Canadian Performance Guideline for Structural Plate Corrugated Steel Pipe and Deep Corrugated Structural Plate Structures

1.0 Introduction

The purpose of this Guideline is to assist practitioners in selecting appropriate structure type, end protection details and the optimum coating and plate thickness combination to enable corrugated steel plate structures to meet design service life specifications. Consideration of the application exposure, location and the site specific environmental conditions are key parameters when estimating the material service life of buried flexible steel structures. This guideline is intended to supplement local knowledge of the performance of buried plate structures.

Common applications for Corrugated Plate, some of which are shown in Figure 1 pictures, include:

- Culverts on watercourses - Full periphery round, pipe-arch and elliptical pipes
- Short span bridges on watercourses - Open bottom arches and box shapes
- Grade separations (non-watercourse applications) - Vehicular, pedestrian or wildlife underpasses or overpasses; utility crossings

Figure 1 – Structural Plate Installations

PIPE-ARCH CULVERT WITH BURIED INVERT ON WATERCOURSE

OPEN BOTTOM ARCH ON WATERCOURSE

PEDESTRIAN UNDERPASS

Corrugated steel plate can be exposed to a variety of environmental conditions, as shown in Table 1.

Table 1 – Application and Structure Exposure

Application	Structure Type	Location On Structure	
		Interior Exposure	Exterior Exposure
Watercourse	Round, Pipe-Arch, Ellipse	Bedload Material, Water (invert, sides), Infill Soil, Deicing Salt	Backfill Soil Envelope, Groundwater, Salt Spray and Seepage
	Open Bottom Arch, Box Culverts	Water, Infill Soil, Deicing Salts (sides below design water elevation)	Backfill Soil Envelope, Groundwater, Salt Spray and Seepage
Grade Separation	Underpass, Round, Ellipse	Infill Materials (invert), Deicing Salts (sides, invert)	Backfill Soil Envelope, Groundwater, Salt Spray and Seepage
	Open Bottom Arches	Deicing Salts (sides)	Backfill Soil Envelope, Groundwater, Salt Spray and Seepage

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Definitions

- AASHTO – American Association of State Highway and Transportation Officials
- AH – Horizontal Ground Acceleration Ratio
- ASTM – American Society for Testing and Materials
- CHBDC – Canadian Highway Bridge Design Code (CSA S6)
- CSA – Canadian Standards Association
- CSA G401 – Canadian Standards Association standard for Corrugated Steel Pipe Products (available through CSPI)
- CSPI – Corrugated Steel Pipe Institute
- DCSP – Deep Corrugated Structural Plate
- DL – Dead Load
- DSL – Design Service Life
- DWE – Design Water Elevation
- EAA – Ethylene Acrylic Acid
- EMSL – Estimated Material Service Life
- LL – Live Load
- LFRD – Load and Resistance Factor Design
- MSE – Mechanically Stabilized Earth
- SPCSP – Structural Plate Corrugated Steel Pipe
- SRB – Sulfate Reducing Bacteria
- TDS – Total Dissolved Solids

Available Coatings and Linings

Plate Coatings (per CSA G401)

- Hot Dip Galvanized
- Polymer Coated

Plate Linings

- Concrete
- Steel Plate

It should be noted that this document is not applicable to CSP (Corrugated Steel Pipe) culvert performance. CSP durability is covered by a separate document entitled “Canadian Performance Guideline for Corrugated Steel Pipe Culverts (300 mm to 3600 mm Diameter)” – available from CSPI.

This Guideline is not a substitute for professional engineering advice and is made without guarantee or representation as to the results. Although every reasonable effort has been made to assure its accuracy, neither the Corrugated Steel Pipe Institute (CSPI) nor any of its members or representatives warrants or assumes liability or responsibility for its use or suitability for any given application.

