BURIED BRIDGES, MORE RESILIENT & SUSTAINABLE

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Abstract

By offering better alternatives to traditional bridges, Buried Bridges using Corrugated Structural Plate now deliver maximum value and road safety. Continuous research, product improvements, and more durable coatings have elevated the performance characteristics of buried bridges to the point where they are now legitimate contenders in markets, environments, and sites from which they were previously excluded. From projects across Canada, the resilience of buried bridges has demonstrated their ability to withstand extreme weather events, over time. After surviving severe flooding, and even hurricane events, buried bridges were often the one bridge left standing. By minimizing the natural and financial resources required, Buried Bridges yield a positive environmental impact with a low carbon footprint that continues to be lowered annually. Mitigated durability, hydraulic flows, traffic disruptions, and climate change risks are among their accrued benefits; along with high recycled content and reduced construction waste as verified in the Environmental Product Declaration. Maximizing value to owners contributes to benefit the entire population.

CORRUGATED STEEL PIPE INSTITUTE

The Corrugated Steel Pipe Institute (CSPI) is the association that represents Canadian corrugated steel pipe (CSP) manufacturers. We are an impartial organization that collaborates with our member manufacturers, along with municipalities and engineers around the world, to gather and compile relevant information, news, innovations, and performance data. In Canada, we serve as the country's essential information resource regarding water & soil management practices. Armed with more than a hundred years of engineering knowledge, data, and technical expertise, we provide ongoing assistance to the public, government officials, and construction engineers seeking the most prudent solutions for their projects, to maximize their return on every dollar spent.

1. BURIED BRIDGE DEFINITION

Buried bridges are:

- bridges with spans greater than 3 meters, which resist and protect structures from the potential ravages of hostile elements within the surrounding soil
- distinct from bridges, in that buried bridges require methods of design analyses that consider and address potential soil-interactions with CSP
- distinguished from culverts, in that they pertain to larger structures that are of critical importance for highway safety

Structural plate corrugated steel (SPCS) has been manufactured and used in Canada since 1934. For decades, Canada has been responsible for the development and introduction of many technical performance innovations to structural plate products and has exported these improved technologies to customers and organizations domestically and around the world.
The oldest corrugated structural plate buried bridge in Canada was built in 1934 during the Great Depression period at 6688 3rd Line West Centre, in Wellington Ontario. The structure was 6" x 11/2" corrugation profile with no circumferential bolts. The plate lengths were 6' and 8' which is shorter than what is used today. Measurements are in imperial which was used during that time. The span was 9' 10" and the material coating was galvanized. The water was tested on July 24, 2024 and the readings were hardness 425 ppm, PH 7, and chlorides 18 ppm. There are rust stains at the bolt holes and on the plates below the water line. No perforations were observed. After 90 years in service, the structure is performing well.

Figure 1: Oldest Corrugated Structural Plate Buried Bridge - 1934



2. PROFILES & SHAPES

In the early days of production, the conventional corrugation profile of SPCS was 152mm pitch (crest to crest), by 51mm depth (crest to valley). These early structures required circumferential stiffening

members (ribs), horizontal sizing cables, and struts, or supports, for long span structures. These developments made it possible to achieve clear spans up to 18 meters, and clear areas up to 100m2.

In the 1990s, extensive research and development resulted in the creation of larger corrugation profiles, which featured both increased pitch and depth. These profile innovations enabled the development of new SPCS products offering larger profiles than previously available. Profiles in CSA G401-14 include 152mm x 51mm, 381mm x 140mm, 400mm x 150mm and 500mm x 237mm.

These new, deeper corrugated profiles eliminated the need for the additional strengthening and stiffening requirements of earlier SPCS structures. The increased stiffness and load resistance of these larger profiles have significantly increased the practical application limits of SPCS structures, which can now accommodate spans of up to 30 meters, or more. Although they are technically still considered to be 'flexible' structures, during installation these deep corrugation profiles effectively produce rigid structures.

Detailed design procedures covering installation of these long span structures can be found in the Canadian Highway Bridge Design Code, CHBDC, (CSA 2019), as well as in the latest edition of the AASHTO LRFD Bridge Design Specifications, Sections 12.7 and 12.8 (AASHTO 2014). These standards provide for the selection of acceptable combinations of plate thickness, minimum cover requirements, plate radius, and other design factors.

