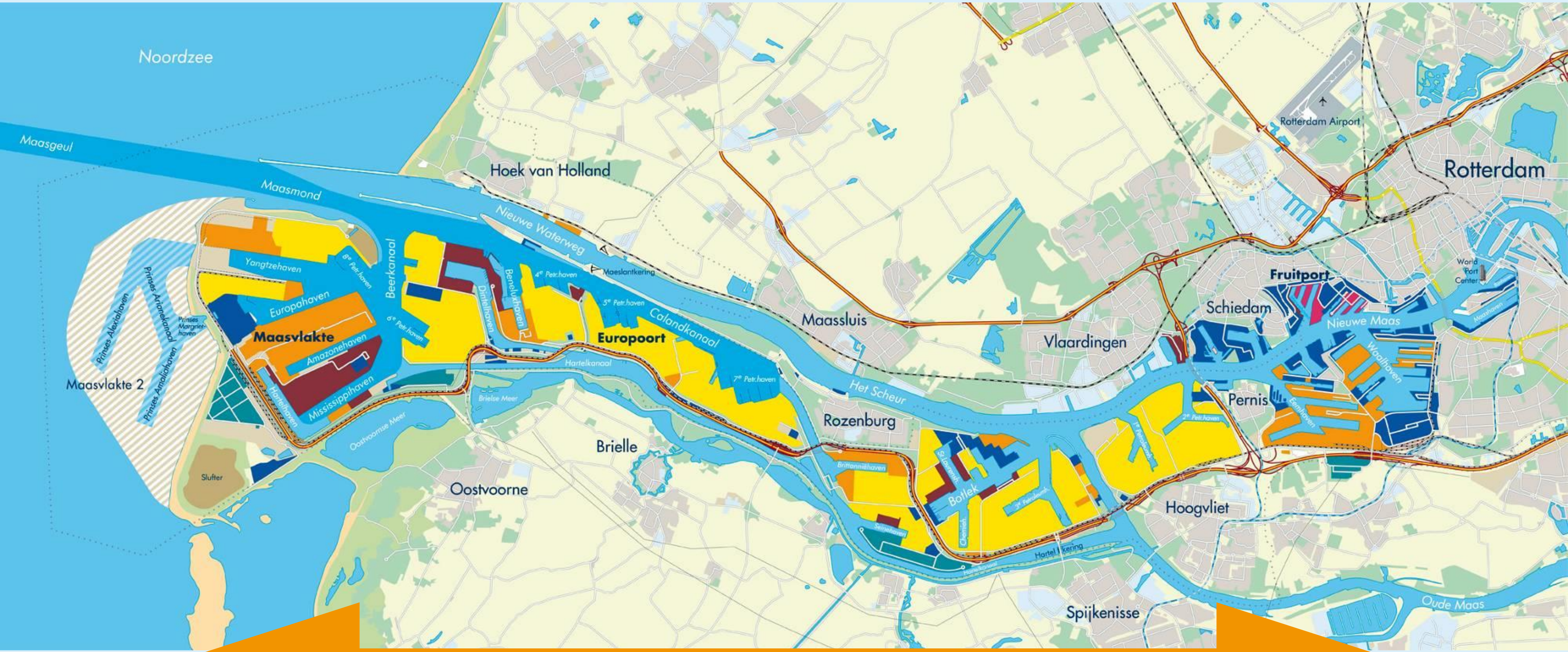
Modelling of corrosion in the Port of Rotterdam

Port of Rotterdam

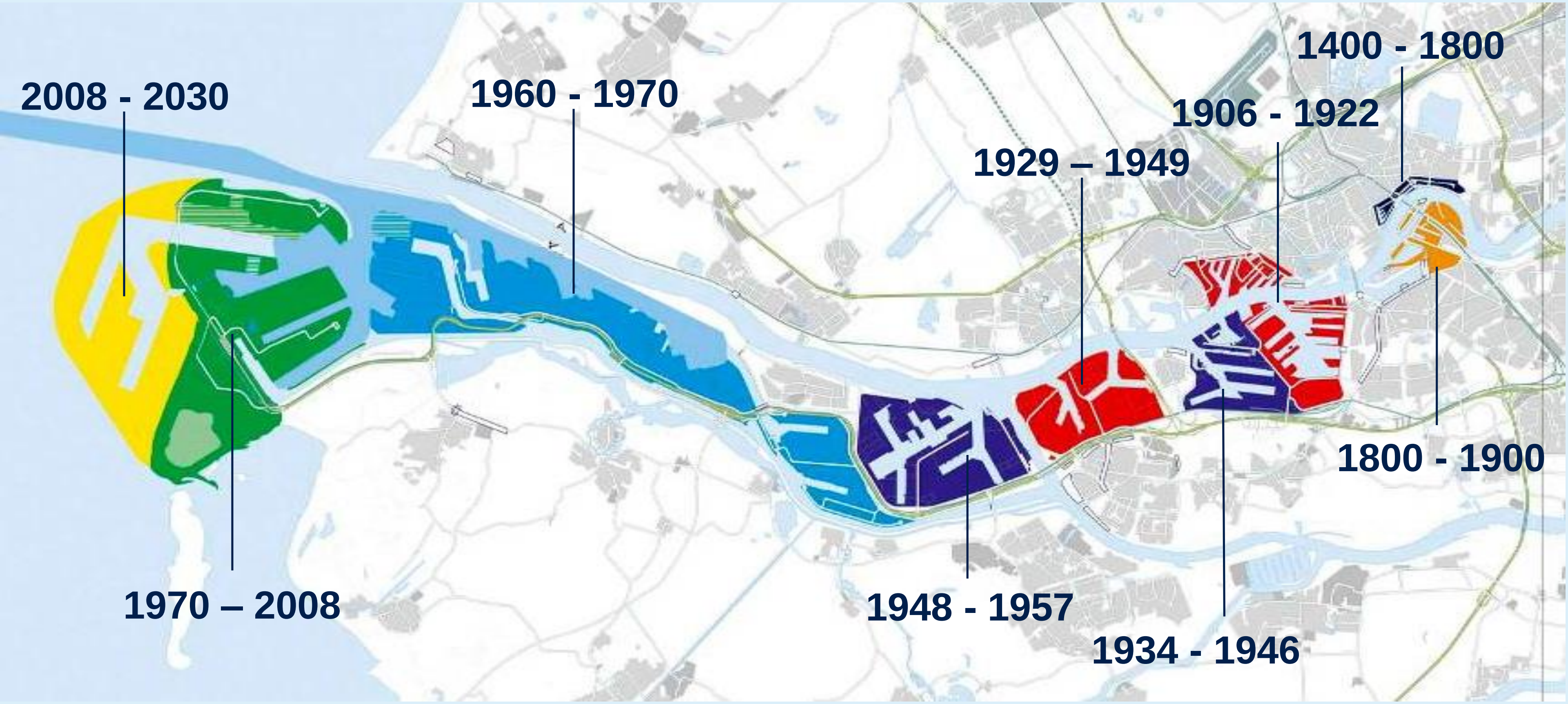
From measurements to prediction of the intervention time