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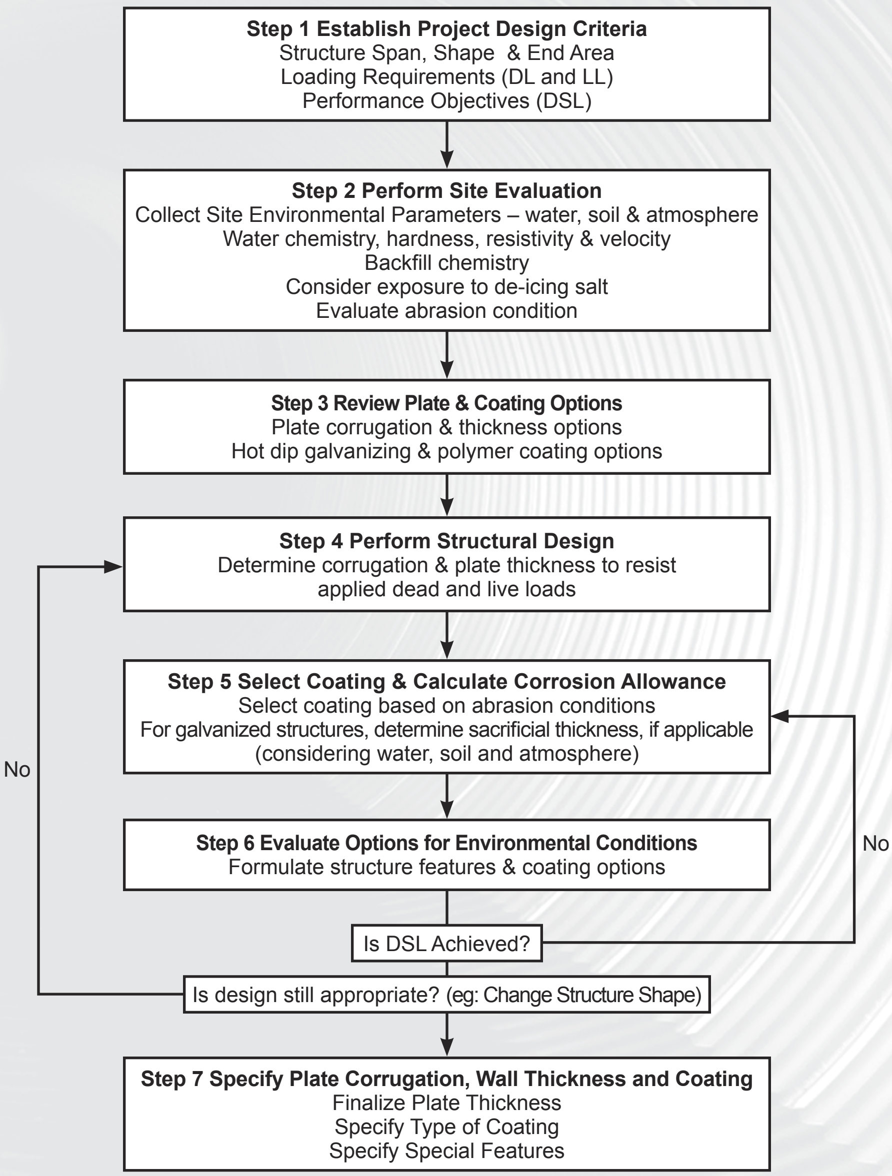
2.0 Guideline for Plate and Coating Selection

There are 7 basic steps to select a suitable Design Plate Thickness and Coating. The steps and information related to the details under each step are outlined in Figure 2.

Figure 2 – Steps for Plate and Coating Selection



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3.0 Steps for Plate and Coating Selection

Step 1 – Establish Project Design Criteria

It is anticipated that the designer will collect the required design criteria, such as site geometry, hydraulic requirements, and overall application needs.

This guideline is applicable to any structural plate or deep corrugated structural plate application, regardless of its physical dimensions and corrugation profile. The available structure shapes and sizes can be found in the CSPI Handbook of Steel Drainage & Highway Construction Products. More detailed information pertaining to available structure shapes is available through the member companies of the CSPI.

The loading conditions include the depth of the overburden above the crown of the structure (DL), the load imposed by vehicles (LL), and seismic loads determined by the horizontal ground acceleration ratio (AH) for the site.

The design service life (DSL) is defined as the number of years the structure is to be in use. The DSL of roadway structures typically varies from 25 to 75 years. Public agencies having jurisdiction for infrastructure projects normally establish DSL as a function of the type and importance of roadway, traffic volumes and future growth patterns.

Step 2 – Perform Site Evaluation

Field tests and observations have determined that buried plate performance and durability is a function of protecting against environmental parameters. The primary environmental parameters (water, soil and atmosphere) and their inter-relationship with performance objectives are discussed below.

