Designing for Durability

Richard Morales, M.Sc., FASCE, P.E.
Designing for Durability

• Sacrificial Thickness
• Corrosion Resistant Steel
  • Mariner Steel ASTM A690
  • Weathering Steel ASTM A588
• Protective Coatings
  • Coat Tar Epoxy (CTE)
  • Fusion Bond Epoxy for Pipe (FBE)
• Multi-Coat Systems
• Galvanizing
• Metalizing
  • Thermal Spray Zinc
  • Thermal Spray Aluminum
• Cathodic Protection
• Higher Yield Steel
Corrosion Zones

- zone of high-attack (splash zone)
- intertidal zone
- zone of high-attack (low water zone)
- permanent immersion zone

Illustration | sea-water aggressivity | corrosion rate distribution | typical bending moment distribution
## Eurocode 3: Design of Steel Structures

### Part 5: Piling (ENV 1993-5)

### Loss of Thickness (mm)

Note: CALTRANS Corrosion Guidelines are more stringent than EuroCode 3.

<table>
<thead>
<tr>
<th>Soil, with or without groundwater:</th>
<th>DESIGN LIFE:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 years</td>
</tr>
<tr>
<td>Undisturbed natural soils</td>
<td>0.00 mm</td>
</tr>
<tr>
<td>Polluted natural soils and industrial grounds</td>
<td>0.15 mm</td>
</tr>
<tr>
<td>Aggressive natural soils (swamp, marsh, peat...)</td>
<td>0.20 mm</td>
</tr>
<tr>
<td>Non-compacted and non-aggressive fills® (clay, schist, sand, silt...)</td>
<td>0.18 mm</td>
</tr>
<tr>
<td>Non-compacted and aggressive fills® (ashes, slag...)</td>
<td>0.50 mm</td>
</tr>
</tbody>
</table>

### Water

<table>
<thead>
<tr>
<th>Condition of fresh water (river, ship canal..., in the zone of high attack (water line))</th>
<th>DESIGN LIFE:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 years</td>
</tr>
<tr>
<td>Common fresh water (river, ship canal..., in the zone of high attack (water line))</td>
<td>0.15 mm</td>
</tr>
<tr>
<td>Very polluted fresh water (sewage, industrial effluent..., in the zone of high attack (water line))</td>
<td>0.30 mm</td>
</tr>
<tr>
<td>Sea water in temperate climate in the zone of high attack (low water and splash zones)</td>
<td>0.55 mm</td>
</tr>
<tr>
<td>Sea water in temperate climate in the submerged zone or tidal zone</td>
<td>0.25 mm</td>
</tr>
</tbody>
</table>

**A.** Values are provided for guidance only. Local knowledge may lead to the use of other values for design. The values given for 5 and 25 years are based on measurements, whereas other values are extrapolated.

**B.** In compacted fills, these corrosion losses should be divided by two.

**C.** The highest corrosion rate is usually found at the splash zone of marine environments or at the low water level in tidal waters. However, in most cases, the highest bonding occurs in the submerged zone.
Corrosion Guidelines
September 2003
Version 1.0

For structural elements, the Department considers a site to be corrosive if one or more of the following conditions exist for the representative soil and/or water samples taken at the site:

- Chloride concentration is 500 ppm or greater, sulfate concentration is 2000 ppm or greater, or the pH is 5.5 or less.

If a site is corrosive based on the definition listed above, then corrosion mitigation is required.

The Department currently uses the following corrosion rates for steel piling exposed to corrosive soil and/or water.

<table>
<thead>
<tr>
<th>Soil Embedded Zone</th>
<th>0.025 mm (0.001 in) per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immersed Zone</td>
<td>0.100 mm (0.004 in) per year</td>
</tr>
<tr>
<td>Scour Zone</td>
<td>0.125 mm (0.005 in) per year</td>
</tr>
</tbody>
</table>

The corrosion rates apply only if the soil and/or water are corrosive. If a site is characterized as non-corrosive, then no corrosion allowance (sacrificial metal loss) is necessary. This information is also included in Bridge Memo to Designers 3-1, (http://www.dot.ca.gov/hrqesc/techpubs).

For steel piling driven into undisturbed soil, the region of greatest concern for corrosion is the portion of the pile from the bottom of the pile cap or footing down to 1 m (3 ft) below the water table. This region of undisturbed soil typically has a replenishable source of oxygen needed to sustain corrosion. A corrosion rate of 0.025 mm per year should be used for the length of pile in this region. No corrosion rate is required for the length of pile outside of this region.

The corrosion rates listed above should be doubled for steel H-piling since there are two surfaces on either side of the web and flanges that are exposed to the corrosive soil and/or water. For example, the length of a steel H-pile that is immersed in corrosive water and has a 75-year design life should have a corrosion allowance of 15 mm (0.6 in), calculated using 0.1 mm/yr (0.004 in/yr) x 75 years x 2 exposure faces.

For steel pipe piling, used in corrosive soil and/or water, the corrosion allowance is only needed for the exterior surface of the pile. The interior surface of the pile (soil plug side) will not be exposed to sufficient oxygen to support significant corrosion.

The above corrosion rates and allowances for piles are also applicable to permanent steel shells, used at corrosive sites that are intended to carry axial or lateral structural load.
Corrosion Protection Considerations

FIGURE 1. CORROSION PROTECTION CONSIDERATIONS

- Temporary Structure
  - No
  - Nonstructural Application
    - Atmospheric Exposure
      - Is the appearance of rust acceptable?
        - Yes
          - Individually Notre Subject to Rain or Other Corrosive Materials
        - No
          - Apply a Coating
          - SP (See Figure 1 for critical zones)
    - Water Exposure
      - Is there a marine/seawater environment?
        - Yes
          - Select Paint
        - No
          - SP
    - Soil Exposure
      - Are the natural soils undisturbed?
        - Yes
          - Select Paint
        - No
          - SP

LEGEND
- NSF = No Supplemental Protection
- SP = Consider Supplemental Protection if projected steel loss impacts service life of structure
Summary of Calculated Section Modulus and Moment of Inertia for Thickness Reduction from 0.000” – 0.250”

<table>
<thead>
<tr>
<th>Thickness Reduction (in.)</th>
<th>Section Modulus (in³ / ft)</th>
<th>NEW</th>
<th>Moment of Inertia (in⁴ / ft)</th>
<th>NEW</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>PZ27</td>
<td>PZC13</td>
<td>PZC18</td>
<td>PZC26</td>
</tr>
<tr>
<td>0.0000</td>
<td>30.20</td>
<td>24.17</td>
<td>33.50</td>
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<tr>
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<td>11.49</td>
<td>16.05</td>
<td>29.74</td>
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</table>

Reference: Richard Hartman, Ph.D., P.E.

