*West Pomeranian University of Technology, Szczecin*
Faculty of Maritime Technology and Transportation
Chair of Structure, Mechanics and Ship Fabrication

EMship Advanced Design

**MASTERS THESIS DEFENSE**

# Project: Analysis of ultimate capacity of the structural elements of single hull VLCC subject to corrosion

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## Content of presentation

1. **Introduction**
2. **The details points will be presented :**

   **2.1 The new corrosion model comparing with others models and the assumed data to defined the depth the corrosion of the ship structure**

   **2.2 Various Parameters Influence the Ultimate Strength of the plate**

   **2.3 Application : ULS capacity of the tanker ship including effect the corrosion**

- **ULS capacity of the plates, and panels**
- **The Progressive hull girder collapse analysis**

**3. Summary and conclusions**

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## Introduction

❑Computational comparison between PULS theory and other candidate models discussing ULS capacity of the plates and stiffened panels subject to the corrosion

❑Computational comparison between CSR and other candidate models discussing progressive collapse of the hull girder subject to the corrosion

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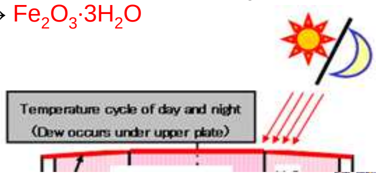
## Corrosion models

Atmospheric corrosion

$Fe + 2OH^- \rightarrow Fe(OH)_2 + 2e^-$
$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$
$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3$
$2Fe(OH)_3 \rightarrow Fe_2O_3 \cdot 3H_2O$




Source: http://www.jfe-steel.co.jp/en/release/2008/080129.html

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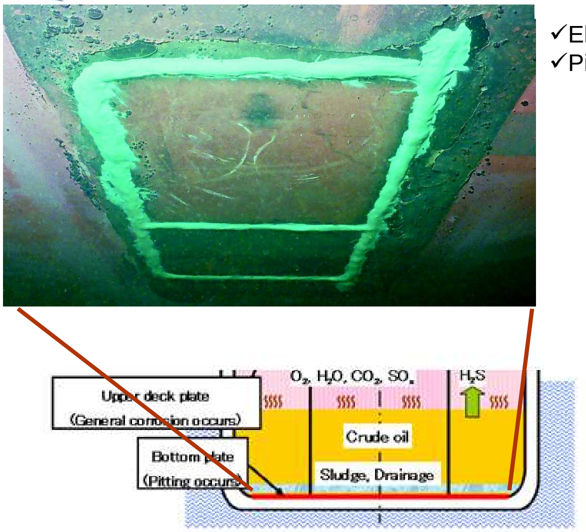
## Corrosion models




✓Electrochemical corrosion
✓Pitting corrosion

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## Corrosion models

### The candidates models

- The corrosion model is based to this equation :

$$d(t) = d_\infty \left[1 - exp\left(-\left(\frac{t-T_{st}}{\eta}\right)^\beta\right)\right] \qquad \text{If} \quad t > Tst$$

- If β=1 then we get the Guedes Soares and Garbatov model:

$$d(t) = d_\infty \left[1 - exp\left(-\left(\frac{t-T_{st}}{\eta}\right)\right)\right]$$

- If η=1 by using Taylor series we keep the first term linear we get the Paik /al model :

$$d(t) = d_\infty (t - T_{st})^\beta$$

- Finally if we take β=0.6257 , $d_\infty = 0.1207$and $T_{st} = 0$, we get the Melcher model:

$$d(t) = 0.1207t^{0.6257}$$

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# Corrosion models

## Solve basic equation using LSM

$$d(t) = d_\infty \left[1 - exp\left(-\left(\frac{t - T_{st}}{\eta}\right)^\beta\right)\right]$$

Using the least squares method we get the Model (1) :

$$\frac{1}{1 - \frac{d(t)}{d_\infty}} = exp\left(\left(\frac{t - T_{st}}{\eta}\right)^\beta\right) \longrightarrow ln ln\left[\frac{1}{1 - f(t)}\right] = \beta \ln(t - T_{st}) - \beta \ln(\eta)$$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} ln ln\left[\frac{1}{1 - \frac{i}{n+1}}\right]$$