Water

Watercourse applications, whereby the water may be in regular contact with the invert and/or sidewall plates of the structure, require an assessment of the following chemistry and flow parameters. Water conditions are considered whenever a part of the structure lies below the design water elevation (DWE). The DWE is to be determined by the owner. It is noted that some owners determine the DWE as the Q2 water elevation (maximum water elevation during a two year storm event) + 300 mm.

Water Chemistry

- pH level – pH is a measure of the acidity or basicity of the water. In acidic solutions, pH is less than 7 ($pH < 7$) and for basic solutions pH is greater than 7 ($pH > 7$). A solution with $pH = 7$ is considered neutral.

- Resistivity (ohm-cm) – resistivity is an indication of water's inability to carry an electrical current. It is a function of the concentration of total dissolved solids (TDS) or salt ions in the water.

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- Chlorides (Cl) – chlorides are highly soluble compounds commonly found in deicing salts, seawater and evaporation pools. Chloride ions are the most likely contributor to low resistivity values and will promote the corrosion of unprotected steel.

- Sulfates (SO_4) – soluble sulfates occur naturally. They are also commonly found in polluted air and are deposited on soil and in water. They contribute to lower pH levels in water (acid rain). They may decrease resistivity and support sulfate reducing bacteria (SRB) in anaerobic conditions. Any of these may promote the corrosion of unprotected steel.

- Total Hardness – hardness is indicated by the amount of calcium carbonate ($CaCO_3$) dissolved in the water and will determine the buffering capacity, or ability of the water to neutralize acidity. Natural soft water has a low concentration of $CaCO_3$ which, despite high resistivity, may indicate a corrosive potential for galvanized steel. Hard water is rich in $CaCO_3$ which neutralizes acidity and forms a protective scale on galvanized steel.

Environmental limits for galvanized steel and polymer coated plate products are presented in Table 2.

Table 2

Environmental Limits For Galvanized Steel and Polymer Coated Steel

Environmental Parameter	Suggested Limits Galvanized Steel	Suggested Limits for Polymer Coated Steel		
		50 Year EMSL	75 Year EMSL	100 Year EMSL
pH Preferred Range	5 - 9	3 to 12	4 to 9	5 to 9
Resistivity	2,000 - 8,000 ohm -cm	>100 ohm cm	> 750 ohm cm	>1,500 ohm cm
Chlorides	< 250 ppm	NA[1]	NA[1]	NA[1]
Sulfates	< 600 ppm	NA[1]	NA[1]	NA[1]
Hardness	> 80 ppm $CaCO_3$	NA[1]	NA[1]	NA[1]

Note:
[1] Resistivity is relative to total dissolved solids (TDS) and therefore may indicate the presence of chlorides, sulfates, calcium and other ions.

Flow Velocity

Flow Velocity has a direct influence on the bedload and thus the abrasion rating. Abrasion can degrade the plate finish and lead to a loss of plate thickness on the upstream corrugation crests due to impacts by aggregate or debris suspended in the flow. Table 3 defines the abrasion conditions (1 through 4) based on a bedload description and flow velocity.

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Table 3

Abrasion Flow Parameters

Abrasion Level	Bedload Description	Anticipated Maximum Flow Velocity (m/s)[1]
1	**Non Abrasive** – very low velocities and no bedload (e.g. storm sewers, stormwater detention systems, arches)	NA
2	**Low Abrasive** – Minor bedloads of sand and gravel	1.5
3	**Moderately Abrasive** – Moderate bedloads of sand and gravel	4.5
4	**Severely Abrasive** – Heavy bedloads of sand, gravel and rock	> 4.5

Note:
[1] Abrasion velocities should be evaluated on the basis of frequency and duration. A frequent storm, such as a two year event (Q2) or mean annual discharge (Q2.33), should be used to determine the velocity.

Soil

Backfill Materials – engineered backfill materials that encase buried plate structures are selected based on known physical (structural) properties, but they must also meet specified electrochemical properties. Backfill must be a free draining granular material, devoid of organics, with a known density and electrochemical properties as defined in Table 4. These materials are typically imported and their properties may be vastly different than native materials. Engineered backfill envelopes isolate the structure from native materials of unknown properties.