Note: PZC28 Effective Corrosion based on Caltrans Corrosive Rate for Soil Embedded Zone.
# Flat Web Sheet Pile

Gerdau SSP Sections are Included
In USACE Specification Guide UFGS-31 41 16
February 24, 2010

![Diagram of Flat Web Sheet Pile](image.png)

<table>
<thead>
<tr>
<th>Section</th>
<th>Width</th>
<th>Web Thickness</th>
<th>Weight</th>
<th>Moment of Inertia</th>
<th>Section Modulus</th>
<th>Nominal Coating Area</th>
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<tbody>
<tr>
<td></td>
<td>in.</td>
<td>in.</td>
<td>lb / ft</td>
<td>lb / ft²</td>
<td>in² / wft</td>
<td>ft² / 1ft</td>
</tr>
<tr>
<td></td>
<td>mm</td>
<td>mm</td>
<td>kg / m</td>
<td>kg / m²</td>
<td>cm² / wm</td>
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<tr>
<td>PS 27.5</td>
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<td>500</td>
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<tr>
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<tr>
<td></td>
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<td>12.7</td>
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<td>52</td>
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</table>
Graphs of Calculated Section Modulus for Thickness Reduction from 0.000” – 0.250”

* Reference: Richard Hartman, Ph.D., P.E.
# PZC™ Hot Rolled Steel Piling

## Specifications

<table>
<thead>
<tr>
<th>Section</th>
<th>Width</th>
<th>Height</th>
<th>Web Thickness</th>
<th>Flange Thickness</th>
<th>Weight</th>
<th>Moment of Inertia</th>
<th>Section Modulus</th>
<th>Nominal Coating Area</th>
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<tr>
<td></td>
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<td>in.</td>
<td>in.</td>
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<td>lb / ft</td>
<td>lb / ft²</td>
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<td>in³ / wft</td>
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<tr>
<td></td>
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<td>75.1</td>
<td>106.0</td>
<td>14,694</td>
<td>920</td>
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<td></td>
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<td>1.87</td>
</tr>
</tbody>
</table>

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*PZC™: WIDER–LIGHTER–STRONGER*
### PZC Hot Rolled Steel Piling

#### PZC™
**WIDER–LIGHTER–STRONGER**

<table>
<thead>
<tr>
<th>Section</th>
<th>Width (in.)</th>
<th>Height (in.)</th>
<th>Web Thickness (in.)</th>
<th>Flange Thickness (in.)</th>
<th>Weight (lb/ft)</th>
<th>Weight (lb/ft^2)</th>
<th>Moment of Inertia (in^4)</th>
<th>Moment of Inertia (in^4/wft)</th>
<th>Section Modulus (in^3)</th>
<th>Section Modulus (in^3/wft)</th>
<th>Nominal Coating Area (ft^2/lft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PZC 13</td>
<td>27.88</td>
<td>12.56</td>
<td>0.375</td>
<td>0.375</td>
<td>50.4</td>
<td>21.7</td>
<td>353.0</td>
<td>152.0</td>
<td>56.2</td>
<td>24.2</td>
<td>5.6</td>
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<td>319</td>
<td>9.5</td>
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<td>106.0</td>
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<td>73.9</td>
<td>31.8</td>
<td>994.3</td>
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<td>112.4</td>
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<td>58,460</td>
<td>1,840</td>
<td>2,600</td>
<td>1.87</td>
</tr>
</tbody>
</table>
Cold Rolled Form Piling

Intermediate Heavyweight Sheeting Cross Section

<table>
<thead>
<tr>
<th>Section Type</th>
<th>Thickness Nominal</th>
<th>Weight Lb/Square Ft.</th>
<th>Weight Lb/Linear Ft.</th>
<th>Sec. Mod. Inch²(FT.Wall)</th>
<th>Moment of Inertia Inch⁴(FT.Wall) Per Pile</th>
<th>Moment of Inertia Inch⁴(FT.Wall) Per Ft. of Wall</th>
<th>Coating Area Sq.Ft./LF</th>
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</thead>
<tbody>
<tr>
<td>SZ - 21</td>
<td>.350</td>
<td>20.3</td>
<td>45.3</td>
<td>18.1</td>
<td>191.5</td>
<td>86.0</td>
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</tr>
</tbody>
</table>
The Eurocode, USACE and others consider the end of design life to occur when any part of the pile reaches the max permissible working stress through corrosion loss. Design life being from the point that the Sacrificial Thickness Corrosion has reached the maximum permissible stress.

Many State DOT’s (including Florida) require the Reduction for Cold Form Piling to 85% of Full Section values.

The latest (Nov 2008) USACE UFGS 31 41 16 Specifications Section 2.1 (page 13) Limits the use of Cold Form Piling as suitable only for applications with a minimum sheet thickness no more than 0.250” restricted for uses only with low bending, low corrosion resistances and low interlocked joint strength in tension.
# Hot Rolled Nucor Piling

## PZ 22

![Diagram of Hot Rolled Nucor Piling]

### Sheet Pile Section Properties

<table>
<thead>
<tr>
<th>Nominal Width (In)</th>
<th>Area (In²)</th>
<th>Weight (Lbs)</th>
<th>Moment of Inertia (In⁴)</th>
<th>Section Modulus (In³)</th>
<th>Surface Area (Ft²/Ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single Section</td>
<td>Per Linear Foot of Wall</td>
<td>Per Linear Foot of Wall</td>
<td>Total Area</td>
<td>Nominal Coating Area</td>
</tr>
<tr>
<td>22,00</td>
<td>12.00</td>
<td>6.65</td>
<td>41.5</td>
<td>22.6</td>
<td>156.0</td>
</tr>
</tbody>
</table>

* *Excludes socket interior & tail of interior.*
Cold Rolled Form Piling

The Eurocode, USACE and others consider the end of design life to occur when any part of the pile reaches the max permissible working stress through corrosion loss. Design life being from the point that the Sacrificial Thickness Corrosion has reached the maximum permissible stress.