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} \ln(t_i)$$

$$\hat{\beta} = \frac{\left\{n \sum_{i=1}^{n} \ln(t_i) ln ln\left[\frac{1}{1 - \frac{i}{n+1}}\right]\right\} - \left\{\sum_{i=1}^{n} ln ln\left[\frac{1}{1 - \frac{i}{n+1}}\right] \sum_{i=1}^{n} \ln(t_i)\right\}}{\left\{n \sum_{i=1}^{n} (\ln(t_i))^2\right\} - \left\{\sum_{i=1}^{n} \ln(t_i)\right\}^2}$$

$$\hat{\eta} = exp\left(\bar{y} - \frac{\bar{x}}{\hat{\beta}}\right)$$

$$d(t) = d_\infty \left[1 - exp\left\{-\left(\frac{t - T_{st}}{26}\right)^{0.2}\right\}\right]$$

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# Corrosion models

Describe the new model (2) from the assumption of the Paik/al ,keep the second order of Taylor series :

$$d(t) = d_\infty \left(\left(\frac{t - T_{st}}{\eta}\right)^\beta - \frac{1}{2}\left(\frac{t - T_{st}}{\eta}\right)^{2\beta}\right)$$

To make computation we take for : $d_\infty = 3.3\ mm\ , T_{st} = 5\ years$

For new model developing as follow Paik/al model : we made analysis of flexibility to the distribution of the rate corrosion to fixe two parameters β and η .

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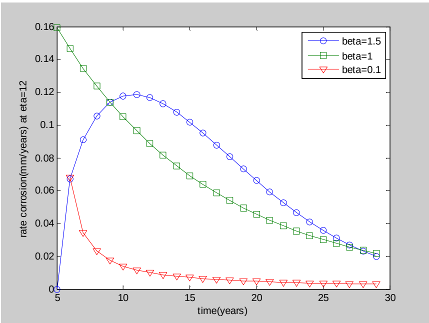
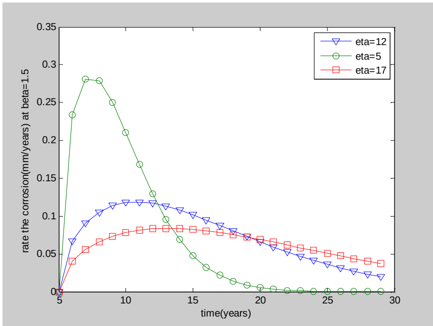
# Corrosion models

## The flexibility of the rate corrosion distribution

$$r(t) = \begin{cases} 0 & if\ t < T_{st} \\ d_{\infty} \frac{\beta}{\eta}\left(\frac{t-T_{st}}{\eta}\right)^{\beta-1} exp\left(\left(\frac{t-T_{st}}{\eta}\right)^{\beta}\right) \end{cases}$$

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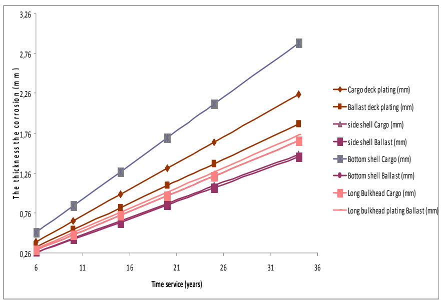
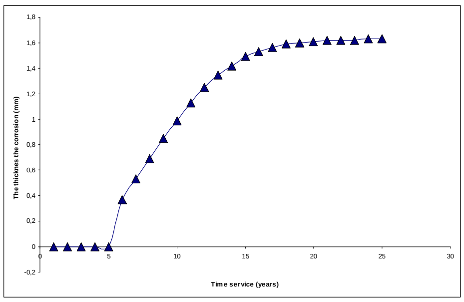
# Corrosion models

## The reference data : ABS ref and the assumed data (ref paper Shengping Qin and Weicheng Cui School of Naval Architecture and Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200030, China )




The data ref ABS




The assumed data (ref paper Shengping Qin and Weicheng Cui School of Naval Architecture and Ocean Engineering, Shanghai Jiao Tong University, Shanghai, 200030, China )

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# Corrosion models

| Parameters | β | η | D inf |
|---|---|---|---|
| Run 1 | 0.62 | 20 | 3.3 |
| Run 2 | 0.7 | 19.3 | 3.3 |

