thickness of 2 mm is adequate for 68 mm x 13 mm corrugated steel pipe.

*Installing a fully paved sanitary sewer.*

**DEPTH OF COVER**

Tables for the selection of the steel wall thickness in millimeters depending upon the pipe diameter and depth of cover requirements, are presented as Tables 7.5 through 7.16. Each table is for a circular pipe, pipe arch or an arch of a particular corrugation profile. The tables include the effect of live loads (surface loads) that do not exceed a CS-600, H-25 or E-80 live load, as indicated.

In addition, Tables 7.17 through 7.21 give the minimum cover requirements for round pipe under airplane wheel loads of various magnitudes.

The tables are for trench installations and reasonable care should be exercised in handling and installation. The pipes must be installed and the backfill must be compacted as outlined in Chapter l0, "Construction."

If other loading conditions are encountered, the designer should consult with the industry sources for recommended practices.

**Table 7.5** Thickness in millimetres for CSP sewers –

38mm x 6.5mm corrugation CS-600, H-25, or E-80 live load

| Diameter of pipe (mm) | For maximum depth of cover above top of pipe equal to 12m |
|---|---|
| 150 | 1.3 |
| 200 | 1.3 |
| 250 | 1.3 |

Notes: 1. Minimum depth of cover over top of pipe is 300mm.
2. Backfill around pipe must be compacted to a specified S.P.D. of 90%.
3. Use reasonable care in handling and installation.
4. Zinc coated steel sheet thickness shown is based on commercially available sheets.

**Table 7.6** Depth of cover for CSP sewers –

68mm x 13mm corrugation CS-600, H-25, or E-80 live load

| | Minimum cover | | Maximum cover, m | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Specified wall thickness, mm | | | | | |
| Diameter of pipe (mm) | CS-600 or H-25 (mm) | E-80 (mm) | 1.3 | 1.6 | 2.0 | 2.8 | 3.5 | 4.2 |
| 300 | 300 | 300 | 56 | 70 | 91 | | | |
| 400 | 300 | 300 | 42 | 53 | 68 | | | |
| 500 | 300 | 300 | 33 | 42 | 54 | 79 | | |
| 600 | 300 | 300 | 28 | 35 | 45 | 66 | | |
| 700 | 300 | 300 | | 30 | 39 | 57 | | |
| 800 | 300 | 300 | | 26 | 34 | 50 | | |
| 900 | 300 | 300 | | 23 | 30 | 44 | 56 | |
| 1000 | 300 | 300 | | 21 | 27 | 40 | 50 | 63 |
| 1200 | 300 | 300 | | | 23 | 33 | 42 | 52 |
| 1400 | 300 | 500 | | | | 27 | 35 | 43 |
| 1600 | 300 | 500 | | | | 22 | 28 | 35 |
| 1800 | 300 | 500 | | | | | 22 | 27 |
| 2000 | 400 | 500 | | | | | | 22 |

Notes: 1. For E-80 loading minimum steel thickness is 1.6mm.
2. Backfill around pipe must be compacted to a specified S.P.D. of 90%.
3. Use reasonable care in handling and installation.

**Table 7.7** Depth of cover for CSP sewers – 76mm x 25mm corrugation CS-600, H-25, or E-80 live load

| Diameter of pipe (mm) | Minimum cover CS-600 or H-25 (mm) | Minimum cover E-80 (mm) | Maximum cover, m – Specified wall thickness, mm 1.6 | 2.0 | 2.8 | 3.5 | 4.2 |
|---|---|---|---|---|---|---|---|
| 1200 | 300 | 500 | 20 | 26 | 38 | | |
| 1400 | 300 | 500 | 17 | 22 | 32 | 41 | |
| 1600 | 300 | 500 | 15 | 19 | 28 | 36 | 44 |
| 1800 | 300 | 500 | 13 | 17 | 25 | 32 | 39 |
| 2000 | 300 | 500 | 12 | 15 | 22 | 29 | 35 |
| 2200 | 400 | 700 | 11 | 14 | 20 | 26 | 32 |
| 2400 | 400 | 700 | | 13 | 19 | 24 | 29 |
| 2700 | 500 | 700 | | 11 | 16 | 21 | 25 |
| 3000 | 500 | 1000 | | | 14 | 17 | 21 |
| 3300 | 600 | 1000 | | | 12 | 15 | 18 |
| 3600 | 600 | 1000 | | | | 12 | 15 |

Notes: 1. For E-80 loading the following minimum steel thicknesses apply: 2mm for 2700 to 3000mm diameter, and 2.8mm for 3000 to 3600mm in diameter.
2. Backfill around pipe must be compacted to a specified S.P.D. of 90%.
3. Use reasonable care in handling and installation.

**Table 7.8** Depth of cover for CSP sewers – 125mm x 26mm corrugation CS-600, H-25, or E-80 live load

| Diameter of pipe (mm) | Minimum cover CS-600 or H-25 (mm) | Minimum cover E-80 (mm) | Maximum cover, m – Specified wall thickness, mm 1.6 | 2.0 | 2.8 | 3.5 | 4.2 |
|---|---|---|---|---|---|---|---|
| 1200 | 300 | 500 | 18 | 23 | 34 | | |
| 1400 | 300 | 500 | 15 | 20 | 29 | 35 | 45 |
| 1600 | 300 | 500 | 13 | 18 | 25 | 31 | 39 |
| 1800 | 300 | 500 | 12 | 16 | 22 | 28 | 35 |
| 2000 | 300 | 500 | 11 | 14 | 20 | 25 | 31 |
| 2200 | 400 | 700 | 10 | 12 | 18 | 23 | 29 |
| 2400 | 400 | 700 | 9 | 11 | 17 | 21 | 26 |
| 2700 | 500 | 700 | | 10 | 15 | 18 | 23 |
| 3000 | 500 | 1000 | | | 13 | 16 | 21 |
| 3300 | 600 | 1000 | | | 11 | 14 | 19 |
| 3600 | 600 | 1000 | | | | 12 | 17 |

Notes: 1. For E-80 loading the following minimum steel thicknesses apply: 2mm for 2700 to 3000mm diameter, and 2.8mm for 3000 to 3600mm in diameter.
2. Backfill around pipe must be compacted to a specified S.P.D. of 90%.
3. Use reasonable care in handling and installation.