Many State DOT’s (including Florida) require the Reduction for Cold Form Piling to 85% of Full Section values.

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ASTM states: “The steel has approximately two to three times greater resistance to seawater “Splash Zone” corrosion than ordinary carbon steel (Specifications A36/A36M and A328/A328M).”

• ASTM has stated A690 exhibited 2 to 3 times more resistance in Splash Zone thus allowing for Design Purposes a Reduction of the Corrosion Rate by a factor of Two (2) to Three (3) times.
Designing with Higher Yield Steel

• The Eurocode, USACE and others consider the end of design life to occur when any part of the pile reaches the max permissible working stress through corrosion loss. Design life being from the point that the Sacrificial Thickness Corrosion has reached the maximum permissible stress.

• By Designing to Grade 50 but utilizing a higher Grade 60 steel, the proportional increase in stress provides a 20% Increase in the Life of the Pile.
Based on AGA’s Tropical Marine exposure to corrosive elements below, the galvanized system will have a projected life (to 5% surface rust) in excess of 75 years.

- A galvanized coating’s life is determined primarily by thickness and severity of exposure conditions.
- The shaded area of the chart represents minimum thickness requirements found in the galvanized specification ASTM A 123.
- Galvanized coatings commonly exceed the min requirement, typically ranging between 3 and 7 mils.
- The expected service life is defined as the life until 5% rusting of the steel substrate. At 5% surface rust, there is no steel integrity lost; however, it indicates it is time to consider applying new corrosion protection methods.
Cathodic Protection

• There are two major variations of the cathodic method of corrosion protection:
  • Impressed current
  • Sacrificial anode.
• In the impressed current method an external current source is used to impress a cathodic charge on all the iron or steel to be protected. While such systems generally do not use a great deal of electricity, they are often very expensive to install.
• The sacrificial anode method requires placing a metal or alloy anodic to the metal to be protected in the circuit, which will then become the anode. The protected metal becomes the cathode and does not corrode. The anode corrodes, thereby providing the desired sacrificial protection. In nearly all electrolytes encountered in everyday use, zinc is anodic to iron and steel.
• Cathodic protection needed if Life Expectancy not achieved by other methods or after the end of a coating life for buried or submerged surfaces.
• Typical Life Expectancy is 20 years with a definite maintenance program for replacement of anode upgrades.
Designing for Durability
Example #1

• What is the Life Expectancy for a Cold Form
SZ21 with 0.350” Thickness with No Coating?

\[ t_{\text{final}} = 0.250” \text{ minimum usable thickness as required by USACE} \]
\[ t_{\text{sacrificial}} = 0.350” - 0.250” = 0.10” \]

• Life\(_{\text{Max Moment}}\) = \((0.10”)/(0.05\text{mm/yr})\times(0.039370078\text{in/mm}) = 50\text{ yrs}\)

• Life\(_{\text{Splash Zone}}\) = \((0.10”)/(0.18\text{mm/yr})\times(0.039370078\text{in/mm}) = 14\text{ yrs}\)

• Life\(_{\text{State DOT}}\) = \((0.05”)/(0.18\text{mm/yr})\times(0.039370078\text{in/mm}) = 7\text{ yrs}\)

• Note: Governed by State DOT Req’ts (such as Florida for instance) for Limiting
Cold Form Steel to 85% Full Section Values

• Life Expectancy = 14 years.
Assumptions:

- Zone of High Attack
- Max Sacrificial Thickness Allowed to comply with USACE
- Use USACE req’ts for Cold Form Steel in Latest UFGS 31 41 16 (11/08) for Minimum Allowable Thickness req’d = 0.25”
- Florida State DOT requires Cold Form Steel Reduction of 85% full section values

Designing for Durability
Example #1

- What is the Life Expectancy for a Cold Form SZ21 with 0.350” Thickness with Cold Tar Epoxy Coating of 16 mils DFT?

- Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 14 yrs + 20 yrs = 34 years

- Note if State DOT Req’ts used for Limiting Cold Form Steel to 85% Section Values, Life Expectancy = 27 years.
Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to comply with USACE
- Use USACE req’ts for Cold Form Steel in Latest UFGS 31 41 16 (11/08) for Minimum Allowable Thickness req’d = 0.25”
- Florida State DOT requires Cold Form Steel Reduction of 85% full values
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (@ 95 percentile)

Example #1

- What is the Life Expectancy for a Cold Form SCZ16 with 0.276” Thickness with No Coating?

\[ t_{\text{final}} = 0.250” \text{ minimum usable thickness as required by USACE} \]
\[ t_{\text{sacrificial}} = .276” - .250” = 0.026” \]

- Life_{\text{Max Moment}} = (0.026”)/(0.05mm/yr)x(0.039370078in/mm) = 13 yrs
- Life_{\text{Splash Zone}} = (0.026”)/(0.18mm/yr) x (0.039370078 in/mm) = 4 yrs
- Life_{\text{State DOT}} = (0.022”)/(0.18mm/yr) x (0.039370078 in/mm) = 3 yrs

- Note: Governed by State DOT Req’ts (such as Florida for instance) for Limiting Cold Form Steel to 85% Full Section Values

- Life Expectancy = 3 years.
**Assumptions:**

- Zone of High Attack at Max Corrosion
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion Max at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

**Example #1**

- What is the Life Expectancy for a Hot Rolled WS1 with 0.375” Thickness with No Coating?

  \[ t_{sacrificial} = 0.375” \text{ - } 0.1875” \]

  \[ = 0.188”(3/16”) \]

  \[ \text{Life Expectancy @ Zone of Max Corrosion} = \frac{0.1875”}{0.18\text{mm/yr}} \times 0.039370078 \text{ in/mm} = 27 \text{ yrs} \]

  then:

  - **Life Expectancy = 27 years**
Assumptions:

- Zone of High Attack at Max Corrosion
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion Max at Splash Zone = 0.09 mm/yr (mean)

Designing for Durability
Example #1

- What is the Life Expectancy for a Hot Rolled PS31 with 0.500” Thickness with No Coating?

\[ t_{\text{sacrificial}} = .500” - .250” = 0.250” (1/4”) \]

- Life Expectancy @ Zone of Max Corrosion = \((0.25”)/(0.09\text{mm/yr}) \times (0.039370078 \text{ in/mm}) = 71 \text{ yrs}\)

then:

- Life Expectancy = 71 years
Assumptions:

- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)

Designing for Durability
Example #1

- What is the Life Expectancy for a Hot Rolled PS31 with 0.500” Thickness with Coal Tar Epoxy Coating of 16 mils DFT?

- Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 71 yrs + 20 yrs = 91 years
Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

Example #1

What is the Life Expectancy for a Hot Rolled PZC13 with 0.375” Thickness with No Coating?

\[ t_{\text{sacrificial}} = .375” - .1875” = 0.1875” \ (3/16”) \]

- Life Expectancy @ Zone of Max Moment = \((0.1875”)/(0.05\text{mm/yr}) \times (0.039370078 \text{ in/mm}) = 95 \text{ yrs} \]
- Life Expectancy @ Zone of Max Corrosion = \((0.1875”)/(0.18\text{mm/yr}) \times (0.039370078 \text{ in/mm}) = 27 \text{ yrs} \)

then:
- Life Expectancy = 27 years

Designing for Durability

Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)
Assumptions:

- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion for Fresh Water Application = 0.09 mm/yr

What is the Life Expectancy for a Hot Rolled PZC13 with Thickness = 0.375” & Produced to A572 Grade 50 Steel with No Coating?

\[ t_{\text{sacrificial}} = 0.375” - 0.1875” = 0.1875” \ (3/16”) \]

• Life Expectancy @ Zone of Max Moment = 0.05 mm/yr

\[ \frac{(0.1875”)}{(0.05\text{mm/yr})} \times (0.039370078 \text{ in/mm}) = 95 \text{ yrs} \]

• Life Expectancy @ Zone of Fresh Water Corrosion = 0.09 mm/yr

\[ \frac{(0.1875”)}{(0.09\text{mm/yr})} \times (0.039370078 \text{ in/mm}) = 53 \text{ yrs} \]

Then:

• Life Expectancy = 53 years
**Designing for Durability**

**Example #1**

- What is the Life Expectancy for a Hot Rolled PZ22 with 0.375” Thickness with No Coating?

  \[ t_{\text{sacrificial}} = .375” - .1875” = 0.1875” \ (3/16”) \]

- Life Expectancy @ Zone of Max Moment =

  \[
  \frac{(0.1875”)}{(0.05\text{mm/yr})} \times (0.039370078 \text{ in/mm}) = 95 \text{ yrs}
  \]

- Life Expectancy @ Zone of Max Corrosion =

  \[
  \frac{(0.1875”)}{(0.18\text{mm/yr})} \times (0.039370078 \text{ in/mm}) = 27 \text{ yrs}
  \]

  then:

  - Life Expectancy = 27 years
Designing for Durability
Example #1

- What is the Life Expectancy for a Hot Rolled PZC13 with 0.375” Thickness with Coal Tar Epoxy Coating of 16 mils DFT?

- Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 27 yrs + 20 yrs = 47 years
Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone & Fresh Water Application = 0.09 mm/yr

Designing for Durability Example #1

- What is the Life Expectancy for a Hot Rolled PZC13 with 0.375” Thickness with Coal Tar Epoxy Coating of 16 mils DFT?

- Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 53 yrs + 20 yrs = 73 years
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC13 with 0.375” Thickness with Fusion Bonded Epoxy Coating of 16 mils DFT?

• FBE has Extensive Industry Experience in the coatings for Pipe and has shown Coating can provide approximately 25+ years of Service

Therefore for this example in comparison purposes only:

Life Expectancy = 27 yrs + 25 yrs = 52 years
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC13 with 0.375” Thickness Produced to ASTM A690 Steel with No Coatings?

• Life Expectancy @ Zone of Max Corrosion =

(0.1875”) x 2 times/(0.18mm/yr)x(0.039370078 in/mm) = 53 yrs

to

(0.1875”) x 3 times/(0.18mm/yr)x(0.039370078 in/mm) = 80 yrs

then:

• Life Expectancy Uncoated PZC13 = +27 yrs

Therefore:

Life Expectancy = 53 years
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC13 with 0.375” Thickness Produced to ASTM A690 Steel with No Coatings?

• Life Expectancy @ Zone of Max Corrosion = (0.1875”) x 2 times/(0.09mm/yr)x(0.039370078 in/mm) = 105 yrs to (0.1875”) x 3 times/(0.09mm/yr)x(0.039370078 in/mm) = 159 yrs then:

• Life Expectancy Uncoated PZC13 = +53 yrs

Therefore:

Life Expectancy = +158 years (Only in Splash Zone)
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC18 with 0.375” Thickness with No Coating?

\[ t_{sacrificial} = 0.375" - 0.1875" = 0.1875" \text{ (3/16”)} \]

• Life Expectancy @ Zone of Max Moment = 
\[ \frac{0.1875”}{0.05 \text{ mm/yr}} \times 0.039370078 \text{ in/mm} = 95 \text{ yrs} \]

• Life Expectancy @ Zone of Max Corrosion = 
\[ \frac{0.1875”}{0.18 \text{ mm/yr}} \times 0.039370078 \text{ in/mm} = 27 \text{ yrs} \]

then:
• Life Expectancy = 27 years

Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC18 with 0.375” Thickness with No Coating?

\[ t_{\text{sacrificial}} = 0.375” - 0.1875” = 0.1875” \ (3/16”) \]

• Life Expectancy @ Zone of Max Moment =
\[ \frac{0.1875”}{0.05 \text{mm/yr}} \times 0.039370078 \text{ in/mm} = 95 \text{ yrs} \]

• Life Expectancy @ Zone of Fresh Water Corrosion =
\[ \frac{0.1875”}{0.09 \text{mm/yr}} \times 0.039370078 \text{ in/mm} = 53 \text{ yrs} \]

then:
• Life Expectancy = 53 years
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC18 with 0.375” Thickness with Coal Tar Epoxy Coating of 16 mils DFT?

• Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 27 yrs + 20 yrs = 47 years
Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Fresh Water at High Attack Zone = 0.09 mm/yr

Designing for Durability Example #1

- What is the Life Expectancy for a Hot Rolled **PZC18** with 0.375” Thickness with Coal Tar Epoxy Coating of 16 mils DFT?

- Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 53 yrs + 20 yrs = 73 years
Assumptions:

- Zone of High Attack
- FBE Typically Applied to Pipe Piling Outside Diameter
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

**Designing for Durability Example #1**

- What is the Life Expectancy for a Hot Rolled **PZC18** with 0.375” Thickness with Fusion Bonded Epoxy Coating of 16 mils DFT?

- FBE has Extensive Industry Experience in the coatings for Pipe and has shown Coating can provide approximately 25+ years of Service

Therefore for this example in comparison purposes only:

Life Expectancy = 27 yrs + 25 yrs = 52 years
Assumptions:

- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- A690 Increases Life 2 to 3 times above A36 & A328 Steels
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

Example #1

- What is the Life Expectancy for a Hot Rolled PZC18 with 0.375” Thickness Produced to ASTM A690 Steel with No Coatings?

- Life Expectancy @ Zone of Max Corrosion =

  \[
  (0.1875”) \times 2 \text{ times/}(0.18 \text{mm}/\text{yr}) \times (0.039370078 \text{ in/mm}) = 53 \text{ yrs}
  \]

  to

  \[
  (0.1875”) \times 3 \text{ times/}(0.18 \text{mm}/\text{yr}) \times (0.039370078 \text{ in/mm}) = 80 \text{ yrs}
  \]

  then:

  - Life Expectancy = +26 years

Therefore:

Life Expectancy = 53 years
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC18 with 0.375” Thickness Produced to ASTM A690 Steel with No Coatings?

• Life Expectancy @ Zone of Max Corrosion =

\[(0.1875”) \times 2 \text{ times}/(0.18 \text{ mm/yr}) \times (0.039370078 \text{ in/mm}) = 53 \text{ yrs}\]

to

\[(0.1875”) \times 3 \text{ times}/(0.18 \text{ mm/yr}) \times (0.039370078 \text{ in/mm}) = 80 \text{ yrs}\]

then:

• Life Expectancy = +26 years

Therefore:

Life Expectancy = 53 years
Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

What is the Life Expectancy for a Hot Rolled PZC19 with 0.420” Thickness with No Coating?

\[ t_{sacrificial} = 0.420” - 0.210” = 0.210” \]

- Life Expectancy @ Zone of Max Moment = 
  \[ \frac{0.210”}{0.05 \text{mm/yr}} \times \frac{0.039370078 \text{ in/mm}} = 107 \text{ yrs} \]

- Life Expectancy @ Zone of Max Corrosion = 
  \[ \frac{0.210”}{0.18 \text{mm/yr}} \times \frac{0.039370078 \text{ in/mm}} = 30 \text{ yrs} \]

then:
- Life Expectancy = 30 years
Assumptions:
- Zone of High Attack
- Sacrificial Thickness of 0.045” Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

What is the Life Increase for a Hot Rolled PZC19 with 0.420” Thickness vs AZ19-700 with 0.375” Thickness?

\[ t_{\text{sacrificial}} = 0.42” - 0.375” = 0.045” \]

- Life Expectancy @ Zone of Max Moment = 
  \[ \frac{0.045”}{0.05 \text{ mm/yr}} \times 0.039370078 \text{ in/mm} = 23 \text{ yrs} \]

- Life Expectancy @ Zone of Max Corrosion = 
  \[ \frac{0.045”}{0.18 \text{ mm/yr}} \times 0.039370078 \text{ in/mm} = 6 \text{ yrs} \]
  then:

  - Life Exceeds at Least 6 years more for PZC19 vs AZ19-700
Assumptions:
- Zone of High Attack
- Sacrificial Thickness of 0.045” Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

• What is the Life Increase for a Hot Rolled PZC19 with 0.420” Thickness vs AZ20-700 with 0.394” Thickness?

\[ t_{\text{sacrificial}} = 0.42” - 0.394” = 0.026” \]

• Life Expectancy @ Zone of Max Moment =

\[ \frac{(0.026”)}{(0.05\text{mm/yr})} \times (0.039370078\text{ in/mm}) = 13\text{ yrs} \]

• Life Expectancy @ Zone of Max Corrosion =

\[ \frac{(0.026”)}{(0.18\text{mm/yr})} \times (0.039370078\text{ in/mm}) = 4\text{ yrs} \]

then:

• PZC19 Life Exceeds at Least 4 years more vs AZ20-700
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC19 with 0.420” Thickness with Coal Tar Epoxy Coating of 16 mils DFT?

• Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 30 yrs + 20 yrs = 50 years

Assumptions:

➢ Zone of High Attack

➢ Max Sacrificial Thickness Allowed to 50% of Original Thickness

➢ Corrosion at Max Moment = 0.05 mm/yr

➢ Corrosion at Splash Zone = 0.09 mm/yr (mean)

➢ Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC26 with Flange Thickness = 0.600” and Web thickness = 0.525” & Produced to A572 Grade 50 Steel with No Coating?

\[ t_{\text{sacrificial}} = .525” - .26” = 0.26” \]

• Life Expectancy @ Zone of Max Moment = \[ \frac{(0.26”)}{(0.05\text{mm/yr}) \times (0.039370078 \text{ in/mm})} = 132 \text{ yrs} \]

• Life Expectancy @ Zone of Max Corrosion = \[ \frac{(0.26”)}{(0.18\text{mm/yr}) \times (0.039370078 \text{ in/mm})} = 37 \text{ yrs} \] then:

• Life Expectancy = 37 years

Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)
Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Given Corrosion Allowance = 0.0625"
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)

Example #1

• What is the Life Expectancy for a Hot Rolled PZC26 with Flange Thickness = 0.600” and Web thickness = 0.525” & Produced to A572 Grade 50 Steel with No Coating?

\[ t_{\text{sacrificial}} = 0.525” - 0.0625” = 0.463” \]

