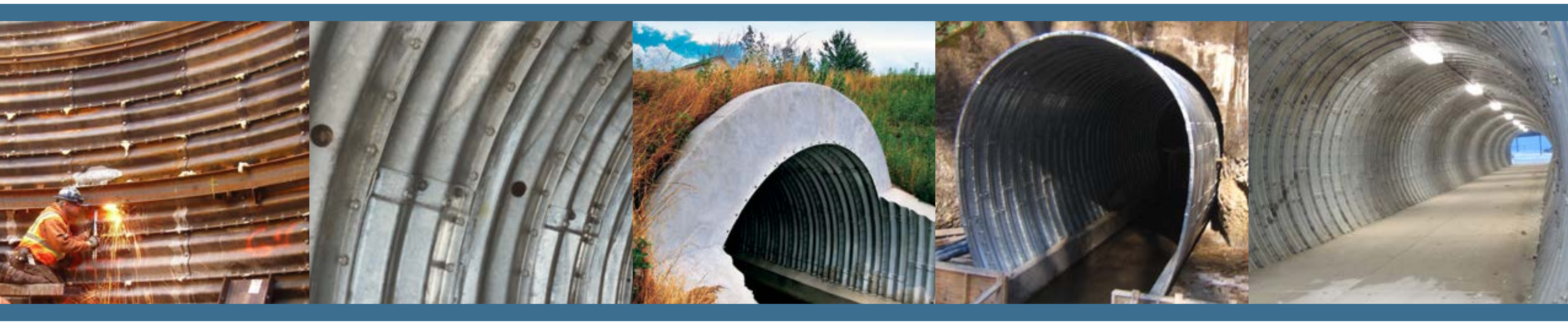
CONTECH
ENGINEERED SOLUTIONS
A QUIKRETE® COMPANY

# 2-Flange Tunnel Liner Plate Design Guide

## 2nd Edition



### Steel Tunnel Liner Plate

### Aluminum Tunnel Liner Plate

# Contech 2-Flange Tunnel Liner Plate

Contech® 2-Flange Tunnel Liner Plate provides optimum stability and protection when constructing new tunnels, relining structures under highways and railroads, and vertical shafts. It offers the highest continuous ring stiffness and high compression joint strength.

2-Flange Tunnel Liner Plate has effective stiffness that is more than twice that of the same gage (thickness) of 4-Flange Liner Plate.

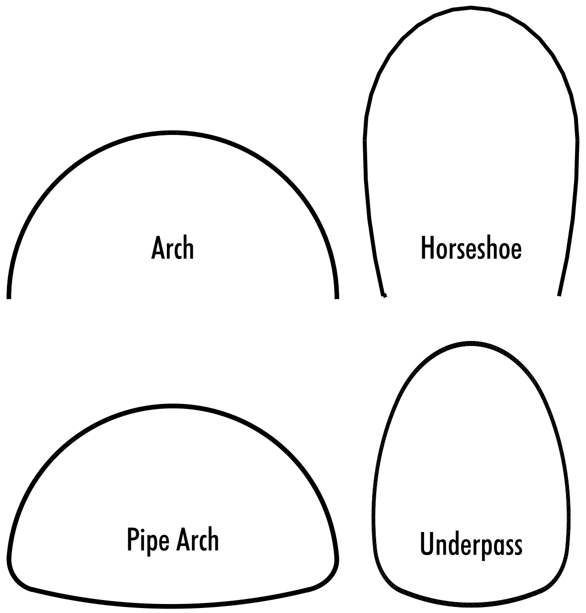
## Applications

- Tunnel Lining
- Relining (rehabilitation of failing structures)
- Both Vertical and Horizontal Shafts

## Features & Benefits

- Minimizes installation expense
- Optimizes stability in both horizontal and vertical applications
- Unsurpassed in strength and safety

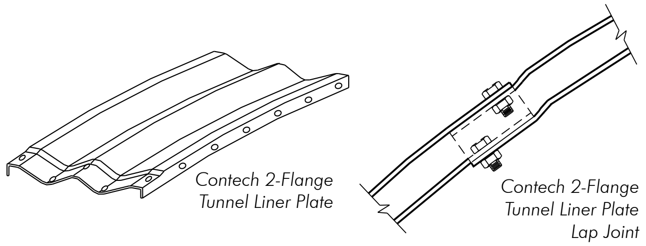
## Special shapes of Contech Liner Plate





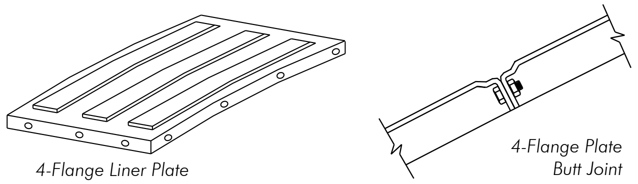

# Contech 2-Flange Tunnel Liner Plate vs. 4-Flange Liner Plate

**2-Flange** Tunnel Liner Plate from Contech provides corrugations extending through the lapped longitudinal joint. When assembled, this liner functions as a corrugated pipe with continuous circumferential corrugations. The result is more effective corrugation performance for the highest stiffness and strength in the industry. It has the strength to handle the loads encountered during construction, providing a safer working environment.




*Deep, full length corrugations and lapped joints for more effective stiffness and ring compression.*

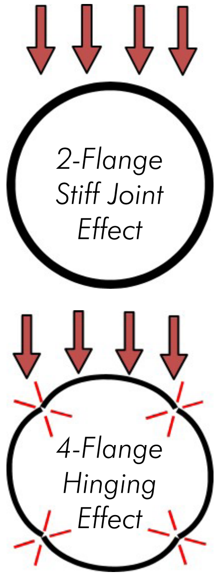
**4-Flange** Liner Plate feature shallow, partial corrugations that do not extend fully to the joint. When assembled, ring stiffness is limited by both the joint strength and lack of a continuous corrugation. The result is less stiffness and a hinge action joint.

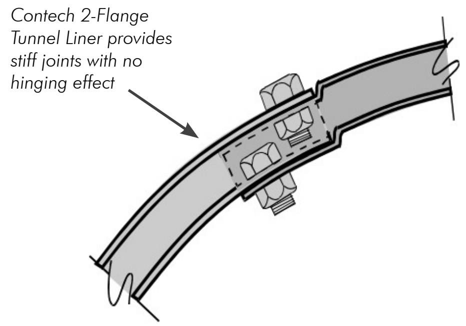



*Shallow corrugations and hinged joint.*

## Key Performance Differences

- Bending strength of the deep, fully corrugated 2-Flange Tunnel Liner Plate is much greater than 4-Flange Liner Plate.
- AASHTO Design Specifications for Tunnel Liner Plate, Section 15, states that effective stiffness of 2-Flange Tunnel Liner Plate is 2.22 x stiffer than equal thickness 4-Flange Liner Plate (111/50 = 2.22 – see Table 1A).
- The overlapped joint of 2-Flange Tunnel Liner Plate provides greater effective stiffness, when assembled, than 4-Flange Liner Plate.
- AASHTO Design Specifications for Tunnel Liner Plate, Section 15, states that the seam strength of 2-Flange Tunnel Liner Plate is up to 30% greater than 4-Flange Liner Plate.




## What is the practical meaning of all this?

During tunnel construction, slough-ins and other concentrated loads are unpredictable and can be catastrophic without adequate protection. A sufficiently stiff tunnel liner functions as a safety zone for workers and equipment. The required amount of liner stiffness depends upon soils, tunnel size and construction methods.

If minimum effective stiffness required for a project is related in terms of thickness of Contech 2-Flange Tunnel Liner Plate, an equally stiff 4-Flange Liner Plate must have more than twice the moment of inertia. Minimum installation stiffness often governs the plate thickness, and in the case of Contech 2-Flange Tunnel Liner Plate, provides the most economical Liner Plate option.

**Table 1A - Equal Stiffness of 2-Flange vs. 4-Flange**

| 2-Flange Tunnel Liner Plate Thickness | Equivalent 4-Flange Liner Plate Thickness |
|---|---|
| 0.075 | 0.179 |
| 0.105 | 0.239 |
| 0.135 | 0.375 |

**Table 1B - Minimum Installation Stiffness**

| 2-Flange Tunnel Liner Plate | Equivalent 4-Flange Liner Plate |
|---|---|
| 50 | 111 |

*NOTE: Per AASHTO Design Specifications for Tunnel Liner Plates, Section 15.*

# AASHTO Design*

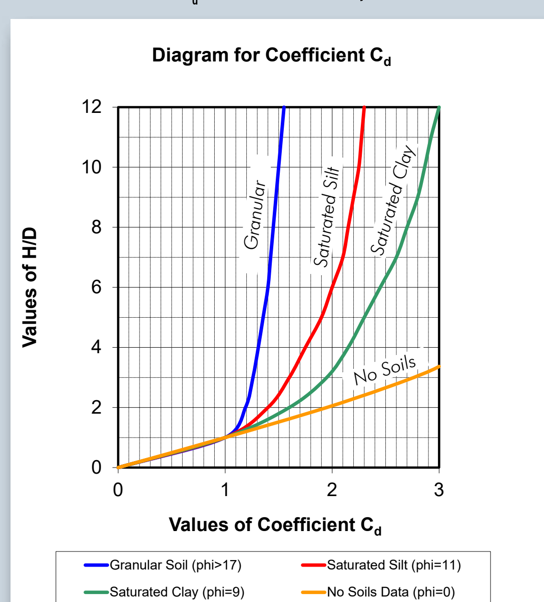
## Loading Considerations

The load carrying capacity of a non-rigid tunnel lining such as a steel Liner Plate results from its ability to deflect under load so that side restraint developed by the lateral resistance of the soil constrains further deflection. Deflection tends to equalize radial pressures resulting in ring compression.

