PDHonline Course S110 (3 PDH)

Durability Design of Corrugated Steel Pipes

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NATIONAL CORRUGATED STEEL PIPE ASSOCIATION

CSP Durability Guide

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■ This Guide provides environmental ranges for CSP products. Service Life of CSP will vary within these ranges. For estimating average invert service life, refer to the Service Life Prediction section in this Guide or the Durability chapters of the AISI publication *Handbook of Steel Drainage & Highway Construction Products* or the *Modern Sewer Design*. ■ This Guide is not a substitute for professional engineering advice and is made without guarantee or representation as to results. Although every reasonable effort has been made to assure its accuracy, neither the National Corrugated Steel Pipe Association nor any of its members or representatives warrants or assumes liability or responsibility for its use or suitability for any given application.

Product Usage Guidelines for Corrugated Steel Pipe

● Shaded Circles Indicate Applicable Coatings
* See AISI Chart

COATING	WATERSIDE: Normal Conditions	Mildly Corrosive	Corrosive	Non-Abrasive/Low Abrasion (Lvl. 1 & 2)	Moderate Abrasion (Level 3)	High Abrasion (Level 4)	Provides Additional Soil Side Protection
Zinc Coated (Galvanized)	●*	●*	○	●	○	○	○
Aluminum Coated Type 2	●	●	○	●	○	○	○
Asphalt Coated	●	●	●	●	○	○	●
Asphalt Coated and Paved	●	●	●	●	●	○	●
Polymerlzed Asphalt Invert Coated*	●	●	○	●	●	○	○
Polymer Precoated	●	●	●	●	●	○	●
Polymer Precoated and Paved	●	●	●	●	●	●	●
Polymer Precoated w/ Polymerlzed Asphalt	●	●	●	●	●	●	●
Aramid Fiber Bonded Asphalt Coated	●	●	●	●	○	○	●
Aramid Fiber Bonded and Asphalt Paved	●	●	●	●	●	○	●
High Strength Concrete Lined	●	●	○	●	●	○	○
Concrete Paved Invert (75mm (3”) Cover)	●	●	○	●	●	●	○

* Use Asphalt Coated Environmental Ranges for Fully Coated Product

Note: Coatings listed under additional soil side protection are generally considered to provide 100 years service life from a soil side perspective within appropriate environmental conditions.[1]

ENVIRONMENTAL RANGES:

- **Normal Conditions:** pH = 5.8 – 8.0 (for R > 2000 ohm-cm)
- **Mildly Corrosive:** pH = 5.0 – 5.8 and/or for R = 1500 to 2000 ohm-cm
- **Corrosive:** pH < 5.0 (for R < 1500 ohm-cm)

ABRASION

Invert Protection/Protective Coatings can be applied in accordance with the following abrasion criteria. Abrasion velocities should be evaluated on the basis of frequency and duration. Consideration should be given to a frequent storm such as a two year event (Q_2) or mean annual discharge ($Q_{2.33}$) or less when velocity determination is necessary.

ABRASION LEVELS

The following qualitative definitions are provided as guidance to evaluate abrasion conditions when necessary.

Non-Abrasive (Level 1): No bedload regardless of velocity; or storm sewer applications.

Low Abrasion (Level 2): Minor bedloads of sand and gravel and velocities of 5 ft./sec. or less.

Moderate Abrasion (Level 3): Bedloads of sand and small stone or gravel with velocities between 5 and 15 ft./sec.

Severe Abrasion (Level 4): Heavy bedloads of gravel and rock with velocities exceeding approximately 15 ft./sec.

Protective Coatings and Pavings

All corrugated steel pipes have a metallic coating for corrosion protection. When the coating selected does not provide the required service life or is outside the appropriate environmental conditions, an alternate coatings system can be selected. Often the required service life can also be achieved by increasing the sheet thickness; this alternative should be weighed against the cost of supplemental coatings. Galvanizing is the most widely used metallic coating and is the basis for the Service Life Chart shown on page 4.

A. METALLIC COATINGS

Zinc-coated (Galvanized) Steel (AASHTO M36, ASTM A929) is produced with a coating weight of 610 g/m^2 (2 oz/ft^2) of surface (total both sides) to provide zinc coating thickness of 43 µm (0.0017 in.) on each surface.

