CORROSION ASSESSMENT 2019-2020

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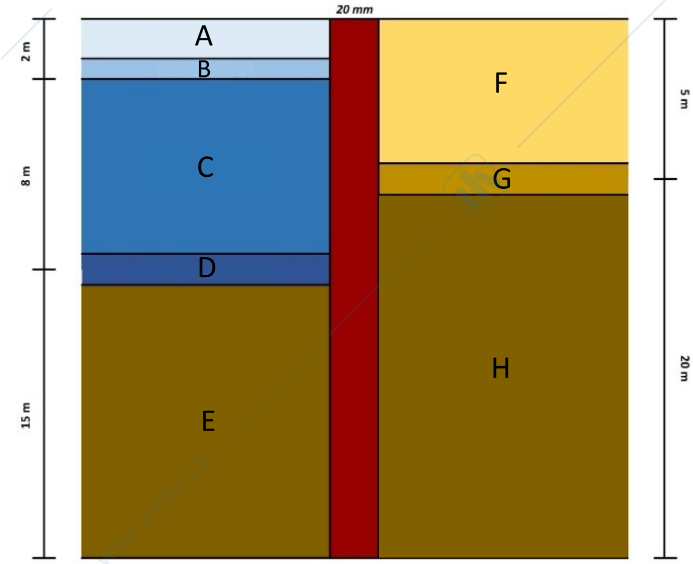
In order to properly assess the structure we decide to divide it in:



EXTERNAL CORROSION
- **A:** Atmospheric Zone
- **B:** Splash Zone
- **C:** Submerged Zone
- **D:** Sea-mud Interface
- **E:** Mud Zone

INTERNAL CORROSION

For the sheets
- **F:** Soil Zone
- **G:** Transition Zone
- **H:** Mud Zone

For the rebars
- **I:** Soil Zone

For each part we are going to analyze the main possible corrosion phenomena, the parameters that affect them and the possible solutions that could reduce the corrosion rate.

EXTERNAL CORROSION

Before starting we should do an assumption: the structure we are analyzing is probably subjected to stray current corrosion because of the presence of electrical sources and electrical cables that interfere with it. We could reasonably suppose that proper prevention actions (e.g. insulating coating on cables) have been already made in order to avoid this kind of problem so we do not focus on this phenomenon in the assessment.

A. Atmospheric zone

- Type of corrosion: general corrosion in highly polluted, marine area
- Affecting Parameters: metereological factors (rain, time of wetness, humidity, temperature), atmospheric contaminants (SO_2, SO_3, NO_x, CL^-)
- Calculation:

According to ISO 9223 we could calculate the first year corrosion rate for the carbon steel structure.

Symbol [unit]	Meaning	Value
$T=[°C]$	Annual average temperature	15
$RH=[\%]$	Annual average relative humidity	65
$P_d=[\frac{mg}{m^2 \cdot day}]$	Annual average SO_2 deposition	120
$S_d=[\frac{mg}{m^2 \cdot day}]$	Annual average Cl^- deposition	500

$$CR_{1Y}=1{,}77 \cdot P_d^{0{,}52} \cdot e^{0{,}020 \cdot RH + f_{St}} + 0{,}102 \cdot S_d^{0{,}62} \cdot e^{0{,}033 \cdot RH + 0{,}040 \cdot T} = 134 \frac{\mu m}{y}$$

$$f_{St}=0{,}150 \cdot (T-10) \text{ for } T \le 10\,°C$$

$$f_{St}=-0{,}054 \cdot (T-10) = -0{,}27 \text{ for } T \ge 10\,°C$$

The corrosion rate we found is 134 μm/y in accordance with standard values for carbon steel in C5 category that are usually 80< r_{corr}<200. We estimate the total penetration depth D in 50 years of designed life, considering the b factor= 0,5 because we are dealing with steel.

$$D=CR_{1Y} \cdot t^b = 951{,}8\,\mu m$$

B. Splash zone

- Type of corrosion: general corrosion in seawater
- Affecting Parameters: oxygen corrosion and mechanical actions of waves and tide.
- Calculation:

We consider the waves effect as less impactful than in offshore case because our structure is placed in the harbour that is a limited, closed area. Breakwater are probably used, limiting the erosion effect of the waves. We assume that the flow regime is laminar.

