# MASTER THESIS PRESENTATION

## Fatigue and fracture assessment of butt welds


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|---|---|
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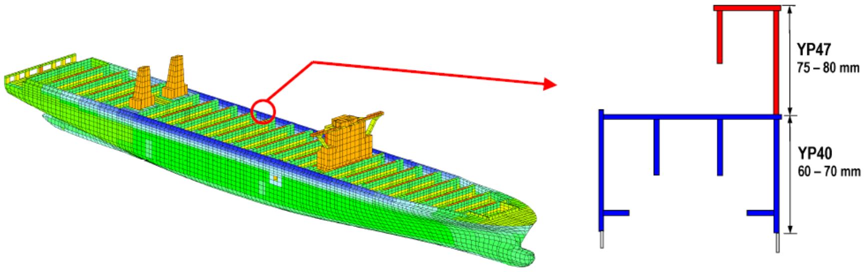
# INTRODUCTION

## Motivation & Objective

- **Trend**: Increasing size of vessels
- **Result**: Extensive use of high tensile strength steel with plates of great thicknesses and welded joints
- **Example:** Coaming and top plate of large container ships
- **Objective:** Investigation of fatigue behavior of butt welds made of high tensile steel YP47 (460 N/mm$^2$)






# INTRODUCTION

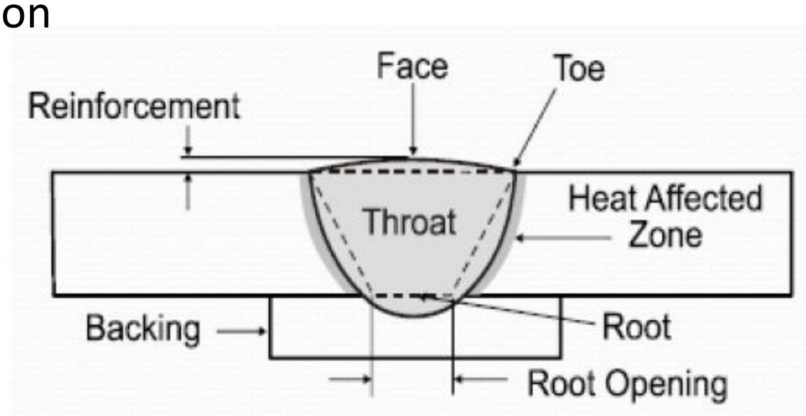
## Basic Principles – Fatigue

- Occurs as a result of cumulative effect due to cycling fluctuating loading
- Important structural parameter for ships
- 3 Stages: 1)Crack initiation – 2)Propagation – 3)Failure
- Initiates at a stress concentration point

# INTRODUCTION

## Basic Principles – Butt Welds

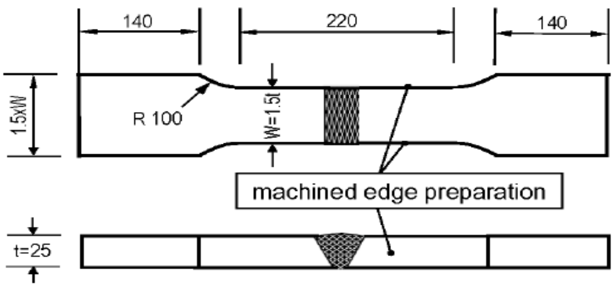
- Assembly process obtained by material fusion
- Fatigue crack initiates at the weld toe (less often at root)
- Propagates through the thickness, perpendicular to load direction






# Part I: Evaluation of Fatigue Tests of Butt Welds

- 2nd Joined Development Programme (JDP II) between GL and Korean shipyards (confidential results)
- Fatigue tests of butt welds made of YP47 steel of various plate thicknesses (25-50-60-80mm)
- Specimens manufactured by 6 different yards and tested in 4 different facilities
- Objectives: Investigate the thickness effect and fatigue performance of YP47



# Part I: Evaluation of Fatigue Tests of Butt Welds

**Thickness Effect:** Decrease of fatigue strength of welded joint or component with the increasing of plate thickness

$$f_t = \left(\frac{t_{ref}}{t_{eff}}\right)^n$$

Where:

$t_{ref}$: reference plate thickness (usually 25mm)