The load carried by the tunnel liner plate is dependent on the type of soil. In granular soil, with little or no cohesion, the load is a function of the internal friction angle (phi,Ø) of the soil and the diameter of the tunnel. In cohesive soils, such as clays and silty clays, the load carried by the tunnel liner is dependent on the shearing strength of the soil above the tunnel.

An appropriate soil test should be performed at each installation site.

Chart I – Coefficient $C_d$ for Tunnels in Soil (ø = Internal Friction Angle)




*Per AASHTO Standard Design Specifications for Tunnel Liner Plates, Section 15 and AASHTO LRFD Section 12.13.*



| TABLE 2 | | | |
|---|---|---|---|
| Live Load Pressure at Tunnel Top ($P_L$) | | | |
| Highway[1] | | Railroad[2] | |
| Height of Cover (ft.) | H 20 Load (lb. per ft.$^2$) | Height of Cover (ft.) | E 80 Load (lb. per ft.$^2$) |
| 4 | 400 | 4 | 3,000 |
| 5 | 250 | 5 | 2,400 |
| 6 | 200 | 8 | 1,600 |
| 7 | 175 | 10 | 1,100 |
| 8 | 100 | 12 | 800 |
| 9 | 90 | 15 | 600 |
| 10 | 75 | 20 | 300 |
| > 10 | 0 | 30 | 100 |

*1. Based on AASHTO Design Specifications*
*2. AREMA Manual for Railway Engineering, Section 1.4*

## Loads per AASHTO Section 15.2

External load on any circular tunnel liner may be predicted by various methods, including actual tests. In cases where more precise methods of analysis are not employed, the external load, P, can be predicted by the following:

- If the grouting pressure is greater than the computed external load, the external load P on the tunnel liner shall be the grouting pressure.
- In general the external load can be computed by the formula:

  $P = P_L + P_d$ (eq. 15-1)

  $P_d = C_d \times W \times D$ (eq. 15-2)

Where:

- P = The external load on the tunnel liner.
- $P_L$ = The vertical load at the level of the top of the tunnel liner due to live loads (see Table 2 for approximate values).
- $P_d$ = The vertical load at the level of the top of the tunnel liner due to dead load.
- $C_d$ = Coefficient for tunnel liner (see Chart I).
- W = Total (moist) unit weight of soil.
- D = Neutral axis diameter of span.*
- H = Height of soil over the top of the tunnel.

Values of $P_d$ may be calculated using Marston's formula for load or any other suitable method.

Eq. 15-1 is a form of the Marston formula. It proportions the amount of total overburden pressure acting on the tunnel based on the internal friction angle of the soil to be tunneled.

In the absence of adequate borings and soil tests, the full overburden height should be the basis for $P_d$ in the Tunnel Liner Plate design: ($P_d$ = H x W).

In addition to the loads described above, grouting pressures should be considered on the tunnel liner.

** D (diameter) as referenced in this brochure always represents a neutral axis dimension.*

# AASHTO Design

## Design Criteria

The following criteria must be considered in the design of Liner Plates:

- Joint strength
- Minimum stiffness for installation
- Critical buckling of the Liner Plate wall
- Deflection or flattening of tunnel section

The design criteria described is per AASHTO design. Other design methodologies and publications may allow different factors of safety and minimum stiffness values.

*Note: Sizes shown in this brochure are to the neutral axis, not the inside diameter.*

## Joint Strength

Seam strength for Liner Plates should be sufficient to withstand the thrust developed from the total load supported by the Liner Plate. This thrust, T, in pounds per linear foot is:

$T = P \times D/2$

Where: P = Load as defined on Page 4.
D = Neutral axis diameter or span.

Thrust, T, multiplied by the factor of safety (FS) as required should not exceed the ultimate seam strength shown in Table 4 on Page 9.

## Minimum Stiffness for Installation

The Liner Plate ring should have enough rigidity to resist the unbalanced loadings of normal construction, including grouting pressure, local slough-ins, and miscellaneous concentrated loads.

The minimum stiffness required for these loads can be expressed for convenience by the following formula.

It must be recognized, however, that the limiting values given here are only recommended minimums. Actual job conditions may require higher values (greater effective stiffness). Final determination on this factor of safety should be based on intimate knowledge of the project, soil conditions, and practical experience.

The minimum stiffness for installation is determined by the formula:

Minimum stiffness = $EI/D^2$

Where: D = Neutral axis diameter or span.
E = Modulus of elasticity, psi.
I = Moment of inertia, (in$^4$/in).

For 2-Flange: $EI/D^2$ = 50 minimum

For 4-Flange: $EI/D^2$ = 111 minimum

*Note: An appropriate factor of safety is recommended. The effect of such an increase in factor of safety on the installed cost of a tunnel is typically very small.*

# AASHTO Design

## Critical Buckling

Wall buckling stresses are determined from the following formulas:

*Determine $D_c$ the critical pipe diameter or span:*

$$D_c = \frac{r}{k}\sqrt{\frac{24E}{f_u}}$$

*For diameters less than $D_c$:*

$$f_{cr} = f_u - \left[\frac{f_u^2}{48E} \times \left(\frac{kD}{r}\right)^2\right] \text{(psi}$$

*For diameters greater than $D_c$ then:*

$$f_{cr} = \frac{12E}{\left(\frac{kD}{r}\right)^2} \text{ (psi)}$$

*Variables as defined by AASHTO Section 15.*

Where: $f_u$ = Minimum specified tensile strength, psi.

$f_{cr}$ = Buckling stress, psi. $f_{cr}$ cannot exceed $f_y$.

k = Soil stiffness factor, will vary from 0.22 for soils with $\varnothing > 15°$ to 0.44 for soils $\varnothing < 15°$.

D = Pipe diameter or max span, inches.

r = Radius of gyration of section, inches.

E = Modulus of elasticity, psi.

ø = Internal friction angle of soil.

Design for buckling is accomplished by limiting the ring compression thrust, T, to the buckling stress multiplied by the effective cross-sectional area of the Liner Plate, A, divided by the factor of safety:

Where: T = Thrust per linear foot.

A = Effective cross-sectional area of Liner Plate, $in^2$/ft.

FS = Factor of safety (2) for buckling.

## Deflection and Grouting

Deflection of a tunnel depends significantly on the amount of over-excavation of the bore and is also affected by delay in grouting or inadequate grouting. The magnitude of deflection is not primarily a function of soil modulus or the Liner Plate properties, so it cannot be computed with usual deflection formulas. Where the tunnel clearances are important, the designer should oversize the structure to provide for normal deflection.

## Minimum Cover

For tunneling, a minimum cover of four feet, depending upon soil material, should be considered to prevent loss of overhead material.

However, actual minimum cover required for a specific tunnel application is highly dependent on various factors, including site conditions, tunnel diameter, soil characteristics, and live load conditions, and must be determined by a qualified engineer or tunneling contractor.



# Design Example

2-Flange Tunnel Liner Plate is designed to provide effective continuous ring stiffness and high compression joint strength. Continuous ring stiffness in 2-Flange Tunnel Liner Plate prevents hinge action at longitudinal joints. This bending strength is useful to maintain structure shape during installation and grouting.

After installation and back grouting, the ring must possess sufficient compressive wall strength and buckling resistance to carry the final loading on the ring. These loads approach a pattern of symmetry and thus place the 2-Flange Tunnel Liner Plate ring primarily in compression.

## Design Example (Steel)

**Assumed**

H = 20' E80 Live Load

D = Dia. = 144" (12')

W = 120 lb./CF (saturated clay)

K = 0.44

E = $29 \times 10^6$ psi

$f_u$ = 42,000 psi*

$f_y$ = 28,000 psi*

**These values are prior to cold working and are conservative for 2-Flange Tunnel Liner Plate.*

Stiffness is often the control for plate thickness, so the calculation for it will be done first.

## I. Minimum Stiffness for Installation

### Construction Load Design

The design engineer should use an appropriate factor of safety for stiffness. Final determination of this factor of safety should be based on intimate knowledge of the project soil conditions and the contractor's experience. In this example a factor of safety of 1.5 was selected.