For β=[0.62,0.7] we describe the ratio between the parameters β and η equal to :

$$\frac{\eta}{\beta} = 30$$

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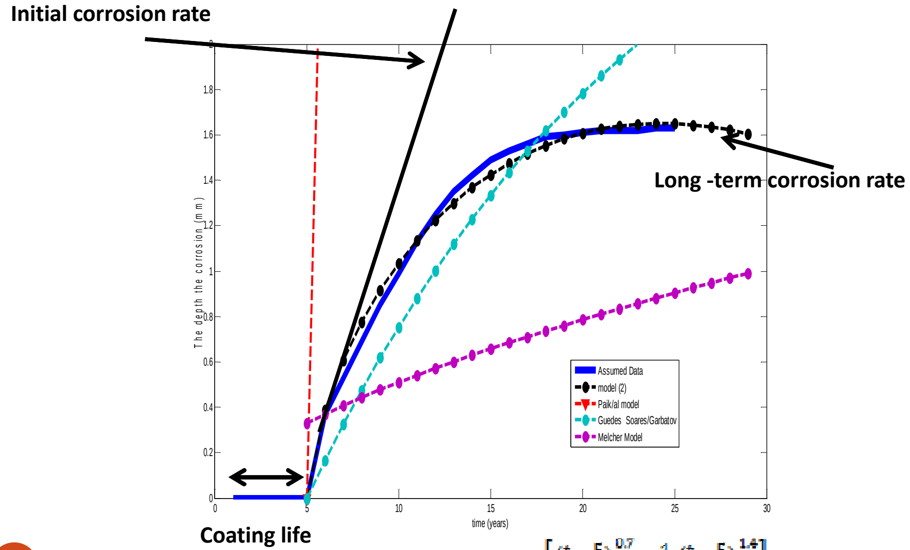
# Corrosion models




$$d(t) = 3.3\left[\left(\frac{t-5}{19.3}\right)^{0.7} - \frac{1}{2}\left(\frac{t-5}{19.3}\right)^{1.4}\right]$$

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## Corrosion models

### The flexibility of the rate corrosion distribution

**Basic equation**

$$r(t) = \begin{cases} 0 \quad if\ t < T_{st} \\ d_\infty \dfrac{\beta}{\eta}\left(\dfrac{t - T_{st}}{\eta}\right)^{\beta-1} exp\left(-\left(\dfrac{t - T_{st}}{\eta}\right)^{\beta}\right) \end{cases}$$

**New Model**

$$r(t) = \begin{cases} 0 \quad if\ t < T_{st} \\ d_\infty \dfrac{\beta}{\eta}\left\{\left(\dfrac{t - T_{st}}{\eta}\right)^{\beta-1} - \left(\dfrac{t - T_{st}}{\eta}\right)^{\beta}\right\} \end{cases}$$

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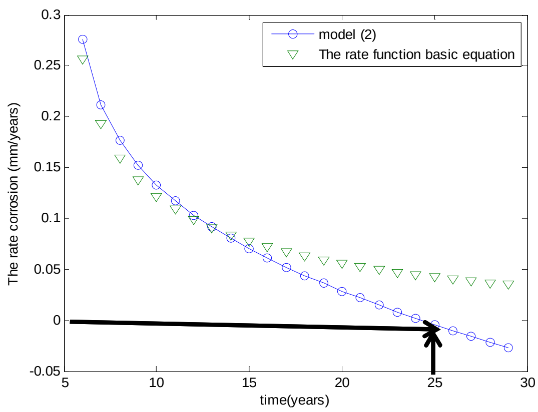
## Corrosion models

### The flexibility of the rate corrosion distribution




$$\lim_{t \to \infty} r(t) = 0$$

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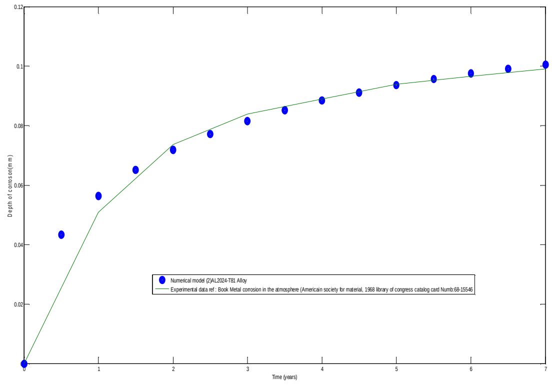
## Corrosion models

Ref. experimental data: Book Metal corrosion in the atmosphere (1968 library of congress catalog card Numb: 68-15546).