**Table 7.9** Depth of cover for CSP pipe-arch sewers –

68mm x 13mm corrugation CS-600 or H-25 live load

| Span (mm) | Rise (mm) | Min. specified wall thickness, (mm) | Maximum depth of cover (metres) over pipe-arch for the following corner bearing pressures | | |
|---|---|---|---|---|---|
| | | | 200 kPa | 300kPa | 400 kPa |
| 450 | 340 | 1.6 | 6.0 | 8.9 | 11.9 |
| 560 | 420 | 1.6 | 5.9 | 8.9 | 11.8 |
| 680 | 500 | 1.6 | 5.9 | 8.8 | 11.7 |
| 800 | 580 | 1.6 | 5.8 | 8.7 | 11.7 |
| 910 | 660 | 1.6 | 5.8 | 8.7 | 11.6 |
| 1030 | 740 | 1.6 | 5.7 | 8.6 | 11.5 |
| 1150 | 820 | 2.0 | 5.7 | 8.5 | 11.3 |
| 1390 | 970 | 2.8 | 5.6 | 8.4 | 11.2 |
| 1630 | 1120 | 3.5 | 5.5 | 8.2 | 11.0 |
| 1880 | 1260 | 3.5 | 5.4 | 8.1 | 10.8 |
| 2130 | 1400 | 3.5 | 5.3 | 8.0 | 10.6 |

Notes: 1. Soil bearing capacity refers to the soil in the region of the pipe corners. The remaining backfill around the pipe-arch must be compacted to a specified S.P.D. of 90%.
2. Use reasonable care in handling and installation.
3. Minimum cover is 450mm for 200 kPa bearing capacity.
350mm for 300 kPa bearing capacity.
300mm for 400 kPa bearing capacity.

**Table 7.10** Depth of cover for CSP pipe-arch sewers –

76mm x 25mm and 125mm x 26mm corrugation CS-600 or H-25 live load

| Span (mm) | Rise (mm) | Min. specified wall thickness, (mm) | | Maximum depth of cover (metres) over pipe-arch for the following corner bearing pressures | | |
|---|---|---|---|---|---|---|
| | | 76 x 25 | 125 x 26 | 200 kPa | 300 kPa | 400 kPa |
| 1330 | 1030 | 1.6 | 1.6 | 5.6 | 8.4 | 11.2 |
| 1550 | 1200 | 1.6 | 1.6 | 5.5 | 8.2 | 11.0 |
| 1780 | 1360 | 1.6 | 2.0 | 5.4 | 8.1 | 10.8 |
| 2010 | 1530 | 2.0 | 2.0 | 5.3 | 8.0 | 10.6 |

Notes: 1. Soil bearing capacity refers to the soil in the region of the pipe corners. The remaining backfill around the pipe-arch must be compacted to a specified S.P.D. of 90%.
2. Use reasonable care in handling and installation.
3. Minimum cover is 450mm for 200 kPa bearing capacity.
350mm for 300 kPa bearing capacity.
300mm for 400 kPa bearing capacity.

*The following table is not compiled by theoretical corner pressure but is instead based on experience.*

**Table 7.11** Minimum specified wall thickness for CSP pipe-arch sewers –

68mm x 13mm corrugation E-80 live load

| Span (mm) | Rise (mm) | Minimum specified wall thickness, mm | | | |
|---|---|---|---|---|---|
| | | Depth of cover range, m | | | |
| | | 0.6 to 0.9 | 0.9 to 1.5 | 1.5 to 2.4 | 2.4 to 4.6 |
| 560 | 420 | 2.8 | 2.0 | 2.0 | 2.0 |
| 680 | 500 | 2.8 | 2.8 | 2.0 | 2.0 |
| 800 | 580 | 3.5 | 2.8 | 2.8 | 2.8 |
| 910 | 660 | | 3.5 | 2.8 | 2.8 |
| 1030 | 740 | | 3.5 | 3.5 | 2.8 |
| 1150 | 820 | | | 3.5 | 3.5 |
| 1390 | 970 | | | | 3.5 |

Notes: 1. Minimum corner bearing capacity is 300 kPa. Remaining fill to be compacted to S.P.D. of 90%.
2. Use reasonable care in handling and installation.

*Outfall for 2200mm CSP storm sewer. Entire line averaged 5% grade, which is suited to choice of steel*

**Table 7.12** Depth of cover for CSP sewers –

Spiral rib pipe CS-600 or H-25 live load 19mm x 19mm x 190 corrugation

| | Maximum depth of cover above top of pipe (m) | | | Minimum depth of cover above top of pipe (mm) | | |
|---|---|---|---|---|---|---|
| Dia. (mm) | 1.6 | 2.0 | 2.8 | 1.6 | 2.0 | 2.8 |
| 450 | 21 | 29 | – | 300 | 300 | – |
| 525 | 18 | 25 | 42 | 300 | 300 | 300 |
| 600 | 16 | 22 | 37 | 300 | 300 | 300 |
| 750 | 13 | 17 | 30 | 300 | 300 | 300 |
| 900 | 11 | 15 | 24 | 300 | 300 | 300 |
| 1050 | 9 | 13 | 21 | 300 | 300 | 300 |
| 1200 | 8 | 11 | 18 | 300 | 300 | 300 |
| 1350 | 7 | 10 | 16 | 400 | 400 | 300 |
| 1500 | 6 | 9 | 15 | 400 | 400 | 300 |
| 1650 | – | 8 | 14 | – | 500 | 400 |
| 1800 | – | 7 | 12 | – | 500 | 400 |
| 2100 | – | 7 | 11 | – | 500 | 500 |
| 2400 | – | – | 9 | – | – | 600 |
| 2600 | – | – | 9 | – | – | 800 |

Notes: 1. Allowable minimum cover is measured from top of pipe to bottom of flexible pavement or top of pipe to top of rigid pavement. Minimum cover in unpaved areas must be maintained.

**INSTALLATION AND BACKFILL OF SPIRAL RIB PIPE**

Satisfactory backfill material, proper placement, and compaction are key factors in obtaining satisfactory performance.