Stiffness = $EI/D^2$

To provide FS = 1.5, set minimum stiffness equal to 1.5 x 50 = 75. Find requirement of moment of inertia (I).

$$I = \frac{D^2 \times (\text{Minimum Stiffness})}{E} = \frac{(144)^2 (75)}{29 \times 10^6} = 0.0536 \text{ in}^4/\text{in}$$

Select 0.1345" 2-Flange Tunnel Liner Plate with I = 0.064 $in^4$/in (from Table 3 on Page 8).

$$\frac{H}{D} = \frac{20}{12} = 1.67$$

## II. Final Load Design

1. **Find Load**

   Now use Chart I to find that $C_d$ = 1.36

   $P_d = C_d \times W \times D$

   $P_d$ = 1.36 x 120 x 12 = 1,958 lb/$ft^2$

   From Table 2, $P_L$ = 300 lb/$ft^2$

   $P = P_d + P_L$ = 1,958 + 300 = 2,258 lb/$ft^2$

2. **Joint Strength**

   Actual thrust

   T = P x D/2

   T = 2,258 x 12/2

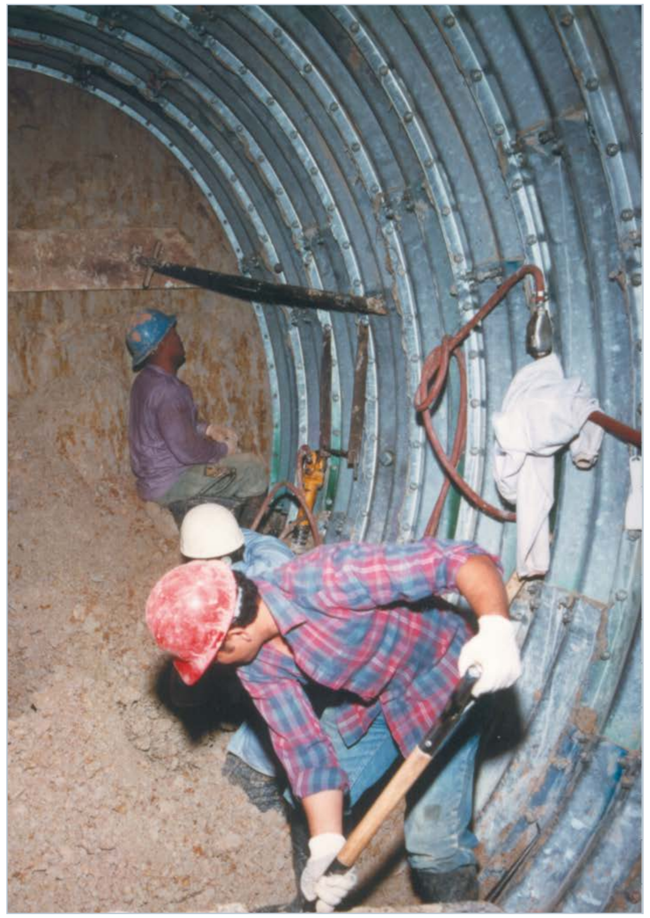
   T = 13,548 lb./LF

Minimum factor of safety required (AASHTO) = 3

From Table 4, 0.1345 2-Flange Tunnel Liner Plate (ultimate seam strength is 47,000 lb./LF)

Check factor of safety 47,000/13,548 = 3.47

3.47 > 3.0, therefore the factor of safety for 2-Flange Tunnel Liner Plate is sufficient for the joint strength.



3. **Critical Buckling**

From Table 3, radius of gyration "r" for 0.1345 plate = 0.606

$$\frac{r}{k}\sqrt{\frac{24E}{f_u}} = \frac{0.606}{0.44}\sqrt{\frac{(24)(29{,}000{,}000)}{42{,}000}} = 177$$

Tunnel diameter (144") is less than 177, therefore use

$$f_y = f_u - \left[\frac{f_u^{\,2}}{48E} \times \left(\frac{D}{r}\right)^2\right]$$

$$= 42{,}000 - \left[\frac{(42{,}000)^2}{48 \times (29 \times 10)^6} \times \left(\frac{0.44 \times 144}{0.606}\right)^2\right] = 28{,}169$$

This exceeds the yield point of the corrugated plate (28,000 psi), therefore use $f_y$ = 28,000 psi. Check factor of safety for 0.1345 2-Flange Tunnel Liner Plate where A = 0.174 in²/ft (Table 3).

The resulting factor of safety is 4.32, which is greater than the required FS of 2.

**TABLE 3 - Properties and Dimensions of 2-Flange Tunnel Liner Plate**

| Nominal Thickness (Inches) t | Area (In² per Inch) A | Section Modulus (In³ per Inch) S | Moment of Inertia (In⁴ per Inch) I | Radius of Gyration (Inches) r | X* (Inches) | Approx. Plate Weights including Bolts (Pounds) | | |
|---|---|---|---|---|---|---|---|---|
| **STEEL** | | | | | | 12 Pi. Plate | 14 Pi. Plate | 16 Pi. Plate |
| 14 GA** / 0.0747 | 0.096 | 0.0323 | 0.034 | 0.595 | 0.757 | 25 | 28 | 31 |
| 12 GA / 0.1046 | 0.135 | 0.0457 | 0.049 | 0.602 | 0.779 | 33 | 37 | 42 |
| 10 GA / 0.1345 | 0.174 | 0.0590 | 0.064 | 0.606 | 0.799 | 41 | 47 | 52 |
| 8 GA / 0.1644 | 0.213 | 0.0726 | 0.079 | 0.609 | 0.819 | 49 | 56 | 63 |
| 7 GA / 0.1793 | 0.233 | 0.0798 | 0.087 | 0.611 | 0.831 | 53 | 61 | 68 |
| 5 GA / 0.2092 | 0.272 | 0.0928 | 0.103 | 0.615 | 0.848 | 61 | 70 | 79 |
| 3 GA / 0.2391 | 0.312 | 0.1065 | 0.118 | 0.615 | 0.869 | 70 | 80 | 90 |
| **ALUMINUM** | | | | | | 12 Pi. Plate | 14 Pi. Plate | 16 Pi. Plate |
| 0.125 | 0.160 | 0.0540 | 0.0583 | 0.603 | 0.782 | 15 | 17 | 19 |
| 0.150 | 0.191 | 0.0649 | 0.0711 | 0.610 | 0.799 | 17 | 19 | 22 |
| 0.175 | 0.227 | 0.0756 | 0.0842 | 0.610 | 0.827 | 19 | 22 | 25 |
| 0.200 | 0.260 | 0.0864 | 0.0972 | 0.611 | 0.842 | 21 | 24 | 27 |
| 0.225 | 0.292 | 0.0972 | 0.1108 | 0.615 | 0.851 | 24 | 27 | 30 |
| 0.250 | 0.325 | 0.1080 | 0.1230 | 0.615 | 0.874 | 26 | 30 | 33 |

* X = Distance from outer face to neutral axis, in inches. See page 9, Section B-B.

** 14 GA is available upon special request.

Refer to AASHTO Standard Specifications for Highway Bridges Section 15, and AASHTO LRFD Bridge Design Specifications Section 12.

Refer to Section 12.13 for t, A, I, and r; and Table 12.13.3.1-1 for nominal thicknesses (uncoated). Aluminum values are determined by the same design method.



# Additional Data for 2-Flange Tunnel Liner Plate

*Full depth corrugation with offset end.*

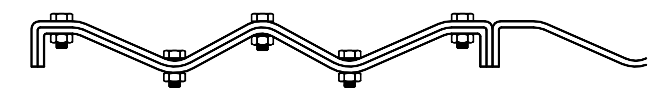
*Full depth corrugation with standard end.*

**TABLE 4 - Ultimate Longitudinal Seam Strength for 2-Flange Tunnel Liner Plate (lb/LF)**

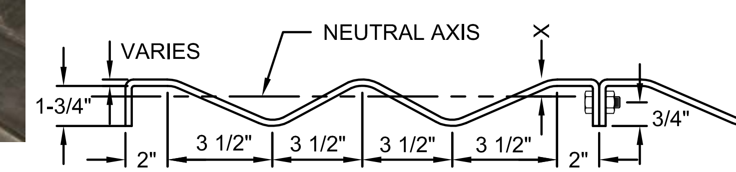
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **STEEL** | | | | | | | |
| Specified Thickness | 0.0747 | 0.1046 | 0.1345 | 0.1644 | 0.1793 | 0.2092 | 0.2391 |
| Strength lb./ft. | 20,000 | 30,000 | 47,000 | 55,000 | 62,000 | 87,000 | 92,000 |
| **ALUMINUM** | | | | | | | |
| Specified Thickness | | 0.125 | 0.150 | 0.175 | 0.200 | 0.225 | 0.250 |
| Strength lb./ft. | | 35,000 | 45,000 | 50,000 | 60,000 | 70,000 | 74,000 |

*Note: In 0.0747 through 0.1793 thickness structures, longitudinal bolts are ASTM A 307, Grade A, 5/8" diameter by 1 1/4" long. For a thickness greater than 0.1793", the bolts are ASTM A449 Type 1, 5/8" diameter by 1 1/2" long.*