Depth of corrosion versus time for Al2024-T-81 Alloy

$$d(t) = 0.215\left[\left(\frac{t}{13.5}\right)^{0.45} - \frac{1}{2}\left(\frac{t}{13.5}\right)^{0.9}\right]$$

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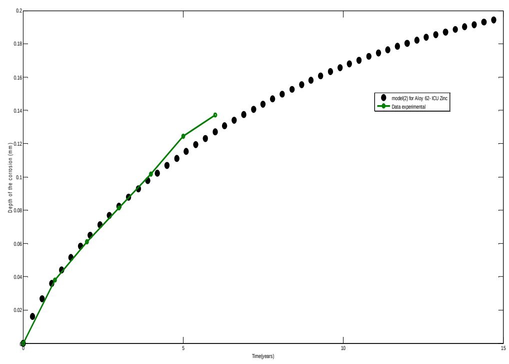
## Corrosion models

Ref. experimental data: Book Metal corrosion in the atmosphere (1968 library of congress catalog card Numb: 68-15546).




Depth of corrosion versus time for Aloy 62-ICU Zinc

$$d(t) = 0.42\left[\left(\frac{t}{22.5}\right)^{0.75} - \frac{1}{2}\left(\frac{t}{22.5}\right)^{1.5}\right]$$

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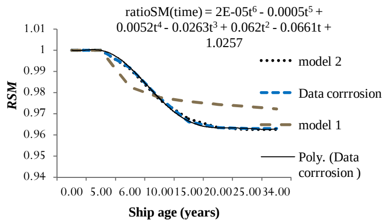
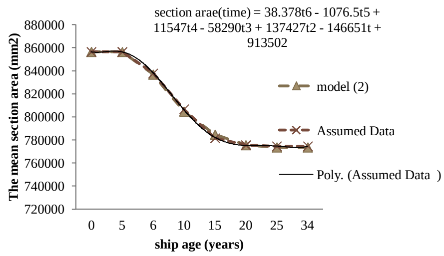
# Corrosion models

## Effect of the corrosion to reduce the section modulus and the section area for cargo deck of SHVLCC




We lost 5% the section modulus during 15 years the service




We lost 9,3% the mean section area during 25 years the service

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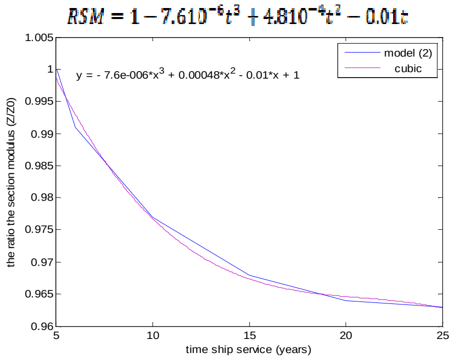
# Corrosion models

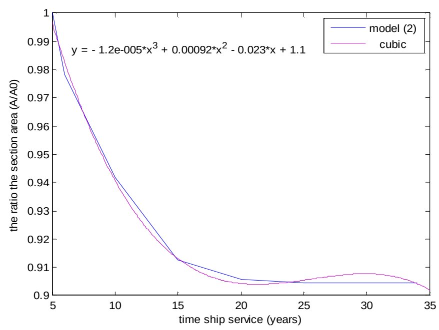
## Effect of the corrosion to reduce the section modulus and the section area for cargo deck of SHVLCC

$$RSM = 1 - 7.6\,10^{-6}t^3 + 4.8\,10^{-4}t^2 - 0.01t$$




The fit of the curve section modulus versus ship age, subject to the uniform corrosion

$$RSA = 1.1 - 1.2\,10^{-5}t^3 + 9.2\,10^{-4}t^2 - 0.023t$$




The fit of the curve section area versus ship age, subject to the uniform corrosion

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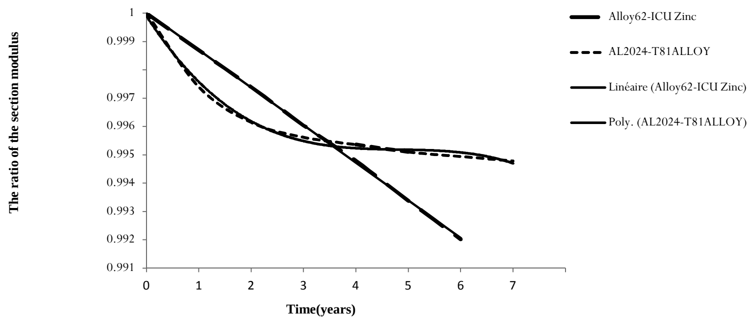
## Corrosion models