4 Ounce Zinc-coated (Galvanized) Steel is a new coating produced with a coating weight of 1220 g/m^2 (4 oz/ft^2) of surface (total both sides) to provide zinc coating thickness of µ6 mm (0.0034 in.) on each surface. This coating has been evaluated in the lab and is currently being evaluated in field installations. Initial lab tests have indicated increased corrosion and abrasion protection. Specific performance recommendations will be provided when further data is available.

Aluminum Coated Type 1 (AASHTO M36, ASTM A929) is an aluminum coating with 5 to 11% silicon. It is produced with a coating weight of 305 g/m^2 (1 oz/ft^2) of surface (total both sides) to provide a coating thickness of 48 µm (0.0019 in.) on each surface. Service life will be addressed when sufficient data becomes available.

Aluminum Coated Type 2 (AASHTO M274, ASTM A929) is a pure aluminum coating (no more than 0.35% silicon). It is produced with a coating weight of 305 g/m^2 (1 oz/ft^2) of surface (total both sides) to provide a coating thickness of 48 µm (0.0019 in.) on each surface.

B. NON-METALLIC COATING & PAVINGS

Asphalt Coated (AASHTO M190, ASTM A849). An asphalt coating is applied to the interior and exterior surface of the pipe with a minimum thickness of 1.3 mm (0.05 in.) in both fully coated and half coated.

Invert Paved with Asphalt Material (AASHTO M190, ASTM A849). An asphalt material is used to fill the corrugations and provide a minimum thickness of 3.2 mm (1/8 in.) above the crest of the corrugations for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Invert Paved with Concrete Material (ASTM A849, ASTM A979). A 75 mm (3 in.) thick concrete layer is placed in the installed pipe for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Fully Lined with Asphalt Material (ASTM A849). An asphalt material is used to fill the corrugations and provide a minimum thickness of 3.2 mm (1/8 in.) above the crest of the corrugations providing a smooth surface over the entire pipe interior.

Fully Lined with Concrete Material (ASTM A849, ASTM A979). A high strength concrete material is used to fill the corrugations and provide a minimum thickness of 3.2 mm (1/8 in.) above the crest of the corrugations providing a smooth surface over the entire pipe interior.

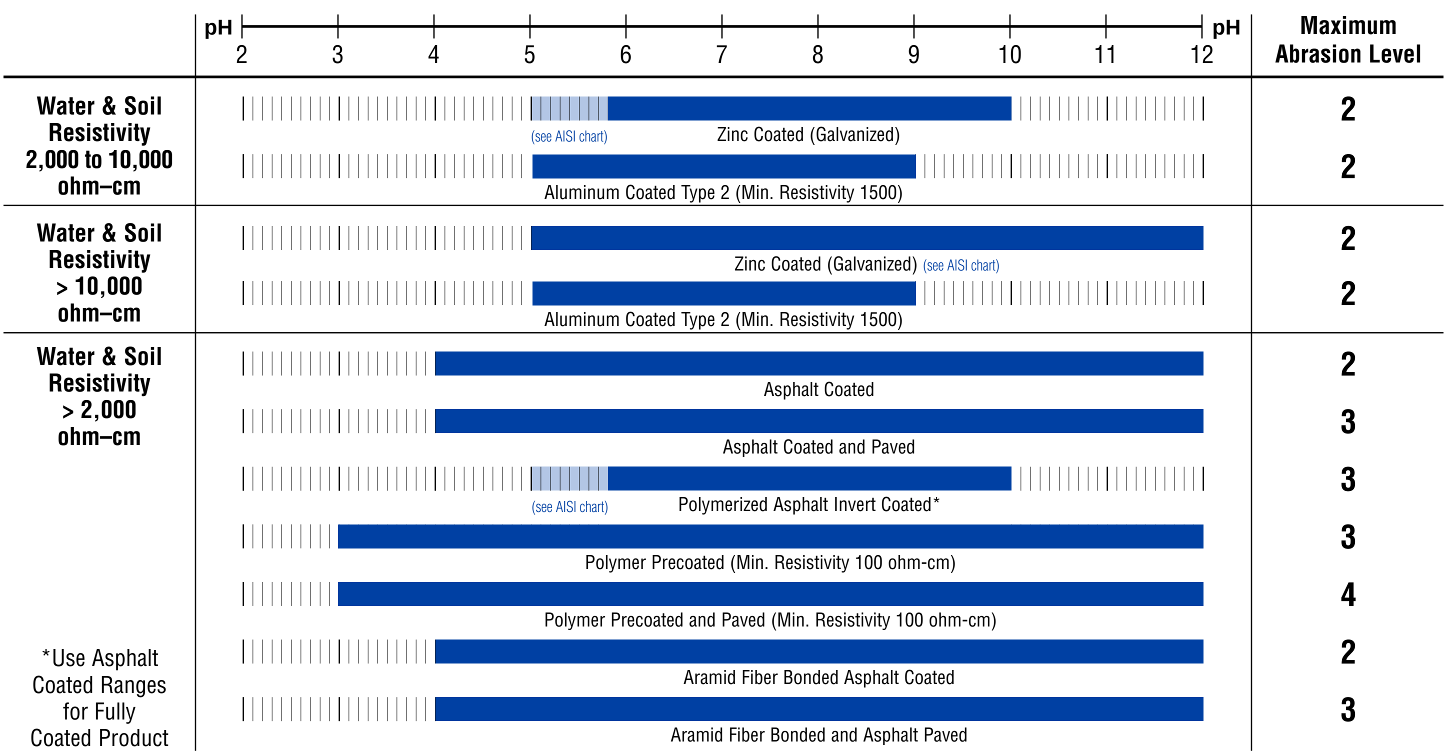
Invert Coated with Polymerized Asphalt Material (ASTM A849). A polymer modified asphalt material is used to provide a minimum thickness of 1.3 mm (0.05 in.) for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch. Generally used for invert treatments only.