$$CR_{SPLASH}=3\cdot C\,R_{¿}=0{,}27\,\frac{mm}{y}$$

$$D=CR_{SPLASH}\cdot t=0{,}27\cdot 50=13{,}5\,mm$$

C. Submerged zone

- Type of corrosion: general corrosion in seawater
- Affecting Parameters: sea temperature, oxygen amount, water velocity and environmental conditions
- Calculation:

Symbol [unit]	Meaning	Value
$T=[°C]$	Annual average water temperature	19
$v=[\frac{m}{s}]$	Average water velocity	0,2
$[O_2]=[\frac{mg}{L}]$	Average oxygen content in seawater	6

$$CR_{¿}=1{,}2\cdot i_L=1{,}2\cdot 10\cdot\left[O_2\right]\cdot\left[1+v^{0{,}5}\right]\cdot 2^{\frac{T-25}{25}}=88{,}23\,\frac{\mu m}{y}$$

$$D=CR_{¿}\cdot t=0{,}08823*50=4{,}4\,mm$$

- Type of corrosion: localized corrosion in seawater
- Affecting Parameters: scale formation is not uniform
- Calculation:

$$CR_{localized}=3\cdot C\,R_{¿}=0{,}27\,\frac{mm}{y}$$

The value of the coefficient to estimate the localized corrosion rate can be between 2 and 3. We take 3 in a preventive way.

$$D=CR_{localized}*t=0{,}27*50=13{,}5\,mm$$

D. Sea-mud interface

- Type of corrosion: differential aeration
- Affecting Parameters: oxygen amount, environmental condition, water resistivity and S_C/S_A ratio
- Calculation.

We approximate our structure as a plate and we get a preventive S_C/S_A ratio; in real case we should run a FEM analysis in order to obtain a more reliable result

Symbol [unit]	Meaning	Value
$K=[\sqrt{m}]$	Natural environment coefficient	20
$i_C=[\frac{mA}{m^2}¿=10\cdot\left[O_2\right]$	Corrosion current	60
$\rho=[\Omega m]$	Resistivity sea water+soil	20,2
$\Delta V_{MAX}=[mV]$	Corrosion potential	200
$[O_2]=[\frac{mg}{L}]$	Average oxygen content in seawater	6

$$\left(\frac{S_C}{S_A}\right)_{MAX}=K\cdot\sqrt{\frac{\Delta V_{MAX}}{i_C\cdot(\rho+0{,}8)}}=¿36{,}5¿$$

$$C\,R_{DiffAer}=1{,}2\cdot i_L\cdot\left(\frac{S_C}{S_A}\right)_{MAX}=1{,}2\cdot 10\cdot\left[O_2\right]\cdot\left(\frac{S_C}{S_A}\right)_{MAX}=573\,\frac{\mu m}{y}$$

$$D=CR_{DiffAer}\cdot t=0{,}573*50=28{,}7\,mm$$

E. Mud zone

- Type of corrosion: MIC corrosion (SRB is the worst bacteria)
- Affecting Parameters: oxygen absence, type of soil, presence of microbiological activity
- Calculation:

$$C\,R_{mud}=1\,\frac{mm}{y}$$

$$D=CR_{mud}\cdot t=1\cdot 50=50\,mm$$

INTERNAL CORROSION

In order to define the internal corrosion assessment, we need to define the amount of oxygen that could arrive to our structure. We suppose that the concrete coverage lets the oxygen enter because of its porosity and because it is placed above the metal sheets.

We are considering the worst possible condition assuming $[O_2]=6\frac{mg}{L}$.

Another aspect to be considered is the installation period: we could have stagnant water in contact with the sheet, affecting the corrosion rate. Considering a short time of installation we could neglect this aspect.
We avoid any kind of tubercles attacks because the concentration of sulphates is lower than the critical value (1000ppm).
We start analysing the **SHEETS** corrosion.

F. S.il zone

- Type of corrosion: generalized corrosion
- Affecting Parameters: oxygen content, type of soil (pH, salt content, water content in order to define its resistivity)
- Calculation:

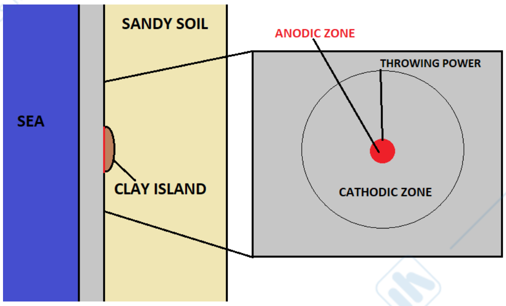
In a clayey soil, oxygen content is lower than 2 mg/L, whereas in a sandy soil the oxygen content could be 8 mg/L. In our case we have a mixture of sand and clay and we have a concrete cover that acts as a sort of barrier so we assume an average value of 6 mg/l.