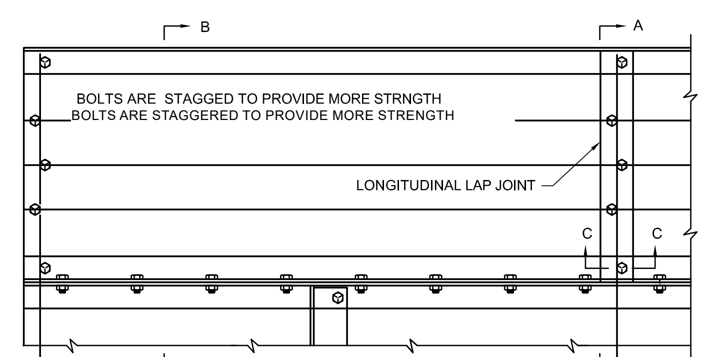
*2-Flange Lap Joint*

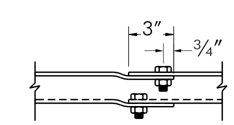


Section A-A

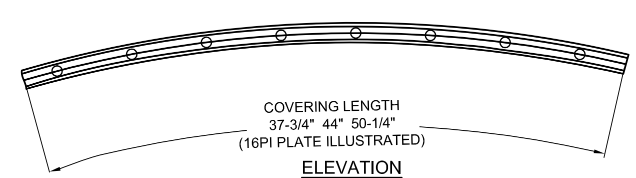



Section B-B




Section C-C




## Inside Dimensions

Actual reduction from neutral axis to inside value is less than the theoretical dimensions in Section B-B. To determine inside dimension, average reduction of all gages is 1 1/8" on radii or 2 1/4" on diameter.

Minimum Curving Radius = 24" (neutral axis)

# General Considerations

## Construction and Design

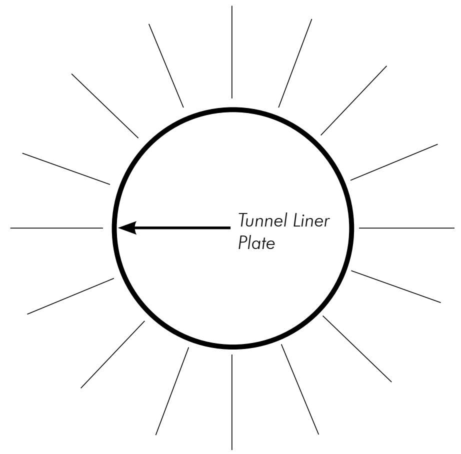
Tunnel loads vary widely in magnitude and classification, depending on the soils encountered and construction practices. Loads encountered during the tunneling operation are entirely different from those on the finished and grouted tunnel.

Once construction is finished and the tunnel has been grouted, a relatively uniform load distribution develops around the structure. These final loads consist of dead and live loads, if applicable.

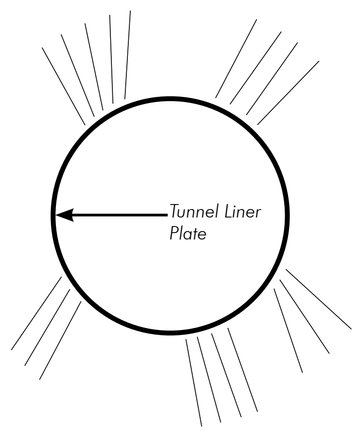
Since loads that develop during construction depend on the tunneling procedure and soil conditions, they are difficult to predict. The installing contractor often encounters slough-ins, hydrostatic soil pressures and other forms of point loading. Handling these temporary loads, prior to backgrouting, requires proper equipment and good techniques to maintain the correct shape of the tunnel liner.

The designer should be aware that construction loads typically control the design especially in soft ground or hand-mined tunnels.

Contractors and designers utilize effectively designed liner structures with high bending resistance (stiffness) to resist concentrated loads that are common during construction.




Final Load




Construction Load
*(often controls)*

## Material and Coating Considerations

**Black Steel »** Offers both the lowest cost and high strength. Good for temporary and sacrificial requirements.

**Dip-Galvanized Steel »** Longer Service life than that of black steel.

**Dip-Galvanized & Asphalt Coated Steel »** Additional corrosion resistance & abrasion resistance.

**Aluminized Steel Type 2 (ALT2) »** Provides longer service life in certain environmental conditions that would be detrimental to a zinc/galvanic coating. Only available in 10 and 12 gages.

**Aluminum »** Provides longer service life in certain environmental conditions that would be detrimental to a zinc/galvanic coating. It is a lighter material and is easily carried into the structure. Most often considered for relines, where steel or galvanized steel has deteriorated.

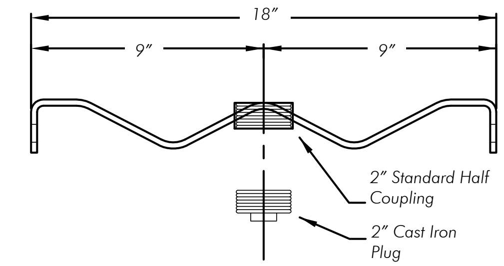


# Grout Options

## Grout Coupling with Plug

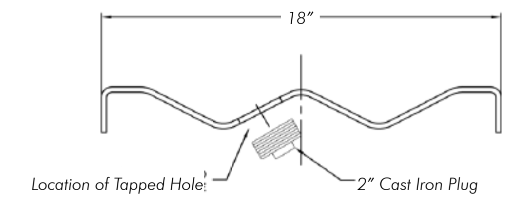
For pressure grouting, liner sections may be supplied with 2″ standard pipe half couplings welded into a hole in the center corrugation. Couplings are fitted with threaded plugs. These couplings are used:

- For lighter gages
- When required by specification



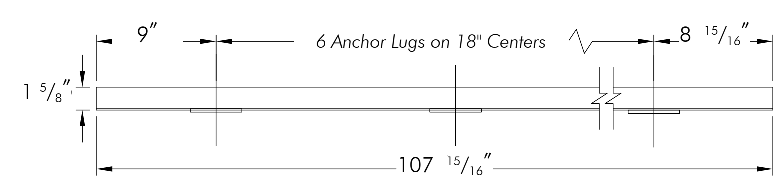

## Tapped Grout Holes

As an option, grout holes may be supplied as threaded holes on 12 GA steel and heavier plates for 2″ standard pipe located in the side of the center corrugation, in the middle of the plate.

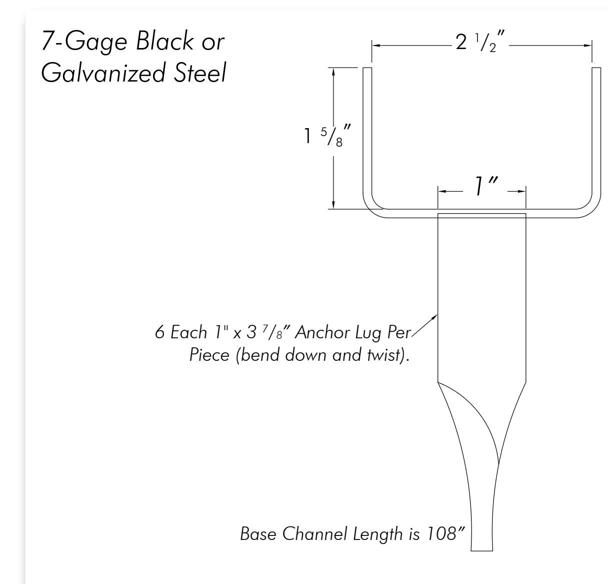



## Base Channel for Arches

Base channels are used to support arch-shaped tunnel liners.




Side View




Section View

# Specification Guidelines

## Scope

This specification covers 2-Flange Tunnel Liner Plate, fabricated to permit field assembly of structure. The tunnel structure shall match the neutral axis diameter and/or shape and gage shown on the plans.

## Material

Plates shall be accurately curved to suit the tunnel cross-section and shall be of uniform fabrication to allow plates of similar curvature to be interchanged. All plates shall be punched for bolting on both the longitudinal and circumferential seams and shall be fabricated as to permit complete erection from the inside of the tunnel. Circumferential bolt hole spacing will be a multiple of the plate length to allow staggering of the longitudinal seam. Circumferential bolt spacing shall be 6 1/4" unless otherwise specified. All materials shall be fabricated in the U.S.A.

Grout holes shall be two inches (2") in diameter and shall be provided as shown on the shop drawings to permit grouting as the assembly of the Liner Plate proceeds.

### STEEL - per ASTM A1011 & A1018

## Dip-Galvanized & Asphalt Options

Material to be galvanized shall be zinc coated in accordance with ASTM Specification A123, except that the zinc shall be applied at the rate of two ounces per square foot total for both sides or may be manufactured from galvanized steel (AASHTO M218). When specified, plates shall be bituminous coated to conform to AASHTO M190.

## Aluminized Steel Type 2

Material to be coated in accordance with AASHTO M274. Available in 10 GA and 12 GA.