Invert Paved with Polymerized Asphalt Material (ASTM A849). An asphalt material is used to fill the corrugations and provide a minimum thickness of 1.3 mm (0.05 in.) above the crest of the corrugations for at least 25% of the circumference of round pipe and 40% of the circumference for pipe arch.

Polymer Precoated (AASHTO M245, ASTM A742). A laminate film is applied over protective metallic coatings. The 10/10 grade (10 mils thickness, each side) is the primary product used.

Aramid Fiber Bonded Asphalt Coated (ASTM A885). An aramid fiberfabric is embedded in the zinc coating while it is still molten, which improves bonding to the asphalt coating.

Environmental Guidelines for Corrugated Steel Pipe



Service Life for Corrugated Steel Pipe

A. METALLIC COATINGS

As discussed above, CSP coatings can be classified into two broad categories, metallic and non-metallic coatings and pavings. Metallic coatings commercially available include zinc (galvanized) and aluminum coated (Type 2). Several non-metallic coatings are available as shown in this document. The following discussion explains the differences and similarities of the two metallic coatings.

All metals form some type of corrosion product when they corrode, regardless of whether they are protective metallic coatings such as aluminum or zinc, or the base steel. Typically the corrosion product, such as an oxide, is more stable and its buildup will result in a decreasing corrosion rate. In practice, corrosion products formed through the galvanic cell (pit) may be deposited in small discontinuities in the coating and serve to stifle further corrosion just as films of corrosion products protect solid surfaces. Thus, the development of scales on metal surfaces is an important consideration when using metals in waters.[1]

Zinc-Coated (Galvanized)[2]

Zinc corrodes much more slowly then steel in natural environments and it galvanically protects steel at small discontinuities in the coating. Its excellent resistance to corrosion is due to the formation of protective films on zinc during exposure. On the average, the rate of attack of zinc is approximately 1/25 that of steel in most atmospheres and various waters.

High corrosion rates in strongly acidic and strongly alkaline solutions can be attributed to the absence of film on the metal surface (stable films are present on the surface when the corrosion rates are low). Lab test indicated stable films in the pH range from about 6 to 12.5.

Aluminum Coated Type 2

"Aluminum is a reactive metal, but it develops a passive aluminum oxide coating or film that protects it from corrosion in many environments."[3] This film is quite stable in neutral and many acid solutions but is attacked by alkalies greater than a pH of 9. From a corrosion standpoint, aluminum has an advantage over galvanized in lower pH and in soft water due to the formation of the oxide film. (Soft waters are generally classified as waters with a hardness of 50 parts per million CaCo3 or less.) The coatings are essentially equal under abrasion[8] and in waters where the zinc oxide film forms rapidly.

Service Life

The service life of zinc coated galvanized is determined using the AISI Chart on page 4.
This chart predicts a variable service life based on pH and resistivity of water and soil and has been an industry standard for many years. Many specifying agencies view service life of aluminum coated type 2 as having additional service life over galvanized.[4,5,6,7]This advantage varies throughout the country from minimal to significant depending on the environment and the geographic location. Users are encouraged to review the practices in their area.