Figure 2: recommended span sizes to corrugation profiles

152mmx 51mm	381mm x 140mm 400mm x 150mm	500mm x 237mm





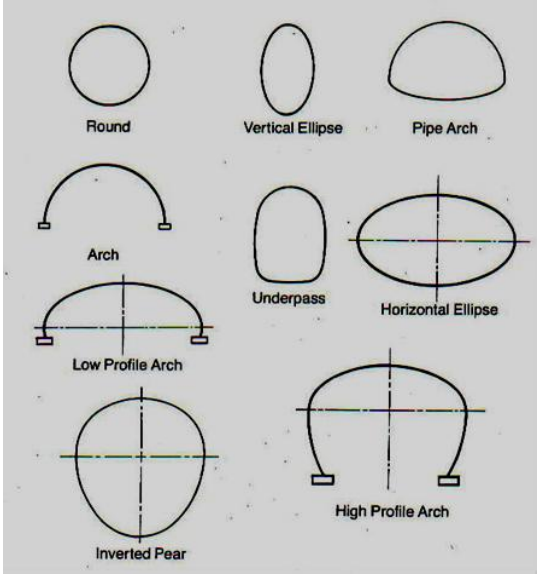


1.5 – 8m	8 – 24m	8 – 30m +

Span – width of footing to footing in m

Designers can choose from a wide range of standard cross-sectional shapes of corrugated steel and structural plate conduits, as shown in Figure 3. Prudent designers must determine the optimum shape based on criteria, including the size of the structure and its service use, but must also consider other factors, such as the strength and economy of the design. (CSPI Handbook 2017).

Figure 3: Shapes



3. BENEFITS OF BURIED STRUCTURES

The myriad of applications in which buried CSP structures serve include bridges, highway and railroad overpasses, stream enclosures, tunnels, culverts, and conveyor conduits. Because these structures offer so many advantageous benefits over other materials, they are extremely popular for bridge replacement projects. When used in this manner, buried CSP bridges:

1. eliminate icing problems on bridge decks
2. prevent bridge deck deterioration
3. end the need for constant maintenance of bridge approaches and painting of the superstructure
4. permit the use of a constant roadway section in the vicinity of the structure
5. enable the roadway to be easily widened, simply by extending the ends
6. are readily available and can be field assembled with unskilled labour
7. reduce the time required for design and construction, thereby facilitating faster project completion
8. are environmentally superior, in that they reduce carbon footprints, while retaining the natural appearance of a site's earth slope and vegetation
9. are more economical and lightweight, which reduces transportation costs
10. offer a 75+ years material service life for specific environments

In 2013, there was a major flood event – an alluvial fan – in Canmore, Alberta. Extremely heavy rains, combined with a mountain snow melt, quickly and violently transformed the neighbourhood creeks of this picturesque small town into raging torrents. Estimated damage to the homes along Cougar Creek alone was more than $6 million CDN. However, one bridge did survive – a corrugated structural plate buried steel bridge. Why did it withstand the ferocious flooding when others were quickly washed out? Because it was designed with careful attention to proper headwall treatment of stone riprap sealed by Portland cement grout and was, therefore, kept clear of debris, allowing water to run through freely. (Geddes 2014).

Figure 4: Canmore, Alberta after the flood

a) Cougar Creek overflows



Residents watch the flooding Cougar Creek as it takes out Eagle Terrace Road (C) and nears the top of the Elk Run Blvd Bridge June 20, 2013 in Canmore, Alberta.

b) Eagle Terrace Road which collapsed



CANMORE, CANADA- JUNE 21: A woman walks along the edge of Eagle Terrace Road which collapsed into the river, looks at the destruction along the Cougar Creek June 21, 2013.

4. DURABILITY OF COATINGS

As per CSA G401-24, there are two plate coatings available: Hot Dip Galvanized and Polymer Coated. Galvanized coatings date back to 1930 and are well known within the bridge industry. Polymer Coated CSP was developed in 2005 to improve durability of the product when installed in environments with specific, corrosive, and abrasive chemistry. There are three primary environmental conditions to consider when determining what materials will be most durable for a buried structure application: soil, water, and anthropogenic impacts. The thermoplastic polymer system is comprised of the steel substrate, a zinc rich primer, containing a minimum of 60 wt.% zinc, and an ethylene acrylic acid (EAA) copolymer topcoat, containing a minimum of 85 wt.% EAA. (CSA G401 2024).

