



Designation: B790/B790M – 11

Standard Practice for Structural Design of Corrugated Aluminum Pipe, Pipe- Arches, and Arches for Culverts, Storm Sewers, and Other Buried Conduits¹

This standard is issued under the fixed designation B790/B790M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

1. Scope*

1.1 This practice is intended for the structural design of corrugated aluminum pipe and pipe-arches, and aluminum structural plate pipe, pipe-arches, and arches for use as culverts and storm sewers and other buried conduits. This practice is for pipe installed in a trench or embankment and subjected to highway, railroad, and aircraft loadings. It must be recognized that a buried corrugated aluminum pipe is a composite structure made up of the aluminum ring and the soil envelope, and both elements play a vital part in the structural design of this type of structure.

1.2 Corrugated aluminum pipe and pipe-arches shall be of annular fabrication using riveted seams, or of helical fabrication having a continuous lockseam.

1.3 Structural plate pipe, pipe-arches, and arches are fabricated in separate plates that when assembled at the job site by bolting form the required shape.

1.4 This specification is applicable to design in inch-pound units as Specification B790 or in SI units as Specification B790M. Inch-pound units and SI units are not necessarily equivalent. SI units are shown in brackets in the text for clarity, but they are the applicable values when the design is done in accordance with Specification B790M.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

¹ This practice is under the jurisdiction of ASTM Committee B07 on Light Metals and Alloys and is the direct responsibility of Subcommittee B07.08 on Corrugated Aluminum Pipe and Corrugated Aluminum Structural Plate.

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2. Referenced Documents

2.1 ASTM Standards:²

B745/B745M Specification for Corrugated Aluminum Pipe for Sewers and Drains

B746/B746M Specification for Corrugated Aluminum Alloy Structural Plate for Field-Bolted Pipe, Pipe-Arches, and Arches

B788/B788M Practice for Installing Factory-Made Corrugated Aluminum Culverts and Storm Sewer Pipe

B789/B789M Practice for Installing Corrugated Aluminum Structural Plate Pipe for Culverts and Sewers

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft³ (600 kN-m/m³))

D1556 Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method

D2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method

D6938 Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

2.2 FAA Standards:³

AC No. 150/5320-5B, Advisory Circular, "Airport Drainage," Department of Transportation, Federal Aviation Administration, Publication No. SN-050-007-00149-5, 1970

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098.

*A Summary of Changes section appears at the end of this standard

2.3 *AASHTO Standards*:⁴
 LRFD Bridge Design Specifications
 LRFD Bridge Construction Specifications

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *arch, n*—a pipe shape that is supported on footings and does not have a full metal invert.

3.1.2 *bedding, n*—the earth or other material on which the pipe is laid consist of a thin layer of important material on top of the in-situ foundation.

3.1.3 *haunch, n*—the portion of the pipe cross section between the maximum horizontal dimension and the top of the bedding.

3.1.4 *invert, n*—the lowest portion of the pipe cross section; also, the bottom portion of the pipe.

3.1.5 *pipe, n*—a conduit having a full circular shape or, in a general context, all structure shapes covered by this practice.

3.1.6 *pipe-arch, n*—a pipe shape consisting of an approximate semicircular top portion, small radius corners, and large radius invert.

4. Symbols

4.1 The symbols used in this practice have the following significance:

<i>A</i>	= required wall area, in. ² /ft [mm ² /mm],
<i>AL</i>	= maximum highway design axle load, lbf [N],
<i>d</i>	= depth of corrugation, in. [mm],
<i>E</i>	= modulus of elasticity, 10 × 10 ⁶ lbf/in. ² [69 × 10 ³ MPa],
<i>EL</i>	= earth load, lbf/ft ² [kPa],
<i>f_c</i>	= critical buckling stress, lbf/in. ² [MPa],
<i>FF</i>	= flexibility factor, in./lbf [mm/N],
<i>f_y</i>	= specified minimum tensile strength, = 31 000 lbf/in. ² [215 MPa] for corrugated aluminum pipe per B745/B745M using Alclad Alloy 3004–H34, = 27 000 lbf/in. ² [185 MPa] for corrugated aluminum pipe per B745/B745M using Alclad Alloy 3004–H32, = 35 000 lbf/in. ² [245 MPa] for 0.100 through 0.150 inch [2.52 through 3.81 mm] thick aluminum structural plate per B746/B746M , = 34 000 lbf/in. ² [235 MPa] for 0.175 through 0.250 inch [4.44 through 6.35 mm] thick aluminum structural plate per B746/B746M ,

⁴ Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001.

