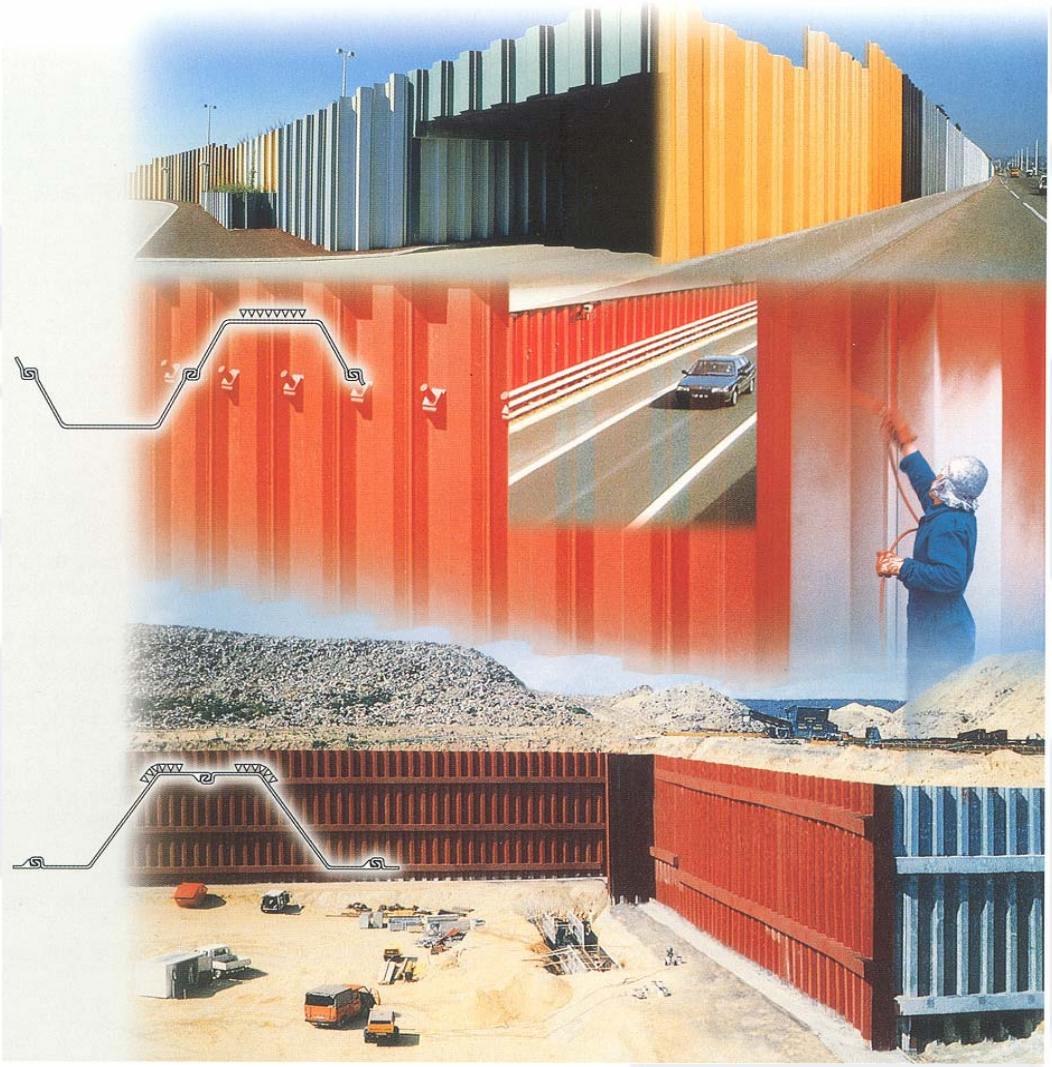
Designing for Durability



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Durability by Design - Steps 1 to 5

Develop durability by establishing the contribution to design life from some or all of the areas below:

1. **Sacrificial Thickness**
2. **Marine Grade Steel ASTM A690**
3. **Higher Yield Steel to extend life**
4. **Protective Coatings**
5. **Cathodic Protection**

Durability by Design – Step 1

1. **Sacrificial Thickness**
   a. Establish rates of corrosion at each zone on a marine wall
   b. Find Max moment at each zone
   c. Calculate minimum section modulus at each zone
   d. Choose pile for largest modulus
   e. Use Section Graphs (from supplier) to find Sacrificial Thickness
   f. Use Corrosion rates & Sacrificial thickness to give design life

An example of how this works follows:

Durability by Design – Step 1 (a)

Reference: Eurocode 3: Design of steel structures
Part 5: Piling (ENV 1993-5)

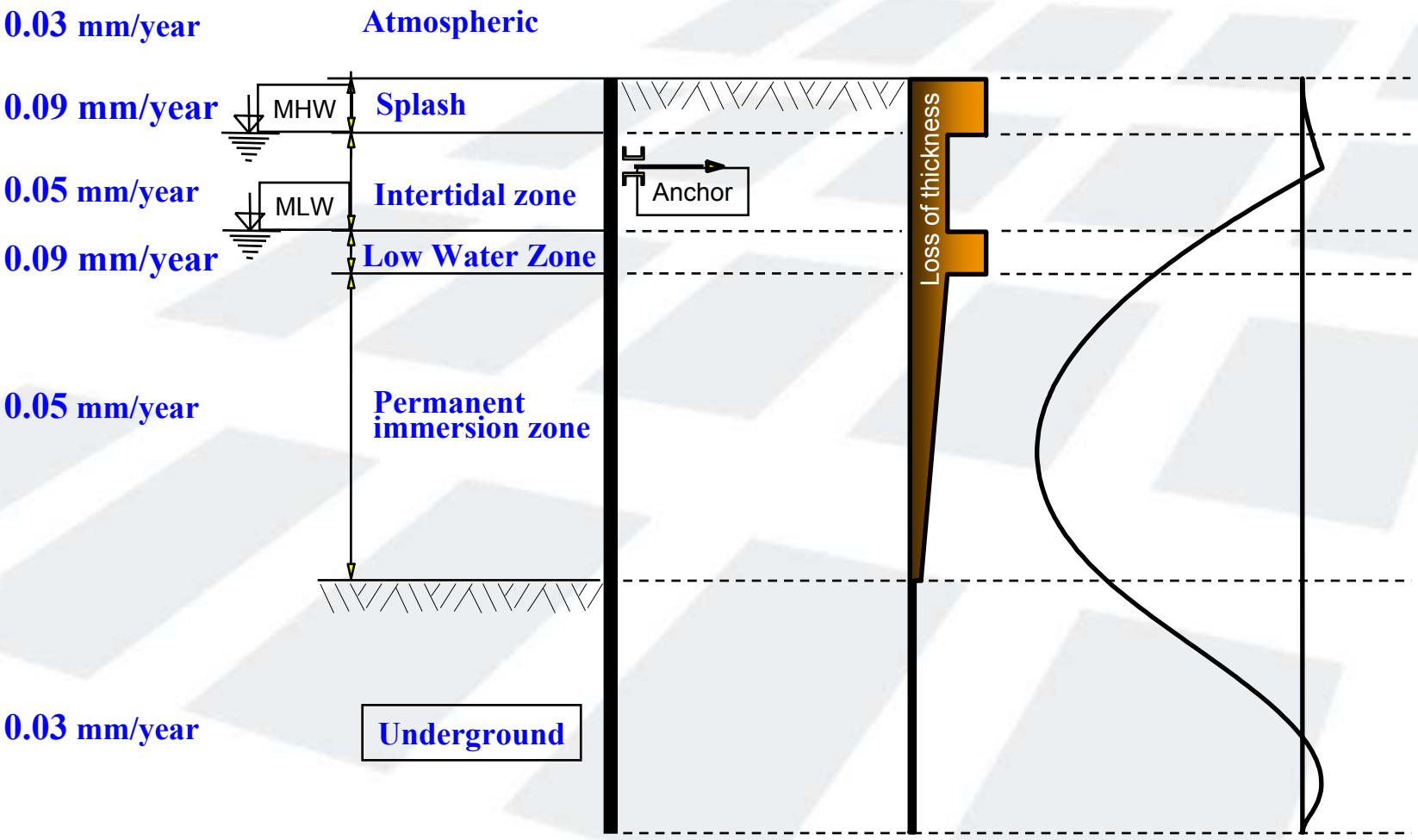
Loss of thickness (mm)