- Organics – organic material in the backfill can initiate the formation of anaerobic pockets of soil which could be contaminated with SRB, thereby initiating microbial attack in the form of severe pitting. Low organic content is also required for structural purposes. Total organic content should be limited to 1 percent by weight of the total soil fraction as determined in accordance with AASHTO T-267 “Standard Method of Test for Determination of Organic Content in Soils by Loss on Ignition”.

- Sulfates (SO_4) – sulfates are generally considered to be more benign than chloride ions for metallic corrosion. However, the presence of sulfates does pose a risk for metallic materials in the sense that sulfates can be converted to highly corrosive sulfides by anaerobic SRB. Because sulfate represents only one of the fractions in which sulfur can exist in the soil, the extraction and quantification of soil sulfur can be a complex process. AASHTO T-290 “Standard Method of Test for Determining Water-Soluble Sulfate Ion Content in Soil” describes a chemical titration method for measuring water soluble sulfate concentrations.

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Table 4

Backfill Material Parameters and Test Methods

Backfill Material Parameters	AASHTO Test	ASTM Test	Galvanized Limits	
			UK[1]	AASHTO
pH	T289-91	G-51	6 - 9	5 - 10
Resistivity	T288-91	G-57	> 3000 ohm-cm	> 3000 ohm-cm
Chlorides	T291-91	D-512	< 50 ppm	< 100 ppm
Sulfates	T290-91	D-516	< 240 ppm	< 200 ppm
Organics	T267-86	NA	< 1%[2]	< 1%[2]

Notes:
[1] The plasticity index of the fraction passing through a 425 μm sieve should be ≤ 6.
[2] Low organics content is required for structural purposes.

Atmosphere

Atmospheric exposure is considered to have a minimal effect on the performance of plate structures with the exception of structures subject to heavily concentrated industrial gases, extreme heat sources or coastal areas with salinity.

Step 3 – Review Plate and Coating Options

This guideline is applicable to any structural plate or deep corrugated structural plate application, regardless of its physical dimensions and corrugation profile. The available corrugation profiles can be found in the CSPI Handbook. More detailed information pertaining to available structure shapes is available through the member companies of the CSPI.

Structural plate products are available in two primary corrugation profiles – shallow or deep. Both products can be found in CSA G401.

The shallow profile structural plate corrugated steel pipe (SPCSP) has a corrugation with a 152.4 mm pitch x 50.8 mm depth. It is available in nominal plate thicknesses of 2.69 to 7.0 mm.

The deep profile deep corrugated structural plate (DCSP) is available in two corrugation profiles, Type 1 or Type 2.

- Type 1 DCSP has a 381 mm pitch x 140 mm deep corrugation. It is available in 4.19 to 7.94 mm nominal plate thicknesses.
- Type 2 DCSP has a 400 mm pitch x 150 mm deep corrugation. It is available in 4.30 to 7.94 mm nominal plate thicknesses.

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Structural plate products are available with hot dip galvanized coating options as detailed in Table 5.

Table 5

Zinc Coverage for Galvanized Structural Plate Products from CSA G401

Nominal Plate Thickness (mm)	Standard Zinc Coverage		Non-Standard Zinc Coverage	
	Total Mass – Both Sides (g/m^2)	Thickness per side (μm)	Total Mass – Both Sides (g/m^2)	Zinc Thickness per side (μm)
< 4.0	915	64	NA	NA
4.0 – 8.0	915	64	1220	87

Polymer coating can be used to eliminate or minimize contact of the steel with the environment for a period of time. Polymer coating is a two part system whereby ethylene acrylic acid (EAA) copolymer is applied over a zinc based layer to provide the longest service life coating available for structural plate products. Bolts and nuts are available galvanized, field coated or pre-coated with a barrier coating. The choice of bolt and nut materials is subject to environmental parameters. Several test reports, evaluating the polymer coating system are available through CSPI member companies. The coating is factory applied and coated plate performance exceeds that of steel sheet products manufactured to ASTM A742 “Standard Specification for Steel Sheet, Metallic Coated and Polymer Precoated for Corrugated Steel Pipe”.

Step 4 – Perform Structural Design

The corrugation profile and plate thickness required to satisfy the loading conditions defined in Step 1 can be determined from three references.

1. The CSPI Handbook of Steel Drainage & Highway Construction Products (2007) contains design methods, a number of tables and design examples.