<i>f_y</i>	= specified minimum yield strength, = 20 000 lbf/in. ² [140 MPa] for corrugated aluminum pipe per B745/B745M using Alclad Alloy 3004–H32, = 24 000 lbf/in. ² [165 MPa] for all other corrugated aluminum pipe and structural plate per B745/B745M and B746/B746M ,
<i>H</i>	= depth of fill above top of pipe, ft [m],
<i>H_{max}</i>	= maximum depth of fill, ft [m],
<i>H_{min}</i>	= minimum depth of fill, ft [m],
<i>I</i>	= moment of inertia of corrugation, in. ⁴ /in. [mm ⁴ /mm], see Tables 2-7),
<i>IL</i>	= impact load, lbf/ft ² [kPa],
<i>k</i>	= soil stiffness factor—0.22 for good sidefill material compacted to 90 % of standard density based on Test Method D698 ,
<i>LL</i>	= live load, lbf/ft ² [kPa],
<i>P</i>	= total design load or pressure, lbf/ft ² [kPa],
<i>P_f</i>	= Factored crown pressure, lbf/ft ² [kPa],
<i>r</i>	= radius of gyration of corrugation, in. [mm], see Tables 1-7 ,
<i>r_c</i>	= corner radius of pipe-arch, ft [mm],
<i>R_f</i>	= Factored resistance for each limit state, lbf/ft [kN/m],
<i>R_n</i>	= Nominal resistance for each limit state, lbf/ft [kN/m],
<i>s</i>	= pipe diameter or span, in. [mm],
<i>S</i>	= pipe diameter or span, ft [m],
<i>SF</i>	= safety factor,
<i>SS</i>	= required seam strength, lbf/ft [kN/m],
<i>T</i>	= thrust in pipe wall, lbf/ft [kN/m],
<i>T_f</i>	= Factored thrust in pipe wall, lbf/ft [kN/m],
<i>W</i>	= the unit force derived from 1 ft ³ [m ³] of fill material above the pipe, lbf/ft ³ [kN/m ³]. When the actual fill material is not known, use 120 lbf/ft ³ [19 kN/m ³],
<i>φ</i>	= Resistance factor.

NOTE 1—For pipes meeting **B745/B745M**, both minimum yield and minimum tensile strengths are based on the H-32 temper material.

5. Basis of Design

5.1 The recommendations presented herein, represent generally accepted design practice. The design engineer shall, however, determine that these recommendations meet particular project needs.

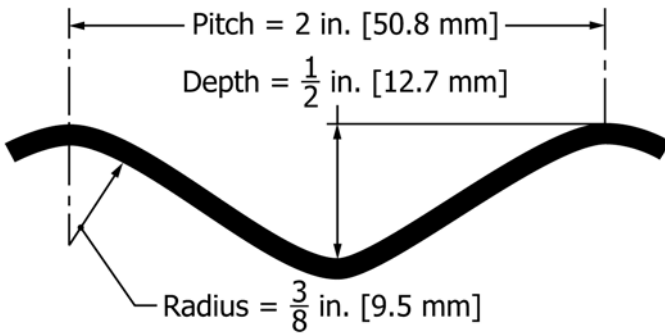
6. Loads

6.1 The design load or pressure on a pipe is comprised of earth load (EL), live load (LL), and impact load (IL). These loads are applied as a fluid pressure acting on the pipe periphery.

6.2 For aluminum pipe buried in a trench or in an embankment on a yielding foundation, loads are defined as follows:

6.2.1 *Earth Load*—The earth load *EL* is the weight of the column of soil directly above the pipe calculated as:

TABLE 2 Sectional Properties of Corrugated Aluminum Sheets for Corrugation: 2 by 1/2 in. [51 by 13 mm] (Helical)



NOTE 1—Inch-pound dimensions shown in this figure are exact values used in calculating the section properties. Nominal values for some of these dimensions are used in other places in this practice.

Specified Thickness, in. [mm]	Area of Section A, in. ² /ft [mm ² /mm]	Moment of Inertia, I × 10 ⁻³ in. ⁴ /in. [mm ⁴ /mm]	Radius of Gyration, r, in. [mm]
0.048 [1.22]	0.652 [1.380]	1.533 [25.12]	0.1682 [4.272]
0.060 [1.52]	0.815 [1.725]	1.942 [31.82]	0.1690 [4.293]
0.075 [1.91]	1.019 [2.157]	2.458 [40.28]	0.1700 [4.318]
0.105 [2.67]	1.428 [3.023]	3.542 [58.04]	0.1725 [4.382]

$$EL = HW \quad (1)$$

6.2.2 *Live Loads*—The live load *LL* is that portion of the weight of the vehicle, train, or aircraft moving over the pipe that is distributed through the soil to the pipe.