	5 yrs	**25** yrs	**50** yrs	**75** yrs	**100** yrs
undist. soil	**0.00**	**0.30**	**0.60**	**0.90**	**1.20**
fresh water	**0.15**	**0.55**	**0.90**	**1.15**	**1.40**
sea water	**0.25**	**0.90**	**1.75**	**2.60**	**3.50**
splash zone	**0.55**	**1.90**	**3.75**	**5.60**	**7.50**

Rates reduce over time as oxidation products limit corrosion action.
Values shown are for guidance. Local conditions may give corrosion rates that are lower or higher than the average values in the table above.

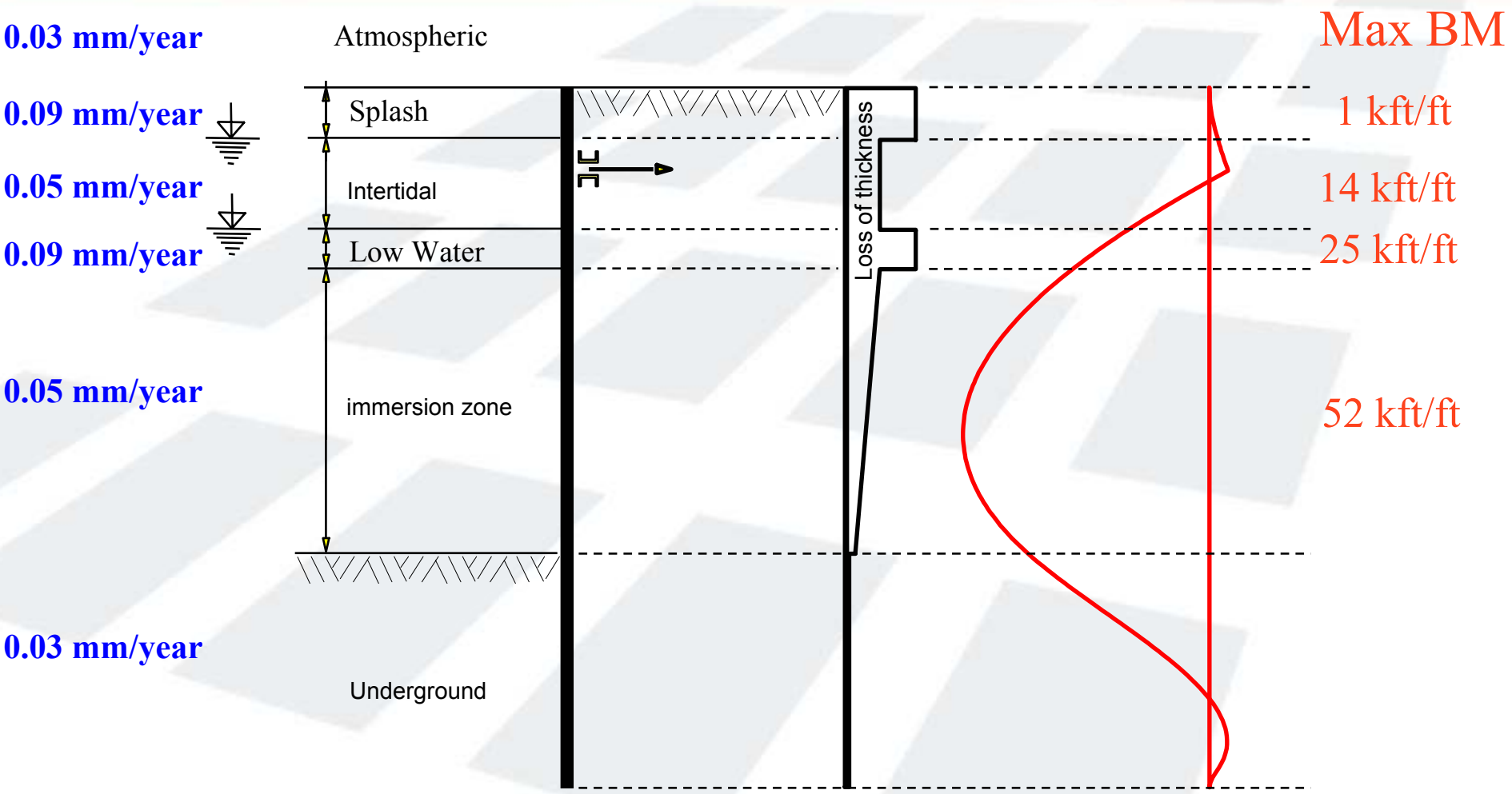
For rates per year refer to the following table or pro-rata rates from this table