Minimum pipe metal thickness is dependent upon minimum and maximum cover and installation TYPE I, II, or III, as noted in the fill height table. Backfill in the pipe envelope shall be granular materials with little or no plasticity; free from rocks, frozen lumps, and foreign matter that could cause hard spots or that could decompose and create voids; compacted to a minimum 90% S.P.D.

**Installation types are:**

**Type I** Installations can be in an embankment or fill condition. Installations shall meet ASTM A798 requirements. ML and CL materials are typically not recommended. Compaction equipment or methods that cause excessive deflection, distortion, or damage shall not be used.

**Type II** Installations require trench-like conditions where compaction is obtained by hand, or walls behind equipment, or by saturation and vibration. Backfill materials are the same as for TYPE I installations. Special attention should be paid to proper lift thicknesses. Controlled moisture content and uniform gradation of the backfill may be required to limit the compaction effort while maintaining pipe shape.

**Type III** Installations have the same requirements as TYPE II installations except that backfill materials are limited to clean, non-plastic materials that require little or no compaction effort (GP, SP), or to well graded granular materials classified as GW, SW, GM, SM, GC, or SC with a maximum plastic index (PI) of 10. Maximum loose lift thickness shall be 200mm. Special attention to moisture content to limit compaction effort may be required. Soil cement or cement slurries may be used in lieu of the selected granular materials.

**Note:** Simple shape monitoring - measuring the rise and span at several points in the run - is recommended as good practice with all types of installation. It provides a good check on proper backfill placement and compaction methods. Use soil placement and compaction methods which will insure that the vertical pipe dimension (rise) does not increase in excess of 5% of the nominal diameter. Use methods which will insure that the horizontal pipe dimension (span) does not increase in excess of 3% of the nominal diameter. These guidelines will help insure that the final deflections are within normal limits.

**Table 7.13** Depth of cover for structural plate pipe sewers –

| 152mm x 51mm corrugation | | | CS-600, H-25, or E-80 live loads | | | | |
|---|---|---|---|---|---|---|---|
| | Minimum cover (mm) | | Maximum height of cover (m) | | | | |
| | | | Specified steel thickness (mm) | | | | |
| Diameter of pipe (mm) | CS-600 or H-25 | E-80 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 |
| 1500 | 400 | 600 | 32 | 44 | 56 | 68 | 80 |
| 1660 | 400 | 600 | 29 | 40 | 51 | 62 | 72 |
| 1810 | 400 | 600 | 27 | 37 | 47 | 57 | 66 |
| 1970 | 400 | 600 | 25 | 34 | 43 | 52 | 61 |
| 2120 | 400 | 600 | 23 | 31 | 40 | 49 | 57 |
| 2280 | 400 | 600 | 21 | 29 | 37 | 45 | 53 |
| 2430 | 400 | 600 | 20 | 28 | 35 | 43 | 50 |
| 2590 | 600 | 600 | 19 | 26 | 33 | 40 | 47 |
| 2740 | 600 | 600 | 18 | 25 | 31 | 38 | 44 |
| 3050 | 600 | 600 | 16 | 22 | 28 | 34 | 40 |
| 3360 | 600 | 750 | 14.5 | 20 | 26 | 31 | 36 |
| 3670 | 600 | 750 | 13.5 | 18 | 23 | 28 | 33 |
| 3990 | 1000 | 1000 | 12.5 | 17 | 22 | 26 | 31 |
| 4300 | 1000 | 1000 | 11.5 | 16 | 20 | 24 | 28 |
| 4610 | 1000 | 1000 | 10.5 | 14.5 | 19 | 23 | 26.5 |
| 4920 | 1000 | 1000 | 10 | 14 | 17.5 | 21 | 25 |
| 5230 | 1000 | 1250 | 9.5 | 13 | 16.5 | 20 | 23 |
| 5540 | 1000 | 1250 | | 12 | 15 | 18 | 21.5 |
| 5850 | 1000 | 1250 | | 11 | 14 | 17 | 20 |
| 6160 | 1300 | 1500 | | | 13 | 15.5 | 18 |
| 6470 | 1300 | 1500 | | | 12** | 14.5 | 16.5 |
| 6780 | 1300 | 1500 | | | 11 | 13 | 15.5 |
| 7090 | 1300 | 1500 | | | | 12** | 14 |
| 7400 | 1300 | 1500 | | | | 11 | 13 |
| 7710 | 1300 | 1750 | | | | | 12** |
| 8020 | 1300 | 1750 | | | | | 10.5 |

Notes: 1. Backfill around pipe must be compacted to a specified S.P.D. of 90%.
2. Use reasonable care in handling and installation.

**Limit due to flexibility.

**Table 7.14** Depth of cover for structural plate pipe-arch sewers –
152mm x 51mm corrugations CS-600 or H-25 live load

| Span (mm) | Rise (mm) | Minimum thickness (mm) | Minimum cover (mm) | Maximum depth of cover (m) over pipe-arch for soil bearing capacities | | | |
|---|---|---|---|---|---|---|---|
| | | | | 100kpa | 200kpa | 300kpa | 400kpa |
| 2060 | 1520 | 3.0 | 300 | 3.5 | 7.0 | 11.0 | 14.0 |
| 2240 | 1630 | 3.0 | 300 | 3.0 | 6.5 | 10.0 | 13.5 |
| 2440 | 1750 | 3.0 | 300 | 3.0 | 6.5 | 9.5 | 13.0 |
| 2590 | 1880 | 3.0 | 500 | 3.0 | 6.5 | 9.5 | 13.0 |
| 2690 | 2080 | 3.0 | 500 | 3.5 | 7.0 | 10.5 | 14.0 |
| 3100 | 1980 | 3.0 | 500 | | 5.0 | 7.5 | 10.0 |
| 3400 | 2010 | 3.0 | 500 | | 4.0 | 6.0 | 8.0 |
| 3730 | 2290 | 3.0 | 500 | | 5.0 | 7.0 | 9.5 |
| 3890 | 2690 | 3.0 | 500 | | 5.0 | 7.5 | 10.0 |
| 4370 | 2870 | 3.0 | 750 | | 4.5 | 6.5 | 9.0 |
| 4720 | 3070 | 3.0 | 750 | | 3.5 | 6.0 | 8.0 |
| 5050 | 3330 | 4.0 | 750 | | 3.5 | 6.0 | 8.0 |
| 5490 | 3530 | 4.0 | 750 | | | 5.5 | 7.5 |
| 5890 | 3710 | 4.0 | 1000 | | | | 6.5 |
| 6250 | 3910 | 4.0 | 1000 | | | | 6.5 |

Notes: 1. Soil bearing capacity refers to the soil in the region of the pipe corners. The remaining backfill around the pipe-arch must be compacted to a specific S.P.D. of 90%.
2. Use reasonable care in handling and installation.