### ALUMINUM - per ASTM B746

## Aluminum

Material to be fabricated from aluminum plates conforming to the chemical and mechanical properties of the base metal for Alloy 5052-H141 temper. Plates shall be of the gage shown on the plans and shall be curved to suit the tunnel cross section shown.

## Bolts and Nuts

Bolts and nuts shall be 5/8" in diameter and length as recommended by the manufacturer. Galvanizing shall conform to ASTM B695, Class 50.

## Design

Liner Plate shall be designed per the methodology of the AASHTO Standard Design Specification for Tunnel Liner Plates Section 15, AASHTO LRFD Section 12, or AREMA.

## Installation and Grouting

Liner Plate shall be assembled in accordance with manufacturer's recommendations. Longitudinal seams shall be staggered between rings. After rings have been installed, back grouting to fill any voids should be conducted in a manner to prevent buckling or shifting of the liner ring. The grouting crews should be scheduled as soon as practical behind the assembly operation. Staged grouting in proper lifts is important. Grouting material to be determined by the project specification.

## Excavation

Care should be taken during excavation to eliminate voids and maintain maximum plate-to-ground contact. Efficient tunneling reduces the quantity and frequency of back grouting, helps maintain tunnel shape, and proper ring compression of the Liner Plate.

In unstable soils, it is important that tunnel headings be continuously protected against any loss of ground materials. Poling plates, breast boards, shields, and soil solidification have been successful in controlling tunnel headings under unstable conditions. Use of any one of a combination of these methods may be necessary for the proper and safe advancement of the tunnel. The contractor shall be responsible for the safety of his/her employees and agents. Adequate safety measure is the contractor's responsibility and shall be given to all personnel employed by his/her firm.

## Stiffness

Wherever the soil becomes unstable, the loads on the tunnel tend to increase. Maximum ring stiffness under these conditions becomes of prime importance.

*Contech Tunnel Liner Plate is fabricated in the United States of America.*



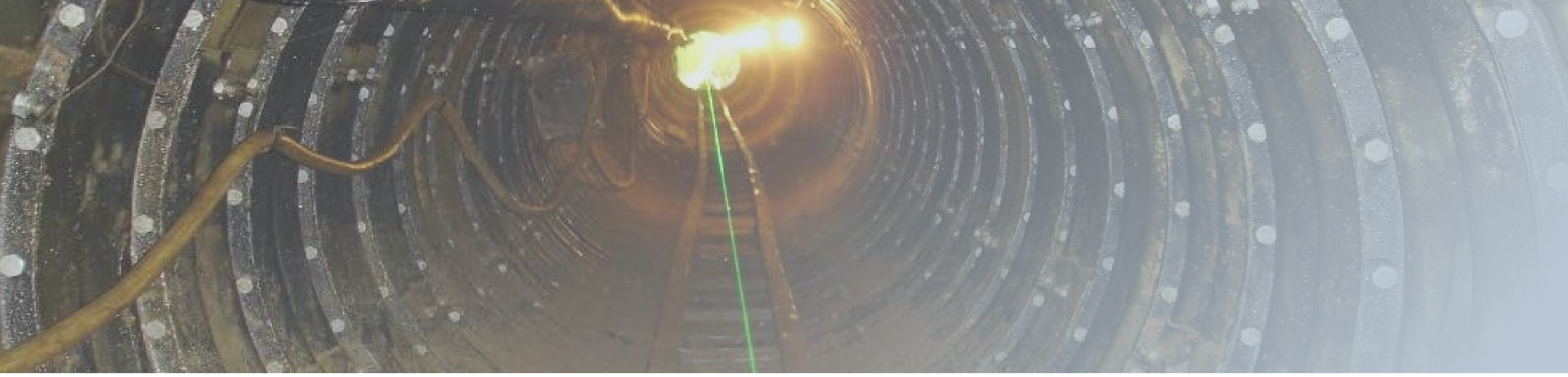
**TABLE 5**

**Table of Available Diameters and Dimensions, Including Number of Specific Types of Plates Required**

| Neutral Axis Diameter- | Approx. Inside Diameter-Inches | Approx. Outside Diameter-Inches | Approx. Outside Area-SF | Total Number Required | Plates Per Ring Plate Lengths and Offsets* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 12 Pi Plate | | | 14 Pi Plate | | | 16 Pi Plate | | |
| | | | | | N | S | D | N | S | D | N | S | D |
| 48 | 45.25 | 49.25 | 13.2 | 4 | 1 | 2 | 1 | | | | | | |
| 50 | 47.25 | 51.25 | 14.3 | 4 | | 2 | 1 | 1 | | | | | |
| 52 | 49.25 | 53.25 | 15.5 | 4 | | 2 | | 1 | | 1 | | | |
| 54 | 51.25 | 55.25 | 16.6 | 4 | | | 1 | 1 | 2 | | | | |
| 56 | 53.25 | 57.25 | 17.9 | 4 | | | | 1 | 2 | 1 | | | |
| 58 | 55.25 | 59.25 | 19.1 | 4 | | | | | 2 | 1 | 1 | | |
| 60 | 57.25 | 61.25 | 20.4 | 4 | | | | | 2 | | 1 | | 1 |
| 62 | 59.25 | 63.25 | 21.8 | 4 | | | | | | 1 | 1 | 2 | |
| 64 | 61.25 | 65.25 | 23.2 | 4 | | | | | | | 1 | 2 | 1 |
| 66 | 63.25 | 67.25 | 24.6 | 5 | 1 | | 1 | | 3 | | | | |
| 68 | 65.25 | 69.25 | 26.1 | 5 | | | 1 | 1 | 3 | | | | |
| 70 | 67.25 | 71.25 | 27.7 | 5 | | | | 1 | 3 | 1 | | | |
| 72 | 69.25 | 73.25 | 29.2 | 5 | | | | | 3 | 1 | 1 | | |
| 74 | 71.25 | 75.25 | 30.8 | 5 | | | | | 3 | | 1 | | 1 |
| 76 | 73.25 | 77.25 | 32.5 | 5 | | | | 1 | | 1 | | 3 | |
| 78 | 75.25 | 79.25 | 34.2 | 5 | | | | | | 1 | 1 | 3 | |
| 80 | 77.25 | 81.25 | 36.0 | 5 | | | | | | | 1 | 3 | 1 |
| 82 | 79.25 | 83.25 | 37.8 | 6 | | | 1 | 1 | 4 | | | | |
| 84 | 81.25 | 85.25 | 39.7 | 6 | | | | 1 | 4 | 1 | | | |
| 86 | 83.25 | 87.25 | 41.6 | 6 | | | | | 4 | 1 | 1 | | |
| 88 | 85.25 | 89.25 | 43.5 | 6 | | | | | 4 | | 1 | | 1 |
| 90 | 87.25 | 91.25 | 45.4 | 6 | | | | | 3 | | 1 | 1 | 1 |
| 92 | 89.25 | 93.25 | 47.4 | 6 | | | | 1 | | 1 | | 4 | |
| 94 | 91.25 | 95.25 | 49.4 | 6 | | | | | | 1 | 1 | 4 | |
| 96 | 93.25 | 97.25 | 51.5 | 6 | | | | | | | 1 | 4 | 1 |
| 98 | 95.25 | 99.25 | 53.6 | 7 | | | | 1 | 5 | 1 | | | |
| 100 | 97.25 | 101.25 | 55.8 | 7 | | | | | 5 | 1 | 1 | | |
| 102 | 99.25 | 103.25 | 58.1 | 7 | | | | | 5 | | 1 | | 1 |
| 104 | 101.25 | 105.25 | 60.3 | 7 | | | | | 4 | | 1 | 1 | 1 |
| 106 | 103.25 | 107.25 | 62.6 | 7 | | | | 1 | 1 | 1 | | 4 | |
| 108 | 105.25 | 109.25 | 65.0 | 7 | | | | 1 | | 1 | | 5 | |
| 110 | 107.25 | 111.25 | 67.5 | 7 | | | | | | 1 | 1 | 5 | |
| 112 | 109.25 | 113.25 | 70.0 | 7 | | | | | | | 1 | 5 | 1 |
| 114 | 111.25 | 115.25 | 72.5 | 8 | | | | | 6 | 1 | 1 | | |
| 116 | 113.25 | 117.25 | 75.0 | 8 | | | | | 6 | | 1 | | 1 |
| 118 | 115.25 | 119.25 | 77.5 | 8 | | | | | 5 | | 1 | 1 | 1 |
| 120 | 117.25 | 121.25 | 80.1 | 8 | | | | | 4 | | 1 | 2 | 1 |
| 122 | 119.25 | 123.25 | 82.9 | 8 | | | | 1 | 1 | 1 | | 5 | |
| 124 | 121.25 | 125.25 | 85.8 | 8 | | | | 1 | | 1 | | 6 | |
| 126 | 123.25 | 127.25 | 88.5 | 8 | | | | | | 1 | 1 | 6 | |
| 128 | 125.25 | 129.25 | 90.5 | 8 | | | | | | | 1 | 6 | 1 |
| 130 | 127.25 | 131.25 | 93.9 | 9 | | | | | 7 | | 1 | | 1 |
| 132 | 129.25 | 133.25 | 96.8 | 9 | | | | | 6 | | 1 | 1 | 1 |
| 134 | 131.25 | 135.25 | 99.8 | 9 | | | | | 5 | | 1 | 2 | 1 |
| 136 | 133.25 | 137.25 | 102.8 | 9 | | | | | 4 | | 1 | 3 | 1 |
| 138 | 135.25 | 139.25 | 105.8 | 9 | | | | 1 | 1 | 1 | | 6 | |
| 140 | 137.25 | 141.25 | 108.8 | 9 | | | | 1 | | 1 | | 7 | |
| 142 | 139.25 | 143.25 | 111.9 | 9 | | | | | | 1 | 1 | 7 | |
| 144 | 141.25 | 145.25 | 115.0 | 9 | | | | | | | 1 | 7 | 1 |
| 146 | 143.25 | 147.25 | 118.1 | 10 | | | | | 7 | | 1 | 1 | 1 |
| 148 | 145.25 | 149.25 | 121.3 | 10 | | | | | 6 | | 1 | 2 | 1 |
| 150 | 147.25 | 151.25 | 124.5 | 10 | | | | | 5 | | 1 | 3 | 1 |
| 152 | 149.25 | 153.25 | 128.0 | 10 | | | | | 4 | | 1 | 4 | 1 |
| 154 | 151.25 | 155.25 | 131.5 | 10 | | | | 1 | 1 | 1 | | 7 | |
| 156 | 153.25 | 157.25 | 135.0 | 10 | | | | 1 | | 1 | | 8 | |
| 158 | 155.25 | 159.25 | 138.5 | 10 | | | | | | 1 | 1 | 8 | |
| 160 | 157.25 | 161.25 | 141.9 | 10 | | | | | | | 1 | 8 | 1 |
| 162 | 159.25 | 163.25 | 145.5 | 11 | | | | | 7 | | 1 | 2 | 1 |
| 164 | 161.25 | 165.25 | 149.0 | 11 | | | | | 6 | | 1 | 3 | 1 |
| 166 | 163.25 | 167.25 | 152.6 | 11 | | | | | 5 | | 1 | 4 | 1 |
| 168 | 165.25 | 169.25 | 156.3 | 11 | | | | | 4 | | 1 | 5 | 1 |
| 170 | 167.25 | 171.25 | 160.0 | 11 | | | | 1 | 1 | 1 | | 8 | |
| 172 | 169.25 | 173.25 | 163.8 | 11 | | | | 1 | | 1 | | 9 | |
| 174 | 171.25 | 175.25 | 167.6 | 11 | | | | | | 1 | 1 | 9 | |
| 176 | 173.25 | 177.25 | 171.5 | 11 | | | | | | | 1 | 9 | 1 |
| 178 | 175.25 | 179.25 | 175.5 | 12 | | | | | 7 | | 1 | 3 | 1 |
| 180 | 177.25 | 181.25 | 179.5 | 12 | | | | | 6 | | 1 | 4 | 1 |
| *Larger diameters, in 2" increments, are available on request.* | | | | | | | | | | | | | |

