Designing for Durability

Richard Morales, M.Sc., 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
**Eurocode 3:**
**Design of Steel Structures**
**Part 5: Piling**
**(ENV 1993-5)**

**Loss of Thickness**
**(mm)**

<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>
<tr>
<td>Water:</td>
<td></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 general 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 Protection Considerations

![Corrosion Protection Diagram](image)
<table>
<thead>
<tr>
<th>Thickness Reduction (in.)</th>
<th>Section Modulus (in$^3$ / ft)</th>
<th>Moment of Inertia (in$^4$ / ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PZ27</td>
<td>PZC13</td>
</tr>
<tr>
<td>0.0000</td>
<td>31.80</td>
<td>24.17</td>
</tr>
<tr>
<td>0.0625</td>
<td>27.96</td>
<td>21.10</td>
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<td>0.1250</td>
<td>24.07</td>
<td>17.96</td>
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<td>0.1875</td>
<td>20.10</td>
<td>14.76</td>
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<tr>
<td>0.2500</td>
<td>16.10</td>
<td>11.49</td>
</tr>
</tbody>
</table>

* Reference: Richard Hartman, Ph.D., P.E.
Graphs of Calculated Section Modulus and Moment of Inertia for Thickness Reduction from 0.000” – 0.250”

* Reference: Richard Hartman, Ph.D., P.E.
<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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<tbody>
<tr>
<td></td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>in.</td>
<td>lb / ft</td>
<td>lb / ft²</td>
<td>in³</td>
<td>ft² / lft</td>
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<tr>
<td></td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>kg / lm</td>
<td>kg / m²</td>
<td>cm⁴</td>
<td>cm³ / wm</td>
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<tr>
<td></td>
<td>in²</td>
<td>m²</td>
<td>cm²</td>
<td>cm² / m</td>
<td>m³ / l</td>
<td>m³ / lm</td>
<td>cm³ / l</td>
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<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>708</td>
<td>319</td>
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<tr>
<td></td>
<td>9.5</td>
<td>9.5</td>
<td>75.1</td>
<td>106.0</td>
<td>14694</td>
<td>20753</td>
<td>635</td>
<td>1300</td>
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<tr>
<td>PZC 18</td>
<td>25.00</td>
<td>15.25</td>
<td>0.375</td>
<td>0.375</td>
<td>50.4</td>
<td>24.2</td>
<td>635</td>
<td>1300</td>
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<td></td>
<td>9.5</td>
<td>9.5</td>
<td>75.1</td>
<td>118.2</td>
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<td>34888</td>
<td>1124</td>
<td>1801</td>
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<td>PZC 26</td>
<td>27.88</td>
<td>17.70</td>
<td>0.525</td>
<td>0.600</td>
<td>73.9</td>
<td>31.8</td>
<td>708</td>
<td>450</td>
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<td>15.2</td>
<td>110.0</td>
<td>155.4</td>
<td>41390</td>
<td>58460</td>
<td>1840</td>
<td>2600</td>
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</tbody>
</table>

PZC™
WIDER–LIGHTER–STRONGER

PZC Hot Rolled Steel Piling

LB Foster
Piling
Cold Rolled Form Piling

**Intermediate Heavyweight Shooting Cross Section**

<table>
<thead>
<tr>
<th>Section Type</th>
<th>Thickness Nominal</th>
<th>Weight Lb/Square Ft</th>
<th>Weight Lb/Lineal Ft</th>
<th>Sec. Mod. Inch$^3$(Ft/Wall)</th>
<th>Moment of Inertia Inch$^4$(Ft/Wall) Per Pile</th>
<th>Moment of Inertia Inch$^4$(Ft/Wall) Per Ft. of Wall</th>
<th>Coating Area Sq.Ft/LF</th>
</tr>
</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>
<td>5.75</td>
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</tbody>
</table>
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.

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.
• **ASTM** states:

  1.2 The atmospheric corrosion resistance of this steel is substantially better than that of ordinary carbon steels with or without copper addition (see Note 1). The steel has also shown to have substantially greater resistance to seawater “Splash Zone” corrosion than ordinary carbon steel (Specifications A 36/A 36M and A 328/A 328M) where exposed to the washing action of rain and the drying action of the wind or sun, or both. Where the steel is not boldly exposed, the usual provisions for the protection of ordinary carbon steel should be considered.

• **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.
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 is 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})x(0.039370078\text{in/mm}) = 50\text{ yrs} \\
• Life\text{Splash Zone} = (0.10”)/(0.18\text{mm/yr}) x (0.039370078 \text{ in/mm}) = 14\text{ yrs} \\
• Life\text{State DOT} = (0.05”)/(0.18\text{mm/yr}) x (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.
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 section values
Designing for Durability
Example #1

- What is the Life Expectancy for a Cold Form SZ21 with 0.350” 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 = 14 yrs + 25 yrs = 39 years

- Note if State DOT Req’ts used for Limiting Cold Form Steel to 85% Full Section Values, Life Expectancy = 32 years.

Assumptions:
- Zone of High Attack
- FBE Typically Applied to Pipe Piling Outside Diameter
- 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
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 PZC13 with 0.375” Thickness with No Coating?