**Table 7.15** Depth of cover for structural plate arches –
CS-600 or H-25 live load

| Size | | Min. cover (m) | Maximum height of cover (m) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Specified steel thickness (mm) | | | | |
| Span (mm) | Rise (mm) | | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 |
| 1520 | 810 | .4 | 16 | 22 | 28 | 34 | 40 |
| 1830 | 840 | | 13 | 18 | 23 | 28 | 32.5 |
| | 970 | | 13.5 | 18.5 | 23.5 | 28.5 | 33 |
| 2130 | 860 | | 11 | 15.5 | 19.5 | 24 | 28 |
| | 1120 | | 11.5 | 15.5 | 20 | 24.5 | 28.5 |
| 2440 | 1020 | | 10 | 13.5 | 17.5 | 21 | 24.5 |
| | 1270 | .4 | 10 | 14 | 17.5 | 21.5 | 25 |
| 2740 | 1180 | .6 | 9 | 12 | 15.5 | 18.5 | 21.5 |
| | 1440 | | 9 | 12 | 15.5 | 19 | 22 |
| 3050 | 1350 | | 8 | 11 | 14 | 17 | 19.5 |
| | 1600 | | 8 | 11 | 14 | 17.5 | 20 |
| 3350 | 1360 | | 7 | 10 | 12.5 | 15 | 17.5 |
| | 1750 | | 7.5 | 10 | 13 | 15.5 | 18 |
| 3660 | 1520 | | 6.5 | 9 | 11.5 | 14 | 16.5 |
| | 1910 | .6 | 6.5 | 9 | 11.5 | 14 | 16.5 |
| 3960 | 1680 | 1.0 | 6 | 8.5 | 10.5 | 13 | 15 |
| | 2060 | | 6 | 8.5 | 11 | 13 | 15.5 |
| 4270 | 1840 | | 5.5 | 8 | 10 | 12 | 14 |
| | 2210 | | 5.5 | 8 | 10 | 12 | 14 |
| 4570 | 1870 | | 5 | 7 | 9 | 11 | 13 |
| | 2360 | | 5.5 | 7.5 | 9.5 | 11.5 | 13.5 |
| 4880 | 2030 | | | 7 | 8.5 | 10.5 | 12 |
| | 2520 | | | 7 | 9 | 10.5 | 12.5 |
| 5180 | 2180 | | | 6.5 | 8 | 10 | 11.5 |
| | 2690 | | | 6.5 | 8 | 10 | 11.5 |
| 5490 | 2210 | | | 5.5 | 7 | 9 | 10.5 |
| | 2720 | | | 6 | 7.5 | 9 | 10.5 |
| 5790 | 2360 | | | | 7 | 8 | 9.5 |
| | 2880 | 1.0 | | | 7 | 8.5 | 10 |
| 6100 | 2530 | 1.3 | | | 6 | 7.5 | 9 |
| | 3050 | 1.3 | | | 6.5 | 8 | 9 |

**Table 7.16** Depth of cover for structural plate arches – E-80 live load

| Size | | Min. cover (m) | Maximum height of cover (m) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Specified steel thickness (mm) | | | | |
| Span (mm) | Rise (mm) | | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 |
| 1520 | 810 | .6 | 16 | 22 | 28 | 34 | 40 |
| 1830 | 840 | | 13 | 18 | 23 | 28 | 32.5 |
| | 970 | | 13.5 | 18.5 | 23.5 | 28.5 | 33 |
| 2130 | 860 | | 11 | 15.5 | 19.5 | 24 | 28 |
| | 1120 | | 11.5 | 15.5 | 20 | 24.5 | 28.5 |
| 2440 | 1020 | | 10 | 13.5 | 17.5 | 21 | 24.5 |
| | 1270 | | 10 | 14 | 17.5 | 21.5 | 25 |
| 2740 | 1180 | | 8.5 | 12 | 15.5 | 18.5 | 21.5 |
| | 1440 | | 8.5 | 12 | 15.5 | 19 | 22 |
| 3050 | 1350 | | 7.5 | 11 | 14 | 17 | 19.5 |
| | 1600 | .6 | 7.5 | 11 | 14 | 17.5 | 20 |
| 3350 | 1360 | 1.0 | 6.5 | 10 | 12.5 | 15 | 17.5 |
| | 1750 | | 6.5 | 10 | 13 | 15.5 | 18 |
| 3660 | 1520 | | 5.5 | 9 | 11.5 | 14 | 16.5 |
| | 1910 | | 5.5 | 9 | 11.5 | 14 | 16.5 |
| 3960 | 1680 | | | 8 | 10.5 | 13 | 15 |
| | 2060 | | | 8 | 11 | 13 | 15.5 |
| 4270 | 1840 | | | 7 | 10 | 12 | 14 |
| | 2210 | | | 7 | 10 | 12 | 14 |
| 4570 | 1870 | | | 4.5 | 8.5 | 11 | 13 |
| | 2360 | 1.0 | | 5.0 | 9.0 | 11.5 | 13.5 |
| 4880 | 2030 | 1.2 | | | 8.0 | 10.5 | 12 |
| | 2520 | | | | 8.5 | 10.5 | 12.5 |
| 5180 | 2180 | | | | 7.0 | 10 | 11.5 |
| | 2690 | | | | 7.0 | 10 | 11.5 |
| 5490 | 2210 | | | | 5.0 | 8.5 | 10.5 |
| | 2720 | | | | 5.5 | 9.0 | 10.5 |
| 5790 | 2360 | | | | | 7.5 | 9.5 |
| | 2880 | | | | | 8.0 | 10 |
| 6100 | 2530 | | | | | | 8.5 |
| | 3050 | 1.2 | | | | | 8.5 |

