Multi-Plate® Installation & Design

Multi-Plate® Installation

Fabricated from factory-curved corrugated steel plates, Multi-Plate® is a field-assembled flexible soil-steel structure. As with any buried structure, proper installation is critical in providing long-term, worry-free, performance of the structure.

In practical terms, installation can be broken into three major operations: preparation of the foundation (or, for arches, installation of the footings), assembly of the Multi-Plate structure, and backfilling and compacting the engineered soil envelope. Following the Armtec installation guidelines for each of these operations will ensure a problem-free installation and a long service life.

Foundation preparation

Soil-steel structures depend upon the inherent flexibility of the steel shell to accommodate small deflections and fully mobilise the support of the granular backfill. While the foundation needs to have sufficient load-bearing capacity to support the pipe, fill, and other applied loads, a rigid foundation is not desirable. For this reason, a compressible "cushion" is installed under the invert of the pipe to allow the corrugations to settle into the granular material. This aids in the mobilization of the backfill to support the structure. A secondary benefit of this cushion is that it creates a controlled, graded, surface upon which to assemble the pipe. The shape and dimensions of this cushion will be defined in Armtec's backfill drawings or determined by the engineer responsible for the installation.

Depending on the shape and size of pipe, compacting under the haunches may be aided by placing the cushion on a pre-shaped bed. This provides better haunch compaction for shapes with tight corner or side radii, such as pipe-arch, underpass, or horizontal ellipse shapes.

In the case of Multi-Plate arches, plates are typically secured to a concrete strip footing. An Armtec supplied unbalanced channel is cast into or anchored to the footing in order to receive the plates. The design of the concrete footing is the responsibility of the owner's consulting engineer or technical representative.

Pipe assembly

Assembly of Multi-Plate is accomplished by bolting adjacent longitudinal and circumferential plates to form the full length and circumference of the structure. All orders are supplied with engineering drawings showing the correct positioning of the plates, plate lapping details, as well as comprehensive backfilling instructions. Supplemental drawings, including the unbalanced channel layout for arches, are provided and will vary depending upon the shape and complexity of the installation.

Assembly may be undertaken plate-by-plate, or by sub-assembling arcs of the structure before lifting into the excavation. While it is typical to assemble the structure in situ, it may be possible to sub-assemble sections in a staging area and then transfer completed sections to the trench to be joined and bolted together. Pipe size and transportability, crane availability and site accessibility will determine if the entire multi-plate structure can be assembled off site. These applications minimize field construction time when the fully assembled structure can be lifted into the excavation.

It is important to tighten bolts to the correct torque and follow a balanced and uniform progression from one end of the structure to the other. Tightening too many bolts at one time on one side of the structure may cause the structure to spiral. Bolt torque should be between 200 N·m and 350 N·m. A calibrated torque wrench should be used to ensure that the correct torque is being achieved.

Backfilling and Compacting the Engineered Soil Envelope

The principle rules for backfilling are:

1. Construct an engineered backfill envelope with approved granular materials
2. Place engineered backfill in maximum 200 mm lifts
3. Ensure specified compaction levels are attained

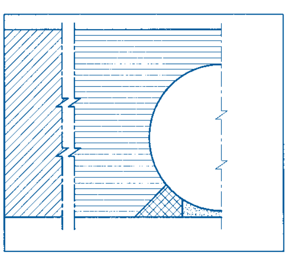
1. The engineered backfill envelope shall be a well-graded, granular, free-draining material. A gradation curve is available from Armtec showing the gradation limits that are required for backfill material. As a rule of thumb, a well-graded pit run gravel with no more than 10% fines and a maximum particle size of 75 mm would usually be considered suitable. Other well-graded fills such as crushed rock or highway road base are generally suitable.

2. Backfill is to be spread in layers of not more than 200 mm thickness prior to compaction, spread evenly on both sides of the structure. Water must be added to dry materials in order to ensure optimum moisture content for compaction. Fill levels on either side of the structure should not be more than 2 lifts (400 mm) out of balance. Material is not to be dumped directly against or on to the structure. Spreading is undertaken parallel to the length of the structure until approximately 3/4 of the rise, at which point spreading and compaction is undertaken perpendicular to the length of the structure. Suitable spreading and compaction equipment are listed in Armtec's backfill instructions. Frozen granular backfill materials are not acceptable within the boundaries of the engineered backfill envelope throughout construction.