Port of Rotterdam

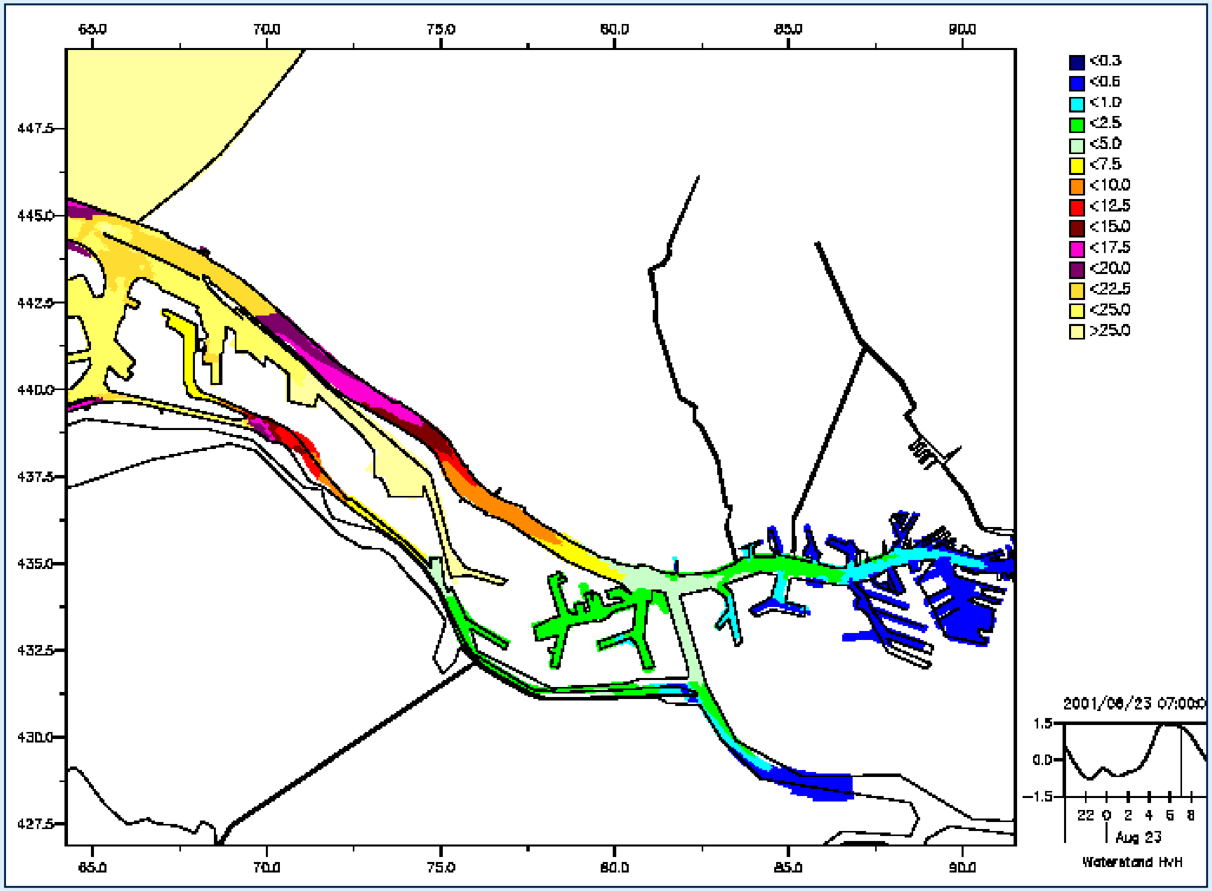


More than 50 kilometres !

Development of the port



Salinity in the port

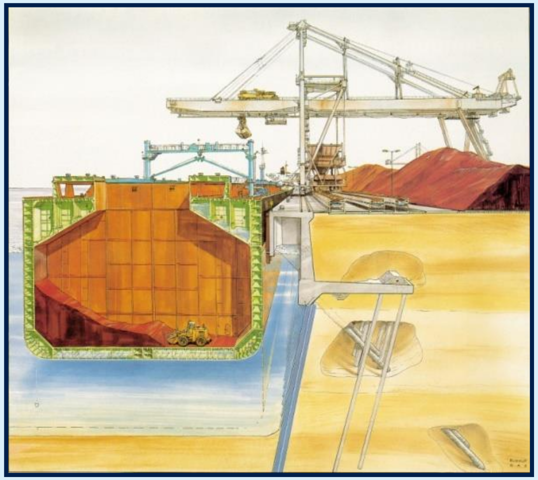


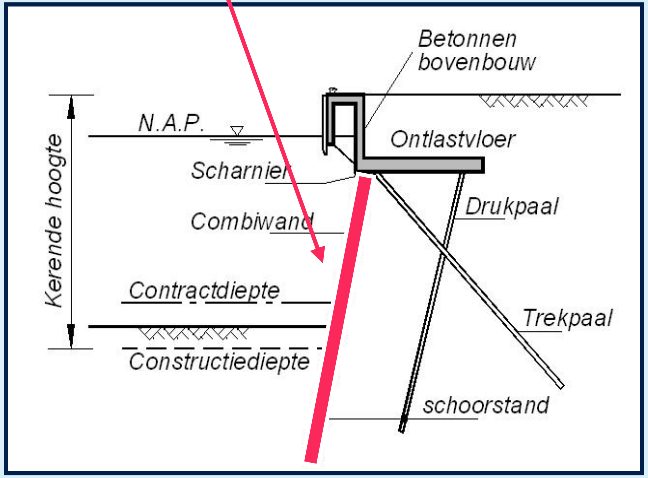
Port in figures

- Total port area 26,000 acres (net 12,500 acres)
- Total employment 350,000 people (140,000 regionally)
- Throughput 430 million tons, 11,1 million TEU (2010)
- Depth up to 75 ft (= 24 m)
- Port is growing westwards from the old town with fresh water of river Rhine into the salt Northsea
- Tidal zone ca. 2 meter in the whole port

Port infrastructure in Rotterdam

- Quay walls: total length 70 km
- Replacement value ~ 1.5 billion €
- About 40 km with steel substructures, like combi walls, sheet piling, etc.