Note: Where the tunnel clearances are important, the designer should size the structure to provide for normal deflection.

* *Type of offset at ends of plate. N = No Offset; S = Single Offset, D = Double Offset; Diameters are available above those shown in the same pattern. Structures designed for 4 Pi (12.5") stagger in longitudinal seams in alternate rings.*



## Table 6
## 2-Flange Steel Tunnel Liner Plate - Weight by Diameter

| Neutral Axis Diameter | | 14 GA | | 12 GA | | 10 GA | | 8 GA | | 7 GA | | 5 GA | | 3 GA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inches | Meters | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M |
| 48 | 1.22 | 65 | 96 | 86 | 128 | 107 | 159 | 127 | 189 | 138 | 205 | 160 | 238 | 183 | 272 |
| 50 | 1.27 | 67 | 99 | 89 | 132 | 111 | 165 | 132 | 196 | 143 | 213 | 166 | 247 | 191 | 284 |
| 52 | 1.32 | 68 | 102 | 91 | 135 | 114 | 170 | 137 | 204 | 148 | 220 | 170 | 253 | 195 | 290 |
| 54 | 1.37 | 71 | 106 | 95 | 141 | 118 | 176 | 142 | 211 | 153 | 228 | 177 | 264 | 207 | 308 |
| 56 | 1.42 | 74 | 109 | 98 | 146 | 122 | 182 | 147 | 219 | 159 | 237 | 183 | 272 | 215 | 320 |
| 58 | 1.47 | 76 | 113 | 101 | 150 | 126 | 187 | 151 | 225 | 164 | 244 | 189 | 281 | 223 | 332 |
| 60 | 1.52 | 79 | 117 | 105 | 156 | 130 | 193 | 156 | 232 | 169 | 251 | 195 | 290 | 230 | 342 |
| 62 | 1.57 | 81 | 121 | 108 | 161 | 134 | 199 | 161 | 240 | 174 | 259 | 207 | 308 | 237 | 353 |
| 64 | 1.63 | 83 | 124 | 111 | 165 | 138 | 205 | 166 | 247 | 179 | 266 | 210 | 312 | 244 | 363 |
| 66 | 1.68 | 88 | 132 | 117 | 174 | 145 | 216 | 174 | 259 | 188 | 280 | 217 | 323 | 256 | 381 |
| 68 | 1.73 | 90 | 134 | 120 | 179 | 149 | 222 | 178 | 265 | 193 | 287 | 223 | 332 | 263 | 391 |
| 70 | 1.78 | 92 | 137 | 123 | 183 | 153 | 228 | 183 | 272 | 198 | 295 | 229 | 341 | 270 | 402 |
| 72 | 1.83 | 95 | 141 | 126 | 187 | 157 | 234 | 188 | 280 | 204 | 304 | 235 | 350 | 277 | 412 |
| 74 | 1.88 | 97 | 144 | 129 | 192 | 161 | 240 | 193 | 287 | 209 | 311 | 241 | 359 | 284 | 423 |
| 76 | 1.93 | 99 | 147 | 132 | 196 | 165 | 245 | 198 | 295 | 214 | 318 | 247 | 367 | 291 | 433 |
| 78 | 1.98 | 101 | 151 | 135 | 201 | 169 | 251 | 202 | 301 | 219 | 326 | 253 | 376 | 298 | 443 |
| 80 | 2.03 | 104 | 155 | 139 | 207 | 173 | 257 | 207 | 308 | 224 | 333 | 259 | 385 | 305 | 454 |
| 82 | 2.08 | 108 | 161 | 144 | 214 | 180 | 268 | 215 | 320 | 233 | 347 | 269 | 400 | 317 | 472 |
| 84 | 2.13 | 110 | 164 | 147 | 219 | 184 | 274 | 220 | 327 | 238 | 354 | 275 | 409 | 324 | 482 |
| 86 | 2.18 | 113 | 168 | 151 | 225 | 188 | 280 | 225 | 335 | 243 | 362 | 281 | 418 | 331 | 492 |
| 88 | 2.24 | 116 | 172 | 154 | 229 | 192 | 286 | 229 | 341 | 248 | 369 | 287 | 427 | 338 | 503 |
| 90 | 2.29 | 118 | 175 | 157 | 234 | 196 | 292 | 234 | 348 | 253 | 376 | 293 | 436 | 345 | 513 |
| 92 | 2.34 | 120 | 179 | 160 | 238 | 200 | 298 | 239 | 356 | 259 | 385 | 299 | 445 | 352 | 524 |
| 94 | 2.39 | 122 | 182 | 163 | 243 | 203 | 302 | 244 | 363 | 264 | 393 | 304 | 452 | 359 | 534 |
| 96 | 2.44 | 125 | 185 | 166 | 247 | 207 | 308 | 248 | 369 | 269 | 400 | 310 | 461 | 367 | 546 |
| 98 | 2.49 | 129 | 192 | 172 | 256 | 214 | 318 | 257 | 382 | 278 | 414 | 320 | 476 | 378 | 562 |
| 100 | 2.54 | 131 | 195 | 175 | 260 | 218 | 324 | 261 | 388 | 283 | 421 | 326 | 485 | 385 | 573. |
| 102 | 2.59 | 134 | 199 | 178 | 265 | 222 | 330 | 266 | 396 | 288 | 428 | 332 | 494 | 392 | 583 |
| 104 | 2.64 | 136 | 202 | 181 | 269 | 226 | 336 | 271 | 403 | 293 | 436 | 338 | 503 | 399 | 594 |
| 106 | 2.69 | 139 | 206 | 185 | 275 | 230 | 342 | 276 | 411 | 298 | 443 | 344 | 512 | 406 | 604 |
| 108 | 2.74 | 141 | 210 | 188 | 280 | 234 | 348 | 280 | 417 | 303 | 451 | 350 | 521 | 414 | 616 |
| 110 | 2.79 | 143 | 213 | 191 | 284 | 238 | 354 | 285 | 424 | 308 | 458 | 356 | 530 | 421 | 626 |
| 112 | 2.84 | 146 | 216 | 194 | 289 | 242 | 360 | 290 | 431 | 314 | 467 | 362 | 539 | 428 | 637 |
| 114 | 2.90 | 150 | 223 | 200 | 298 | 249 | 370 | 298 | 443 | 323 | 481 | 372 | 553 | 439 | 653 |

Notes: Approximate weights may be extrapolated for diameters greater than 180 inches.
Weight based on dip-galvanized material and includes bolts and nuts.
Call for aluminum tunnel liner plate weights.