3. The minimum recommended compaction level for engineered backfills is 95% Standard Proctor Density. A laboratory analysis of the chosen backfill material will determine the characteristics of the material and will permit calibration of the compaction testing equipment in order to achieve the specified density. The allowable size of compaction equipment will depend upon the size of the structure and the proximity of equipment to the steel shell. Plate tampers, jumping jacks and small walk behind drum type compactors are commonly used for Multi-Plate applications. Large operator driven vibratory compactors need to be kept at a safe distance away from the sides of Multi-Plate structures during backfilling. Changes to the pipe's dimensions due to compaction efforts may require alternate compaction equipment and/or adjustment of the operating distance of the equipment from the sides of the structure.

Special considerations under haunches

Particular attention needs to be paid to the area beneath the haunches of a full-periphery pipe in order to provide full support. Hand tamping using rods may be required at these points. Water jetting of material under the haunches is also an option where site conditions provide proper drainage.



Round

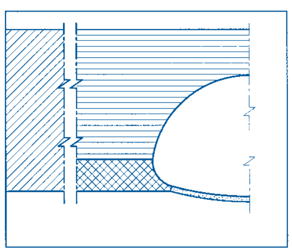
Competent Native Material

Engineered Backfill Zone

Special consideration for pipe arches

The pipe arch series of structures were developed for applications with restricted or limited rise conditions. They also provide improved hydraulics as compared to an equivalent round pipe. Therefore they are better suited for applications with limited cover conditions.

Pipe arches generate radial corner pressures that are greater than the applied pressure at the top of the structure. Special attention must be paid to ensure the site foundation bearing capacity exceeds the pressures generated at the corner (haunch) of the pipe arch. The height of cover limits for pipe arches may be governed by the foundation bearing capacity in this area. For typical installations, a minimum corner bearing capacity of 200 kPa is required. Conditions developing higher corner pressures will typically require high quality backfill material and possibly improvements to the foundation to ensure the bearing pressures are attainable.



Pipe Arches

Area for Special Attention

Granular Cushion Below Pipe

Monitoring

Due to the flexible nature of Multi-Plate structures shape monitoring during construction is necessary. Compaction efforts exceeding and/or not meeting specified densities, unbalanced backfill levels on opposing sides of the pipe or self weight of the plates may cause sagging, peaking, swaying or rolling of the structure. Monitoring of the shape during backfilling will detect and identify these concerns thus allowing for adjustments to be made to ensure proper construction techniques are being followed. This is readily accomplished by suspending plumb-bobs at key locations along the structure's length. Recording periodic measurements of the vertical and horizontal displacement of the plumb-bob relative to a fixed point of reference will ensure the structure's movement is monitored. This will enable corrective measures to be taken to ensure the structure remains within allowable shape tolerances. Other monitoring procedures are also acceptable.

Soil-Steel Interaction and Ring Compression Theory

Soil-steel interaction means that a flexible steel conduit (Corrugated Steel Pipe or Multi-Plate) acts with the surrounding soil (backfill) to support dead and live loads. In order to undertake a design using the theory of ring compression the following information is required:

- The live load
- The height or depth of cover
- The properties of the backfill (unit weight (density) and compaction level)
- The pipe shape and dimensions (span and rise)

Live (Vehicular or Train) Loads

Live or vehicular design loads are typically specified in accordance with the governing design code applicable for the project location. Numerous design vehicles are identified in the CSPI "Handbook of Steel Drainage and Highway Construction Products", Chapter 6 – Structural Design. Live load pressures for AASHTO H-20 and H-25, CHBDC CL-625 and Cooper railway loading can be found in Tables in the CSPI handbook. The effects of live load on soil-steel structures are reduced as the depth of cover increases.

Design Standards
CHBDC (Canadian Highway Bridge Design Code)

Introduced in 2001, Section 7 – Buried Structures of the Canadian Highway Bridge Design Code (CAN/CSA S6-00) addresses the analysis and design of soil-metal structures and metal box structures. It has become the recognized design standard nationally for soil-steel structures in Canada. The height of cover tables in this document were determined in accordance with this standard.

The CHBDC method is based upon the limit states design philosophy and supersedes the Ontario Highway Bridge Design Code (OHBDC) and the older CAN/CSA-S6-88 "Design of Highway Bridges" Standard. Limit states design is based on ultimate strength principles rather than on the traditional working stress or service load design method.

The full CHBDC code is available from CSA International as "CAN/CSA-S6-00 Canadian Highway Bridge Design Code". Additional details, including worked examples, are also available in the CSPI handbook. The Armtec CMP Assistant software (included) may also be used to perform design using the CHBDC.