Asset Management on Quay Walls

- A quay wall's remaining lifetime and system integrity is mainly determined by the quality of the sub and superstructure.
- When the quay wall's integrity is in danger, it's often due to:
  - concrete deterioration in the superstructure
  - accelerated low water corrosion occurring at the substructure

Corrosion strategy (up to 1999)

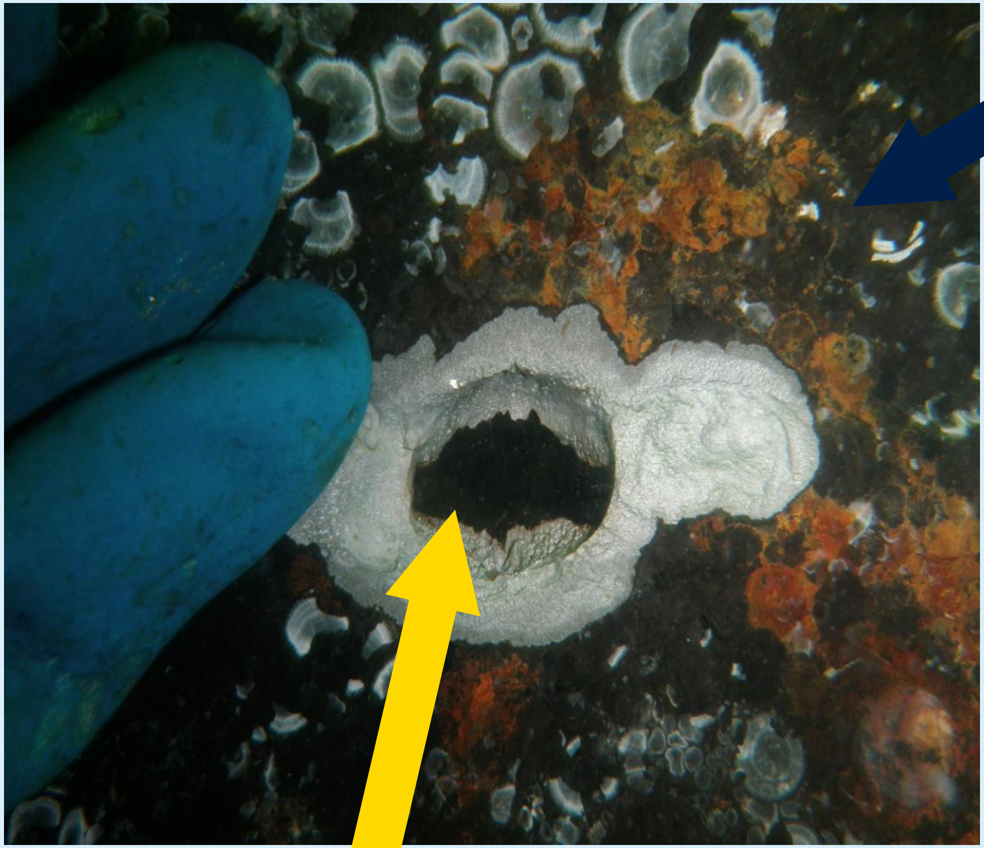
- Corrosion rates according to EAU-Curves
- No steel but concrete in the splash-zone
- Extra thickness added to steel parts
- Inspection of a few quay walls every 5 year

What was discovered ?

Before cleaning with high pressure

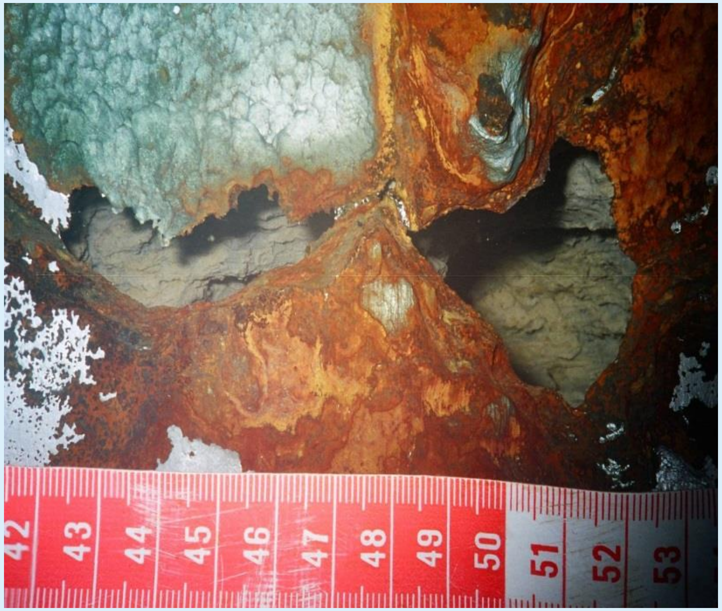
After cleaning with high pressure

Unexpected corrosion



Original thickness including original coating

Hole, followed by loss of soil



Holes in tubular piles

11

Probable causes (long list)

- More salty environment
- Galvanic corrosion of combiwalls
- pitting influences on the strength
- Aeration due to extra oxygen by (bow) thrusters or cooling
- Fabrication process of steel parts
- Water flow
- Cathodic protection to the ship
- Vertical layering of water (temperature, oxygen, salinity)
- MIC
- Etc...