6.2.2.1 *Live Loads Under Highways*—Live load pressures for H20 highway loadings, including impact effects, are as follows:

Height of Cover, ft [mm]	Live Load, lb/ft ² [kPa]
1 [300]	1800 [86.2]
2 [600]	800 [38.3]
3 [900]	600 [28.7]
4 [1200]	400 [19.2]
5 [1500]	250 [12.0]
6 [1800]	200 [9.6]
7 [2100]	175 [8.4]
8 [2400]	100 [4.8]
over 8 [over 2400]	neglect [neglect]

6.2.2.2 *Live Loads Under Railways*—Live load pressures for E80 railway loadings, including impact effects, are as follows:

Height of Cover, ft [mm]	Live Load, lb/ft ² [kPa]
2 [600]	3800 [181.9]
5 [1500]	2400 [114.9]
8 [2400]	1600 [76.6]
10 [3000]	1100 [52.7]
12 [3600]	800 [38.3]
15 [4500]	600 [28.7]
20 [6000]	300 [14.4]
30 [9000]	100 [4.8]
over 30 [over 9000]	neglect [neglect]

Values for intermediate covers may be interpolated.

6.2.2.3 *Live Loads Under Aircraft Runways*— Because of the many different wheel configurations and weights, live load pressures for aircraft vary. Such pressures must be determined for the specific aircraft for which the installation is designed; see the FAA publication “Airport Drainage.”

6.2.3 *Impact Loads*—Loads caused by the impact of moving traffic are important only at low heights of cover. Their effects have been included in live load pressures in 6.2.2.

7. Design Method

7.1 Strength requirements for wall strength, buckling strength, and seam strength may be determined by either the allowable stress design (ASD) method presented in Section 8, or the load and resistance factor design (LRFD) method presented in Section 9. Additionally, the design considerations in other paragraphs shall be followed for either design method.

8. Design by ASD Method

8.1 The thrust in the pipe wall shall be checked by three criteria. Each considers the joint function of the aluminum pipe and the surrounding soil envelope.

8.1.1 Required Wall Area:

8.1.1.1 Determine the design pressure and ring compression thrust in the aluminum pipe wall as follows:

$$P = EL + LL + IL \quad (2)$$

$$T = PS/2 \quad (3)$$

8.1.1.2 Determine the required wall cross-sectional area. The safety factor *SF* on the wall area is 2.

$$A = \frac{T(SF)}{f_y} \quad (4)$$

Select from Tables 1-7 a wall thickness equal to or greater than the required wall area *A*.

8.1.2 *Critical Buckling Stress*—Check corrugations with the required wall area for possible wall buckling. If the critical buckling stress *f_c* is less than the minimum yield stress *f_y*, recalculate the required wall area using *f_c* instead of *f_y*.

$$\text{If } s < \frac{r}{k} \sqrt{\frac{24E}{f_u}} \text{ then } f_c = f_u - \frac{f_u^2}{48E} \left(\frac{ks}{r} \right)^2 \quad (5)$$

$$\text{If } s > \frac{r}{k} \sqrt{\frac{24E}{f_u}} \text{ then } f_c = \frac{12E}{\left(\frac{ks}{r} \right)^2} \quad (6)$$

8.1.3 Required Seam Strength:

8.1.3.1 Since a helical lockseam pipe has no longitudinal seams, this criterion is not valid for this type of pipe.

8.1.3.2 For pipe fabricated with longitudinal seams (riveted or bolted) the seam strength shall be sufficient to develop the thrust in the pipe wall. The safety factor *SF* on seam strength *SS* is 3. Determine the required seam strength as follows:

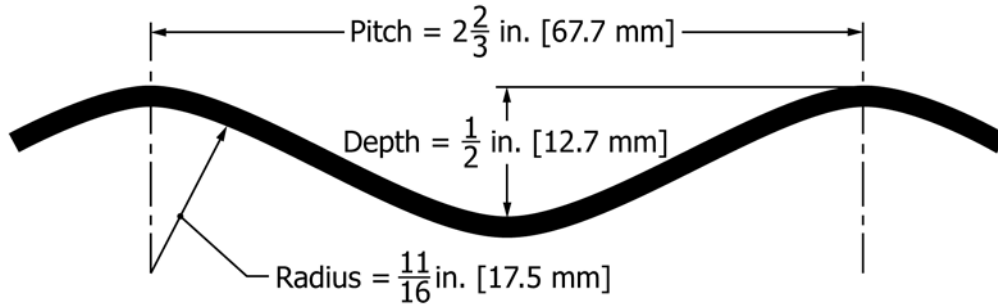
$$SS = T(SF) \quad (7)$$

8.1.3.3 Check the ultimate seam strengths shown in Tables 3 and 4, or Table 5. If the required seam strength exceeds that shown for the aluminum thickness already chosen, use a heavier pipe whose seam strength exceeds the required seam strength.