**Table 7.17** Minimum cover from top surface of flexible pavement* to corrugated steel pipe – corrugations 68 x 13mm for airplane wheel loads

Minimum depths of cover D, mm

| Wall Thickness, mm | Pipe diameter, mm | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 300 | 400 | 600 | 800 | 1000 | 1200 | 1400 | 1600 | 1800 | 2000 |
| Case 1. Loads to 178 kN – dual wheels | | | | | | | | | | |
| 1.3 | 300 | 300 | 450 | 450 | | | | | | |
| 1.6 | 300 | 300 | 300 | 450 | 450 | 450 | | | | |
| 2.0 | 300 | 300 | 300 | 450 | 450 | 450 | 450 | 450 | | |
| 2.8 | | | 300 | 300 | 300 | 300 | 300 | 300 | 450 | |
| 3.5 | | | | 300 | 300 | 300 | 300 | 300 | 300 | 450 |
| 4.2 | | | | 300 | 300 | 300 | 300 | 300 | 300 | 450 |
| Case 2. Loads to 489 kN – dual wheels | | | | | | | | | | |
| 1.3 | 450 | 600 | 600 | 750 | | | | | | |
| 1.6 | 450 | 450 | 600 | 750 | 750 | 750 | | | | |
| 2.0 | 450 | 450 | 600 | 750 | 750 | 750 | 750 | 750 | | |
| 2.8 | | | 450 | 600 | 600 | 600 | 600 | 600 | 750 | |
| 3.5 | | | | 600 | 600 | 600 | 600 | 600 | 600 | 750 |
| 4.2 | | | | 600 | 450 | 450 | 600 | 600 | 600 | 600 |
| Case 3. Loads to 3336 kN – dual-dual | | | | | | | | | | |
| 1.3 | 600 | 750 | 900 | 900 | | | | | | |
| 1.6 | 600 | 750 | 750 | 900 | 900 | 900 | | | | |
| 2.0 | 600 | 600 | 750 | 750 | 750 | 750 | 900 | 900 | | |
| 2.8 | | | 600 | 750 | 750 | 750 | 750 | 750 | 900 | |
| 3.5 | | | | 600 | 600 | 600 | 750 | 750 | 900 | 900 |
| 4.2 | | | | 600 | 600 | 600 | 750 | 750 | 900 | 900 |
| Case 4. Loads to 6672 kN | | | | | | | | | | |
| 1.3 | 750 | 750 | 900 | 900 | | | | | | |
| 1.6 | 750 | 750 | 750 | 900 | 900 | 900 | | | | |
| 2.0 | 750 | 750 | 750 | 750 | 750 | 750 | 900 | 900 | | |
| 2.8 | | | 750 | 750 | 750 | 750 | 900 | 900 | 900 | |
| 3.5 | | | | 750 | 750 | 750 | 750 | 750 | 900 | 900 |
| 4.2 | | | | | | 750 | 750 | 750 | 900 | 900 |

*From Airport Drainage, U.S. Dept. of Transportation F.A.A. July 1990.

**Table 7.18** Minimum cover from top surface of flexible pavement* to corrugated steel pipe – corrugations 76 x 25mm for airplane wheel loads

Minimum depths of cover D, mm

| Wall Thickness, mm | Pipe Diameter, mm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1200 | 1400 | 1600 | 1800 | 2000 | 2200 | 2400 | 2700 | 3000 |
| Case 1. Loads to 178 kN – dual wheels | | | | | | | | | |
| 1.3 | 600 | 600 | 600 | 600 | | | | | |
| 1.6 | 450 | 450 | 450 | 600 | 600 | 600 | 600 | | |
| 2.0 | 300 | 450 | 450 | 450 | 600 | 600 | 600 | 600 | |
| 2.8 | 300 | 300 | 300 | 300 | 450 | 450 | 450 | 600 | 600 |
| 3.5 | 300 | 300 | 300 | 300 | 300 | 300 | 450 | 600 | 600 |
| 4.2 | 300 | 300 | 300 | 300 | 300 | 300 | 450 | 600 | 600 |
| Case 2. Loads to 489 kN – dual wheels | | | | | | | | | |
| 1.3 | 900 | 900 | 900 | 900 | | | | | |
| 1.6 | 750 | 750 | 750 | 900 | 900 | 900 | 900 | | |
| 2.0 | 600 | 750 | 750 | 750 | 900 | 900 | 900 | 900 | |
| 2.8 | 450 | 600 | 600 | 600 | 600 | 600 | 750 | 900 | 900 |
| 3.5 | 450 | 450 | 450 | 600 | 600 | 600 | 600 | 750 | 750 |
| 4.2 | 450 | 450 | 450 | 450 | 600 | 600 | 600 | 600 | 750 |
| Case 3. Loads to 3336 kN – dual -dual | | | | | | | | | |
| 1.3 | 1050 | 1050 | 1050 | | | | | | |
| 1.6 | 900 | 1050 | 1050 | 1050 | 1050 | 1050 | | | |
| 2.0 | 750 | 900 | 900 | 900 | 1050 | 1050 | 1050 | | |
| 2.8 | 600 | 750 | 750 | 750 | 900 | 900 | 1050 | 1050 | 1050 |
| 3.5 | 600 | 600 | 600 | 750 | 900 | 900 | 900 | 1050 | 1050 |
| 4.2 | 600 | 600 | 600 | 600 | 750 | 750 | 750 | 900 | 900 |
| Case 4. Loads to 6672 kN | | | | | | | | | |
| 1.3 | 1050 | 1050 | 1050 | | | | | | |
| 1.6 | 900 | 1050 | 1050 | 1050 | 1050 | 1050 | | | |
| 2.0 | 750 | 900 | 900 | 900 | 1050 | 1050 | 1050 | | |
| 2.8 | 750 | 750 | 750 | 750 | 900 | 900 | 1050 | 1050 | 1050 |
| 3.5 | 750 | 750 | 750 | 750 | 900 | 900 | 900 | 1050 | 1050 |
| 4.2 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 900 | 900 |

*From Airport Drainage, U.S. Dept. of Transportation F.A.A. July 1970.