### Effect of the corrosion to reduce the section modulus using the aluminium and zinc material

RSM aluminum(t) = $-4E\text{-}05t^3 + 0,0006t^2 - 0,0029t + 0,9999$

**RSM zinc(t) = $-0,0013t + 1$**




The fit curve section modulus versus ship age, subject to the uniform corrosion



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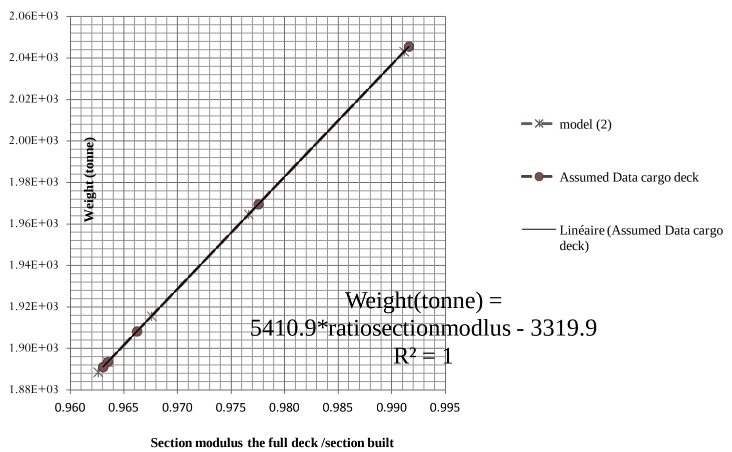
## Corrosion models

### Correlation between weight and ratio of the section modulus of the cargo deck SHVLCC




$$Weight\ (tonne) = 5410.9 * RSM - 3319.9$$

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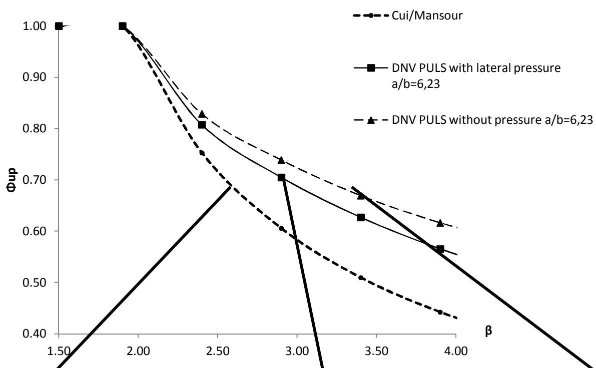
## The ULS computation of the plate subject to the corrosion




$$\Psi_U = \begin{cases} 1 & if\ \beta < 1.9 \\ 0.08 + \frac{1.09}{\beta} + \frac{1.26}{\beta^2} & if\ \beta > 1.9 \end{cases}$$

$$\Psi_{U,P} = \begin{cases} 1 & if\ \beta < 1.9 \\ 0.52 - \frac{0.26}{\beta} + \frac{2.23}{\beta^2} & if\ \beta > 1.9 \end{cases}$$

$$\Psi_U = \begin{cases} 1 & if\ \beta < 1.9 \\ 0.58 + \frac{1.27}{\beta} - \frac{0.9}{\beta^2} & if\ \beta > 1.9 \end{cases}$$

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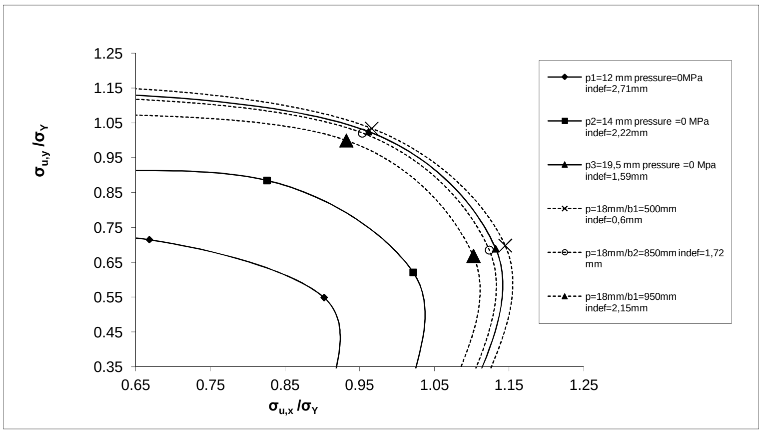
## The ULS computation of the plate subject to the corrosion