9. Design by LRFD Method

9.1 *Factored Loads*—The pipe shall be designed to resist the following combination of factored earth load (*EL*) and live load plus impact (*LL + IL*):

TABLE 3 Sectional Properties of Corrugated Aluminum Sheets for Corrugation: 2 2/3 by 1/2 in. [68 by 13 mm] (Helical or Annular)



NOTE 1—Inch-pound dimensions shown in this figure are exact values used in calculating the section properties. Nominal values for some of these dimensions are used in other places in this practice.

Specified Thickness, in. [mm]	Area of Section A, in. ² /ft [mm ² /mm]	Moment of Inertia, I × 10 ⁻³ in. ⁴ /in. [mm ⁴ /mm]	Radius of Gyration, r, in. [mm]	Ultimate Longitudinal Seam Strength of Riveted Corrugated Aluminum Pipe, Pounds [kN] per Foot [metre] of Seam			
				5/16-in. [7.94 mm] Rivets		3/8-in. [9.53 mm] Rivets	
				Single ^A	Double ^B	Single ^A	Double ^B
0.060 [1.52]	0.775 [1.640]	1.892 [31.00]	0.1712 [4.348]	9000 [131]	14 000 [204]	...	...
0.075 [1.91]	0.968 [2.049]	2.392 [39.20]	0.1721 [4.371]	9000 [131]	18 000 [263]	...	...
0.105 [2.67]	1.356 [2.870]	3.425 [56.13]	0.1741 [4.422]	...	...	15 600 [228]	31 500 [460]
0.135 [3.43]	1.745 [3.694]	4.533 [74.28]	0.1766 [4.486]	...	...	16 200 [237]	33 000 [482]
0.164 [4.17]	2.130 [4.509]	5.725 [93.82]	0.1795 [4.559]	...	...	16 800 [245]	34 000 [496]

^A Single means one row of rivets, one rivet per corrugation.
^B Double means two rows of rivets, one rivet per corrugation per row.

$$P_f = 1.95EL + 1.75(LL + IL) \quad (8)$$

9.2 *Factored Thrust*—The factored thrust, T_f , per unit length of wall shall be determined from the factored crown pressure P_f as follows:

$$T_f = P_f S / 2 \quad (9)$$

9.3 *Factored Resistance*—The factored resistance (R_f) shall equal or exceed the factored thrust. R_f shall be calculated for the limit states of (1) wall resistance, (2) resistance to buckling, and (3) seam resistance (where applicable) as follows:

$$R_f = \phi R_n \quad (10)$$

The resistance factor (ϕ) shall be as specified in Table 8. The nominal resistance (R_n) shall be calculated as specified in 9.4, 9.5, and 9.6.

9.4 *Wall Resistance*—The nominal axial resistance per unit length of wall without consideration of buckling, shall be taken as follows:

$$R_n = f_y A \quad (11)$$

9.5 *Resistance to Buckling*—The nominal resistance calculated using Eq 11 shall be investigated for buckling. If $f_c < f_y$, R_n shall be recalculated using f_c in lieu of f_y . The value of f_c shall be determined from Eq 5 or Eq 6 as applicable.

9.6 *Seam Resistance*—For pipe fabricated with longitudinal seams, the nominal resistance of the seam per unit length of wall, shall be taken as the ultimate seam strength shown in Tables 3 and 4, or Table 5.

10. Handling and Installation

10.1 The pipe shall have enough rigidity to withstand the forces that are normally applied during shipment and placing. Both shop- and field-assembled pipe shall have strength adequate to withstand compaction of the sidefill without interior bracing to maintain pipe shape. Handling and installation rigidity is measured by the following flexibility requirement:

$$FF = \frac{s^2}{EI} \quad (12)$$

10.2 For curve and tangent corrugated pipe, the flexibility factor shall not exceed the following:

Depth of Corrugation, in. [mm]	Flexibility Factor, FF, in./lbf [mm/N]	
	Material Thickness, in. [mm]	FF
1/4 [6.5] and 1/2 [13]	0.060 [1.52]	0.031 [0.18]
	0.075 [1.91]	0.061 [0.35]
	all others	0.092 [0.53]
1 [25]	all	0.060 [0.34]
2 1/2 [64] round pipe	all	0.025 [0.14]
2 1/2 [64] arch and pipe arch	all	0.036 [0.21]

10.3 For ribbed pipes installed in a trench cut in undisturbed soil and provided with a soil envelope meeting the requirements of 17.2.3 to minimize compactive effort, the flexibility factor shall not exceed the following:

Depth of Rib, in. [mm]	Flexibility Factor, FF, in./lbf [mm/N]
3/4 [19]	0.600 ^{1/3} [0.135 ^{1/3}]
1 [25]	0.310 ^{1/3} [0.070 ^{1/3}]