For the purposes of this Guide, aluminum coated type 2 can provide a service life range of a minimum 1.3 times the AISI chart for galvanized (roughly 1 gage) and up to to 75 years (possibly more) in the appropriate environmental conditions. This is consistent with the range of practice by state and federal specifying agencies. The specific multiplier used for design purposes should be based on comparable experience under similar environmental conditions. There may be conditions where the actual performance is more than or less than this range. The significant advantage appears to be either for more corrosive effluent or soft waters where the protective scale forms rapidly for aluminum. In benign environments or where protective scales form rapidly on zinc, there may be little advantage.

AISI Method for Service Life Prediction

The service life of CSP can be reasonably predicted based on the environmental conditions, the thickness of the steel, and life of the coating. The most practical method of predicting the service life of the invert is with the AISI (American Iron and Steel Institute) chart shown on page 4.[9] This chart is based on 16 gage galvanized CSP with a 610 g/m^2 (2 oz/ft^2) coating and can be applied to other thicknesses with the appropriate factor. See discussion above for estimating the service life of aluminum coated type 2.

The AISI chart, which gives service life in terms of resistivity and pH, was developed from a chart originally prepared by the California Department of Transportation(Caltrans).[10] The Caltrans study of durability was based on life to first perforation in culverts that had not received any special maintenance treatment. The results included the combined effects of soil-side and interior corrosion, as well as the average effects of abrasion. For pipes where the pH was greater than 7.3, soil-side corrosion controlled and life could be predicted by resistivity. For pipes where the pH was less than 7.3, the interior invert corrosion generally controlled and both resistivity and pH were important. In the field inspection of 7000 culverts in California for Caltrans, Richard Stratfull, Lead Project Investigator, states he "has no memory of a corrosion perforation being initially found other than in the invert." At least 70 percent of the pipes were expected to last longer than the chart prediction.

The consequences of small perforations are minimal in a gravity flow pipe such as most storm sewers and culverts and do not accurately reflect the actual service life. Because of this fact, the original curves were converted by Stratfull to average service life curves using data on weight loss and pitting in bare steel developed by the National Institute of Standards and Technology. Since storm sewers and culverts are usually designed with a structural safety factor of at least 2.0, a significant safety factor of 1.5 remains at the end of the service life predicted by the chart. Thus, use of the chart is considered reasonably conservative. The Caltrans Method may be appropriate for use under pressure applications. Where service life is controlled by invert performance, rehabilitation of the invert at the end of the predicted life can extend service life significantly

Soil-Side Durability

A study performed by Corrpro Companies in 1986 found that soil-side durability is generally not the limiting factor in designing CSP systems. "Survey results indicate that 93.2 percent of the plain galvanized installations have a soil-side service life in excess of 75 years, while 81.5 percent have a soil-side service life in excess of 100 years."[11]

The study also found that soil moisture contents below 17.5 percent did not exhibit any accelerated corrosion. "Under most circumstances, corrosion rates are directly related to soil moisture content. However, for galvanized steel storm sewer and culvert pipe, the soil moisture content primarily affects the activity of any chloride ions present and the chloride's acceleration of the corrosion. Where the soil moisture content was below 17.5 percent, the chloride ion concentration did not have a significant affect on the corrosion rate of the zinc coating."

A computer program to estimate soil-side service life is included in "Final Report, Condition and Corrosion Survey of Corrugated Steel Storm Sewers and Culvert Pipe," and is available from NCSPA.

Steps in Using the AISI Chart

The durability design chart can be used to predict the service life of galvanized CSP and to select the minimum thickness for any desired service life. Add-on service life values are provided in the table on page 5 for additional coatings.

1) Locate on the horizontal axis the soil resistivity (R) representative of the site.
2) Move vertically to the intersection of the sloping line for the soil pH. If pH exceeds 7.3 use the dashed line instead.
3) Move horizontally to the vertical axis and read the service life years for a pipe with 1.6 mm (0.064 in.) wall thickness.
4) Repeat the procedure using the resistivity and pH of the water; then use whichever service life is lower.
5) To determine the service life for a greater wall thickness, multiply the service life by the factor given in the inset on the chart.