AISI and AASHTO design methods

While simple, easy to understand, and time-tested, the AISI and AASHTO design methods have largely been displaced by the CHBDC method. Their use is generally limited to private development and non-government projects.

Full details of the AISI design procedure, including examples, can be found in the CSPI Handbook. The Armtec CMP Assistant software may also be used to perform design using either of these methods.

BACKFILLING OF STRUCTURES

Typical equipment required for backfilling in critical backfill zone

Small tracked/wheeled equipment for spreading (e.g. D4/JD450/Bobcat)	2
Walk-behind compactor (e.g. Bomag BW75)	4
Vibrating plate tampers	2
Ride-on compactor up to 15 tonnes for larger areas (Not permitted closer than 1.5 m from structure)	1
Tracked (D6) equipment for spreading material when backfill is more than 1.5 m above structure	1
Water truck or water supply	1
Shovels/rakes/other equipment as appropriate for manpower available	
Material supply by truck as required	

Notes: (See Armtec backfill drawing for complete instructions)

- Material is placed loose in 200 mm lifts
- Compaction to 95% Standard Proctor Density
- Compact at optimum moisture content
- Lifts to be placed in a balanced fashion on both sides of structure simultaneously
- No more than 400 mm difference in top of backfill elevation from side to side
- First 1.5 m above structure to be spread using small (typically D4) equipment
- First 600 mm above structure to be lightly compacted (walk-behind equipment)
- Large vibratory equipment to be kept at least 1.5 m away from walls of structure
- Dimensions of critical backfill zone as per Armtec drawings
- Monitoring of structure shape required throughout placement and compaction of backfill in critical zone

Trouble shooting:

- If structure sags there is insufficient side support. Increase compaction equally on both sides.
- If structure peaks there is too much compaction close to sides of structure. Reduce compaction for 1 m either side.
  Top load structure with windrow of material on the advice of the site engineer.
- If structure rolls (leans to one side) there is unequal fill or compaction between one side and the other. Correct by ensuring that levels are constant.

TYPICAL ACCESSORIES FOR ERECTING MULTI-PLATE

Responsibility for the design and selection of appropriate equipment to safely lift, assemble and brace the structure during assembly is the responsibility of the Assembly Contractor.

The following accessories list has been compiled based on site observations of the erection of Armtec structures by various Assembly Contractors.

- Open-jawed wrench for 19 mm (3/4") diameter hex nut, 32 mm (1 1/4") across the flats.
- Clevises, adaptable to 19 mm [3/4"] diameter holes.
- Cables with hooks suitable for lifting cables (two-leg slings). Safety hooks preferred.
- Impact wrenches must be able to torque nuts to a minimum of 200 N·m [150 ft·lb]. For air guns, a 25 mm [1"] drive is essential.
- Turnbuckles for erection sizing cables.
- Eyebolts.
- Ropes to control plates and pre-assembled groups of plates from the ground when lifting into place.
- Props as required for shape control during plate assembly.
- Planks for scaffolding or foothold when erecting.
- Pole and socket for bolt installation (19 mm x 19 mm [3/4" x 3/4"] aluminum tube c/w a 32 mm [1 1/4"] socket attached to one end, length of 1.8 m to 2.4 m [6 ft – 8 ft]).
- Electric extension cords, extension hoses for air supply for plenty of reach during erection in excavation (or moveable compressors & generators).
- Minimum of 2 ladders (length to suit the size of the structure).
- 19 mm [3/4"] diameter pry bar, 0.9 m to 1.2 m [3 ft to 4 ft] long with a tapered end.

Height-of-Cover Tables (Arch Structures)