Action plan for investigation

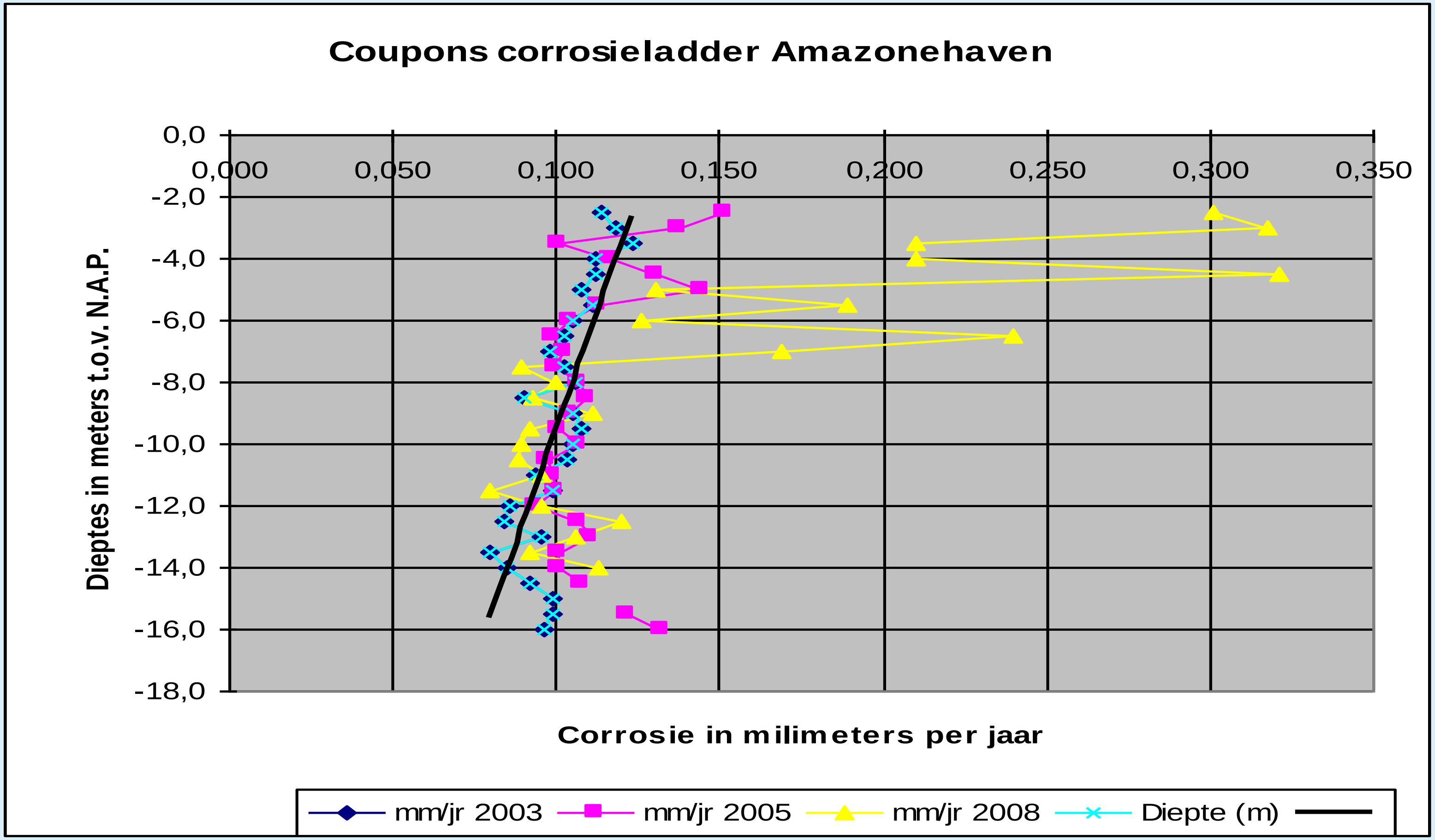
- Stress corrosion test
- Coupon ladder
- Coupons (galvanic cells)
- Micro biological influence
- Weakening due to pitting
- Thickness measurement

Stress corrosion test

Coupons for galvanic corrosion test

Coupon ladder test

Results of coupon ladder

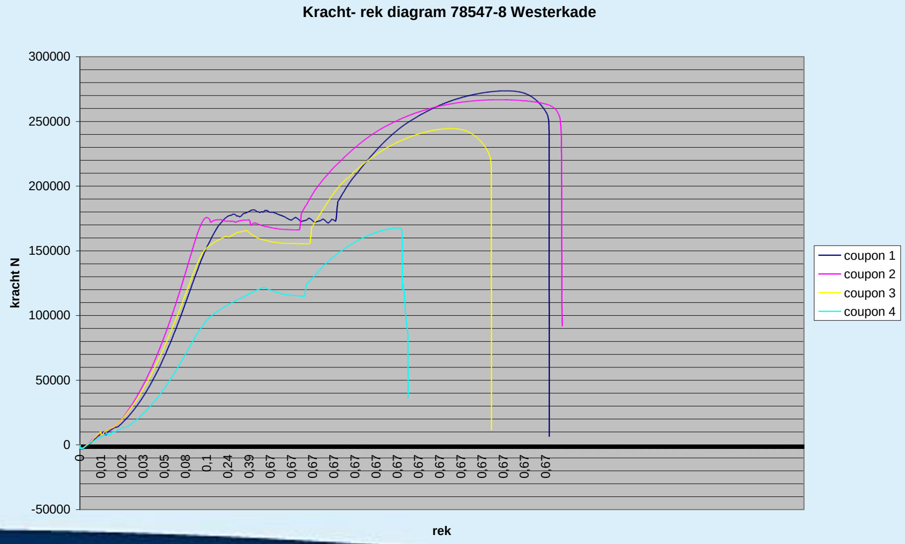


Research influence MIC

Sampling

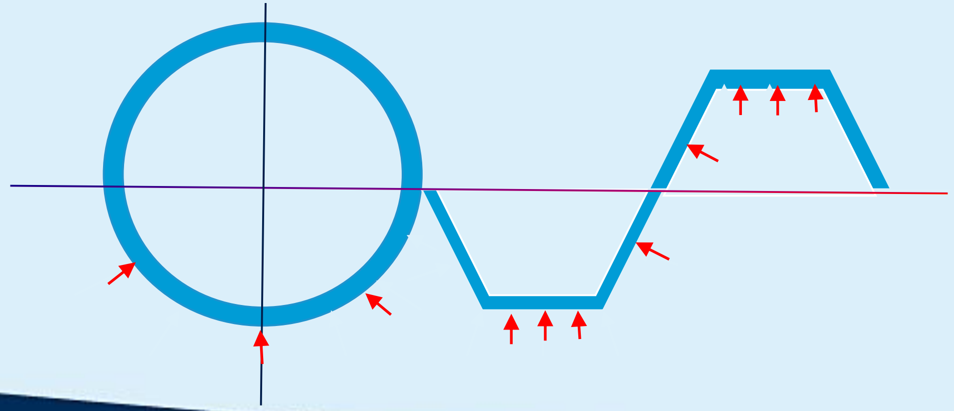
Research bacteria on the back of the sheet piling