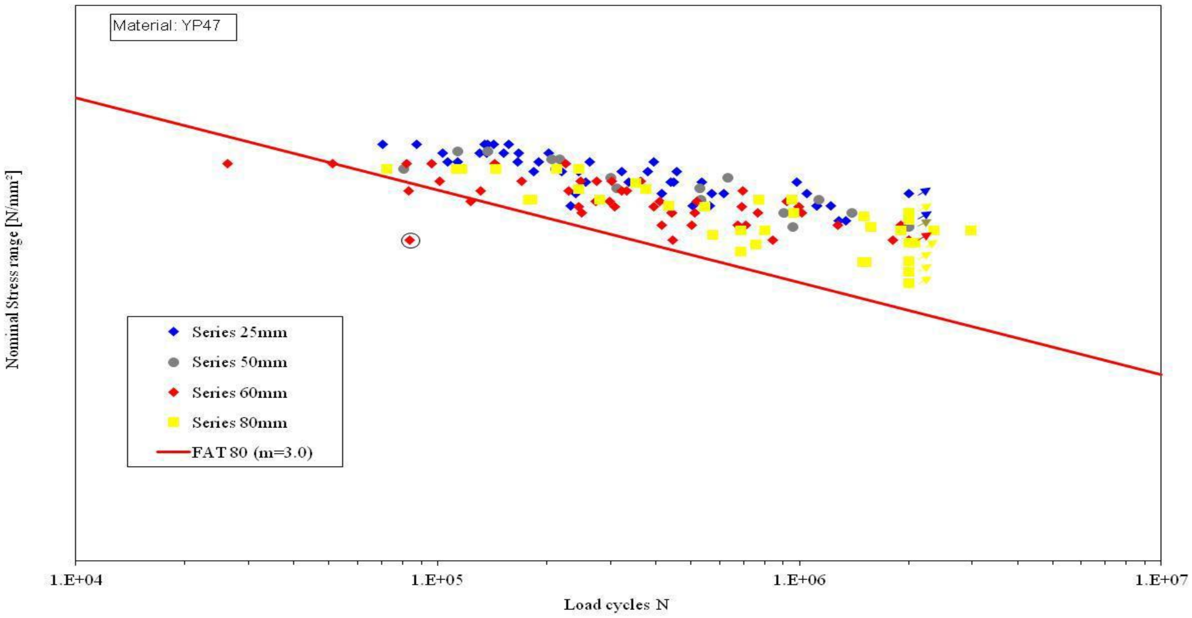
$t_{eff}$: effective plate thickness

n: exponent of the thickness influence law (0.2 or 0.17)



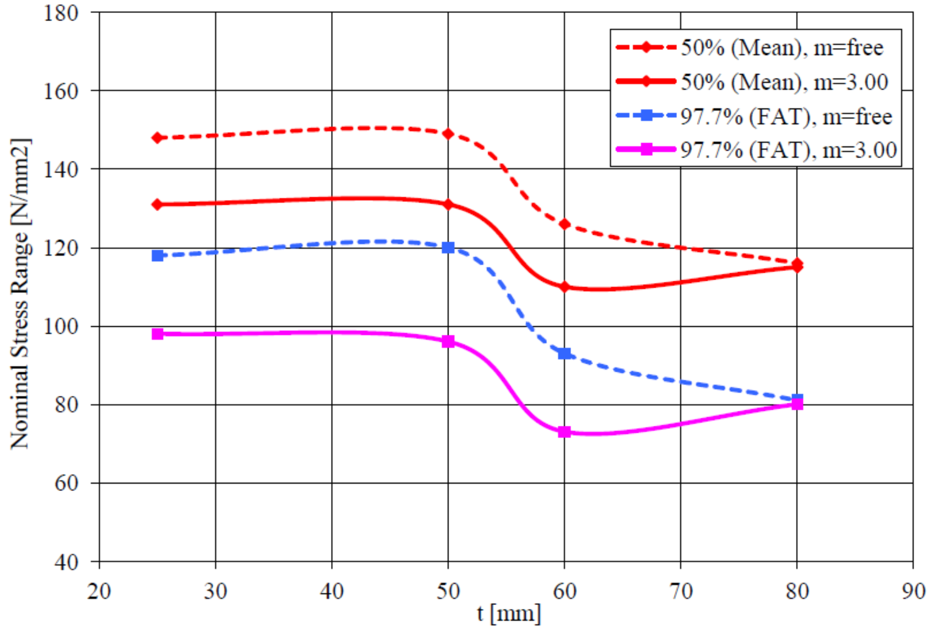
# Part I: Evaluation of Fatigue Tests of Butt Welds