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## The ULS computation of the plate subject to the corrosion

| | | Reduction the ultimate strength the plate |
|---|---|---|
| Hogging | Bottom 1 | 8.10% |
| | Bottom2 | 8.54% |
| | lower longitudinal bulkhead | 7.91% |
| | Lower side | 8.98% |
| Sagging | Deck1 | 8.90% |
| | Deck2 | 8.48% |
| | upper longitudinal bulkhead | 9.35% |
| | Upper side | 7.97% |

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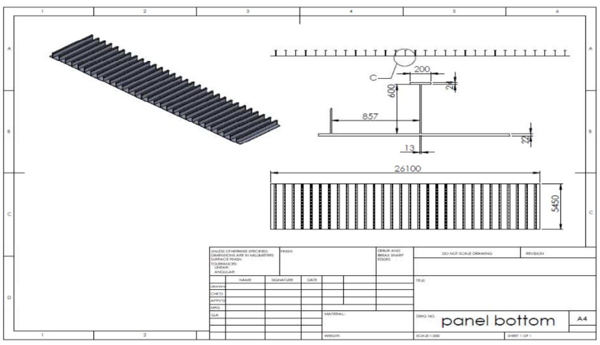
## The ULS computation of the stiffened panel subject to the corrosion

### The dimension of the stiffened panel bottom 1

| Element | ei (breath) mm | bi(height) mm |
|---|---|---|
| Effective plating | 870,00 | 22 |
| Web | 13 | 600 |
| Flange | 200 | 24 |
| The neutrale axis:Zg | 181,64 | mm |
| λ | 0,25 | |
| β | 1,38 | |
| be (effectif width) | 0,804 | m |

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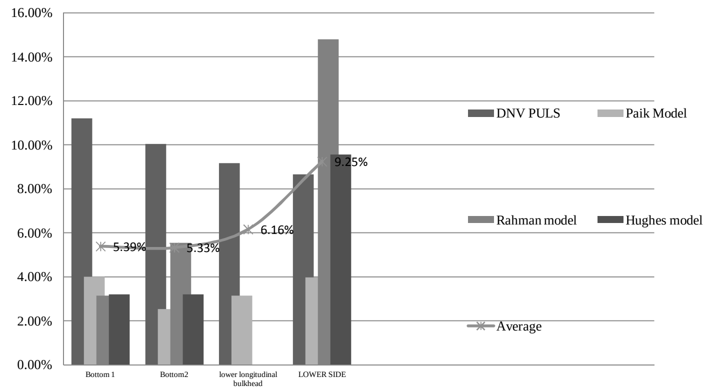
## The ULS computation of the stiffened panel subject to the corrosion

The reduction the ULS of the stiffened panel (effect the uniform corrosion) in hogging

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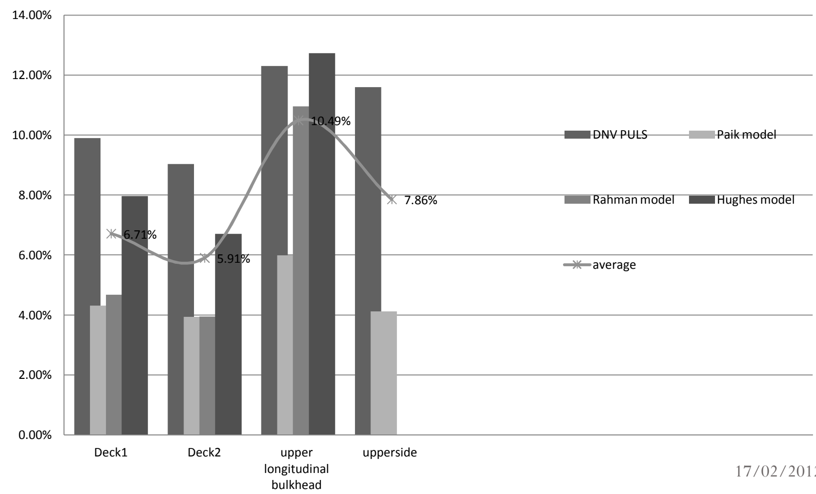
## The ULS computation of the stiffened panel subject to the corrosion

The reduction the ULS of the stiffened panels (effect the uniform corrosion) in sagging