1. Corrosion Zones & Rates



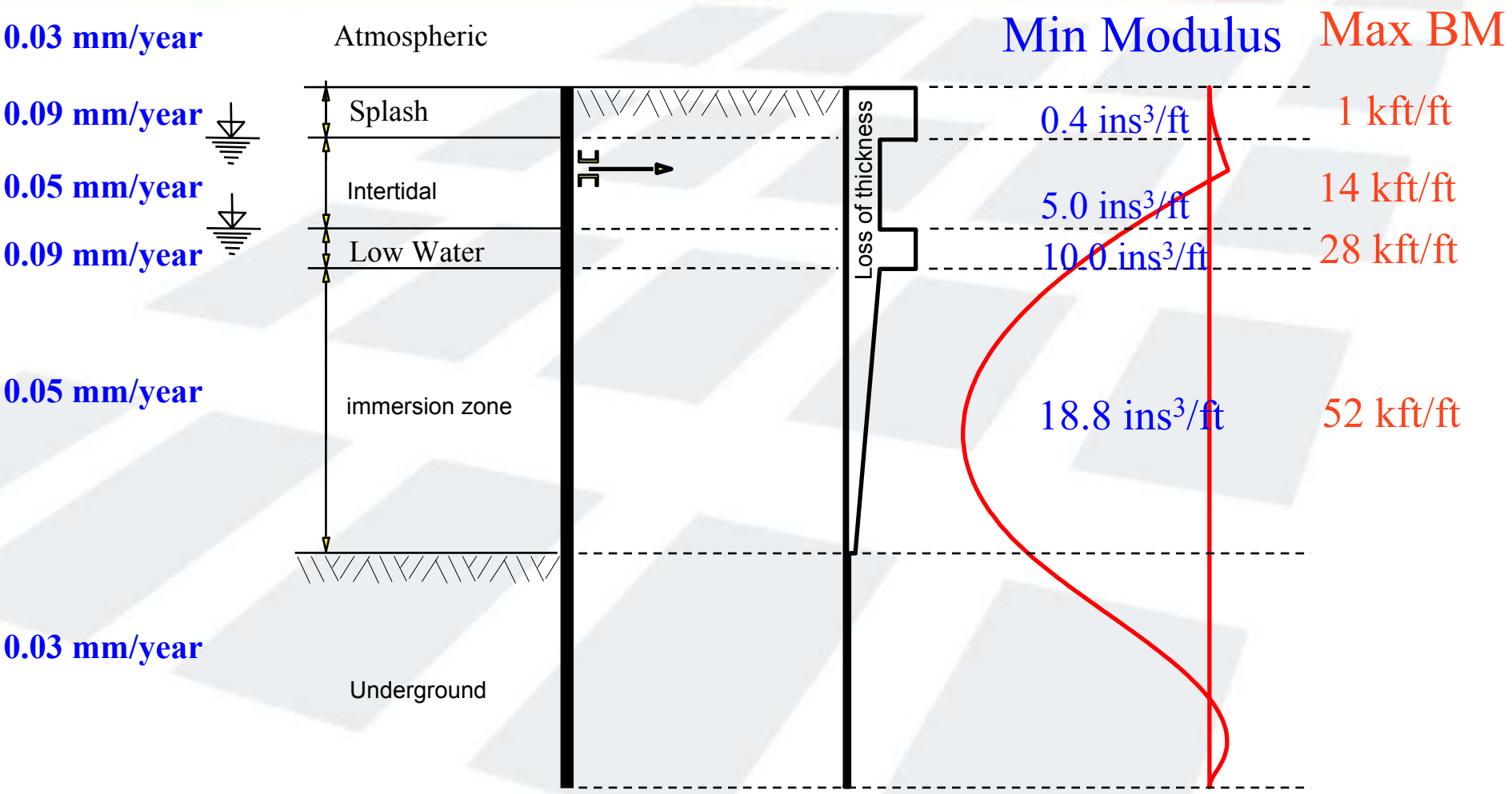
Note: Corrosion rates are measured as total loss of section thickness from both sides of the wall

2. Max BM at Each Zone

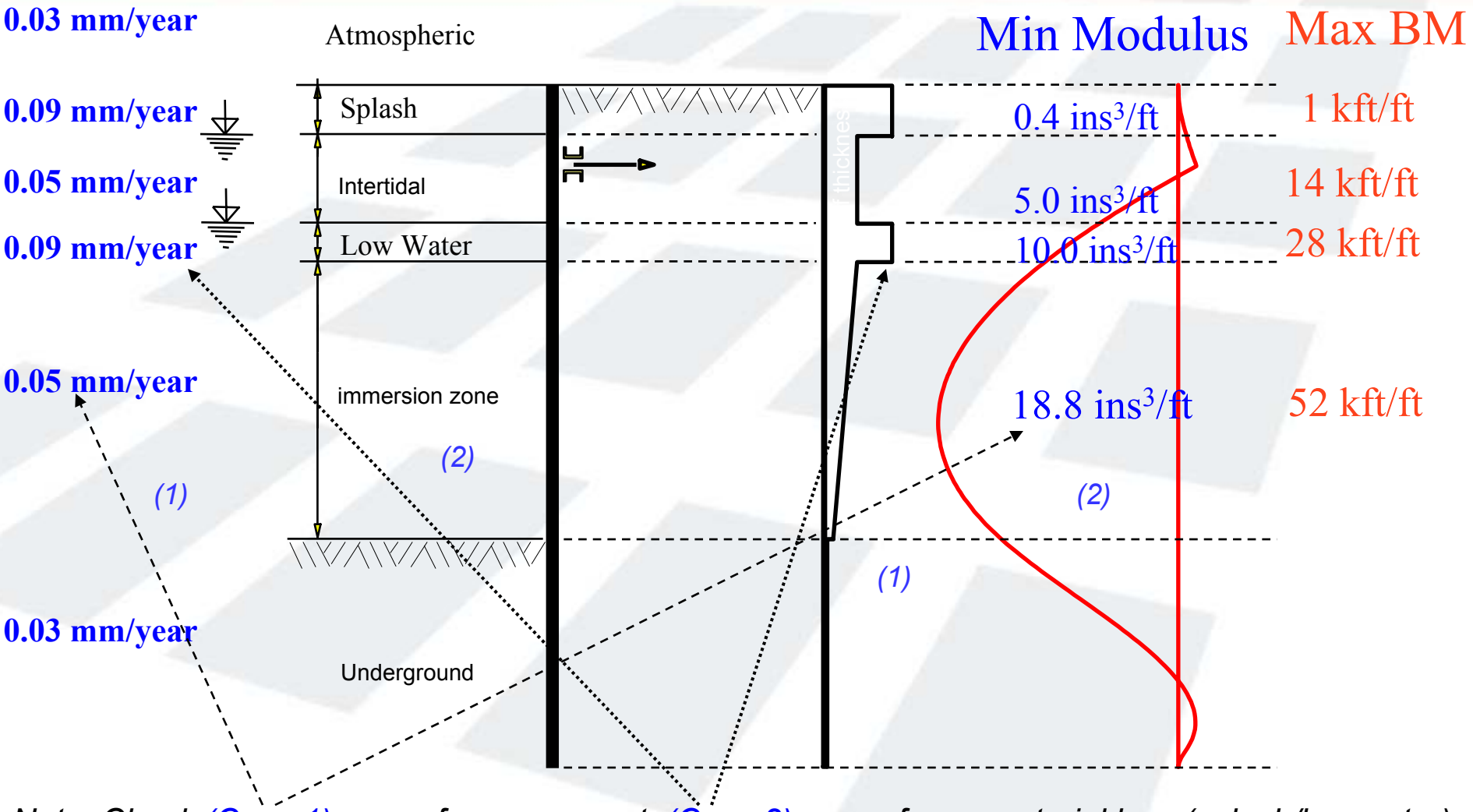


Note: Corrosion rates are measured as total loss of section thickness from both sides of the wall