2. Section 7, Buried Structures, of the Canadian Highway Bridge Design Code (CSA S6), details the design procedures for metal structures having either shallow or deep corrugation profiles.

3. The manufacturers of corrugated plate products can provide design expertise.

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Step 5 – Select Coating & Calculate Corrosion Allowance

The initial selection of coating considers the abrasion condition established in Step 2. Table 6 outlines the coating options relative to the observed abrasion condition.

Table 6
Abrasion Condition Coating Options

<table>
<tr><th colspan="4">Abrasion Condition Coating Options</th></tr>
<tr><td>1 Non</td><td>2 Low</td><td>3 Moderate</td><td>4 Severe</td></tr>
<tr><td colspan="3">Polymer Coated Plate</td><td></td></tr>
<tr><td colspan="2">Galvanized Plate</td><td></td><td></td></tr>
<tr><td colspan="4">Alternate Structure[1] - Composite Systems[2]</td></tr>
</table>

Notes:
[1] Select a bottomless structure to eliminate invert plate abrasion concerns.
[2] Refer to Step 6.

The corrosion allowance is a calculated estimate of the average metal loss expected over the (DSL). By adding a corrosion allowance to the thickness required to resist applied dead and live loads we can ensure that the structure meets the design requirements throughout the DSL. A protective coating can be added to the structure, or portions of the structure, to reduce or eliminate the estimated corrosion allowance. The estimated material service life (EMSL) will exceed the DSL when a steel plate thickness, thicker than the structural plate thickness increased by the corrosion allowance, is specified.

A structure is typically exposed to the basic environments – water, soil and atmosphere. A corrosion allowance is calculated for each environment to which the structure is exposed. Corrosion acts from both the inside and outside of a structure, one corrosion allowance for each side of a plate is to be summed to determine the required total corrosion allowance. For example, for submerged plates on a creek crossing, it may be appropriate to use the water corrosion allowance inside and soil allowance outside.

Water Environments

The corrosion rate in water can be greatly influenced by a variety of factors. Effluent can be classified into three categories based on hardness, pH, resistivity, chlorides and soluble sulfates. Table 7 shows the resulting Corrosivity Classification. The overall classification should be based on the most severe condition and limiting property.

Table 7
Properties of Water and Effluent

Corrosivity Classification	pH	Chloride ion (ppm)	Soluble sulfates (ppm)	Hardness ppm $CaCO_3$	Resistivity (ohm-cm)
Non-Aggressive	6 ≤ pH ≤ 9	≤ 50	≤ 240	> 80	2000-8000
Aggressive	5 ≤ pH < 6	> 50 and ≤ 250	> 240 and ≤ 600	> 80	2000-8000
Very Aggressive	< 5 or > 9	> 250	> 600	< 80	< 2000 or > 8000

For non-aggressive and aggressive corrosivity classifications, zinc and steel corrosion rates can be estimated using the equations in Table 8. Galvanized steel is not recommended for use in very aggressive environments.

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Table 8

Zinc and Steel Corrosion Rates for Non-Aggressive and Aggressive Waters

Rate of corrosion of zinc (µm/year)		Calculation for thickness of sacrificial steel (M, µm)[1]	
Non-Aggressive	Aggressive	Non-Aggressive	Aggressive
4	14	$M = 22.5 * (t - 16)^{0.67}$	$M = 40 * (t - 4.57)^{0.80}$

Note:
[1] t = Design Service Life in years. These formulae assume a zinc thickness of 64 µm per side (coating mass of 915 g/m²).

Table 9 provides the calculated steel corrosion allowance for various timeframes. Note that these loss rates assume that the inside surface of the galvanized steel is continuously immersed. For plates which are only intermittently exposed to water, a reduction in the corrosion allowance would be appropriate

Table 9

Calculated Water Side Steel Corrosion Allowance

	Steel Corrosion Allowance[1] (µm)	
DSL (years)	Non-Aggressive	Aggressive
25	98	447
50	239	847
75	346	1203
75[2]	66	145

Notes:
[1] The steel corrosion allowance is the thickness of steel that must be considered as an add-on to the thickness calculated as a structural requirement.
[2] The steel corrosion allowance for a 75 year DSL when polymer coated is used at a Level 3 (Moderate) abrasion condition.