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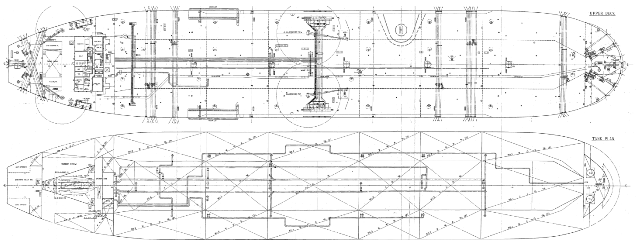
## The ULS computation of the hull girder subject to the corrosion

### SHIP MAIN PARTICULARS

| | | | |
|---|---|---|---|
| **Length O.A of the tanker ship** | **L** | **311** | **m** |
| **Breadth of the tanker ship** | **B** | **57.2** | **m** |
| **Bloc coefficient** | $C_B$ | **0.84** | |
| **Design speed** | **V** | **15.4** | **Kn** |
| **Depth of ship** | **D** | **30.4** | **m** |
| **Dead-weight** | **DWT** | **284497** | |



The general arrangement of the upper deck and the tank plan

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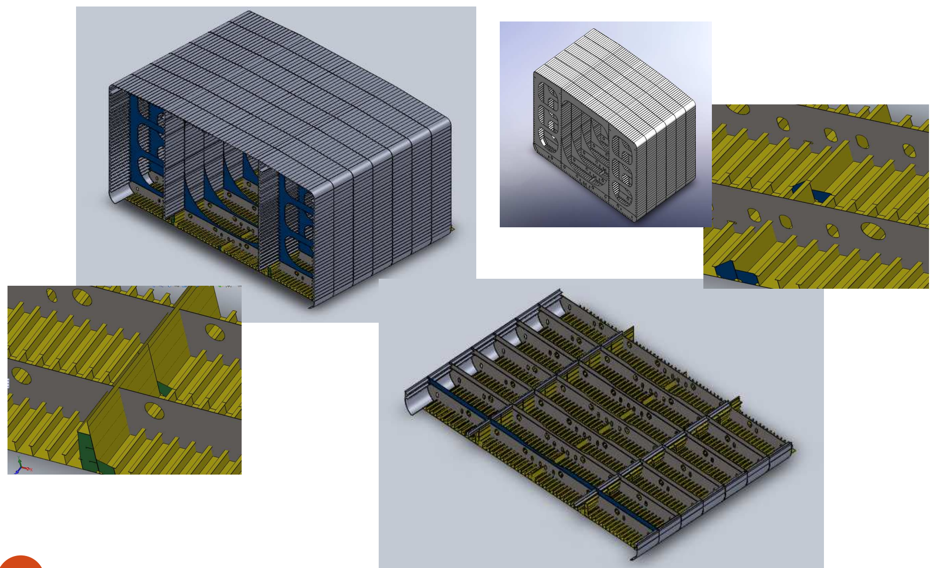
## The 3D views of the tanker ship single hull VLCC



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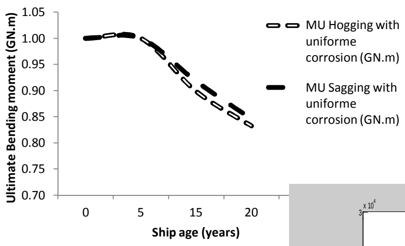
## The ULS computation of the hull girder subject to the corrosion