3. Calculate Section Modulus for Max BM

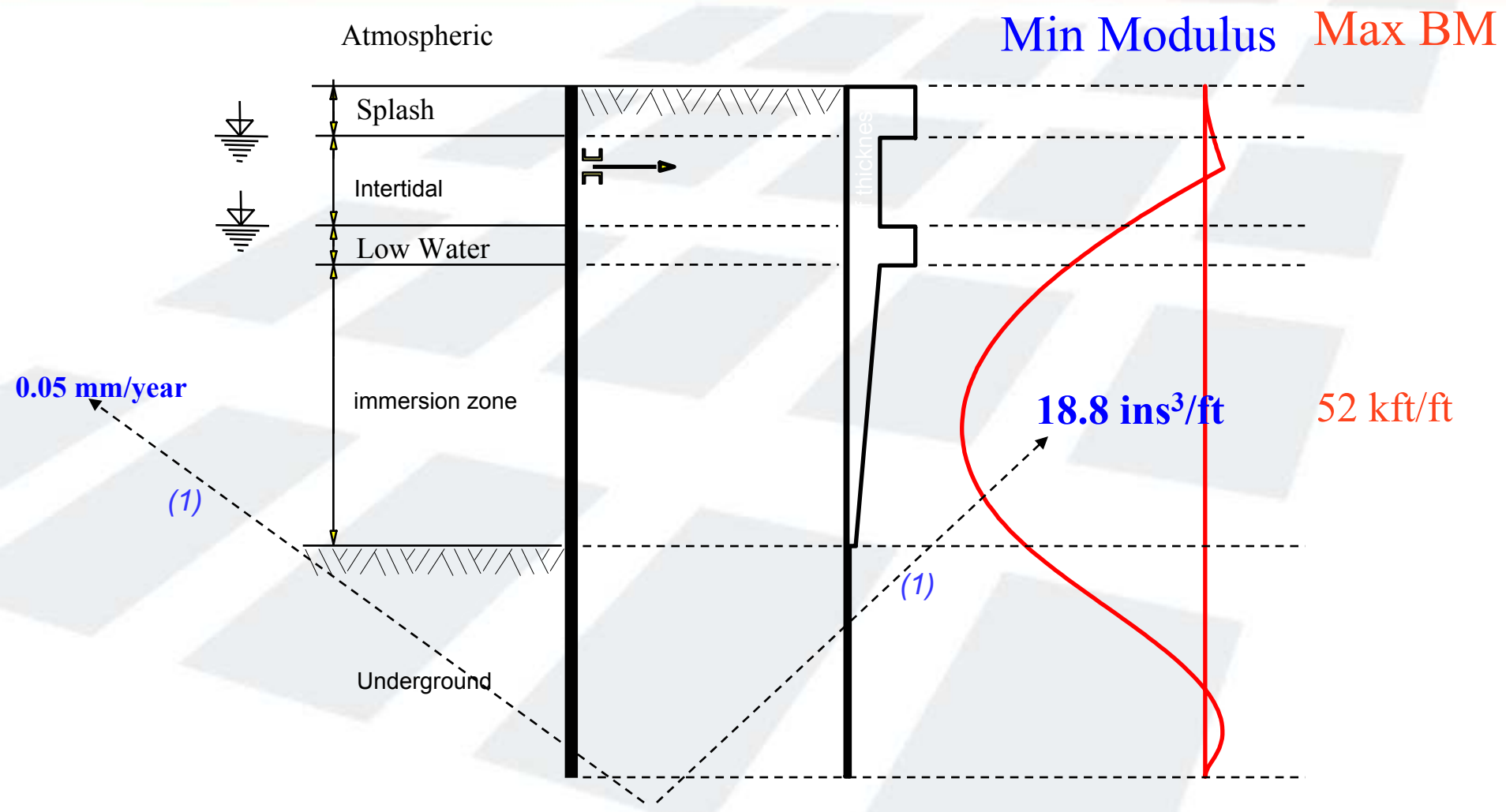


3. Check Major Zones



Note: Check (Case 1) area of max moment, (Case 2) area of max material loss (splash/low water).

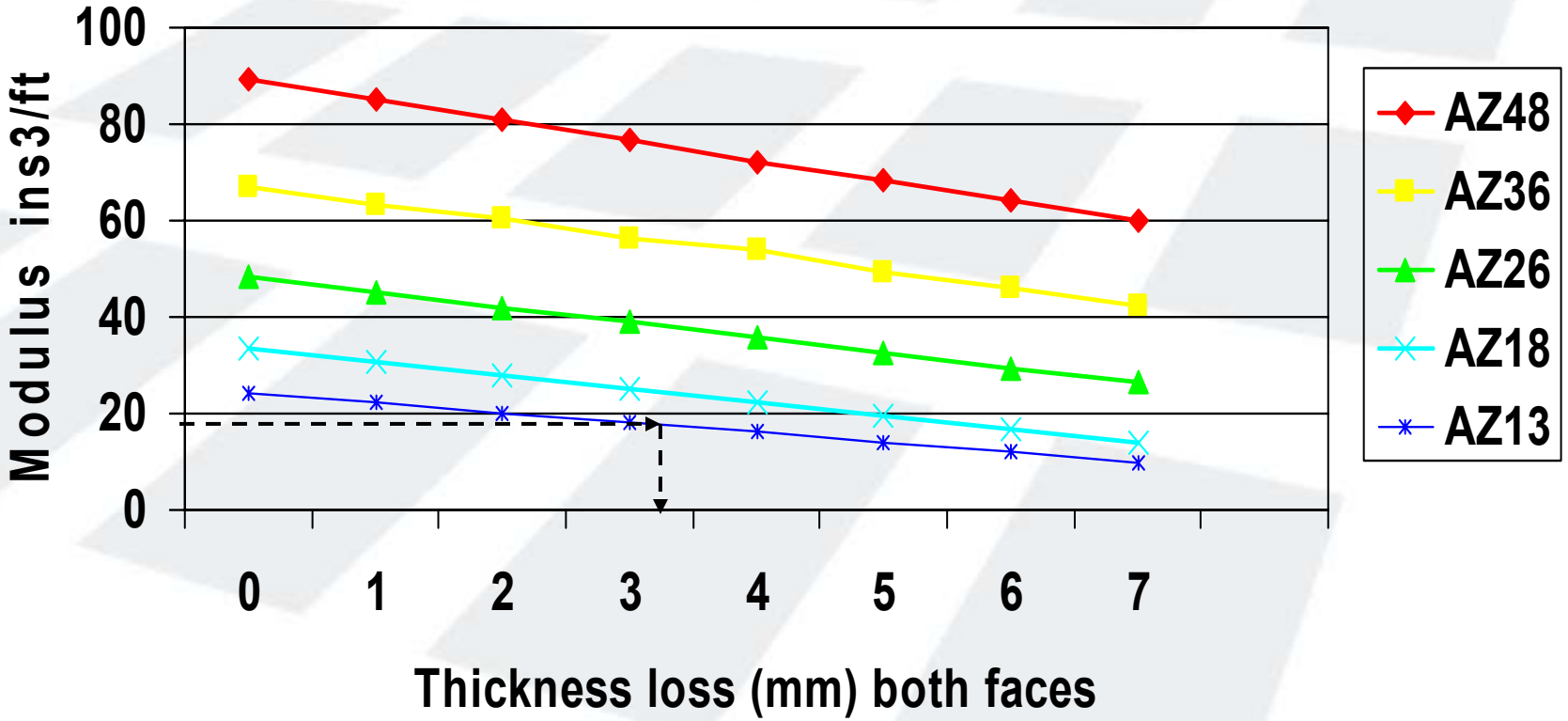
Case 1 – Max moment



Case 1: Check area of max moment (1) with rate of corrosion per year at that location