**Table 7.19** Minimum cover from top surface of flexible pavement to corrugated steel pipe – 19 x 19 x 190mm spiral rib pipe for airplane wheel loads

Minimum depths of cover D, mm

| Wall Thickness, mm | Pipe diameter, mm | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 450 | 600 | 900 | 1200 | 1500 | 1800 | 2000 | 2400 | 2600 |
| Case 1. Loads to 178 kN – dual wheels | | | | | | | | | |
| 1.6 | 300 | 300 | 450 | 450 | 600 | | | | |
| 2.0 | 300 | 300 | 450 | 450 | 450 | 600 | | | |
| 2.8 | | 300 | 300 | 300 | 300 | 450 | 600 | 750 | 750 |
| Case 2. Loads to 489 kN – dual wheels | | | | | | | | | |
| 1.6 | 450 | 600 | 750 | 750 | 900 | | | | |
| 2.0 | 450 | 600 | 750 | 750 | 750 | 1050 | | | |
| 2.8 | | 450 | 600 | 600 | 600 | 750 | 900 | 1050 | 1050 |
| Case 3. Loads to 3336 kN – dual -dual | | | | | | | | | |
| 1.6 | 750 | 750 | 900 | 900 | 1200 | | | | |
| 2.0 | 600 | 750 | 750 | 750 | 900 | 1200 | | | |
| 2.8 | | 600 | 750 | 750 | 750 | 900 | 1050 | 1200 | 1350 |
| Case 4. Loads to 6672 kN | | | | | | | | | |
| 1.6 | 750 | 750 | 900 | 900 | 1200 | | | | |
| 2.0 | 750 | 750 | 750 | 750 | 900 | 1200 | | | |
| 2.8 | | 750 | 750 | 750 | 750 | 900 | 1050 | 1200 | 1350 |

**Table 7.20** Minimum cover for pipe under rigid pavement* for all loadings and all types of pipe

| |
|---|
| 450mm from top of pipe to bottom of slab |

*From Airport Drainage, U.S. Dept. of Transportation F.A.A. July 1970.

**AERIAL SEWERS**

Should the need arise to run sewers above ground to cross ravines or streams, CSP aerial sewers supported on bents afford an economical solution. Table 7.22 provides a table of allowable spans for this purpose. The table provides for pipes flowing full of water, including the weight of an asphalt-coated pipe. The bending moments were calculated on the basis of a simple span and limited to a factored value of ultimate bending moment. Ultimate moments were determined theoretically and verified by limited testing.

Consideration must be given to the design of the pipe support system. Small diameter pipe with short spans can often be placed directly on bents. Larger diameter pipe should be supported in shaped 120 degree concrete cradles or by a ring girder. The severity of the support requirements increases with diameter and span. Design methods used for smooth steel water pipe systems can be adapted to investigate these requirements.

*CSP aerial sewer being installed.*

**Table 7.21** Minimum cover from top surface of flexible pavement* to structural plate pipe – corrugations 152 x 51mm

| Airport wheel loads | | | |
|---|---|---|---|
| 178 kN | 489 kN | 3336 kN | 6672 kN |
| D/8 but not less than 300mm | D/6 but not less than 450mm | D/5 but not less than 600mm | D/4 but not less than 750mm |

*From Airport Drainage, U.S. Dept. of Transportation F.A.A. July 1970.

**DESIGN OF FITTINGS**

Special structural considerations are appropriate to prevent loss of ring strength when designing fittings for branch connections. If the branch line is at 90 degrees to the main line, the branch line will usually serve to reinforce the opening cut in the main line. However, when the branch is at an acute angle, or in wye branches, it may be necessary to use an insert plate to reinforce the opening. This is particularly true for the larger diameter pipe. Again, design methods used for smooth steel water pipe systems can be adapted to investigate these requirements.

**Table 7.22** Allowable span in metres, for CSP aerial sewers flowing full

| Pipe diameter, mm | Specified steel thickness, mm | | | | |
|---|---|---|---|---|---|
| | 1.6 | 2.0 | 2.8 | 3.5 | 4.2 |
| **68 x 13mm corrugation** | | | | | |
| 600 | 4.0 | 4.6 | 6.1 | – | – |
| 800 | 3.7 | 4.6 | 6.1 | 7.6 | – |
| 1000 | 3.7 | 4.6 | 6.1 | 7.6 | – |
| 1200 | 3.4 | 4.3 | 5.8 | 7.6 | 9.1 |
| 1400 | – | 4.3 | 5.8 | 7.3 | 8.8 |
| 1600 | – | 4.3 | 5.8 | 7.3 | 8.8 |
| 1800 | – | – | 5.5 | 7.3 | 8.8 |
| 2000 | – | – | – | 7.0 | 8.5 |
| **125 x 26 & 76 x 25mm corrugation** | | | | | |
| 1200 | 2.7 | 3.4 | 4.6 | – | – |
| 1400 | 2.4 | 3.0 | 4.3 | 5.5 | – |
| 1600 | 2.4 | 3.0 | 4.3 | 5.5 | – |
| 1800 | 2.4 | 3.0 | 4.3 | 5.5 | 6.7 |
| 2000 | 2.4 | 3.0 | 4.3 | 5.5 | 6.7 |
| 2200 | – | 3.0 | 4.3 | 5.5 | 6.7 |
| 2400 | – | 3.0 | 4.3 | 5.5 | 6.7 |
| 2700 | – | – | 4.3 | 5.5 | 6.4 |
| 3000 | – | – | – | 5.2 | 6.4 |
| **152 x 51mm corrugation** | | | | | |
| 1810 | 4.0 | 5.0 | 6.1 | – | – |
| 2120 | 3.6 | 5.0 | 6.1 | 6.9 | 8.0 |
| 3050 | 3.6 | 4.7 | 5.8 | 6.9 | 8.0 |
| 3670 | 3.6 | 4.7 | 5.8 | 6.9 | 8.0 |
| 4300 | 3.2 | 4.7 | 5.8 | 6.6 | 7.8 |
| 4920 | 3.2 | 4.7 | 5.5 | 6.6 | 7.8 |
| 5540 | – | 4.4 | 5.5 | 6.6 | 7.8 |
| 6160 | – | 4.4 | 5.5 | 6.4 | 7.5 |

## STRUCTURAL DESIGN FOR CSP FIELD JOINTS

For many years the design of field joints for conduits has been a "cookbook" or "recipe" process. That is, all joint details and dimensions were spelled out based on traditional mechanical devices. Little thought was given to the functional requirements of individual pipe jobs, the arbitrary "hardware" being spelled out in most specifications.