Weakening due to pitting



Ultrasonic measurements

- Method: Ultrasonic measurement
- Inspection locations: horizontal & vertical
- Amount of inspections: one million points
- Inspection results processed statistically
- Representative values: (incl. pitting!)



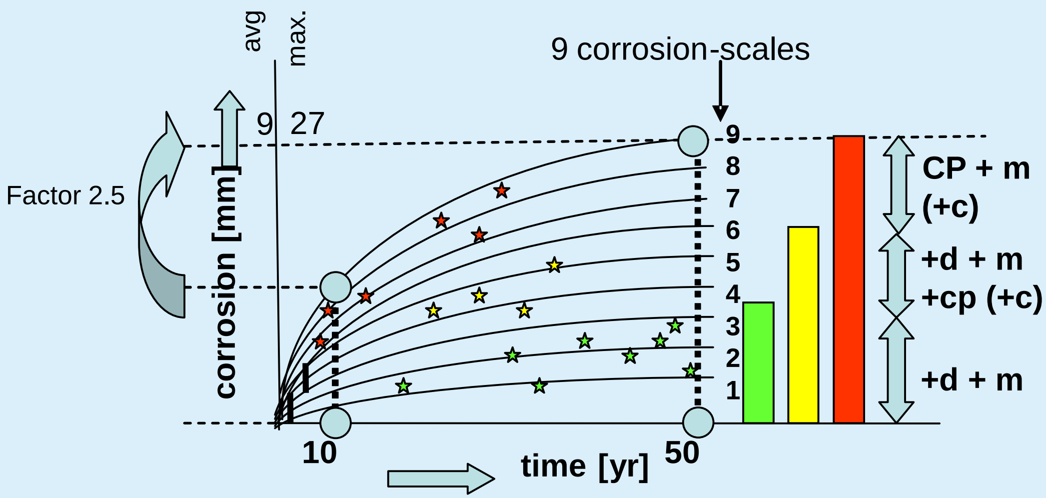
Corrosion rate in specific conditions

- What is the salinity (fresh, 10 ppm < brackish <25 ppm, salt)?
- Steel quality and electro-chemical corrosion?
- Biological activity (general in salt water, sometimes in fresh)?
- Galvanic cells (e.g. combi-walls, repair, welding joints)?
- Fabrication influence (e.g. purity mix, cold rolled)?
- Extra high oxygen level (e.g. propellers, cooling system)?
- High flow velocities because of geometry ?
- Strong vertical differences in fresh and salt layers?
- Cathodic protection on board of moored ships?

Contribution of influences

	Causes / influences	Fresh	Brackish	Salt	
1	Electrochem. Corrosion	5%	5%	9%	
2	Biological activities	5%	9%	18%	
3	Galvanic influence	0%	9%	27%	
4	Fabrication	0%	5%	5%	
5	Aeration	5%	5%	9%	
6	Local high waterflow	0%	5%	9%	
7	Vertical salt-fresh layers	0%	5%	0%	
8	Cath. prot. on board of ship	5%	5%	5%	
9	Splash-zone	18%	18%	18%	
	Relative Contribution	**38%**	**66%**	**100%**	
	Avg. corrosion [mm/50yr]	3,4	5,9	**9,0**	
	Max. corrosion [mm/50yr]	10,3	17,8	**27,0**	

Corrosion scales and measures



Measures:
d = extra thickness
m = monitoring
cp = start with cath. protection
CP= Cathodic protection
(c)= coating if needed

★ Subsets of uniform corrosion conditions and uniformized measurements

Overview

Probable causes

1. **Galvanic working**
2. **Biological activity**
3. **...................**

23. ....

Experts:

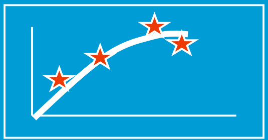
0-hypothesis
(9 main causes)

Measurements on specific aspects:

in lab

in situ

Tuning in practice:

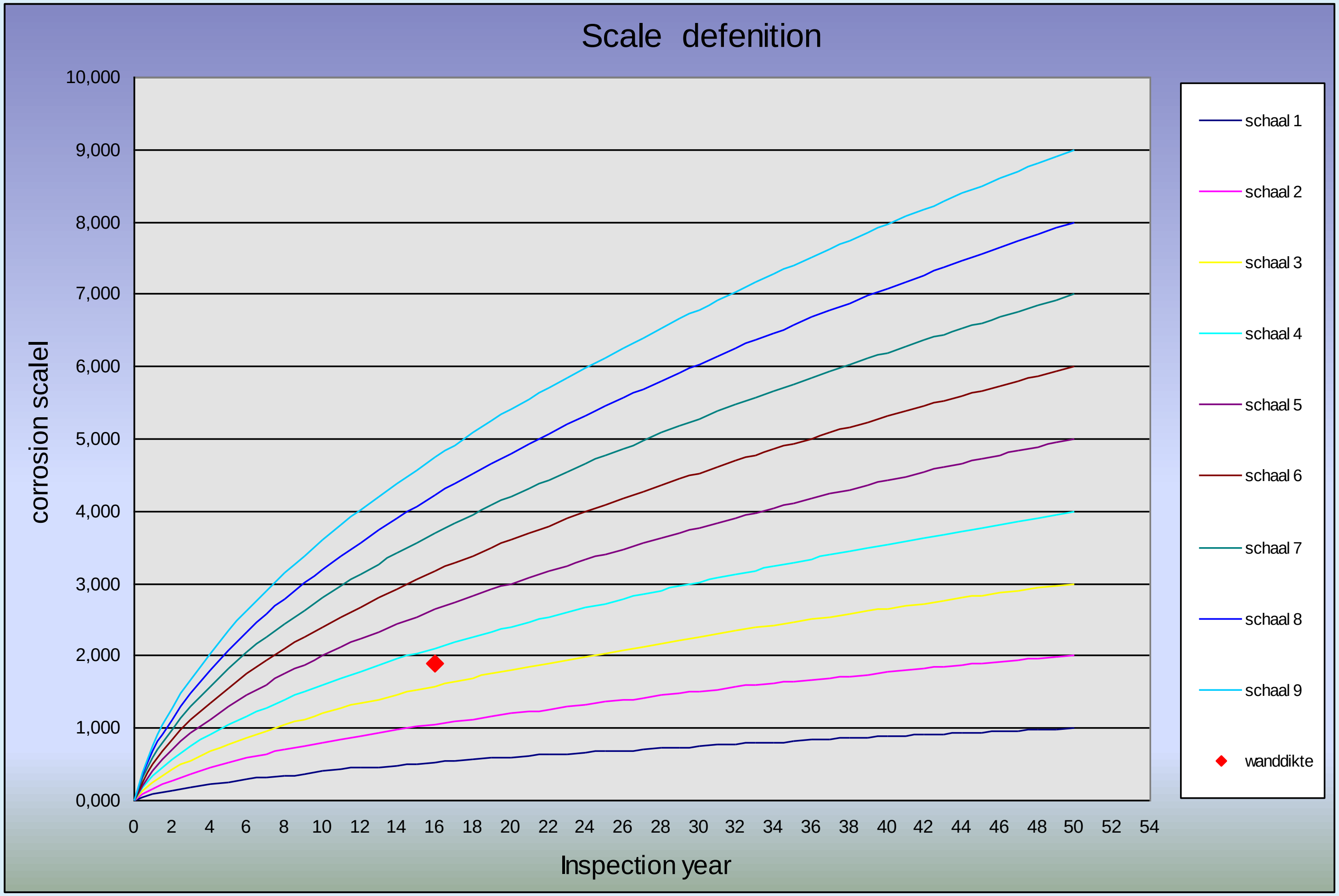


★ **= uniform group**

Then from scale to degradation

- Uniform group of measurements are placed on the corrosion scales (example: average 1,9 mm after 16 years)

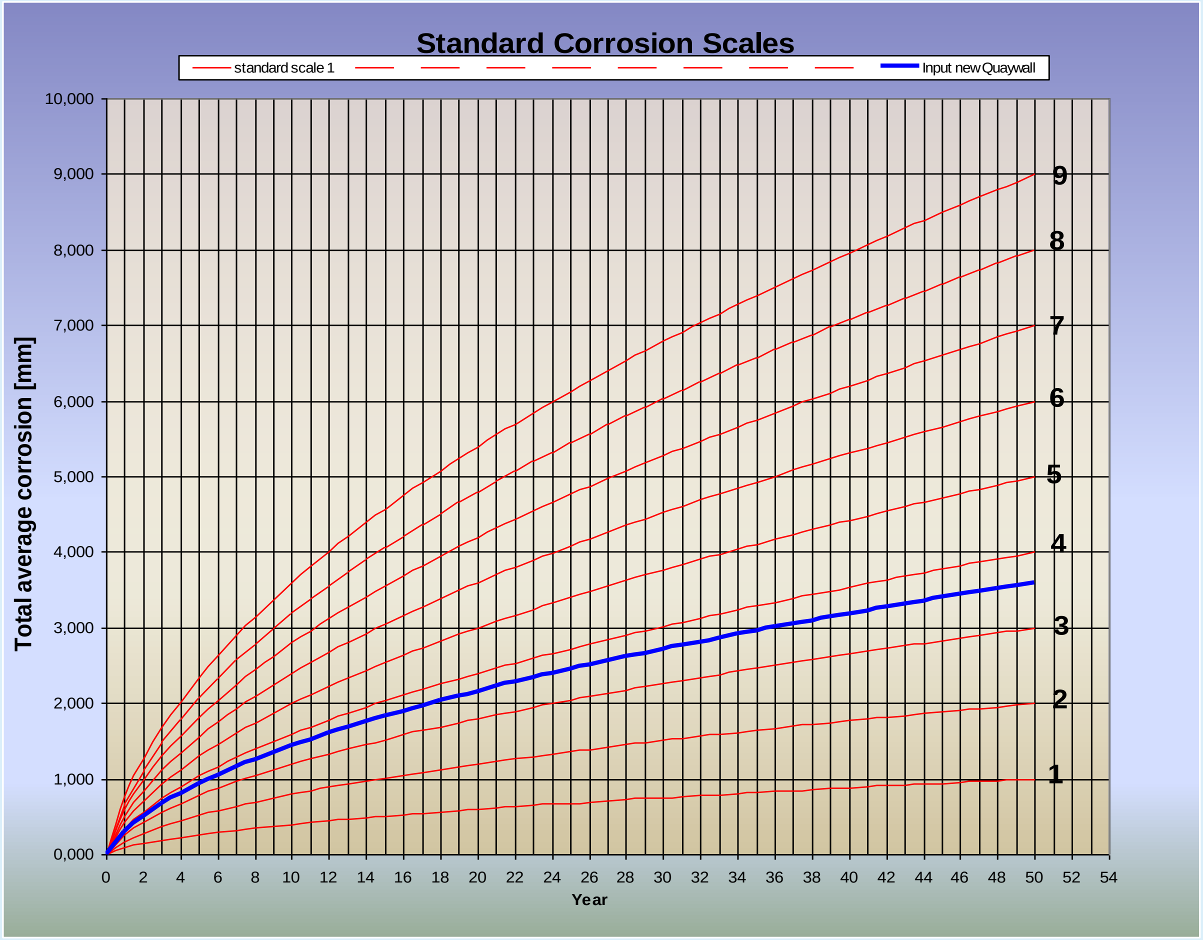
Then from scale to degradation



Then from scale to degradation

- Uniform group of measurements are placed on the corrosion scales
- Extrapolation of corrosion within scales (example between scale 3 and 4)