Additional Service Life

Additional service life can be provided by increasing the thickness of the base steel in accordance with the factors shown in the Chart for Estimating Average Invert Service Life or with the use of additional coating systems. Add-on service life values are provided in the Tables on page 5.

B. NON-METALLIC COATING & PAVINGS

Non-metallic coatings offer advantages over metallic coatings in the form of increased abrasion resistance, wider environmental ranges and longer service life. Inherent in these coatings is less variability in performance which is why specific add-on service life values are recommended under various abrasion levels.

Asphalt Coated – Asphalt coatings are generally used for soil-side protection but also provide additional waterside protection. Numerous studies have concluded that asphalt coating typically provides 10 years additional service life to the inside of the pipe.[12,13,14,15,16] Asphalt coatings provide much higher service life on the soil-side and inherently extend the environmental ranges for soil conditions. According to Corrpro[11], "study results indicate that the addition of an asphalt coating may have provided a soil side service life in excess of 100 years."

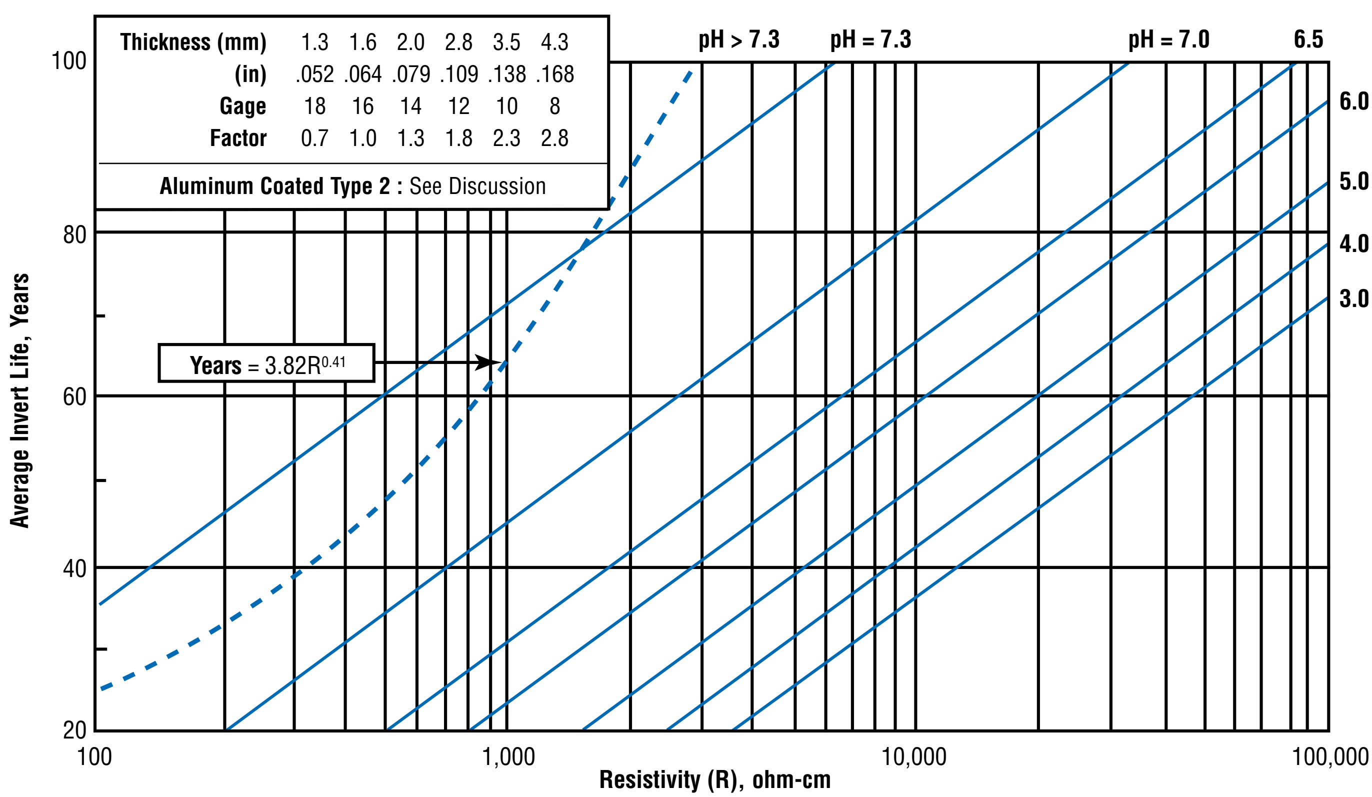
Asphalt Coated and Paved – Asphalt coated and paved provide both additional service life and added abrasion protection on the water side of the pipe. Based on several studies, coated and paved is considered to provide an additional 30 years service life under most abrasion levels.[12,13,15,16,17,18] This is considered a very conservative estimate for non abrasive and low abrasion (level 1 and 2).