Laboratory testing concluded that, in every aspect of performance, polymer coatings far exceeded the protection offered by galvanized. Two of these tests were of primary interest: corrosion resistance, as measured by exposure to salt spray; and abrasion resistance, by sandblasting the product in cycles. In salt spray exposure tests over time, polymer coatings outperformed the metallic coatings by 5,000 hrs. When subjected to abrasion testing, after completing full four cycles, 84% of the original galvanized thickness was gone, but only 0.5% of the thermoplastic polymer coating's thickness was depleted. As a result of the testing, thermoplastic polymer coated structural plate is expected to provide significantly improved longevity for buried steel structures, in a far broader range of environments than was previously possible. Through analysis of all test data and an extensive literature review by a qualified Corrosion Engineer, a predictive model was developed to forecast the long-term field performance of the coated SPCS material. These models and analyses are captured in the Performance Guideline for Buried Steel Structures and its supporting White Paper (at https://cspi.ca). Since its first installation beneath a section of Highway 401, near Kingston, Ontario in 2005, thermoplastic polymer coated plate has grown in popularity and is now spread across Canada. In fact, there are now more than 250 installations in Canada, as verified by Warner Custom Coatings. (Williams and Carrol and West 2012, Villeneuve and Penny 2012).

Table 1: Environmental Limits for Galvanized Steel and Polymer Coated Steel (CSPI 2012)

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	2000–8000 ohm-cm	> 250 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 C_aCO_3	NA[1]	NA[1]	NA[1]
Abrasion[2]	Level 1 or 2	Level 1, 2 or 3	Level 1, 2 or 3	Level 1, 2 or 3

Note:

1. Resistivity is relative to Total Dissolved Solids (TDS) and therefore may indicate the presence of chlorides, sulphates, calcium, and other soluble ions.
2. Abrasion Levels:
   Level 1: Non-Abrasive – very low velocity and no bedload. Anticipated Flow Velocity – NA
   Level 2: Low Abrasion – Minor bedloads of sand and gravel. Anticipated Flow Velocity = 0-1.5 m/s
   Level 3: Moderate Abrasion – Moderate bedloads of sand and gravel. Anticipated Flow Velocity 4.5
   Level 4: Severe Abrasion – Heavy bedloads of sand, gravel, and rock. Anticipated Flow Velocity > 4.5