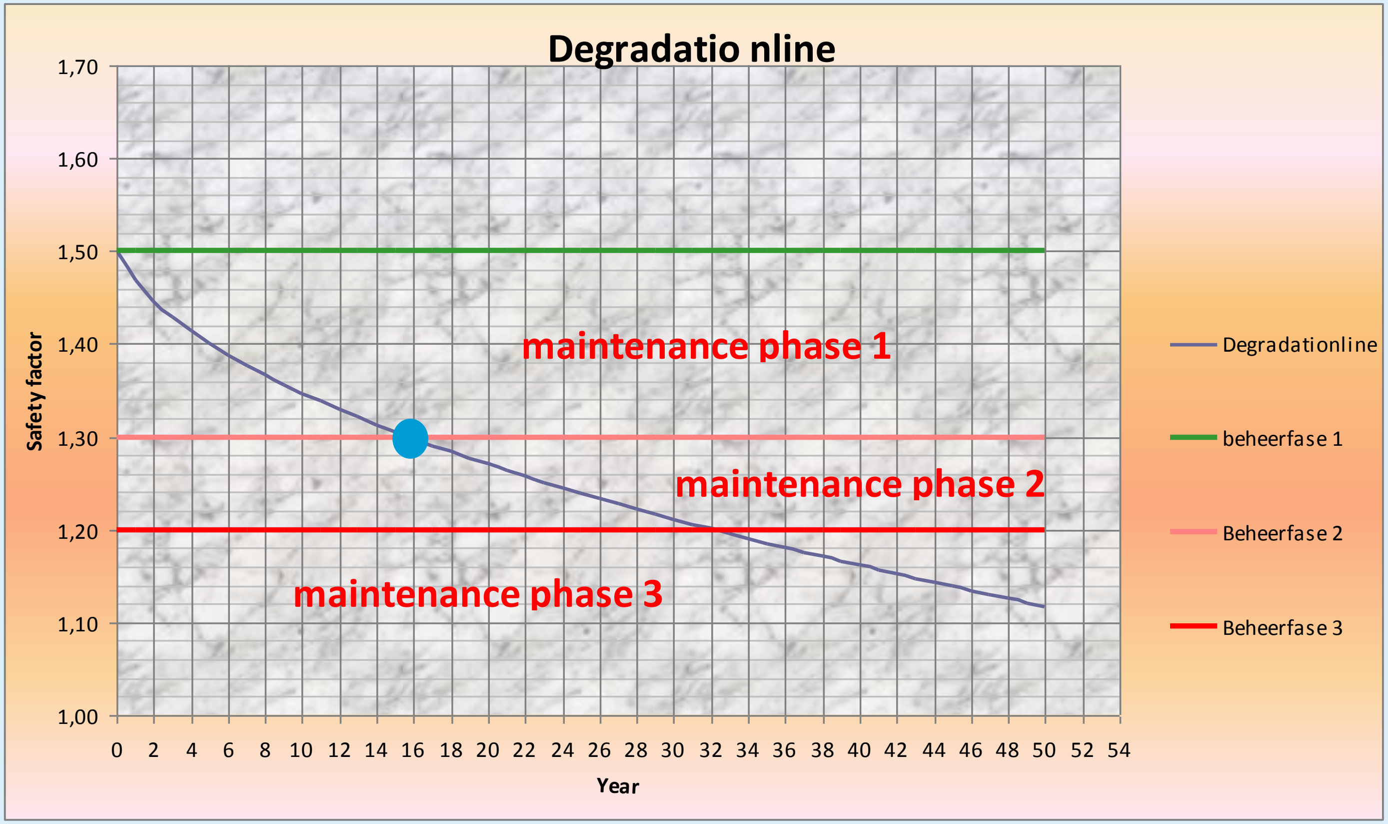
Then from scale to degradation



Then from scale to degradation

- Uniform group of measurements are placed on the corrosion scales
- Extrapolation of corrosion within scales
- Translation of corrosion to degradation (example remaining safety factor 1,30)
- Prediction of remaining lifetime