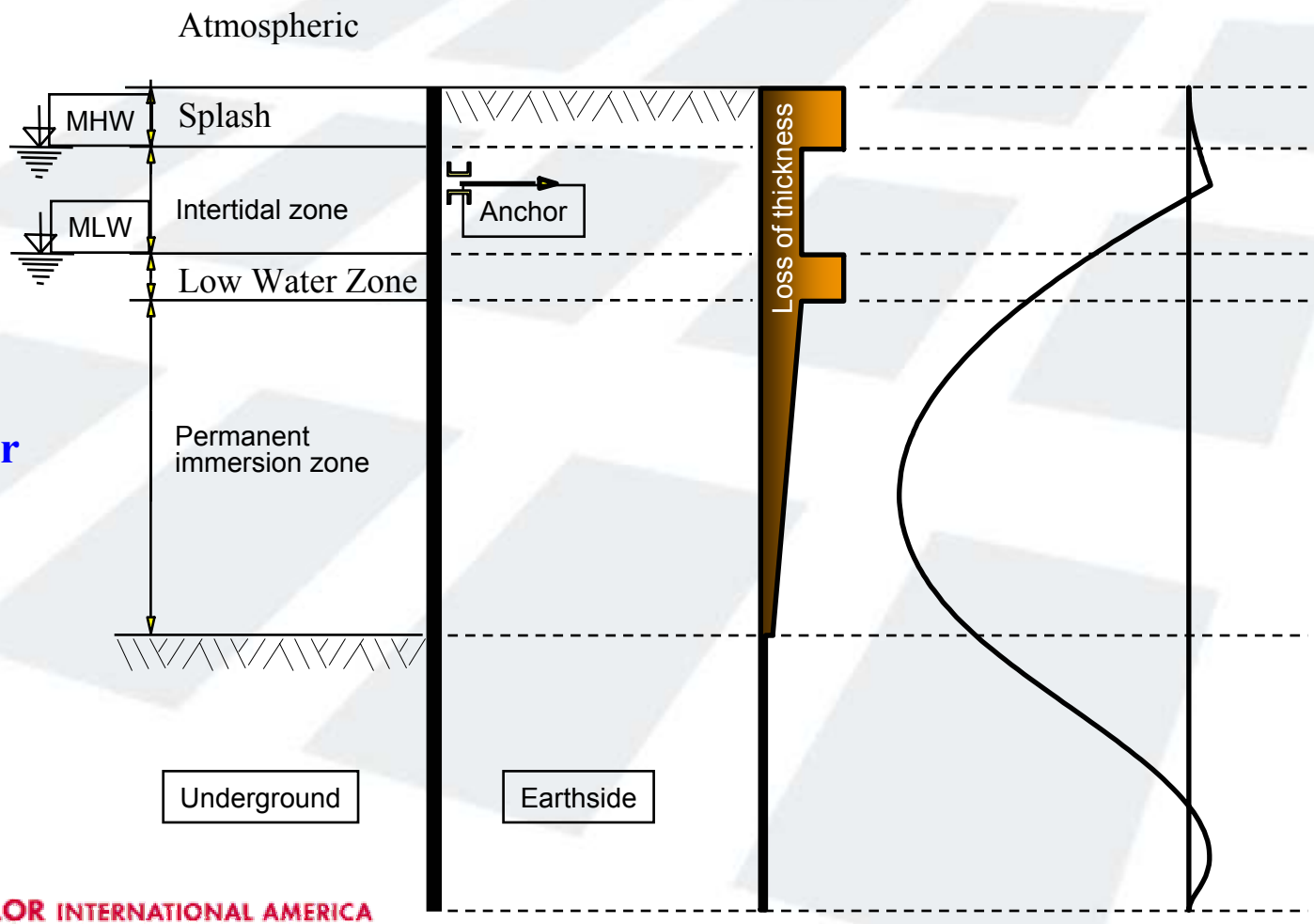
4. Section Graph to Find Sacrificial Thickness

Case (1) Go up to 18.8 ins³/ft & move across graph until a section, in this case AZ13, is intersected then drop down to find sacrificial thickness (3.25mm)



5. Corrosion Rates per Year

✓ Now combine sacrificial thickness **(3.25 mm)** with rate of thickness loss **(0.05 mm/year)** to find design life



0.05 mm/year

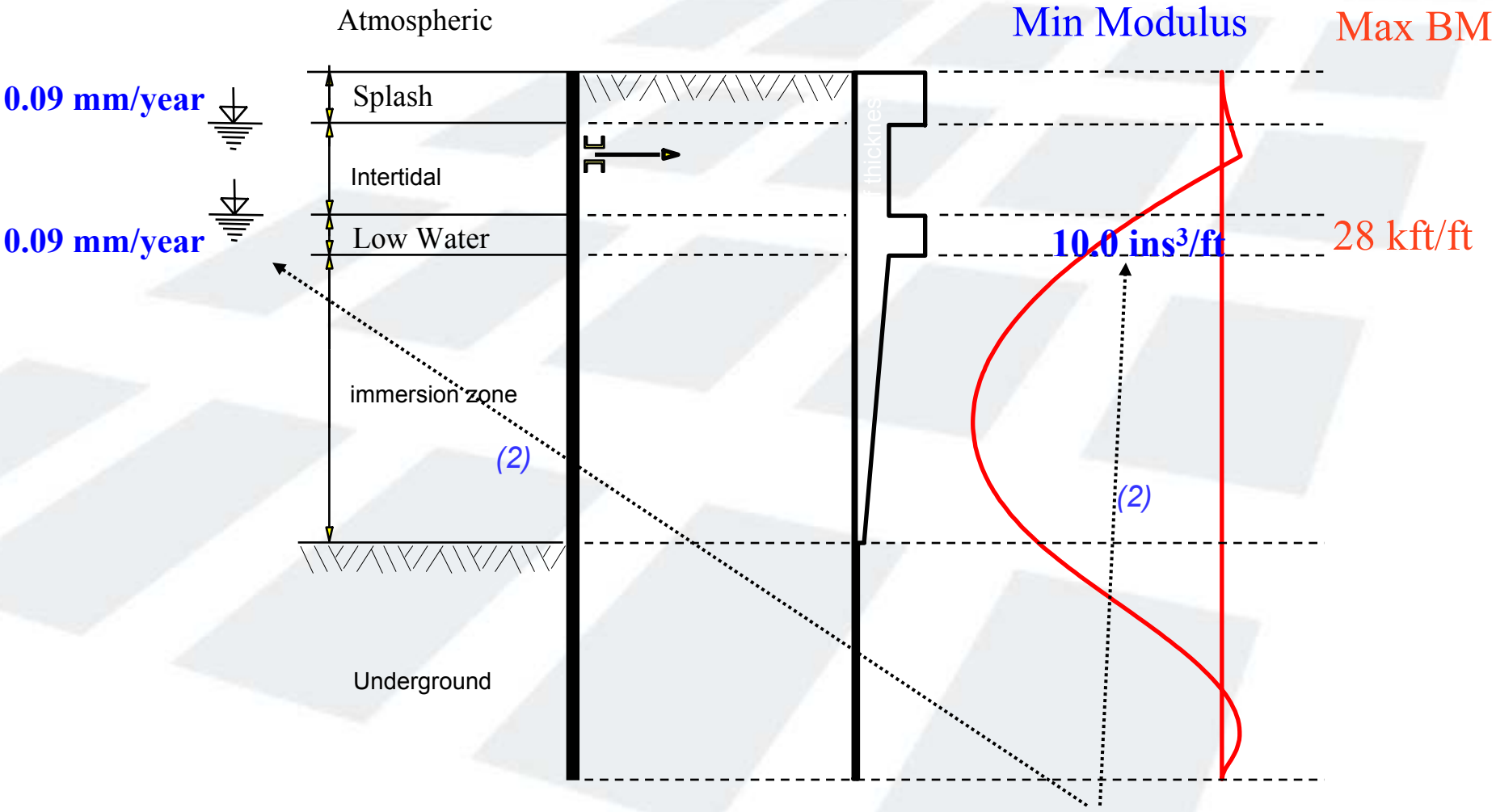
6. Corrosion Rate + Sacrificial Thickness to give design Life for Case 1 – max moment

	Sacrificial thickness		Max rate corrosion per year		Design life
AZ13	*3.25 mm*	/	*0.05 mm/year*	=	*65 Years*

Note: Corrosion rates used are mean rates as referenced by Eurocode and others. In severe cases the designer may wish to use higher values.