• Life Expectancy @ Zone of Max Moment = 
\[ \frac{0.463”}{0.05 \text{ mm/yr}} \times 0.039370078 \text{ in/mm} = 235 \text{ yrs} \]

• Life Expectancy @ Zone of Max Corrosion = 
\[ \frac{0.463”}{0.09 \text{ mm/yr}} \times 0.039370078 \text{ in/mm} = 130 \text{ yrs} \]

then:
• Life Expectancy = 130 years
Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion for Fresh Water Application = 0.09 mm/yr

Example #1

- What is the Life Expectancy for a Hot Rolled PZC26 with Flange Thickness = 0.600” and Web thickness = 0.525” & Produced to A572 Grade 50 Steel with No Coating?

\[
\tau_{\text{sacrificial}} = 0.525" - 0.26" = 0.26"
\]

- Life Expectancy @ Zone of Max Moment =

\[
\frac{0.26”}{0.05 \text{ mm/yr}} \times 0.039370078 \text{ in/mm} = 132 \text{ yrs}
\]

- Life Expectancy @ Fresh Water Application Corrosion =

\[
\frac{0.26”}{0.09 \text{ mm/yr}} \times 0.039370078 \text{ in/mm} = 71 \text{ yrs}
\]

then:
- Life Expectancy = 71 years
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC28 with Flange Thickness = 0.645” and Web thickness = 0.570” & Produced to A572 Grade 50 Steel with No Coating?

\[ t_{\text{sacrificial}} = .570” - .28” = 0.29” \]

• Life Expectancy @ Zone of Max Moment = 
\[ \frac{(0.29”)}{(0.05\text{mm/yr}) \times (0.039370078 \text{ in/mm})} = 147 \text{ yrs} \]

• Life Expectancy @ Zone of Max Corrosion = 
\[ \frac{(0.29”)}{(0.18\text{mm/yr}) \times (0.039370078 \text{ in/mm})} = 40 \text{ yrs} \]

then:

• Life Expectancy = 40 years

Assumptions:
- Zone of High Attack
  - Max Sacrificial Thickness Allowed to 50% of Original Thickness
  - Corrosion at Max Moment = 0.05 mm/yr
  - Corrosion at Splash Zone = 0.09 mm/yr (mean)
  - Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)
Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Fresh Water Application = 0.09 mm/yr

Designing for Durability Example #1

- What is the Life Expectancy for a Hot Rolled PZC28 with Flange Thickness = 0.645” and Web thickness = 0.570” & Produced to A572 Grade 50 Steel with No Coating?

  \[ t_{\text{sacrificial}} = 0.570” - 0.28” = 0.29” \]

  - Life Expectancy @ Zone of Max Moment =
    \[ \frac{(0.29”)}{(0.05\text{mm/yr})} \times (0.039370078 \text{ in/mm}) = 147 \text{ yrs} \]

  - Life Expectancy @ Fresh Water Application Corrosion =
    \[ \frac{(0.29”)}{(0.09\text{mm/yr})} \times (0.039370078 \text{ in/mm}) = 82 \text{ yrs} \]
    then:
    - Life Expectancy = 82 years


**Designing for Durability Example #1**

- What is the Life Expectancy for a Hot Rolled **PZC28** with Flange Thickness = 0.645” and Web thickness = 0.570” & Produced to **A572 Grade 50 Steel** with Coat Tar Epoxy Coating of 16 mils DFT?

- Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 82 yrs + 20 yrs = 102 years
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC37 with Flange Thickness = 0.563” and Web thickness = 0.488” & Produced to A572 Grade 50 Steel with No Coating?

\[ t_{\text{sacrificial}} = 0.488” - 0.24” = 0.244” \]

• Life Expectancy @ Zone of Max Moment =
\[ \frac{(0.244”)}{(0.05\text{mm/yr}) \times (0.039370078 \text{ in/mm})} = 124 \text{ yrs} \]

• Life Expectancy @ Fresh Water Application Corrosion =
\[ \frac{(0.244”)}{(0.09\text{mm/yr}) \times (0.039370078 \text{ in/mm})} = 69 \text{ yrs} \]
then:

• Life Expectancy = 69 years

Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Fresh Water Application = 0.09 mm/yr
Designing for Durability
Example #1

- What is the Life Expectancy for a Hot Rolled **PZC26** with Flange Thickness = 0.600” and Web thickness = 0.525” & Produced to **A572 Grade 50 Steel** with Coat Tar Epoxy Coating of 16 mils DFT?

- Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 37 yrs + 20 yrs = 57 years

**Assumptions:**
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC26 with Flange Thickness = 0.600” and Web thickness = 0.525” & Produced to A572 Grade 50 Steel with Coat Tar Epoxy Coating of 16 mils DFT?

• Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 71 yrs + 20 yrs = 91 years
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC37 with Flange Thickness = 0.600” and Web thickness = 0.525” & Produced to A572 Grade 50 Steel with Coat Tar Epoxy Coating of 16 mils DFT?

• Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 69 yrs + 20 yrs = 89 years
Assumptions:
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

Designing for Durability
Example #1

- What is the Life Expectancy for a Hot Rolled PZC41 with Flange Thickness = 0.600” and Web thickness = 0.525” & Produced to A572 Grade 50 Steel with Coat Tar Epoxy Coating of 16 mils DFT?

- Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 37 yrs + 20 yrs = 57 years
Assumptions:
- Zone of High Attack
  - Max Sacrificial Thickness Allowed to 50% of Original Thickness
  - Corrosion at Max Moment = 0.05 mm/yr
  - Corrosion at Splash Zone = 0.09 mm/yr (mean)
  - Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

Example #1

What is the Life Expectancy for a Hot Rolled PZC41 with Flange Thickness = 0.636” and Web thickness = 0.561” & Produced to A572 Grade 50 Steel with No Coating?

\[ t_{\text{sacrificial}} = 0.561” - 0.28” = 0.28” \]

- Life Expectancy @ Zone of Max Moment =
  \[ \frac{0.28”}{0.05\text{mm/yr}} \times 0.039370078 \text{ in/mm} = 142 \text{ yrs} \]

- Life Expectancy @ Zone of Max Corrosion =
  \[ \frac{0.28”}{0.09\text{mm/yr}} \times 0.039370078 \text{ in/mm} = 79 \text{ yrs} \]

then:
- Life Expectancy = 79 years
**Designing for Durability**

**Example #1**

- What is the Life Expectancy for a Hot Rolled **PZC41** with Flange Thickness = 0.636” and Web thickness = 0.561” & Produced to **A572 Grade 50 Steel** with Coat Tar Epoxy Coating of 16 mils DFT?

- Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 79 yrs + 20 yrs = 99 years

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**Assumptions:**
- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC50 CP with Flange Thickness = 0.600”+0.813” and Web thickness = 0.525” & Produced to A572 Grade 50 Steel with No Coating?

\[ t_{\text{sacrificial}} = 0.525” - 0.26” = 0.265” \]

• Life Expectancy @ Zone of Max Moment = 
\[ \frac{0.27”}{0.05\text{mm/yr}} \times 0.039370078 \text{ in/mm} = 137 \text{ yrs} \]

• Life Expectancy @ Zone of Max Corrosion = 
\[ \frac{0.27”}{0.09\text{mm/yr}} \times 0.039370078 \text{ in/mm} = 76 \text{ yrs} \]

then:

• Life Expectancy = 76 years

Assumptions:

➢ Zone of High Attack

➢ Max Sacrificial Thickness Allowed to 50% of Original Thickness

➢ Corrosion at Max Moment = 0.05 mm/yr

➢ Corrosion at Splash Zone = 0.09 mm/yr (mean)

➢ Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC50-CP with Flange Thickness = 0.600”+ 0.813” and Web thickness = 0.525” & Produced to A572 Grade 50 Steel with Coat Tar Epoxy Coating of 16 mils DFT?

• Extensive Industry Experience has shown that Coal Tar Epoxy Coatings provide approximately 20+ years of Service

Therefore:

Life Expectancy = 76 yrs + 20 yrs = 96 years
Designing for Durability

Example #1

Assumptions:

- Zone of High Attack
- Max Sacrificial Thickness Allowed to 50% of Original Thickness
- A690 Increases Life 2 to 3 times above A36 & A328 Steels
- Corrosion at Splash Zone = 0.09 mm/yr (mean)

What is the Life Expectancy for a Hot Rolled PZC50-CP with Flange Thickness = 0.600” + 0.813” and Web thickness = 0.525” & Produced to ASTM A690 Steel with No Coatings?

Life Expectancy @ Zone of Max Corrosion =

(0.265”) x 2 times/(0.09mm/yr)x(0.039370078 in/mm) = 149 yrs

to

(0.265”) x 3 times/(0.09mm/yr)x(0.039370078 in/mm) = 224 yrs

then:

- Life Expectancy Uncoated PZC50-CP = +76 yrs

Therefore:

- Life Expectancy = 149 years
Designing for Durability
Example #1

• What is the Life Expectancy for a Hot Rolled PZC50-CP with Flange Thickness = 0.600” + 0.813” and Web thickness = 0.525” & Produced to ASTM A572 GRADE 60 ksi Steel with No Coatings?

• By Designing to Grade 50 but utilizing a higher Grade 60 steel, the proportional increase in stress provides a 20% Increase in the Life of the Pile. Therefore:

• Life Expectancy = 76 x 1.20 = 91 years
Designing for Durability
Example #1

- What is the Life Expectancy for a Hot Rolled PZC50-CP with Flange Thickness = 0.600” + 0.813” and Web thickness = 0.525” & Produced to ASTM A572 GRADE 60 ksi Steel with CTE Coatings?

- By Designing to Grade 50 but utilizing a higher Grade 60 steel, the proportional increase in stress provides a 20% Increase in the Life of the Pile. Therefore:

- Life Expectancy = 96 x 1.20 = 115 years
Assumptions:
- Zone of High Attack
- FBE Typically Applied to Piling in Higher Corrosive Environments
- Corrosion at Max Moment = 0.05 mm/yr
- Corrosion at Splash Zone = 0.09 mm/yr (mean)
- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

Designing for Durability
Example #1

- What is the Life Expectancy for a Hot Rolled PZC50-CP Grade 50ksi with Flange Thickness = 0.600” + 0.813” and Web thickness = 0.525” with Fusion Bonded Epoxy Coating of 16 mils DFT?

- FBE has Extensive Industry Experience in the coatings for Pipe Piling and has shown Coating can provide approximately 25+ years of Service

Therefore for this example in comparison purposes only:

Life Expectancy = 76 yrs + 25 yrs = 101 years
## Summary of Life Expectancy
### SCZ21 vs PZC13
#### Example #1

<table>
<thead>
<tr>
<th></th>
<th>SZ21</th>
<th>PZC13</th>
<th>PZC18</th>
<th>PZC26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sacrificial Thickness</td>
<td>3</td>
<td>27</td>
<td>27</td>
<td>37</td>
</tr>
<tr>
<td>Hot Dip Galvanized</td>
<td>75</td>
<td>75</td>
<td>75</td>
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</tbody>
</table>

* Probable Life Expectancy in Years
Summary of Life Expectancy
PZC26 vs PZC28 vs PZC37
Fresh Water Example #1

<table>
<thead>
<tr>
<th></th>
<th>PZC26</th>
<th>PZC28</th>
<th>PZC37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sacrificial Thickness</td>
<td>71</td>
<td>82</td>
<td>69</td>
</tr>
<tr>
<td>Coal Tar Epoxy</td>
<td>91</td>
<td>102</td>
<td>89</td>
</tr>
</tbody>
</table>

* Probable Life Expectancy in Years
# Summary of Life Expectancy
## PZC13 vs PZC18 & PZC26
### Example #1

<table>
<thead>
<tr>
<th></th>
<th>PZC13</th>
<th>PZC18</th>
<th>PZC26</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sacrificial Thickness</strong></td>
<td>27</td>
<td>27</td>
<td>37</td>
</tr>
<tr>
<td><strong>Coal Tar Epoxy</strong></td>
<td>47</td>
<td>47</td>
<td>57</td>
</tr>
<tr>
<td><strong>Cathodic Protection</strong></td>
<td>47</td>
<td>47</td>
<td>57</td>
</tr>
<tr>
<td><strong>Fusion Bond Epoxy</strong></td>
<td>52</td>
<td>52</td>
<td>62</td>
</tr>
<tr>
<td><strong>A690 Grade Steel</strong></td>
<td>53</td>
<td>53</td>
<td>73</td>
</tr>
<tr>
<td><strong>Hot Dip Galvanized</strong></td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