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

• 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
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
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
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)**

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**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 =**

    
    \[
    \begin{align*}
    \text{Life Expectancy} &= \frac{(0.1875”)}{2} \times \frac{1}{0.18 \text{ mm/yr}} \times \frac{0.039370078 \text{ in/mm}}{0.039370078 \text{ in/mm}} = 53 \text{ yrs} \\
    \text{Life Expectancy} &= \frac{(0.1875”)}{3} \times \frac{1}{0.18 \text{ mm/yr}} \times \frac{0.039370078 \text{ in/mm}}{0.039370078 \text{ in/mm}} = 80 \text{ yrs}
    \end{align*}
    \]

    then:

    \[
    \begin{align*}
    \text{Life Expectancy} &= +26 \text{ years}
    \end{align*}
    \]

  Therefore:

  Life Expectancy = 53 years
Designing for Durability
Example #1

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

```
t_{sacrificial} = .375” - .1875” = 0.1875” (3/16”)
```

- 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)

• Life Expectancy @ Zone of Max Moment = 
  
```
(0.1875”)/(0.05mm/yr) x (0.039370078 in/mm) = 95 yrs
```

• Life Expectancy @ Zone of Max Corrosion = 
  
```
(0.1875”)/(0.18mm/yr) x (0.039370078 in/mm) = 27 yrs
```

then:

• Life Expectancy = 27 years
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
- 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 =

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

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

  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)

**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?

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

- 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
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
- FBE Typically Applied to Pipe Piling Outside Diameter
- 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 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 = 37 yrs + 25 yrs = 62 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 = 0.18 mm/yr (95 percentile)**

What is the Life Expectancy for a Hot Rolled **PZC26** with Flange Thickness = 0.600” and Web thickness = 0.525” & Produced to ASTM A690 Steel with No Coatings?

- **Life Expectancy @ Zone of Max Corrosion =**

\[
(0.26”) \times 2 \text{ times} / (0.18 \text{ mm/yr}) \times (0.039370078 \text{ in/mm}) = 73 \text{ yrs}
\]

\[
(0.26”) \times 3 \text{ times} / (0.18 \text{ mm/yr}) \times (0.039370078 \text{ in/mm}) = 110 \text{ yrs}
\]

then:

- **Life Expectancy = +36 years**

Therefore:

Life Expectancy = 73 years
### Summary of Life Expectancy
#### SZ21 vs PZC13 & PZC26

**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>14</td>
<td>27</td>
<td>27</td>
<td>37</td>
</tr>
<tr>
<td>Coat 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>
</tr>
<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
**Assumptions:**
- Zone of High Attack
- Maximum Bending Moment = \(52 \text{K-Ft/ft}\)
- Moment at Splash Zone = \(28 \text{K-Ft/ft}\)
- 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 #2**

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

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

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

**Example #2**

**Assumptions:**

- **PZC13**

- Zone of High Attack

- Controls

- Maximum Bending Moment = 52 K-Ft/ft

- Moment at Splash Zone = 28 K-Ft/ft

- 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)

- Determine Amount of Sacrificial Corrosion from Section Modulus Calculations and utilizing Dr. Hartman, Ph.D., P.E. Graphs (previously shown) for **PZC13** –

  - Section Modulus at Max Moment = $S_{\text{max moment}} = 19.2\text{in}^3/\text{ft}$

  - Section Modulus at Max Corrosion = $S_{\text{max corrosion}} = 10.3\text{in}^3/\text{ft}$

- For Max Moment –

  Sacrificial Corrosion = 0.118 in = 3.0 mm

- For Splash Zone –

  Sacrificial Corrosion = 0.220 in = 5.8 mm

Then:

- $\text{Life}_{\text{Max Moment}} = (3.0\text{mm})/(0.05\text{mm/yr}) = 60\text{ yrs}$

- $\text{Life}_{\text{Splash Zone}} = (5.8\text{mm})/(0.18\text{mm/yr}) = 32\text{ yrs}$
Assumptions:

- **PZC13**
- Zone of High Attack Controls
- Maximum Bending Moment = 52 K-Ft/ft
- Moment at Splash Zone = 28 K-Ft/ft
- 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)
- 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 **PZC13**

- For Max Moment –
  Sacrificial Corrosion = 0.118 in = 3.0 mm
- For Splash Zone –
  Sacrificial Corrosion = 0.220 in = 5.8 mm

Then:

- \( \text{Life}_{\text{Max Moment}} = \frac{3.0 \text{mm}}{0.05 \text{mm/yr}} = 60 \text{ yrs} \)
- \( \text{Life}_{\text{Splash Zone}} = \frac{5.8 \text{mm} \times (2 \text{ times})}{0.18 \text{mm/yr}} = 64 \text{ yrs} \)

Or:

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

Assumptions:

- **PZC26**
- **Zone of High Attack Controls**

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

**Example Calculations:**

- **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:

- **Life**_{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-Ft/ft
- **Moment at Splash Zone** = 28 K-Ft/ft
- **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)

- **A690 Mariner Steel Increases Life from 2 to 3 times above A36 & A328 Steels**

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**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 in = 13.0 mm

Then:

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

Or:

- Increase in Life Expectancy = +72 years
**Summary of Life Expectancy**

**PZC13 & PZC26**

**Example #2**

<table>
<thead>
<tr>
<th></th>
<th>PZC13</th>
<th>PZC26</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sacrificial Thickness</strong></td>
<td>32</td>
<td>72</td>
</tr>
<tr>
<td><strong>Coat Tar Epoxy</strong></td>
<td>52</td>
<td>92</td>
</tr>
<tr>
<td><strong>Cathodic Protection</strong></td>
<td>52</td>
<td>92</td>
</tr>
<tr>
<td><strong>Fusion Bond Epoxy</strong></td>
<td>57</td>
<td>97</td>
</tr>
<tr>
<td><strong>A690 Grade Steel</strong></td>
<td>64</td>
<td>144</td>
</tr>
<tr>
<td><strong>Hot Dip Galvanized</strong></td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

* Probable Life Expectancy in Years
Key Information

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