Now repeat steps 4 – 6 to evaluate Case 2 - area max material loss

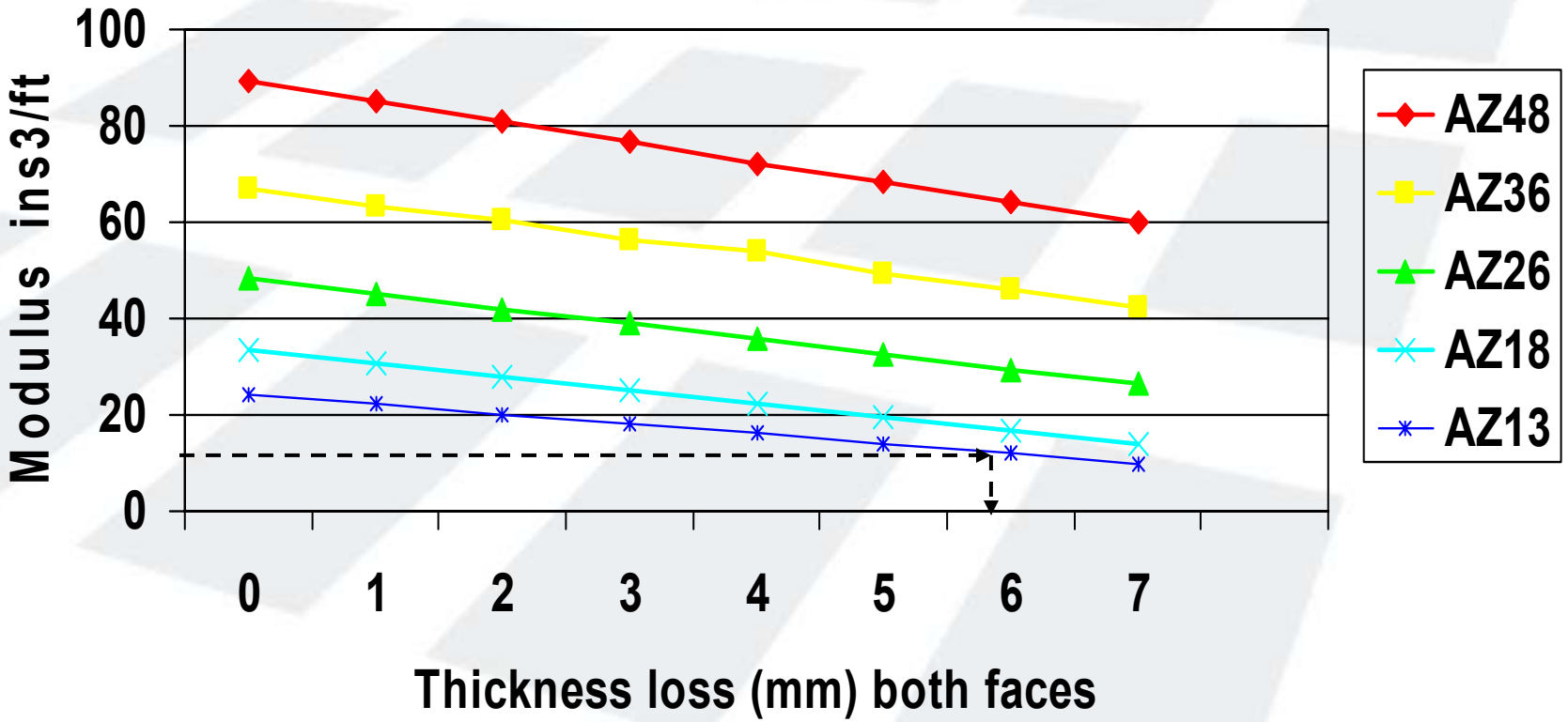
Case 2 - Max material loss



Case 2: Check area of max thickness loss (2) with moment at that location.

4. Section Graph to Find Sacrificial Thickness

Case (2) Go up to 10.0 ins^3/ft & move across graph until a section, in this case AZ13, is intersected then drop down to find sacrificial thickness (5.8 mm)



6. Corrosion Rate + Sacrificial Thickness to give design Life for Case 2

	Sacrificial thickness		Max rate corrosion per year		Design life
AZ13	*5.8 mm*	/	*0.09 mm/year*	=	*64 Years*

Note: Corrosion rates used are mean rates as referenced by Eurocode and others. In severe cases the designer may wish to use higher values.

6. Case 1 & 2 Summary

		Sacrificial thickness		Max rate corrosion per year		Design life
Case 2	AZ13	*5.8 mm*	/	*0.09 mm/year*	=	*64 Years*
Case 1	AZ13	*3.25 mm*	/	*0.05 mm/year*	=	*65 Years*

Corrosion rates used are mean rates as referenced by Eurocode and others. In severe cases the designer may wish to use higher values. An upper rate value corresponding to 95% probability **(0.18 mm/year)** may be used. **This is applied in the area of max corrosion namely Case 2**

Now repeat steps 6 for severe exposure conditions.