* Probable Life Expectancy in Years
## Summary of Life Expectancy
### SZ21 vs PZC13 & PZC26

#### Example #1

<table>
<thead>
<tr>
<th></th>
<th>SCZ16</th>
<th>PZC13</th>
<th>PZC18</th>
<th>PZC26</th>
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</thead>
<tbody>
<tr>
<td>Sacrificial Thickness</td>
<td>14</td>
<td>27</td>
<td>27</td>
<td>37</td>
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<tr>
<td>Coal Tar Epoxy</td>
<td>34</td>
<td>47</td>
<td>47</td>
<td>57</td>
</tr>
<tr>
<td>Cathodic Protection</td>
<td>34</td>
<td>47</td>
<td>47</td>
<td>57</td>
</tr>
<tr>
<td>Fusion Bond Epoxy</td>
<td>39</td>
<td>52</td>
<td>52</td>
<td>62</td>
</tr>
<tr>
<td>A690 Grade Steel</td>
<td>40</td>
<td>53</td>
<td>53</td>
<td>73</td>
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<tr>
<td>Hot Dip Galvanized</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

*Probable Life Expectancy in Years for High Corrosive Zones*
Designing for Durability
Example #2

- Determine Life Expectancy using given Assumed Design Bending Moments and Utilizing Dr Hartman Graphs shown on previous Slides.

- Section Modulus at Max Moment = \( S_{max \ \text{moment}} \)
  \[
  S_{max} = \frac{M_{max}}{F_Y} = \frac{52 \text{K-Ft/ft} \times (12)}{0.65 \times (50 \text{ksi})} = 19.2 \text{in}^3/\text{ft}
  \]

- Section Modulus at Max Corrosion = \( S_{max \ \text{corrosion}} \)
  \[
  S_{max} = \frac{M_{max}}{F_Y} = \frac{28 \text{K-Ft/ft} \times (12)}{0.65 \times (50 \text{ksi})} = 10.3 \text{in}^3/\text{ft}
  \]
Assumptions:

- **PZC13**

- Corrosion at Splash Zone = 0.18 mm/yr (95 percentile)

---

**Designing for Durability**

**Example #2**

- Determine Amount of Sacrificial Corrosion from Section Modulus Calculations and utilizing Dr. Hartman, Ph.D., P.E. Graphs (previously shown) for **PZC13** –
  
  - For Max Moment —
    
    Sacrificial Corrosion = 0.118 in = 3.0 mm
  
  - For Splash Zone —
    
    Sacrificial Corrosion = 0.220 in = 5.8 mm

Then:

- Life_{Max Moment} = (3.0mm)/(0.05mm/yr) = 60 yrs
  
And:

- Life_{Splash Zone} = (5.8mm)/(0.18mm/yr) = 32 yrs

---
Designing for Durability
Example #2

- Next Determine Life Expectancy using Mariner Steel
  Produced from ASTM A690 for PZC13

- For Max Moment –
  Sacrificial Corrosion = 0.118 in = 3.0 mm

- For Splash Zone –
  Sacrificial Corrosion = 0.220 in = 5.8 mm

Then:
- \( L_{\text{Max Moment}} = \frac{3.0\,\text{mm}}{0.05\,\text{mm/yr}} = 60\,\text{yrs} \)
  
And:
- \( L_{\text{Splash Zone}} = \frac{5.8\,\text{mm} \times (2\,\text{times})}{0.18\,\text{mm/yr}} = 64\,\text{yrs} \)

Or:
- Increase in Life Expectancy = +28 years
Designing for Durability
Example #2

- Determine Amount of Sacrificial Corrosion from Section Modulus Calculations and utilizing Dr Hartman, Ph.D., P.E. Graphs (Previously shown) for PZC26 –
  - Section Modulus at Max Moment \( S_{\text{max moment}} = 19.2 \text{in}^3/\text{ft} \)
  - Section Modulus at Max Corrosion \( S_{\text{max corrosion}} = 10.3 \text{in}^3/\text{ft} \)
  - Interpolating from Graph at \( S_{\text{max corrosion}} \)
  - For Splash Zone –
    Sacrificial Corrosion = 0.513 in = 13.0 mm

Then:

- \( S_{\text{Splash Zone}} = (13.0 \text{mm})/(0.18 \text{mm/yr}) = 72 \text{ yrs} \)
Assumptions:

- **PZC26**
- Zone of High Attack
- Maximum Bending Moment = \(52^{K\text{-Ft/ft}}\)
- Moment at Splash Zone = \(28^{K\text{-Ft/ft}}\)
- Corrosion at Max Moment = \(0.05\text{ mm/yr}\)
- Corrosion at Splash Zone = \(0.09\text{ mm/yr (mean)}\)
- Corrosion at Splash Zone = \(0.18\text{ mm/yr (95 percentile)}\)
- A690 Mariner Steel Increases Life from 2 to 3 times above A36 & A328 Steels

### Designing for Durability Example #2

- Next Determine Life Expectancy using Mariner Steel Produced from **ASTM A690** for **PZC26**

  - For Splash Zone –
    - Sacrificial Corrosion = \(0.513\text{ in} = 13.0\text{ mm}\)

Then:

- \(\text{Life}_{\text{Splash Zone}} = (13.0\text{ mm})\times (2\text{ times})/(0.18\text{ mm/yr}) = 144\text{ yrs}\)

Or:

- Increase in Life Expectancy = +72 years
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Sacrificial Thickness</td>
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<td>72</td>
</tr>
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<td>52</td>
<td>92</td>
</tr>
<tr>
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<td>52</td>
<td>92</td>
</tr>
<tr>
<td>Fusion Bond Epoxy</td>
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<td>97</td>
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<tr>
<td>A690 Grade Steel</td>
<td>64</td>
<td>144</td>
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<tr>
<td>Hot Dip Galvanized</td>
<td>75</td>
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</tbody>
</table>

* Probable Life Expectancy in Years
Key Information

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