For the soil side surface of plates exposed to water via saturated soil, the soil side corrosion rates discussed in Table 11 shall be used. The water associated with saturated soil is not rich in oxygen, a key component of the water side corrosion process.

If a polymer coating is being used, it is assumed that no corrosion will occur during the effective lifetime of the coating. Research suggests that polymer coatings can provide an effective life of 80 plus years depending on the abrasion condition. Table 10 shows the recommended “add-on” life to assume for each of three abrasion levels.

Table 10

Effective Protective Life of Polymer Coating

Abrasion Condition	Effective Polymer Coating Life (years)
1 Non	80+
2 Low	80+
3 Moderate	70
4 Severe	Not Recommended

Soil Environments

Various models have been used to estimate a corrosion allowance for galvanized steel structures in contact with backfill soil. The AASHTO model, applicable for buried MSE retaining wall soil mats, is recommended and has been applied by public agencies. It is not a requirement of the CHBDC. For the sake of comparison, this Guideline also includes a UK soil side corrosion model. The corrosion of the zinc coating and the steel substrate can be estimated using the AASHTO values listed in Table 11.

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Table 11

Zinc and Carbon Steel Soil Side Loss Rates

Material	Period	AASHTO Standard Loss Rate/year/side (µm)[1]	UK Non-Aggressive LossRate/year/side (µm)[2]
Zinc Coating	First 2 years	15	4
	Subsequently	4	4
Carbon Steel	After Zinc Depletion	12	M[3]

Notes:
[1] AASHTO LRFD Bridge Construction Specifications, Article 7.6.4.2, Soil Reinforcements.
[2] UK Design Manual for Roads and Bridges BD 12/01 Volume 2, Section 2, Part 6 Design of Corrugated Steel Buried Structures with Spans Greater than 0.9 Metres and up to 8.0 Metres.
[3] M is the UK steel corrosion allowance after zinc depletion, per side in µm (rather than a loss rate / year / side). M is calculated as $M=22.5*t_s^{0.67}$ where t_s is the additional design service life in years after zinc depletion (for a zinc thickness of 64 µm per side t_s = DSL – 16 years).

Where a 64 µm galvanizing thickness is used, the AASHTO soil side steel corrosion allowance can be calculated as follows, where M is the corrosion allowance in microns (µm) and t is the number of years.

$M = 0$ for $t \leq 10.5$ years; and
$M = 12 * (t - 10.5)$, for $t > 10.5$ years

The resulting steel corrosion allowance for a design service life of 25, 50, and 75 years is shown in Table 12.

Table 12

Calculated Soil Side Steel Corrosion Allowance

DSL (years)	AASHTO Steel Corrosion Allowance (µm)[1]	UK Steel Corrosion Allowance (µm)[1]
25	174	98
50	474	239
75	774	346

Note:
[1] The steel corrosion allowance is the thickness of steel that must be considered as an add-on to the thickness calculated as a structural requirement.

These soil side corrosion rates assume that the structure is buried using engineered backfill meeting the parameters summarized in Table 4.

Further references can be found in the CHBDC commentary, Table C7.2.

Atmospheric Environments

A corrosion allowance for galvanized steel structures in atmosphere need not be considered for most applications.

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Step 6 – Evaluate Options for Environmental Conditions

Environmental conditions can include site chemistries beyond the recommended ranges and/or abrasion conditions 3 or 4. Deicing salt is a major factor in altering environmental conditions.

Various design options are available for corrugated structural plate in order to meet DSL requirements whenever extreme environmental conditions challenge the designer.

Full periphery plate structures can incorporate special features to address abrasion and flow velocity concerns; for example, supplementary armour plates, energy dissipaters, or paved inverts.

The segmental nature of structural plate structures can accommodate a combination of galvanized and polymer coated plates within the periphery of the structure. This allows polymer coated plates to be positioned in the zones of known extreme environmental conditions. Similarly, varying the plate thicknesses within the periphery can position heavy plate thicknesses along the invert or sides in the zones of high abrasion levels.

Bottomless arch structures are a common choice when abrasion condition 4 or extreme environmental conditions are encountered. This option eliminates invert wear concerns. If a change from a full periphery structure to a bottomless arch is required, the structural design decision in Step 4 must be re-evaluated.

For open bottom structures on watercourse applications, consideration can be given to increasing the span and top of the footing elevation, such that the plate is not in contact with the water (Figure 3).