6. Corrosion Rate + Sacrificial Thickness to give design Life for Case 1 & 2

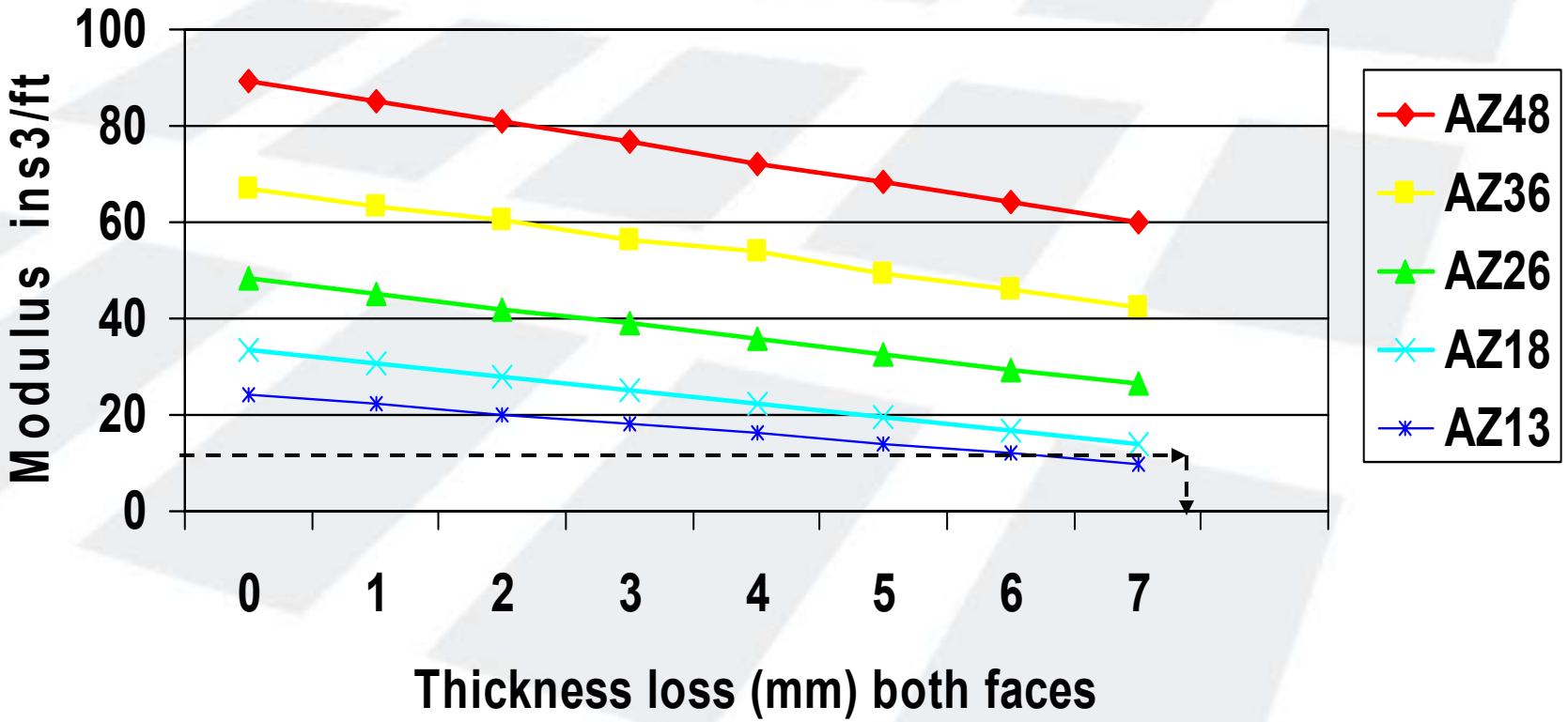
		Sacrificial thickness		Max rate corrosion per year		Design life
Case 2	**AZ13**	*5.8 mm*	/	*0.18 mm/year*	=	*32 Years*
Case 1	**AZ13**	*3.25 mm*	/	*0.05 mm/year*	=	*65 Years*

Note: For this example Case 2 will be used for design

Now repeat steps 4-6 for AZ 18 & AZ26

4. Sacrificial Thickness for AZ 18

Case (1) Go up to 10.0 ins^3/ft & move across graph until a section, in this case AZ18, is intersected then drop down to find sacrificial thickness (7.4 mm)



6. Corrosion Rate + Sacrificial Thickness to give design Life

	Sacrificial thickness		Max rate corrosion per year		Design Life
Using corrosion rate of 0.18 mm/year					
AZ 13	*5.8 mm*	/	*0.18 mm/year*	=	*32 Years*
AZ18	*7.4 mm*	/	*0.18 mm/year*	=	*41 Years*

6. Corrosion Rate + Sacrificial Thickness to give design Life

	Sacrificial thickness		Max rate corrosion per year		Design Life
Similarly AZ 26 gives:					
AZ 13	*5.8 mm*	/	*0.18 mm/year*	=	*32 Years*
AZ18	*7.4 mm*	/	*0.18 mm/year*	=	*41 Years*
AZ26	*10.8 mm*	/	*0.18 mm/year*	=	*60 Years*

Durability by Design Steps 1 – 5 Summary

1. Sacrificial Thickness Options:

AZ13 - 32 years
AZ18 - 41 years
AZ26 - 60 years

2. **Marine Grade Steel ASTM A690**
3. Design Stress – Higher Yield Steel
4. Coatings
5. Cathodic Protection

Now consider Marine Grade ASTM A690

Durability by Design Step 2

2. Marine Grade Steel ASTM A690

a. Extract from A 690: paragraph 1.2

"*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).*"

With A690 reduce Splash zone rate (Case 2) of corrosion by 50% to 0.09 mm/year and re-do Case 2 calculation

AZ13	*5.8 mm*	/ *0.09 mm/year*	=	*64 Years*
AZ18	*7.4 mm*	/ *0.09 mm/year*	=	*82 Years*
AZ26	*10.8 mm*	/ *0.09 mm/year*	=	*120 Years*

Durability by Design Steps 1 – 5 Summary

1. Sacrificial Thickness Options:

   AZ13 - 32 years
   AZ18 - 41 years
   AZ26 - 60 years

2. Marine Grade Steel ASTM A690 Case 2

   AZ13 - + 32 years
   AZ18 - + 41 years
   AZ26 - + 60 years

Now re-check Case 1 to ensure Case 2 remains most severe

3. **Design Stress – Higher Yield Steel**
4. Coatings
5. Cathodic Protection

6. Corrosion Rate + Sacrificial Thickness to give design Life Case 1

	Sacrificial thickness		Max rate corrosion per year		Design Life
Case 1					
AZ13	*3.25 mm*	/	*0.05 mm/year*	=	*65 Years*
AZ18	*5.5 mm*	/	*0.05 mm/year*	=	*110 Years*
AZ26	*8.5 mm*	/	*0.05 mm/year*	=	*170 Years*

Durability by Design Steps 1 – 5 Summary

		Case 2		Case 1
1. Sacrificial Thickness	*AZ13*	*32 years*		
	AZ18	*41 years*		
	AZ26	*60 years*		
2. Marine Grade Steel ASTM A690	AZ13	+ 32 years	= 64 years	65 years
	AZ18	+ 41 years	= 82 years	110 years
	AZ26	+ 60 years	= 120 years	170 years

Case 2 remains worst case

1. **Design Stress – Higher Yield Steel**
2. Coatings
3. Cathodic Protection

Durability by Design - Step 3

3. Design Stress – Higher Yield Steel

a. The Eurocode and others consider the end of design life to occur when any part of the pile reaches the max permissible working stress (0.67 of YS) through corrosion loss. Design life being from the point of initial stress to the point where material loss has increased that stress, to the max permissible stress.

b. By designing to steel stress (A572 –Gr 50) but using a higher Gr 55 or Gr 60 steel quality, the max working stress is proportionally increased and design life is extended by that amount.
In other words the section can afford to lose more steel thickness before the max permissible stress is reached.