Design Procedure as per CHBDC

Span (mm)	Rise (mm)	Minimum Cover (m)		Maximum Height of Cover (metres) for Multi-Plate Arch Structures (Highway Loading)				
				Plate Thickness				
		Highway Loading	Railway Loading (E-80)	3.0 mm	4.0 mm	5.0 mm	6.0 mm	7.0 mm
1520	810	0.3	0.5	18.4	27.7	35.7	42.2	48.2
1830	840	0.3	0.5	15.1	22.8	29.5	35.0	40.0
	970	0.3	0.5	15.4	23.2	30.0	35.5	40.6
2130	860	0.4	0.5	13.1	19.8	25.6	30.4	34.8
	1120	0.4	0.5	13.0	19.7	25.6	30.3	34.7
2440	1030	0.4	0.5	11.5	17.4	22.5	26.8	30.6
	1270	0.4	0.5	11.4	17.3	22.4	26.6	30.5
2740	1180	0.5	0.7	10.0	15.2	19.8	23.5	26.9
	1440	0.5	0.7	10.1	15.4	19.9	23.7	27.1
3050	1340	0.6	0.7	9.0	13.7	17.8	21.2	24.3
	1600	0.6	0.7	9.0	13.8	17.9	21.3	24.4
3350	1360	0.6	0.7	8.1	12.5	16.2	19.3	22.1
	1750	0.6	0.7	8.1	12.4	16.1	19.2	22.0
3660	1520	0.7	1.0	7.4	11.4	14.8	17.7	20.3
	1910	0.6	1.0	7.4	11.4	14.7	17.6	20.2
3960	1680	0.7	1.0	6.7	10.4	13.5	16.1	18.5
	2060	0.7	1.0	6.7	10.4	13.5	16.2	18.6
4270	1840	0.8	1.0	6.2	9.6	12.5	14.9	17.1
	2210	0.7	1.0	6.2	9.6	12.5	14.9	17.2
4570	1870	0.8	1.0	5.8	8.9	11.5	13.8	15.9
	2360	0.8	1.0	5.8	8.9	11.5	13.8	15.9
4880	2030	0.9	1.0	5.4	8.3	10.8	12.9	14.8
	2520	0.8	1.0	5.4	8.3	10.7	12.9	14.8
5180	2180	0.9	1.0	5.1	7.8	10.1	12.1	13.9
	2690	0.9	1.3	5.1	7.8	10.0	12.0	13.8
5490	2210	1.0	1.3	4.8	7.3	9.3	11.2	12.9
	2720	0.9	1.3	4.8	7.3	9.4	11.3	13.0
5790	2360	1.0	1.3		7.0	8.8	10.6	12.2
	2880	1.0	1.3		6.9	8.8	10.5	12.2
6100	2530	1.1	1.3		6.6	8.4	9.9	11.5
	3035	1.1	1.3		6.6	8.3	9.9	11.5

Notes: Heights of cover calculated in the above table are based on the following assumptions:

- Unit weight of backfill material assumed to be 22 kN/m^3
- Backfill is assumed to be compacted to a minimum of 95% Standard Proctor Density.
- Highway Live load used in the design procedure is the CL-625 truck as per Can/CSA S6-00 (CHBDC).
- See Armtec CMP Assistant software.

For AISI height of cover tables, please refer to the Corrugated Steel Pipe Institute (CSPI) "Handbook of Steel Drainage and Highway Construction Products".

Height-of-Cover Tables (Round Structures)

Design Procedure as per CHBDC

Diameter (mm)	Minimum Cover (m)		Maximum Height of Cover (metres) for Multi-Plate Round Structures (Highway Loading)				
	Highway Loading	Railway Loading (E-80)	Plate Thickness				
			3.0 mm	4.0 mm	5.0 mm	6.0 mm	7.0 mm
1500	0.3	0.5	18.6	28.0	36.1	42.7	48.8
1660	0.3	0.5	16.9	25.4	32.8	38.9	44.4
1810	0.3	0.5	15.4	23.3	30.1	35.7	40.8
1970	0.4	0.5	14.2	21.5	27.8	32.9	37.7
2120	0.4	0.5	13.1	19.9	25.8	30.6	35.0
2280	0.4	0.5	12.2	18.5	24.0	28.5	32.6
2430	0.4	0.5	11.4	17.3	22.5	26.7	30.6
2590	0.5	0.7	10.7	16.3	21.1	25.1	28.7
2740	0.5	0.7	10.1	15.3	19.9	23.7	27.1
3050	0.7	0.7	9.0	13.7	17.8	21.2	24.3
3360	0.7	0.7	8.1	12.4	16.1	19.2	22.0
3670	0.7	1.0	7.3	11.3	14.7	17.5	20.1
3990	0.7	1.0	6.7	10.4	13.5	16.1	18.4
4300	0.8	1.0	6.2	9.6	12.4	14.8	17.0
4610	0.9	1.0	5.7	8.8	11.5	13.7	15.8
4920	0.9	1.0		8.2	10.6	12.7	14.7
5230	1.0	1.3		7.7	9.9	11.9	13.7
5540	1.0	1.3		7.3	9.3	11.1	12.8
5850	1.1	1.3			8.7	10.4	12.0
6160	1.1	1.3			8.2	9.8	11.3
6470	1.2	1.5			7.8	9.3	10.7
6780	1.2	1.5				8.8	10.1
7090	1.3	1.5				8.4	9.6
7400	1.3	1.5					9.2
7710	1.4	1.5					8.8

Notes: Heights of cover calculated in the above table are based on the following assumptions:

- Unit weight of backfill material assumed to be 22 kN/m^3
- Backfill is assumed to be compacted to a minimum of 95% Standard Proctor Density.
- Highway Live load used in the design procedure is the CL-625 truck as per Can/CSA S6-00 (CHBDC).
- See Armtec CMP Assistant software.