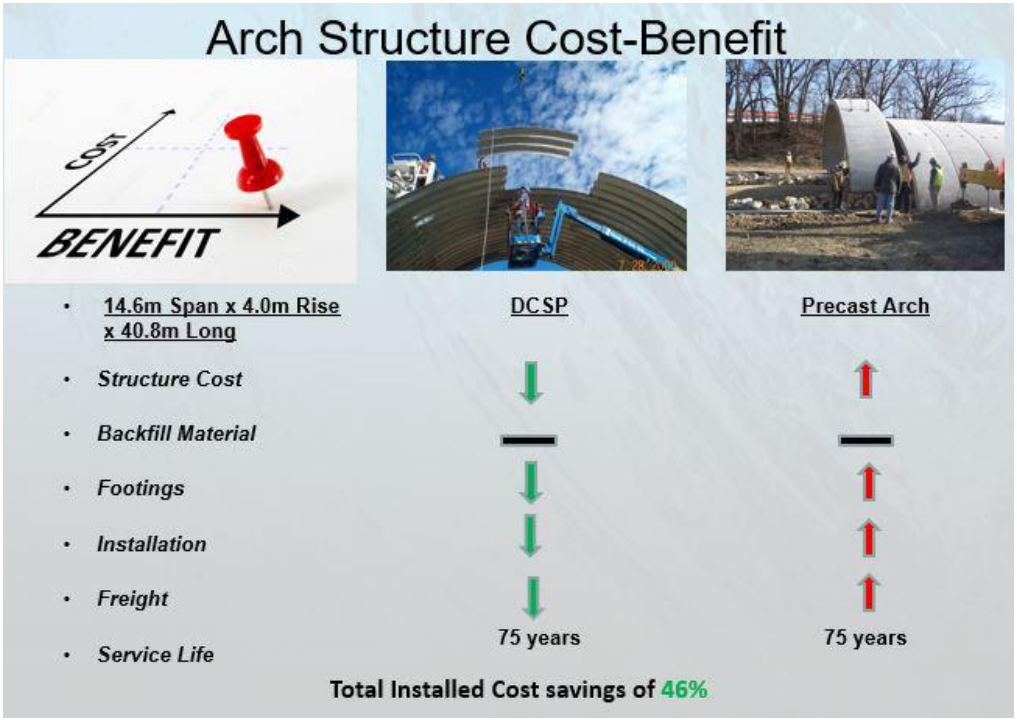
5. DELIVER MAXIMUM VALUE TO OWNERS

Choosing the type of bridge to design involves several factors, including material service life, safety, aesthetics, innovation, access and mobility, maintenance of biodiversity, hydraulics, impact on climate, and the economic impact of the material chosen. Using buried bridges versus traditional bridges reduces installed cost by 33 to 67% (Transportation Research Board – 2012). Substantial savings in transportation and installation form the bulk of the savings. Transportation due to shipping an entire structure on one flatbed truck and minimal lifting equipment required for installation are the reasons. Spinoff benefits resulting from those cost reductions include:

- Reduced construction time (ease of installation – no large cranes needed)
- Increased bid competition
- Reduced environmental footprint
- Reduced maintenance
- Low life cycle cost - 75 to 100 years
- Economical shipping to remote locations – nested on one truck

Figure 5 depicts a recent project in Ontario, comparing a cost benefit comparison of materials:

Figure 5: (CSPI / member Armtec 2016)



6. PROJECTS ACROSS CANADA / WORLD

As a result of ongoing product and material improvements, in tandem with ongoing educational initiatives among transportation departments and engineering consultants, the popularity and preference for constructing corrugated steel buried bridges continues to grow across Canada. In fact, installations can be found in every province, in both rural and urban centers. Recently, the city of Calgary opted to construct buried SPCS bridges in three of its key urban areas, to divert money saved towards their infrastructure budget, as depicted in Figures 6.

Figure 6: Structures in the Calgary area

Mahogany in SE | Elbow Valley SW off Hwy 8 | Quarry Park



The largest corrugated steel span structure at 32.6 meters is in the Guiness Book of World Records.

Figure 7: Dubai UAE



7. SUSTAINABILITY

Most developed countries enjoy a high quality of life; however, they currently do so by consuming materials and finite natural resources at a rate our planet cannot continue to support. This cavalier approach devours precious resources with little restraint, overburdens ecosystems with excess waste and pollution, while neglecting the oversight, care and upgrading of our supporting infrastructures. When aggregated, these failings disrupt the social fabric of our societies, thereby undermining the ability of future generations to sustain the quality of life we currently enjoy. (TAC 2014)

Steel is, in fact, 100% recyclable. Moreover, the steel from which CSP products are manufactured comprises more than 50% recycled steel; importantly, recycled steel suffers no degradation whatsoever, retaining 100% of the properties of virgin steel. Additionally, CSP products are much lighter than competitive products, thus CSP can be nested on trailers, which significantly decreases the energy required for transportation to project sites.

Additionally, within the corrugated steel products sector, R&D drives continuous product and process improvements; accordingly, new alloys and application-specific, protective coatings have kept pace with advancing technology to render today's corrugated steel a leading, state-of-the-art, eco-friendly building material with longer service life.

For the past 25 years, Canada's steel manufacturing industry has continuously lowered its carbon footprint, through enhanced practices in the manufacturing and recycling of steel products, thereby effecting reductions in: greenhouse gas emissions; ozone depletion and smog air, while increasing the

use of renewable energy sources, enhanced waste disposal procedures and more efficient end-of-life recycling. (Coon 2017)

Figure 8: 3 R's



8. ENVIRONMENTAL PRODUCT DECLARATION (EPD)

In 2018, the CSPI on behalf of the member CSP steel manufacturers, released an EPD produced by a third-party. The EPD is a verified report that transparently communicates a product's quantified environmental impacts throughout its entire life cycle. Specifically, the EPD provides an assessment of the environmental impact of corrugated steel products on Global Warming Potential (CO2), Ozone Depletion, Acidification Potential, Eutrophication Potential, Petrochemical Ozone Creation Potential, and Depletion of Abiotic Resources. In 2024 the CSPI released two EPD's. One is based upon ArcelorMittal's (AMD) XCARB steel production and the second is based upon the North American (NA) steel production results. The AMD EPD showed a 33% reduction in CO2 and the NA EPD showed a 3% reduction. The EPD's are available on the CSPI website at https://cspi.ca/csp-sustainability/. Steel is a remarkable material that, when used wisely by qualified designers, can significantly reduce consumption of the world's limited resources.

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