Gr 50 to Gr 55 gives a 10% life enhancement
Gr 50 to Gr 60 gives a 20% life enhancement

Durability by Design Steps 1 – 5 Summary

1. Sacrificial Thickness Options:	*AZ13 - 32 years* *AZ18 - 41 years* *AZ26 - 60 years*
2. Marine Grade Steel ASTM A690	AZ13 - + 32 years AZ18 - + 41 years AZ26 - + 60 years
3. Design Stress – Gr 55 / Gr 60	AZ13 - + 3 / + 6 yrs AZ18 - + 4 / + 8 yrs AZ26 - + 6 / + 12 yrs

4. Coatings

5. Cathodic Protection

Now consider Coatings

Durability by Design Step 4

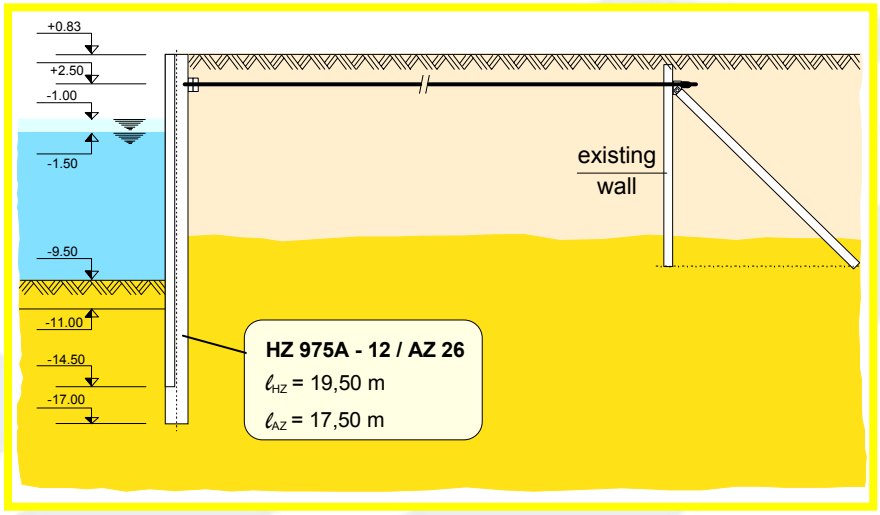
Coatings - Sea Water Immersion
Proposal (ISO 12944 - Table A8)

- Polyamide cured epoxy primer
- Polyamide cured coaltar epoxy coating
- Nominal dry film thickness of 380µm (15 mil)

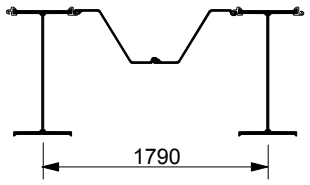
Shop applied coating will give a highly durable finish with up to 20 years protection (without maintenance) before the steel is exposed to corrosion. Maintenance will extend life indefinitely. For design adopt a 15 year life.

Marine Coating example
Skandinavienkai, Lübeck, Germany

Polyamide coal tar epoxy coating



HZ 975 A - 12 / AZ 26



GRADE : S 355 GP
MASS : 246,6 kg / m²
MODULUS : 6460 cm³ / m
TONNES : 992

Durability by Design Steps 1 – 5 Summary

1.	Sacrificial Thickness Options:	*AZ13 - 32 years* *AZ18 - 41 years* *AZ26 - 60 years*
2.	Marine Grade Steel ASTM A690	AZ13 + 32 years AZ18 + 41 years AZ26 + 60 years
3.	Design Stress – Gr 55 / Gr 60	AZ13 + 3 / + 6 yrs AZ18 + 4 / + 8 yrs AZ26 + 6 / + 12 yrs
4.	Coatings	AZ13 + 15 years AZ18 + 15 years AZ26 + 15 years
5.	**Cathodic Protection**	

Now consider Cathodic Protection

Durability by Design Step 5

Cathodic Protection

Needed only if target design life is not achieved by previous factors

If used with a coating system Cathodic Protection is not needed <u>until end of coating life</u>

Types:

1. Sacrificial Anode
2. Impressed Current

Durability by Design Step 5

What Companies do this?

1. Corrpro John Kay
   973-283-8885

- Washington
- San Diego
- Santa Fe Springs

Durability by Design Step 5

What design life benefit ?

1. Continuous as long as system is maintained.
2. Typical 5 year review of system. Maintenance / replacement of base metal anode (aluminum) or electrical continuity upgrade at 20 years.

3. Typical for design to be based on minimum of 20 years life enhancement; but indefinitely with scheduled program of maintenance.

Durability by Design Steps 1 – 5 Summary

1.	Sacrificial Thickness *(Base section design life)*	*AZ13 - 32 years* *AZ18 - 41 years* *AZ26 - 60 years*
2.	Marine Grade Steel ASTM A690	AZ13 + 32 years AZ18 + 41 years AZ26 + 60 years
3.	Design Stress – Gr 55 / Gr 60	AZ13 + 3 / + 6 yrs AZ18 + 4 / + 8 yrs AZ26 + 6 / + 12 yrs
4.	Coatings	AZ13 + 15 years AZ18 + 15 years AZ26 + 15 years
5.	Cathodic Protection	AZ13 + 20 years min AZ18 + 20 years min AZ26 + 20 years min

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✓See following combination table

Durability by Design - Options

Section	1 Sacrificial Thickness years	2 A 690 years	3 / 3a Steel Grade Gr 50 to Gr 55 / Gr 60	4 Coating	5 Cathodic Protection	Design Life Options	Life Yrs	Other Option	Life Yrs
AZ 13	32					1	32		
		+ 32				1 + 2	64	1+2+4	79
			+ 3 / + 6			1 + 3 /3a	35- 38		
				+ 15		1 + 4	33		
					+ 20	1 + 5	47		
AZ 18	41					1	41		
		+ 41				1 + 2	82	1+2+4	97
			+ 4 / + 8			1 + 3 /3a	45-49		
				+ 15		1 + 4	56	1+3a+4	64
					+ 20	1 + 5	61		
AZ 26	60					1	60		
		+ 60				1 + 2	120	1+2+4	135
			+ 6 / + 12			1 + 3 /3a	66-72		
				+ 15		1 + 4	75		

Durability by Design: Design Life Summary

System Indicative Cost Comparison

	AZ13	life	AZ18	life
1. Base AZ section:	$8.0/ft^2	32 yrs	$9.0/ft^2	41 yrs
2. Marine Grade A690:	+$0.75/ft^2	+32 yrs	$0.85/ft^2	+41 yrs
3. Higher Grade Steel:	+$0.22/ft^2	+ 6 yrs	$0.24/ft^2	+ 8 yrs
4. Coatings (both sides)	+$2.60/ft^2	+15 yrs	$2.85/ft^2	+15 yrs
5. Cathodic Protection:	+$6.25/ft^2	+20 yrs	$6.25/ft^2	+20 yrs

Note: CP cost is based on protecting an 800ft x 40 wall, without coating.

Durability by Design - Additional Information

Corrosion Testing

"Testing agencies?

Corrosion Testing Laboratories Inc., Newark, Delaware.
Phone: 302-454-8200

Contact; Richard Corbett

ASTM G31: Standard Practice for Laboratory Immersion Corrosion Testing of Metals

Standard Corrosion reports are available

List of specialist sub-contractors" Corrpro + others

Durability by Design - Conclusion

Summary:

1. The steps outlined above give the designer the means to build substantial durability using steel sheet piling. The method presented is adopted by the Eurocodes and used by designers in many parts of the world.

2. A design life evaluation is a necessary part of structural design. In the example shown using design parameters for severe exposure conditions steel sheet piling can achieve a design life exceeding 100 years.

Durability by Design - Conclusion

Skyline Steel has a team of designers (backed by Arcelor design and research facilities) at your disposal to assist in evaluation of issues such as durability

Contact us on the Hotline 1-866-8 Skyline