## Table 6 (continued)
## 2-Flange Steel Tunnel Liner Plate - Weight by Diameter

| Neutral Axis Diameter | | 14 GA | | 12 GA | | 10 GA | | 8 GA | | 7 GA | | 5 GA | | 3 GA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inches | Meters | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M | LB/FT | KG/M |
| 116 | 2.95 | 152 | 227 | 203 | 302 | 253 | 376 | 303 | 451 | 328 | 488 | 378 | 562 | 446 | 664 |
| 118 | 3.00 | 155 | 230 | 206 | 306 | 257 | 382 | 308 | 458 | 333 | 495 | 384 | 571 | 453 | 674 |
| 120 | 3.05 | 157 | 233 | 209 | 311 | 261 | 388 | 312 | 464 | 338 | 503 | 390 | 580 | 460 | 684 |
| 122 | 3.10 | 159 | 237 | 212 | 315 | 265 | 394 | 317 | 472 | 343 | 510 | 396 | 589 | 468 | 696 |
| 124 | 3.15 | 161 | 240 | 215 | 320 | 269 | 400 | 322 | 479 | 348 | 518 | 402 | 598 | 475 | 707 |
| 126 | 3.20 | 164 | 244 | 219 | 326 | 273 | 406 | 327 | 487 | 353 | 525 | 408 | 607 | 482 | 717 |
| 128 | 3.25 | 167 | 248 | 222 | 330 | 276 | 411 | 331 | 492 | 359 | 534 | 414 | 616 | 489 | 728 |
| 130 | 3.30 | 170 | 253 | 227 | 338 | 283 | 421 | 339 | 504 | 367 | 546 | 424 | 631 | 500 | 744 |
| 132 | 3.35 | 173 | 258 | 231 | 344 | 287 | 427 | 344 | 512 | 372 | 553 | 430 | 640 | 507 | 754 |
| 134 | 3.40 | 176 | 261 | 234 | 348 | 291 | 433 | 349 | 519 | 378 | 562 | 436 | 649 | 514 | 765 |
| 136 | 3.45 | 178 | 264 | 237 | 353 | 295 | 439 | 354 | 529 | 383 | 570 | 442 | 658 | 522 | 777 |
| 138 | 3.51 | 180 | 268 | 240 | 358 | 299 | 445 | 358 | 533 | 388 | 577 | 448 | 667 | 529 | 787 |
| 140 | 3.56 | 182 | 271 | 243 | 362 | 303 | 451 | 363 | 540 | 393 | 585 | 454 | 675 | 536 | 797 |
| 142 | 3.61 | 185 | 275 | 246 | 366 | 307 | 457 | 368 | 548 | 398 | 592 | 460 | 684 | 543 | 808 |
| 144 | 3.66 | 187 | 278 | 249 | 370 | 311 | 463 | 373 | 555 | 403 | 600 | 466 | 693 | 550 | 818 |
| 146 | 3.71 | 191 | 285 | 255 | 379 | 318 | 473 | 381 | 567 | 412 | 613 | 476 | 708 | 561 | 835 |
| 148 | 3.76 | 194 | 288 | 258 | 384 | 322 | 479 | 386 | 574 | 417 | 620 | 482 | 717 | 569 | 847 |
| 150 | 3.81 | 196 | 291 | 261 | 388 | 326 | 485 | 390 | 580 | 422 | 628 | 488 | 726 | 576 | 857 |
| 152 | 3.86 | 199 | 296 | 265 | 394 | 330 | 491 | 395 | 588 | 428 | 637 | 494 | 735 | 583 | 867 |
| 154 | 3.91 | 201 | 299 | 268 | 399 | 334 | 497 | 400 | 595 | 433 | 644 | 499 | 742 | 590 | 878 |
| 156 | 3.96 | 203 | 302 | 271 | 403 | 338 | 503 | 405 | 603 | 438 | 652 | 505 | 751 | 597 | 888 |
| 158 | 4.01 | 206 | 306 | 274 | 408 | 342 | 509 | 409 | 609 | 443 | 659 | 511 | 760 | 604 | 899 |
| 160 | 4.06 | 208 | 309 | 277 | 412 | 346 | 515 | 414 | 616 | 448 | 667 | 517 | 769 | 611 | 909 |
| 162 | 4.11 | 212 | 316 | 283 | 421 | 353 | 525 | 422 | 628 | 457 | 680 | 527 | 784 | 623 | 927 |
| 164 | 4.17 | 215 | 319 | 286 | 426 | 356 | 530 | 427 | 635 | 462 | 687 | 533 | 793 | 630 | 937 |
| 166 | 4.22 | 217 | 322 | 289 | 430 | 360 | 534 | 432 | 643 | 467 | 695 | 539 | 802 | 637 | 948 |
| 168 | 4.27 | 219 | 326 | 292 | 434 | 364 | 542 | 436 | 649 | 472 | 702 | 545 | 811 | 644 | 958 |
| 170 | 4.32 | 221 | 329 | 295 | 439 | 368 | 548 | 441 | 656 | 478 | 711 | 551 | 820 | 651 | 969 |
| 172 | 4.37 | 224 | 334 | 299 | 445 | 372 | 553 | 446 | 664 | 483 | 719 | 557 | 829 | 658 | 979 |
| 174 | 4.42 | 227 | 337 | 302 | 449 | 376 | 559 | 451 | 671 | 488 | 726 | 563 | 838 | 665 | 989 |
| 176 | 4.47 | 229 | 340 | 305 | 454 | 380 | 565 | 456 | 678 | 493 | 733 | 569 | 847 | 672 | 1000 |
| 178 | 4.52 | 233 | 347 | 311 | 463 | 387 | 576 | 464 | 690 | 502 | 747 | 579 | 861 | 684 | 1018 |
| 180 | 4.57 | 236 | 350 | 314 | 467 | 391 | 582 | 468 | 696 | 507 | 754 | 585 | 870 | 691 | 1028 |

Notes: Approximate weights may be extrapolated for diameters greater than 180 inches.
Weight based on dip-galvanized material and includes bolts and nuts.
Call for aluminum tunnel liner plate weights.

# Steel Vertical Shafts

Vertical Shafts are often required as access means for horizontal tunneling and relines. These shafts may vary in diameter from 4 feet to over 70 and depths well over 100 feet.

## Optimizing Shaft Design

In each case, maintaining shaft integrity requires a dependable support system. Various methods are used for vertical shaft lining: sheet piling, unbraced timber, ring beams and timber lagging, concrete, and stacked trench boxes.

## Liner Plate Systems

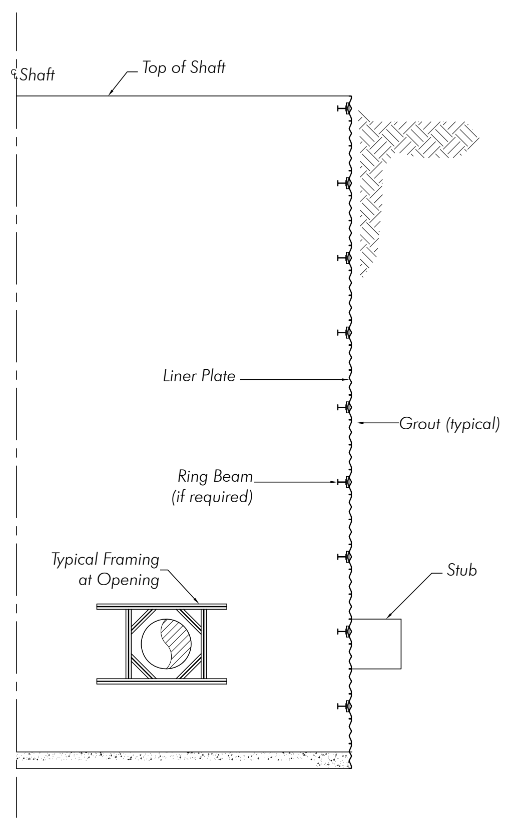
2-Flange Tunnel Liner Plate is used in vertical shafts when the top-down installation is preferred. A net laying depth of 18" permits advancing the shaft in 1.5' increments. Bolts and nuts for 2-Flange Tunnel Liner Plate are easily installed from within the structure and rings of Liner Plate can be quickly installed and backgrouted.

2-Flange Tunnel Liner Plate is the stiffest plate available and, unlike other shaft liner systems, often does not require the use of permanent ring-beam stiffeners.

The Contech Liner Plate system, available in black (uncoated) or galvanized steel, provides strength and safety. Often, the Liner Plate may be dismantled and reused.