For AISI height of cover tables, please refer to the Corrugated Steel Pipe Institute (CSPI) "Handbook of Steel Drainage and Highway Construction Products".

Product Information

Description of Plates:

Structures are made up from curved, corrugated plates of various dimensions:

- Corrugation profile 152 mm x 51 mm
- Plate lengths: 3.05 m and 3.66 m
- Plate widths: 5N, 6N and 9N*
- Plate thickness: 3, 4, 5, 6 and 7 mm
- Galvanizing: 610g/m^2 or 914 g/m^2

* N is defined as the space between end holes. This dimension = 9.6" (244 mm)

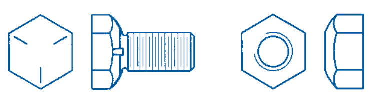
Bolts & Nuts:

- 19 mm diameter galvanized, high strength
- ASTM A449
- Curved faces for automatic centering
- Ribs on Bolt face grip against the plates
- Torque range recommended 200 – 350 N·m
- Bolt length varies from 32 mm to 76 mm

(See installation notes.)

Bolts and Nuts

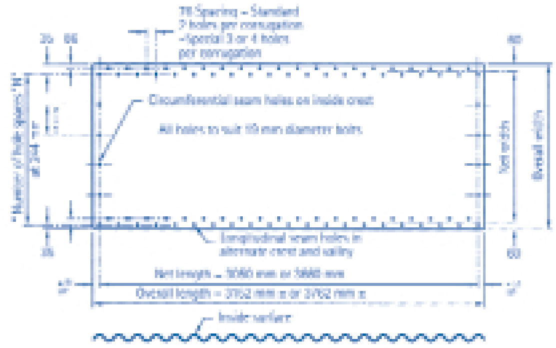
Length** (mm)	Colour	Weight (kg/100)
32	Galv.	14.6
38	Green	15.0
44	Red	16.4
51	Black	17.5
76	Galv.	21.5
Nuts	Galv.	8.8



** For galvanized plates, thicknesses 3.0 mm to 4.0 mm, bolt lengths are 32 and 38 mm, for thicknesses 5.0 mm to 6.0 mm, bolt lengths are 38 and 44 mm, for 7.0 mm thickness, bolt lengths are 38 and 51 mm.

Details of Uncurved Multi-Plate Sections

No. of Holes Spaces*	Net Width (mm)	Overall Width (mm)	No. of Circum. Bolt Holes
5N	1220	1340	6
6N	1465	1585	7
9N	2195	2315	10

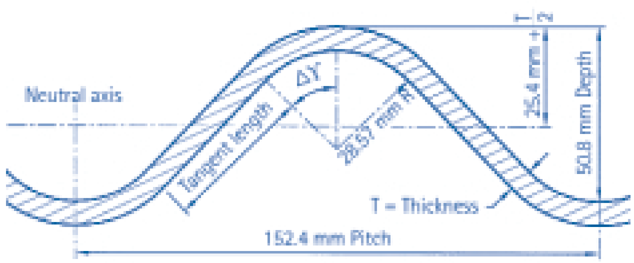


Sectional Properties

Physical Properties of Armtec Multi-Plate (152 x 51mm Corrugation)

Nominal Thickness mm	Design Thickness T mm	Tangent Length mm	Angle Δ in Degrees	Area of Section mm^2/mm	Moment of Inertia mm^4/mm	Section Modulus mm^3/mm	Radius of Gyration mm	D.W.F. Developed*** Width Factor
3.0	2.84	47.876	44.531	3.522	1057.25	39.42	17.327	1.240
4.0	3.89	46.748	44.899	4.828	1457.56	53.30	17.375	1.241
5.0	4.95	45.582	45.286	6.150	1867.16	66.98	17.425	1.242
6.0	6.00	44.396	45.686	7.461	2278.31	80.22	17.475	1.244
7.0	7.00	43.237	46.083	8.712	2675.11	92.56	17.524	1.245

*** Developed width factor measures the increase in profile length due to corrugating.
Profile section properties calculated from design thickness.



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