$$CR=1{,}2\cdot i_L=1{,}2\cdot 10\cdot\left[O_2\right]=72\frac{\mu m}{y}$$

$$D=CR\cdot t=0{,}072\cdot 50=3{,}6\,mm$$

- Type of corrosion: differential aeration clay-sand
- Affecting Parameters: oxygen content, type of soil (pH, salt content, water content in order to define its resistivity), S_C/S_A ratio
- Calculation:

Symbol [unit]	Meaning	Value
i = $[\frac{mA}{m^2}\text{¿}$= $10\cdot\left[O_2\right]$	Corrosion current	60
ρ =[Ωm]	Soil resistivity	20
ΔV_{MAX}=[mV]	Corrosion potential	200
h=[cm]	Radius of anodic area	5
L= [m]	Throwing Power	0.068



$$\left(\frac{S_C}{S_A}\right)_{MAX}=\frac{\pi\cdot L^2}{\pi\cdot h^2}=1{,}85$$

$$L=\frac{1}{2}\cdot\frac{\Delta V}{(\rho+0.8)\cdot(i+10)}=0.068\,m$$

$$C\,R_{DiffAer}=1{,}2\cdot i_L\cdot\left(\frac{S_C}{S_A}\right)_{MAX}=133{,}2\frac{\mu m}{y}$$

$$D=CR_{DiffAer}\cdot t=0{,}1332*50=6{,}66\,mm$$

G. Transition zone

- Type of corrosion: differential aeration
- Affecting Parameters: oxygen content, type of soil (pH, salt content, water content in order to define its resistivity), S_C/S_A ratio
- Calculation:

Symbol [unit]	Meaning	Value
K=[$\sqrt{m}$]	Natural environment coefficient	20
i_C=$[\frac{mA}{m^2}\text{¿}$=$10\cdot\left[O_2\right]$	Corrosion current	60
ρ =[Ωm]	Soil resistivity	20
ΔV_{MAX}=[mV]	Corrosion potential	200

$$\left(\frac{S_C}{S_A}\right)_{MAX}=K\cdot\sqrt{\frac{\Delta V_{MAX}}{i_C\cdot(\rho+0{,}8)}}=\text{¿}8\text{¿}$$

$$C\,R_{DiffAer}=1{,}2\cdot i_L\cdot\left(\frac{S_C}{S_A}\right)_{MAX}=576\frac{\mu m}{y}$$

$$D=CR_{DiffAer}\cdot t=0{,}576*50=28{,}8\,mm$$

H. Mud zone

- Type of corrosion: MIC corrosion (SRB is the worst bacteria)
- Affecting Parameters: oxygen absence, type of soil, presence of microbiological activity
- Calculation:

$$CR_{mud} = 1\frac{mm}{y}$$

$$D = CR_{mud}\cdot t = 1\cdot 50 = 50\,mm$$

Then we have to consider the **REBARS** corrosion:

I. Soil zone

- Type of corrosion: generalized corrosion
- Affecting Parameters: oxygen content, type of soil (pH, salt content, water content in order to define its resistivity)
- Calculation:

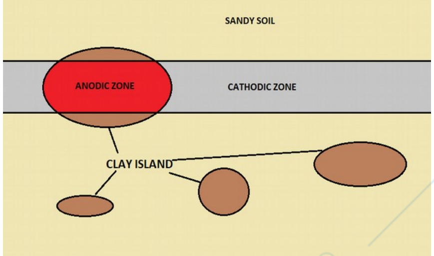
Considering the oxygen content always equal to 6 mg/l:

$$CR = 1{,}2\cdot i_L = 1{,}2\cdot 10\cdot\left[O_2\right] = 72\frac{\mu m}{y}$$

$$D = CR\cdot t = 0{,}072\cdot 50 = 3{,}6\,mm$$

- Type of corrosion: differential aeration clay-sand
- Affecting Parameters: oxygen content, type of soil (pH, salt content, water content in order to define its resistivity), S_C/S_A ratio
- Calculation:

Symbol [unit]	Meaning	Value
$i = [\frac{mA}{m^2}$¿$=10\cdot\left[O_2\right]$	Corrosion current	60
ρ =[Ωm]	Soil resistivity	20
ϕ=[mm]	Rods diameter	50
ΔV_{MAX}=[mV]	Corrosion potential	200
h=[cm]	Radius of Anodic Area	5
L=[m]	Throwing Power	0.83



$$L = 10\sqrt{\frac{\Delta V_{MAX}\cdot\phi}{\left(\rho+0{,}8\right)\cdot\left(i+10\right)}} = \text{¿}0{,}83\,m\,\text{¿}$$

$$\left(\frac{S_C}{S_A}\right)_{MAX} = \frac{2\pi DL}{\pi Dh} = 33{,}2$$

$$CR_{DiffAer} = 1{,}2\cdot i_L\cdot\left(\frac{S_C}{S_A}\right)_{MAX} = 2390{,}4\frac{\mu m}{y}$$

$$D = CR_{DiffAer}\cdot t = 2{,}39\cdot 50 = 119{,}5\,mm$$

CONCLUSIONS

Structure	Zone	$CR_{external}$ [$\frac{mm}{y}$]	$CR_{internal}$ [$\frac{mm}{y}$]	CR_{total} [$\frac{mm}{y}$]	$CR_{50years}$ [mm]	Protection system
Sheet	A+$F_{general}$	0,134	0,072	0,2	4,55	• Coating • Painting cycle • CRA alloy
	A+$F_{diff.aer.}$	0,134	0,1332	0,264	7,6	
	B+$F_{general}$	0,27	0,072	0,34	17	Coating (epoxy with glassy fibers)+CP
	B+$F_{diff.aer.}$	0,27	0,13	0,4	20	
	$C_{general}$+$F_{general}$	0,088	0,072	0,16	8	Cathodic protection
	$C_{general}$+$F_{diff.aer.}$	0,088	0,1332	0,22	11	
	$C_{localized}$+$F_{general}$	0,27	0,072	0,34	17	
	$C_{localized}$+$F_{diff.aer.}$	0,27	0,1332	0,4	20	
	$C_{general}$+G	0,08823	0,576	0,664	33,2	
	$C_{localized}$+G	0,27	0,576	0,846	42,3	
	$C_{general}$+H	0,08823	1	1,088	54,4	
	$C_{localized}$+H	0,27	1	1,27	63,5	
	D+H	0,573	1	1,573	78,6	
	E+H	1	1	2	100	
Rebar	$I_{general}$	-	-	0,072	3,6	

	$I_{diff.aer.}$	-	-	2,39	119,5	Coating Corrosion Allowance Grid

As we could see from the table we have critical values of corrosion rate (values in red) and the structure will fail if we don't apply proper protection techniques. The **rebars** play a fundamental role: they have to maintain the sheets in their position counterbalancing the internal forces due to the thrust of the soil and the concrete. The CR for generalized corrosion is not critical, we can design them by applying a proper corrosion allowance (total metal consumption is 3,6 mm) or by using a coating. Instead the value of the CR by differential aeration is very high and before 50 years the rebar will probably fail. To avoid accumulations of clay and reducing the risk of differential aeration we can use a grid to select the soil. If you want to be more conservative you can encase the rebars in concrete (with a polymeric shell), in order to insulate the rebars leading CR to zero. This technique offers a stable basement that could easily host the concrete plate, placed above it. If you applied this solution, the oxygen content in soil would reduce and the overall CR for the sheets would reduce too. We need to guarantee the **sheet** integrity, too. Protective coatings are applied on one side, both sides, or selected parts of the piles. Organic coatings are widely used because of their low cost. In the submerged and the mud zones we have to apply the cathodic protection because we have high values of CR: it is fundamental to control that all the piles are rightly bonded to ensure electrical continuity. We can apply the cathodic protection by galvanic anodes or by impressed current. In the first case the current density (and consequently the CR) is lowered more or less by 1 order of magnitude. The second case is more protective but much more expensive. In the structural analysis we must define the critical thickness below which we are in critical condition and decide which protection is the best one. The most critical area is E+H. In order to reduce the internal CR is better to provide solutions that reduce to 0 the oxygen content; in this case the galvanic anodes would be enough. By monitoring the structure, we can plan all the interventions we have to take in order to maintain the protection effectiveness. Finally corrosion resistance alloys are an alternative to carbon steel, their corrosion resistance is higher, but considering the dimension of the structure this solution will be too expensive.