More recently, rational structural requirements have been developed for field joints in Corrugated Steel Pipe. Section 23.3 of the AASHTO Bridge Specification contains this important design information. For the convenience of the reader, this section of the AASHTO Specification is reprinted below.

It should be noted that the AASHTO Specification establishes values for required strength parameters of field joints. It does not define any test procedures to measure these values for a specific joint design. It does provide that such values may be determined either by calculation or test.

Many designers have no recourse to make tests and may be unsure of what calculations to make. Such tests and calculations have been made by public agencies and are available.

It should be emphasized that most sewer installations of CSP will require only a "Standard" joint.

*Speed and ease of installation is a major factor in the choice of CSP for storm drainage.*

## 23.3 ASSEMBLY

### 23.3.1 General

**23.3.1.1** Corrugated metal pipe and structural plate pipe shall be assembled in accordance with the manufacturer's instructions. All pipe shall be unloaded and handled with reasonable care. Pipe or plates shall not be rolled or dragged over gravel or rock and shall be prevented from striking rock or other hard objects during placement in trench or on bedding.

**23.3.1.2** Corrugated metal pipe shall be placed on the bed starting at down stream end with the inside circumferential laps pointing downstream.

**23.3.1.3** Bituminous coated pipe and paved invert pipe shall be installed in a similar manner to corrugated metal pipe with special care in handling to avoid damage to coatings. Paved invert pipe shall be installed with the invert pavement placed and centered on the bottom.

**23.3.1.4** Structural plate pipe, pipe arches, and arches shall be installed in accordance with the plans and detailed erection instructions. Bolted longitudinal seams shall be well fitted with the lapping plates parallel to each other. The applied bolt torque for 19mm diameter high strength steel bolts shall be a minimum of l50 Nm and a maximum of 400 Nm. For 19mm diameter aluminum bolts, the applied bolt torque shall be a minimum of 150 Nm and a maximum of 200Nm. There is no structural requirement for residual torque; the important factor is the seam fit-up.

**23.3.1.5** Joints for corrugated metal culvert and drainage pipe shall meet the following performance requirements.

**23.3.1.5.1 Field Joints**

Transverse field joints shall be of such design that the successive connection of pipe sections will form a continuous line free from appreciable irregularities in the flow line. In addition, the joints shall meet the general performance requirements described in items 23.3.1.5.1 through 23.3.1.5.3. Suitable transverse field joints, which satisfy the requirements for one or more of the subsequently defined joint performance categories can be obtained with the following types of connecting bands furnished with the suitable band-end fastening devices.

(a) Corrugated bands.
(b) Bands with projections.
(c) Flat bands.
(d) Bands of special design that engage factory reformed ends of corrugated pipe.
(e) Other equally effective types of field joints may be used with the approval of the Engineer.

*Large diameter twin structures are installed with great savings to the owner.*

**23.3.1.5.2 Joint Types**

Applications may require either "Standard" or "Special" joints. Standard joints are for pipe not subject to large soil movements or disjointing forces; these joints are satisfactory for ordinary installations, where simple slip type joints are typically used. Special joints are for more adverse requirements such as the need to withstand soil movements or resist disjointing forces. Special designs must be considered for unusual conditions as in poor foundation conditions. Downdrain joints are required to resist longitudinal hydraulic forces. Examples of this are steep slopes and sharp curves.

**23.3.1.5.3 Soil Conditions**

(a) The requirements of the joints are dependent on the soil conditions at the construction site. Pipe backfill which is not subject to piping action is classified as "Nonerodible." Such backfill typically includes granular soil (with grain sizes equivalent to coarse sand, small gravel, or larger) and cohesive clays.

(b) Backfill that is subject to piping action, and would tend to infiltrate the pipe to be easily washed by exfiltration of water from the pipe, is classified as "Erodible." Such backfill typically includes fine sands and silts.

(c) Special joints are required when poor soil conditions are encountered such as when the backfill or foundation material is characterized by large soft spots or voids. If construction in such soil is unavoidable, this condition can only be tolerated for relatively low fill heights, because the pipe must span the soft spots and support imposed loads. Backfills of organic silt, which are typically semi-fluid during installation, are included in this classification.

**23.3.1.5.4 Joint Properties**

The requirements for joint properties are divided into the six categories given on Table 23.3. Properties are defined and requirements are given in the following paragraphs (a) through (f). The values for various types of pipe can be determined by a rational analysis or a suitable test.

(a) ***Shear Strength***—The shear strength required of the joint is expressed as a percent of the calculated shear strength of the pipe on a transverse cross section remote from the joint.

(b) ***Moment Strength***—The moment strength required of the joint is expressed as a percent of the calculated moment capacity of the pipe on a transverse cross section remote from the joint.

(c) ***Tensile Strength***—Tensile strength is required in a joint when the possibility exists that a longitudinal load could develop which would tend to separate adjacent pipe section.

(d) ***Joint Overlap***—Standard joints which do not meet the moment strength alternatively shall have a minimum sleeve width overlapping the abutting pipes. The minimum total sleeve width shall be as given in Table 23.3. Any joint meeting the requirements for a special joint may be used in lieu of a standard joint.

(e) ***Soiltightness***—Soiltightness refers to openings in the joint through which soil may infiltrate. Soiltightness is influenced by the size of the opening (maximum dimension normal to the direction that the soil may infiltrate) and the length of the channel (length of the path along which the soil may infiltrate). No opening may exceed 25mm. In addition, for all categories, if the size of the opening exceeds 3mm the length of the channel must be at least four times the size of the opening. Furthermore, for nonerodible or erodible soils, the ratio of $D_{85}$ soil size to size of opening must be greater than 0.3 for medium to fine sand or 0.2 for uniform sand; these ratios need not be met for cohesive backfills where the plasticity index exceeds 12. As a general guideline, a backfill material containing a high percentage of fine grained soils requires investigation for the specific type of joint to be used to guard against soil infiltration. Alternatively, if a joint demonstrates its ability to pass a 14kPa hydrostatic test without leakage, it will be considered soil tight.