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Figure 3 – DCSP Box Culvert Bridge on Footings (Includes Steel Sheet Pile Headwall)

Options for the protection of plate structures with shallow cover from roadway contaminants infiltrating the overburden and coming into contact with the shell include:

- Embedding an impermeable plastic liner and sub-drains in the backfill envelope above the structure span and along its length
- Selecting polymer coating for the plate finish

Roadway contaminants can also come into contact with the structure interior on vehicular underpasses. Protection of the plates from these corrosive elements can be managed by constructing cast-in-place concrete splash walls (Figure 4). Maintenance of underpass structures can include pressure washing the interior in order to extend the service life.

Watercourse applications subject to high flow velocities should include proper end treatment and anti-piping features. These may include, but are not limited to, constructing impermeable headwall/wingwall systems, steel sheet pile cut off walls, anti seepage diaphragms, or concrete headwalls or concrete bevel end collars. End treatment systems provide structural resistance to hydraulic uplift forces, and to ice and debris impact for high water events and protect and contain the engineered backfill envelope from erosion and piping along the exterior of the structure during high flows.

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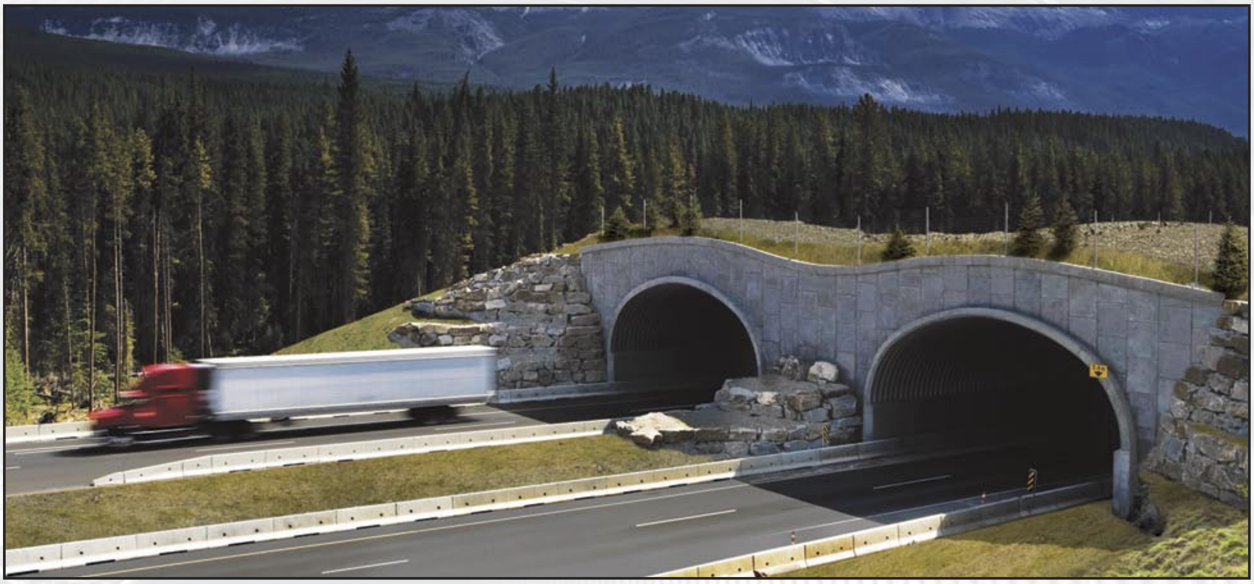
Figure 4 – DCSP Underpass with Splash Walls, Concrete Collars and End Walls



Step 7– Specify Plate Corrugation, Wall Thickness and Coating

The preceding 6 steps enable the designer to specify the following key design deliverables;

- A buried steel plate structure shape to meet the project design criteria
- An appropriate corrugation profile
- Environmental soil parameters for the imported engineered backfill envelope
- The design wall thickness throughout the structure's periphery and length to meet the DSL
- The optimum coating system throughout the structure's periphery and length to meet the DSL
- Special features required to address extreme environmental conditions or events