Polymerized Asphalt Invert Coated – Polymerized asphalt provides improved adhesion and abrasion resistance over standard asphalt products.[8] Full scale abrasion tests conducted by Ocean City Research indicate no deterioration of the coating under moderate abrasion (level 3)[19].

Based on independent test lab results using test method ASTM A926, results indicate that the commercially available polymerized asphalt coating lasts at least 10 times longer than standard asphalt coating and at least three times longer than standard culvert coated and paved. [5]

Polymer Precoat – Polymer precoat provides excellent adhesion to the base steel and extended corrosion and abrasion resistance. The service life recommendation are based on extensive lab and field tests.[8,19,20,21,22] According to PSG[22], "No corrosion was observed on any of the coated (polymer coated) pipes. We can not find any data to suggest the pipe coating would not provide at least one hundred years service." Sites contained environmental conditions with Resistivity as low as 100 ohm-cm and pH as low as 2.1. In addition, PSG conducted current requirement testing that is designed to determine corrosion activity of a given

AISI Chart for Estimating Average Invert Life for Galvanized CSP



Years = 35.85 (Log_{10} R-Log_{10} (2160-2490 Log_{10} pH)) structure. The current requirement data shows polymer coated structures have up to 10,000 times less corrosion versus bare G210 galvanized. Recent tests conducted by Ocean City Research indicate polymer coated withstanding abrasion level three conditions.[19](Note: Corrosion conditions at the extreme limits of the environmental ranges may require adjusting add-on service life values).

Polymer Precoat and Asphalt Paved – Polymer precoat and asphalt paved benefits from the excellent adhesion of the polymer precoat to the base steel and the subsequent adhesion of the paving to the precoat. According to laboratory and field tests, [22,23,] The combination of the three coatings results in a pipe which is highly resistant to acidic effluent. The bituminous material has much better adhesion to the polymeric coating than it does to the galvanizing.

Polymer Precoat with Polymerized Asphalt Invert Coated – Full scale abrasion tests conducted by OCR show equal performance of the polymerized asphalt over polymer precoat as standard asphalt paved.[19] This system has the same bonding characteristics as the polymer precoat and paved. Field sites also indicate improved adhesion.[22]

Aramid Fiber Asphalt Coated/ Aramid Fiber Asphalt Paved – The fibers embedded in zinc provide an anchor for the asphalt coating or paving to improve adhesion.

High Strength Concrete Lined – Concrete linings are typically used for improved hydraulic performance but also provide additional abrasion protection and extended service life. The use of high strength concrete and metallic coated steel provide the high service life values.

Concrete Invert Paved – Concrete inverts provide extreme abrasion protection and extended service life. According to Stratfull[10], "metal pipe with an invert paved with concrete should provide an indefinite service life if it is of sufficient width, thickness and quality. By calculation, a 4-inch thick coating over the invert steel could be expected to postpone its initial time to corrosion by approximately 7.7 times greater than a 3/4 inch coating."

Estimated Service Life

Add-On Service Life for Non-Metallic Coatings (in years)

COATING	WATER SIDE			References
	Level 1 & 2	Level 3	Level 4	
Asphalt Coated	10	N/R	N/R	12, 13, 14, 15, 16
Asphalt Coated and Paved	30	30	30	12, 13, 15, 16, 17, 18, 19
Polymerized Asphalt Invert Coated*	45	35	N/R	5, 8, 19
Polymer Precoat	80+	70	N/R	8, 19, 20, 21, 22
Polymer Precoat and Paved	80+	80+	30	22, 23
Polymer Precoat with Polymerized Asphalt Invert Coated	80+	80+	30	19, 22
Aramid Fiber Asphalt Coated	40	N/R	N/R	20
Aramid Fiber Asphalt Paved	50	40	N/R	20
High Strength Concrete Lined	75	50	N/R	10,24
Concrete Invert Paved (75mm (3 in.) cover)	80+	80+	50	10, 24

N/R Not recommended

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