2-Flange Tunnel Liner Plate is much stiffer, gage for gage, than 4-Flange Liner Plate. Commonly required diameters for 2-Flange Liner Plate will not require Ring-Beam bracing, whereas 4-Flange designs would more than likely require them.

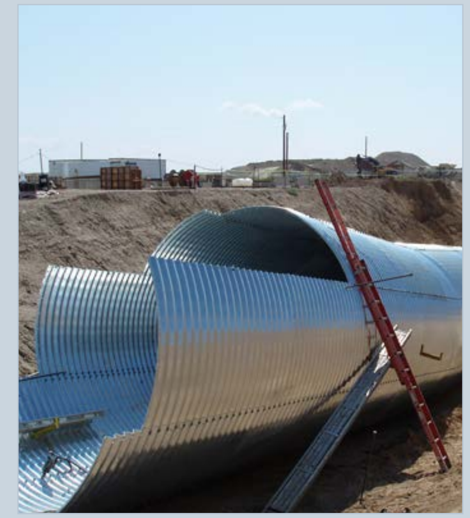
If adjacent structures are sensitive to pile driving, a starter shaft using 2-Flange Tunnel Liner Plate can be used. Once the shaft reaches sufficient depth, pile driving can be commenced and disturbance to nearby foundations, railroads or other structures is minimized or eliminated.




*Typical structure cross-section*



# Additional Contech Products Provide Versatility for Optimum Efficiency



*MULTI-PLATE®*

*HEL-COR®*

## MULTI-PLATE Liner Systems

MULTI-PLATE® can be preassembled on the surface in large diameters and long lengths, then lowered into a pre-excavated or drilled shaft. Once installed, the void between the MULTI-PLATE liner and excavated/drilled shaft is grouted. Soil conditions must allow the shaft walls to be left temporarily exposed until the liner is installed.

MULTI-PLATE shaft liners are also extremely stiff, creating a very safe shaft and, as with 2-Flange Tunnel Liner Plate, ring beam stiffeners are often not required.

## HEL-COR Lining Systems

HEL-COR® corrugated steel pipe, with or without ring beam stiffeners, can be supplied in diameters up to 120" (larger diameters are available at some locations). It is installed in the same manner as MULTI-PLATE structures, and eliminates the need for field assembly of plates. Ring beams, if needed, are installed by the contractor.

## Applications

These additional products offer alternative options for different site or construction conditions. Site restrictions will often not allow drilling shafts. When "hand-digging" or bucket excavation is required, 2-Flange Tunnel Liner Plate is the most effective. If drilling of the shaft is allowed and the site soil will remain stable, then larger diameter shafts can be lined with MULTI-PLATE or HEL-COR corrugated steel pipe.

2-Flange Tunnel Liner Plate and MULTI-PLATE structures can be supplied in round or elliptical shapes. Smaller shaft diameters can be lined with HEL-COR alone or with ring beam stiffeners if required.

Prompt backgrouting, to fill the void between the shaft walls and the liner, is essential to the support and performance of any shaft liner system. Such backgrouting must be done in a controlled and balanced manner. In all cases, use of temporary bracing may be required to provide added protection and stiffness prior to backgrouting.

# Design Considerations for Vertical Shafts

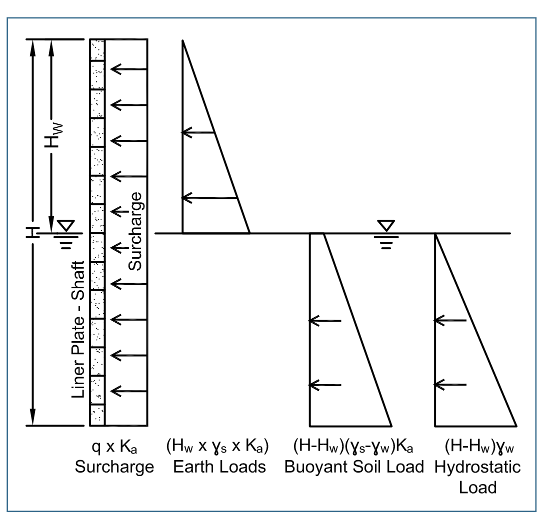
## Typical Required Design Information

- Shaft diameter
- Shaft depth
- Unit weight of soil around the shaft
- Lateral earth pressures due to site soil conditions
- Location of ground water table
- Live loads to include in the design

While the actual design of such shafts is the responsibility of the project engineer, a common procedure for this design process can be summarized as:

## 1. Determine Loads on Shaft Liner

Loads exerted by lateral earth pressures should be determined throughout the depth of the shaft. Any hydrostatic loads due to groundwater should be established and included within the design. The possibility for localized soil instabilities and slough-ins should be assessed and considered. If such localized loads produce differential pressures, then allowances for such unbalanced loads must be considered in the design and detail of the shaft. If the presence of any nearby foundation systems will produce an increase in the ground pressures in the area where the shaft is to be constructed that exceed 100 pounds per square foot, they should be included in the design.




*Loads on Shaft Liner*

## 2. Check the Seam Strength of the Liner

The design thrust in the plate should be computed in the same manner as was shown for tunneling applications. In tunneling applications, a minimum factor of safety of 3.0 on seam strength is common and is required per the AASHTO specifications. However, this does not necessarily apply and may in fact be overly conservative in the design of vertical shafts. The selection of an appropriate factor of safety is left to the discretion of the designer.

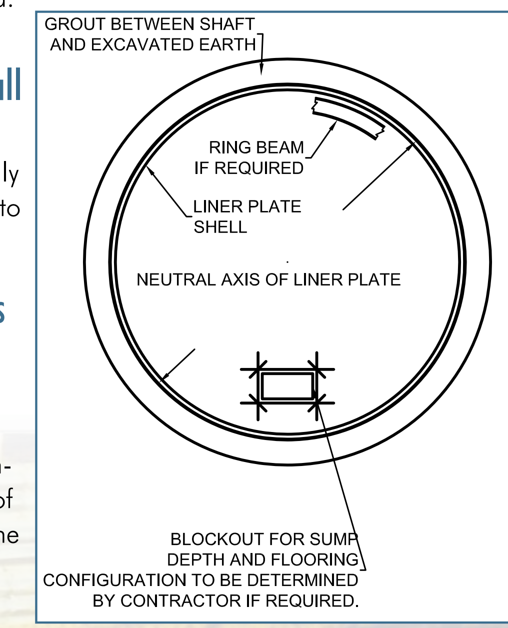
## 3. Check the Liner Stiffness

Due to the inherent stiffness and the moment transfer that the lapped longitudinal seams of 2-Flange Tunnel Liner Plate provide, a large range of depth and diameter combinations of vertical shafts can be constructed without the need for any additional reinforcement. However, while the rings of some larger shafts may be capable of carrying the service loads required by the permanent structure, the shaft may require temporary reinforcement during construction to provide additional stiffness during the assembly and grouting phases of construction. This reinforcement is commonly in the form of curved ring beams that can be temporarily blocked into place during construction, but removed once the shaft is assembled and grouted into place.

If the gage of the structure is controlled by the need for ring stiffness rather than load carrying capacity, many designers choose to design the required plate gage based strictly on what is required to carry the service loads and specify the use of ring beams to provide the necessary stiffness during construction. Generally two or three sets of ring beams is all that is necessary for construction as the ring beams can be moved downward as the shaft construction progresses. This can lead to a substantial reduction in the cost of materials for a large diameter and/or deep tunnel.

## 4. Check the Critical Buckling Stress of the Shaft Liner

This check can be performed using the same buckling equations introduced earlier for Liner Plate tunnels. Due to the strength of 2-Flange Tunnel Liner Plate, many large diameter and deep shafts can be constructed without the need for permanent reinforcement. If the service loads induce stresses beyond the limits that 2-Flange Tunnel Liner Plate alone can carry, permanent reinforcement in the form of ring beams or other means can be used to carry the loads beyond what the plates can accommodate. The addition of these ring stiffeners should be considered in the buckling check and modifications to the buckling check procedure may be required.




## 5. Design Reinforcing for Any Openings Cut in the Shaft Liner Wall

Any openings that may be cut within the Liner Plate may also require permanent reinforcement. In this instance, structural members are generally attached to the Liner Plate around the cut opening in the form of a frame to carry the loads in the vicinity of the opening.

## 6. Grouting the Void Between the Liner Plate and the Shaft Walls

The void between the shaft liner and excavated shaft wall should be grouted in a controlled and balanced manner as soon as possible as the shaft liner construction is advanced. The quicker this void is grouted and the grout cured, the less exposed the shaft liner will be to localized slough-ins, potential unbalanced loads, and unknown load pressures. Selection of grout materials and methods should be discussed and coordinated with the contractor.

*Note: Additional references include the current specifications of AASHTO, AISI, and the NCSPA.*

Contech Engineered Solutions provides site solutions for the civil engineering industry.  Contech's portfolio includes bridges, drainage, retaining walls, sanitary sewer, stormwater, erosion control and soil stabilization products.

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