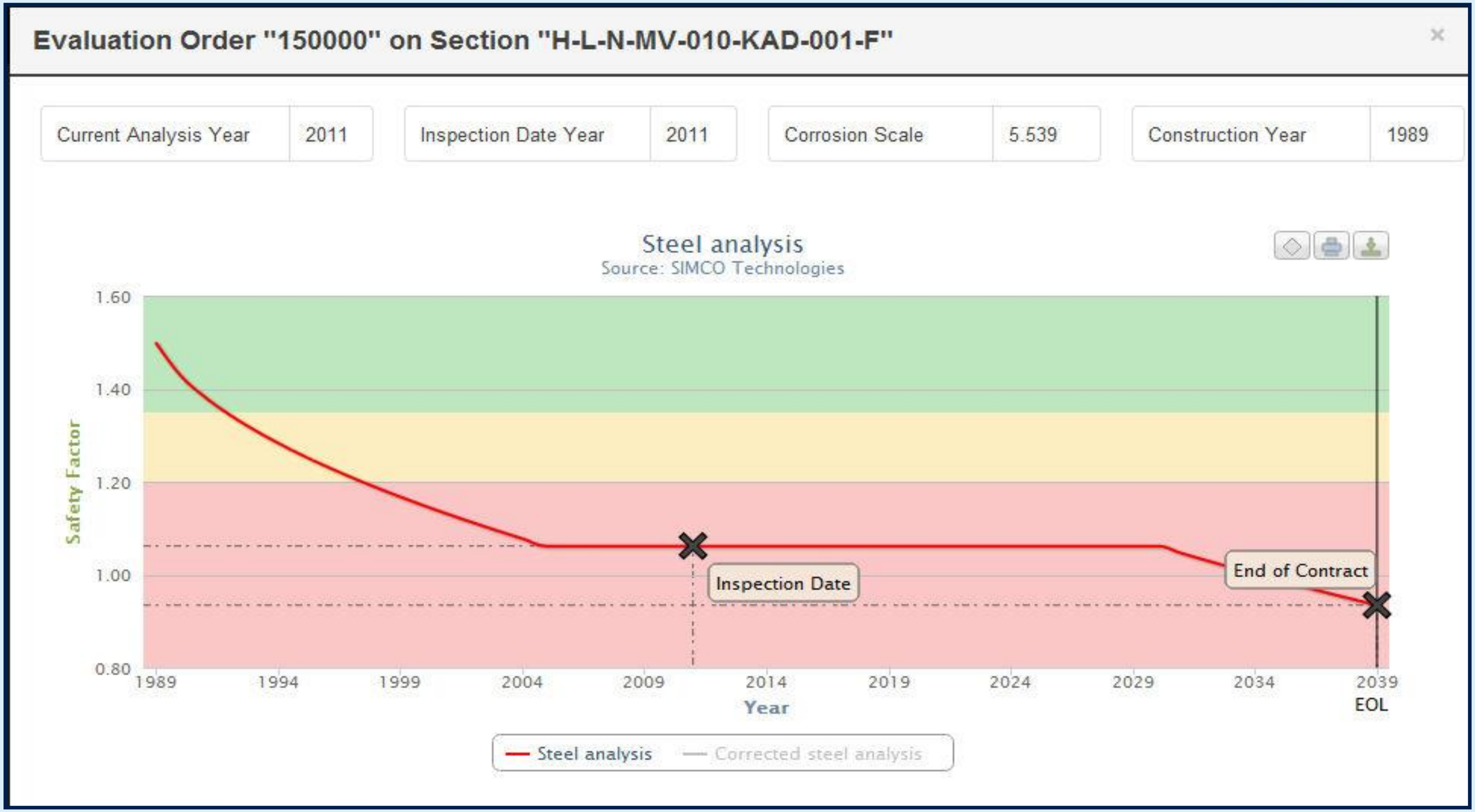
Then from scale to degradation



Input for KMS

- KMS: Quay wall modelling system
- Port of Rotterdam’s next step in asset management
- Supports the asset manager
- Combines technical risk and business value in order to prioritise maintenance measure
- Degradation model is part of KMS

Degradation model in KMS



Ongoing research to improve the steel model

Coupontest on site USA Sohar and the Netherlans (for the reference)

Water measurements:
O_2 - pH - Redox
EC - temp

Lab test coupons

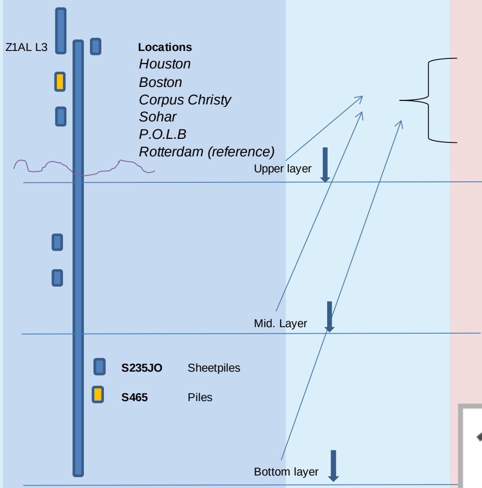
Electrical chemical test for determination of accelerated corrosion rates

Research in 2013

H_1 hypothesis

A +

Coupon frame



B +

Measurement waterconditions

Divice: Hach Lange

O_2
pH
Ec
T
Bart's (Microbiology)

"Bart's test": Research on presence on sulfate reducer

C +

Coupontest

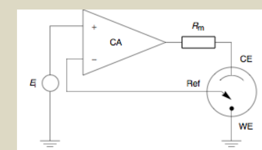
Standard coupons

exhibition coupons in lab

under variation of:
pH
T
O_2

D

Galvanostat/Potentostat-measurement



coupon weighting and measuring of water conditions, is always in combination

potentiostat device

Risks on CP systems

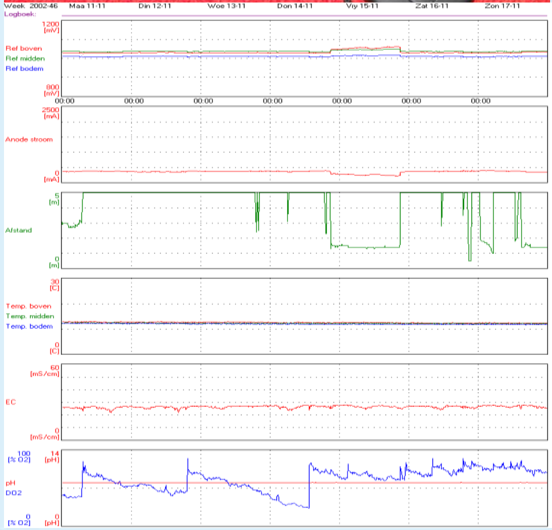
- Unsufficient protection
  Caused by anodes that don't work properly
- Incomplete coverage of structure
  Caused by mechanical damage
- Decrease of the anode lifetime
  Caused by higher load on anode than designed due to changing conditions

Monitoring of CP systems

- Visual inspections with divers
- mV measurement
- Weighing of anode to measure consumption in time
- US thickness measurement
- Condition monitoring

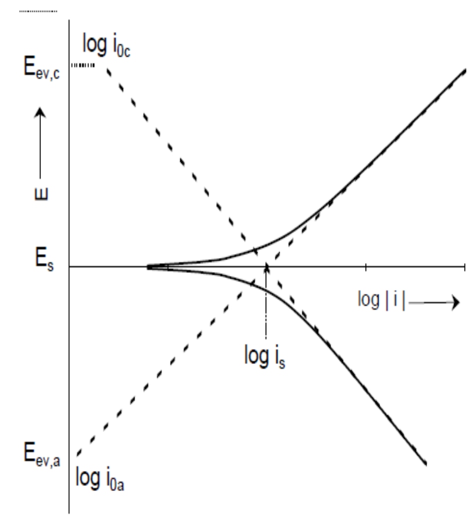
Monitoring water conditions

- Water conditions determine how efficient the system will work
- Monitoring of:
    - Conductivity / Salanity
    - Temperture of the water
    - pH
    - Dissolved oxygen



Results of monitoring @PoR

- mV is more than sufficient
- Brackish/ fresh water : anode consumption is lower than in salt conditions
- In salt water, the consumption is less at end of life of the anode
- Development of anode model



Thanks for your attention !