(f) ***Watertightness***—Watertightness may be specified for joints of any category where needed to satisfy other criteria. The leakage rate shall be measured with the pipe in place or at an approved test facility. The adjoining pipe ends in any joint shall not vary more than 13mm diameter or more than 38mm in circumference for watertight joints. These tolerances may be attained by proper production controls or by match-marking pipe ends.

**Table 7.23** Categories of pipe joints

| | Soil condition | | | | |
|---|---|---|---|---|---|
| | Nonerodible | | Erodible | | |
| | Joint type | | Joint type | | |
| | Standard | Special | Standard | Special | Downdrain |
| Shear | 2% | 5% | 2% | 5% | 2% |
| Moment[a] | 5% | 15% | 5% | 15% | 15% |
| Tensile 0-1000mm diameter | 0 | 10.2 kN | – | 10.2 kN | 10.2 kN |
| 1200 - 2000mm diameter | – | 20.4 kN | – | 20.4 kN | 20.4 kN |
| Joint overlap[c] (min.) | 300mm | NA | 300mm | NA | NA |
| Soiltightness[b] | NA | NA | 0.3 or 0.2 | 0.3 or 0.2 | 0.3 or 0.2 |
| Watertightness | See paragraph 23.3.1.5.4(f) | | | | |

[a] See paragraph 23.3.1.5.4(b).
[b] Minimum ratio of $D_{85}$ soil size to size of opening 0.3 for medium to find sand and 0.2 for uniform sand.
[c] Alternate requirement. See article 23.3.1.5.4(e).
Structural plate pipe, pipe-arches, and arches shall be installed in accordance with the plans and detailed erection instructions.

## *BIBLIOGRAPHY*

Marston, Anson, "The Theory of External Loads on Closed Conduits," Bulletin No. 96, 1930, Iowa Engineering Experimental Station, Ames, IA, pp. 5-8.

White, H. L., and Layer, J. P., "The Corrugated Metal Conduit as a Compression Ring," *Proceedings of the Highway Research Board,* Vol. 39, 1960, pp. 389-397.

Meyerhof, G. G., and Fisher, C L., "Composite Design of Underground Steel Structures," *Engineering Journal of the Engineering Institute of Canada,* Sept. 1963.

Bacher, A. E., "ProofTesting of a Structural Plate Pipe with Varying Bedding and Backfill Parameters," Federal Highway Adminstration Reports in Progress, California Department of Transportation, Sacramento, CA 95805.

Burns, J. A., and Richard, R. H., "Attenuation of Stresses for Buried Cylinders," *Proceedings of a Symposium on Soil-Structure Interation,* University of Arizona, Sept. 1964, pp. 378-392.

Heog, K., "Stresses Against Underground Cylinders," *Journal of Soil*

*Mechanics and Foundation Division,* American Society of Civil Engineers, Vol. 94, SM4, July 1968, pp. 833 858.

Watkins, R. K., and Moser, R. P., "The Structural Performance of Buried Corrugated Steel Pipes," Sept. 1969, Utah State University, Logan, Utah, and American Iron and Steel Institute, Washinton, DC, 56 pp.

*Standard Specifications for Highway Bridges,* American Association of State Highway and Transportation Officials, 444 North Capitol Street, NW, Suite 225, Washington, DC 20001.

"Specifications for Corrugated Structure Plate Pipe, Pipe-Arches and Arches," *Manual of Recommended Practice,* American Railway Engineering Association, 50 F St. N.W., Washington, DC 20001.

Duncan, J. M., "Soil-Culvert Interaction Method for Design of Culverts," *Transportation Research Record 678,* 1978, Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, Washington, DC 20418, pp. 53-59.

Allgood, J. R., "Structures in Soils Under High Loads," *National Structural Engineering Meeting,* American Society of Civil Engineers, April 1970.

Klöppel, K., and Glock, D. (1970), "Theoretische and Experimentelle Untersuchungen zu den Traglast-problem beigeweichen, in die Erde eingebetter Rohre." *Publication No. 10 of the Instiutes fur Statik and Stahlbau der Technischen Hochschule,* Darmstadt, Germany.

Bulletin No. 22, 1936, University of Illinois Engineering Experiment Station.

Timoshenko, S. P., and Gere, J.M., *Theory of Elastic Stability,* 2nd ed., McGraw-Hill, New York, 1964.

Meyerhof, G. G., and Baikie, L. D., "Strength of Steel Culverts Bearing Against Compacted Sand Backfill," *Highway Research Record No. 30,* 1963, Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, Washington, DC 20418, pp. 1-14.

Demmin, J. "Field Verification of Ring Compression Design," *Highway Research Record No. 116,* 1966, Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, Washington, DC 20418, pp. 36-80.

Bakht, Baider, "Live Load Testing of Soil-Steel Structures", SDR-80-4. August 1980, Ministry of Transportation and Communications, 1200 Wilson Avenue, Central Building, Downsview, Ontario M3M 1J8.

ASTM Standards, Vol. 01.06.

Williams, G. M., "Plans for Pipe Culvert Inlet and Outlet Structure," Circular Memo and Sheets No. G-39-66 to G-44-66, 1966, Federal Highway Administration, 400 7th Street, SW, Washington, DC 20590.

Katona, M. G., et. al., "CANDE-A Modern Approach for Structural Design and Analysis of Buried Culverts," FHWARD-77-5, Oct. 1976, Federal Highway Administration, 400 7th Street, SW, Washington, DC 20590.

*Handbook of Steel Drainage & Highway Construction Products,* 3rd ed., American Iron and Steel Institute, 1133-l5th St. NW, Washington, DC 20005-2701, 1983, 414 pp.

Lane, W. W., "Comparative Studies on Corrugated Metal Culvert Pipes," Building Research Laboratory Report No. EES, February 1965, Ohio State University, Columbus, OH.

Abel, J. F., Falby, W. E., Kulhawy, F. H., Selig, E. T., "Review of the Design and Construction of Long-Span, Corrugated Culverts," August 1977, Federal Highway Administration, Office of Research and Development, 400 7th Street, SW, Washington, DC 20590.