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4.0 Design Example

Step 1 – Establish Project Design Criteria

- Hydraulic analysis requires a minimum waterway end area of 18.0 m^2
- A minimum 5.5 m wide structure is required to span the stream bed
- Streambed to top of roadway = 5.6 m
- DWE is 5 m below the roadway
- A full periphery structure is acceptable (eliminates footing requirements)
- Highway live load design vehicle as per CHBDC (CL-625)
- Unit weight of overburden = 22.0 kN/m^3 (soil group I, 90%-95% Standard Proctor Density)
- Site location – London Ontario (seismic zone 0)
- Design Service Life = 75 years

Step 2 – Perform Site Evaluation

- Site water chemistry and flow parameters are as follows;
  - pH = 7.0
  - resistivity = 2600 ohm-cm
  - chlorides = 40 ppm
  - hardness = 120 ppm
  - maximum design flow velocity = 1.4 m/s
  - bedload contains sand & gravel

- Electro-chemical properties of the proposed engineered backfill materials are as follows;
  - pH = 7.0
  - resistivity > 3000 ohm-cm
  - chlorides = 40 ppm
  - sulphates = 100 ppm
- Atmospheric corrosion is not a concern

Step 3 – Review Plate & Coating Options

- Select a standard galvanized structural plate pipe-arch, 152 mm x 51 mm corrugation profile, 6250 mm span x 3910 mm rise, end area = 19.18 m^2, effective end area for flow = 18.22 m^2 (ref Table 2.19, page 42, of the CSPI Handbook of Steel Drainage & Highway Construction Products)
- Select standard zinc coating mass of 915 g/m^2

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Step 4 – Perform Structural Design

- Plate thickness calculations can be found in Example 2, page 264, of the CSPI Handbook. The recommended plate thickness, to satisfy the structural criteria, is 4.0 mm. This is confirmed in Table HC-8 of the CSPI Handbook (page 254).

Step 5 – Calculate Corrosion Allowance & Select Coating

- Referring to Table 3, the flow velocity is designated Low Abrasive (Level 2). The suggested coating option to meet Level 2 abrasion for invert plates is galvanized or polymer coated, as shown in Table 6.
- Water chemistry results in a water Corrosivity Classification of Non-Aggressive (Table 7): for galvanized plates, the water side Steel Corrosion Allowance for a 75 Year DSL is 346 μm (Table 9).
- Backfill chemistry is within UK & AASHTO limits for galvanized steel (Table 4): for galvanized plates, the soil side Steel Corrosion Allowance for a 75 Year DSL is 346 μm (Table 12 using UK model)
- As atmospheric corrosion is not a factor, the Steel Corrosion Allowance for a 75 Year DSL is 0 μm for the interior surface of plates that are above the waterline.

The Steel Corrosion Allowance for the various plate options listed below:

Above the waterline

- The steel thickness for galvanized plates is 4000 μm + 346 μm + 0 μm = 4346 μm.
  The next standard plate thickness is 5.0 mm.
- The steel thickness for polymer coated plates is 4000 μm + 0 μm = 4000 μm.
  The standard thickness of 4.0 mm is adequate.

Below the waterline

- The steel thickness for galvanized plates is 4000 μm + 346 μm + 346 μm = 4692 μm.
  The next standard plate thickness is 5.0 mm.
- The Steel Thickness for polymer coated plates is 4000 μm + 0 μm + 0 μm = 4000 μm.
  The standard plate thickness of 4.0 mm is adequate.

Step 6 – Evaluate Options for Environmental Conditions

- Considering the high flow velocities and potential for scour, cutoff protection is advised.
- In Step 5 it was determined that there are options such that the EMSL can meet the 75 year DSL requirement. The site evaluation performed in Step 2 suggests that further evaluation for extreme conditions is not required.

Step 7 – Specify Plate Corrugation, Wall Thickness and Coating

- A 6250 span x 3910 rise SPCSP pipe-arch meets the project hydraulic, dimensional and structural criteria
- The engineered backfill materials meet the recommended electro-chemical environmental parameters

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- The suggested material and thickness for plates above the waterline is either 5.0 mm galvanized steel or 4.0 mm polymer coated steel.
- The suggested material and thickness for plates below the waterline is 5.0 mm galvanized or 4.0 mm polymer coated steel.
- Galvanized steel sheet piling cut off walls are recommended.

Vehicular Underpass with Top Plates Polymer Coated for Deicing Salt Runoff from Major Highway

SPCSP Pipe-Arch with Polymer Coated Invert Plates