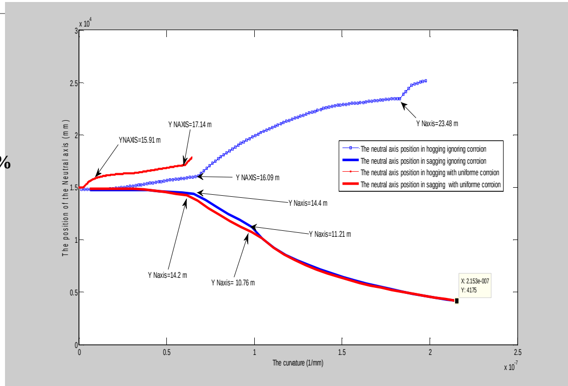



**The reduction the MU hogging with uniform corrosion = 17 % .**

**The reduction the MU sagging with uniform corrosion = 15% .**

**The reduction the N.Axis position in hogging with uniform corrosion = 26 %**

**The reduction the N.Axis position in sagging with uniform corrosion = 4 %**

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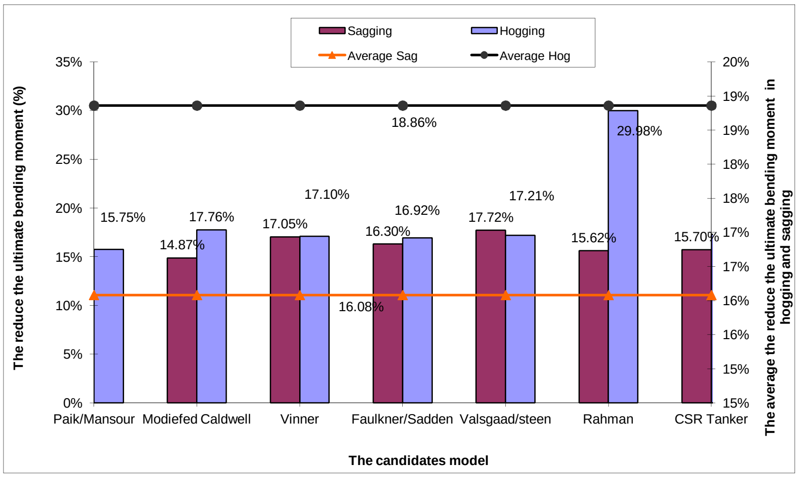
## The ULS computation of the hull girder subject to the corrosion

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## Summary and conclusions

❖ keep the model (2) : $d(t) = d_\infty \left( \left(\frac{t-T_{st}}{\eta}\right)^{\beta} - \frac{1}{2}\left(\frac{t-T_{st}}{\eta}\right)^{2\beta} \right)$

❖ **Reduce 5% the section modulus during 15 years the service subject to the uniform corrosion.**

❖**Reduce 9,3% the mean section area during 25 years the service subject to the uniform corrosion.**

$$Weight\ (tonne) = 5410.9 * RSM - 3319.9$$

❖**Reduce 8% the ultimate strength capacity of the plate .**

❖**Reduce 5-9% the ultimate strength capacity of the stiffened panels .**

❖**The reduction the MU hogging with uniform corrosion = 18.86 %.**

❖**The reduction the MU sagging with uniform corrosion = 16%.**

❖**The reduction the N.Axis position hogging with uniform corrosion = 26 %.**

❖**The reduction the N.Axis position sagging with uniform corrosion = 4 %.**

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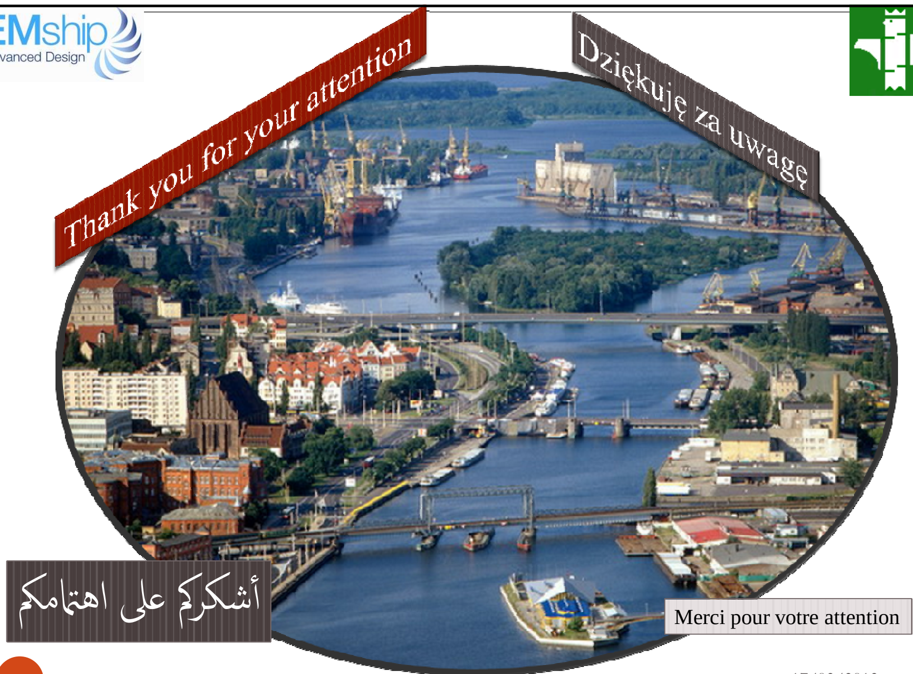


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