**Fatigue Test Results:** Overall



# Part I: Evaluation of Fatigue Tests of Butt Welds

**Fatigue Test Results:** Evaluation of series by thickness






# Part I: Evaluation of Fatigue Tests of Butt Welds

**Conclusions from Part I:**

•Generally good fatigue performance of YP47

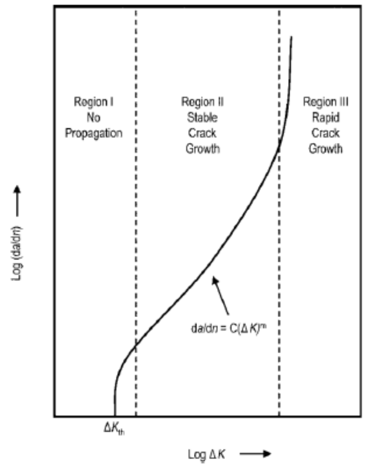
•Doubtful thickness effect results

# Part II: Investigation of Parameters C & m of Paris Equation

**Fracture Mechanics:**

- Propagation from initial ($a_{in}$) to final ($a_f$) crack length
- Stress Intensity Factor range (ΔK): $\Delta K = \Delta K_{max} - \Delta K_{min} = Y \Delta\sigma\sqrt{\pi a}$
  where Y is a correction function depending on geometry
- Paris crack growth equation:

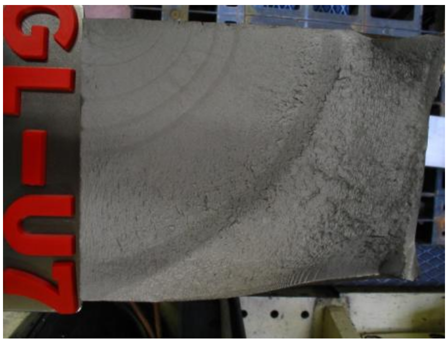
$$da/dn = C(\Delta K)^m$$

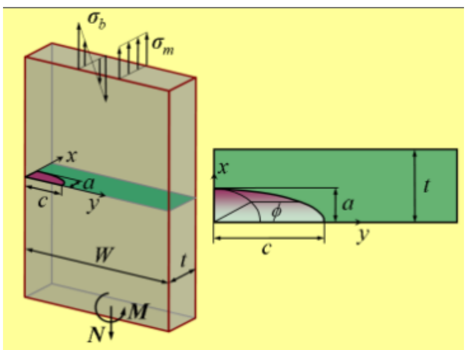





# Part II: Investigation of Parameters C & m of Paris Equation

- Based on experimental results of fatigue tests carried out by GL
- Butt welds specimens (t=80mm, higher tensile steel YP40)
- Creation of beachmarks on the fatigue crack surfaces
- Numerical calculations performed by software VERB



## Part II: Investigation of Parameters C & m of Paris Equation

- For each specimen it is known from the tests:
- The stress range ($\Delta\sigma$ in $N/mm^2$)
- The number of cycles (N) between each beachmark
- The dimensions of the beachmark = dimensions of the crack while it propagates
- For specific value of parameter m (3.5 – 3 – 2.5), VERB calculates value of parameter C of Paris equation
- Repeated for all the specimens, the average value and the upper limit of the obtained results for parameter C is calculated and compared with the one suggested from International Institute of Welding (IIW).



## Part II: Investigation of Parameters C & m of Paris Equation

**Results:**

| | $C\_all_{best\_fit}$ (for m=2,5) | $C\_all_{best\_fit}$ (for m=3) |
|---|---|---|
| A.V: | 2.78E-08 | 3.84E-09 |
| upper limit: | 3.66E-08 | 5.65E-09 |

**Recommended value (from IIW):**

m=3.00, C=1.65E-08

**Conclusion:**

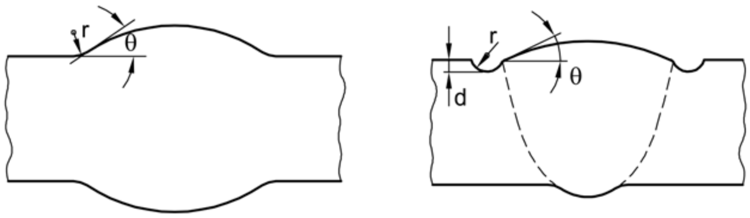
Obtained value smaller than the recommended, leading to longer lifetimes. IIW recommendations proved to be very conservative.

# Part III: Notch Stress and Fracture Mechanics Investigation of Butt Welds

## Notch Stress Approach

Butt welds (t=25, 50 and 80mm) of various weld geometries:

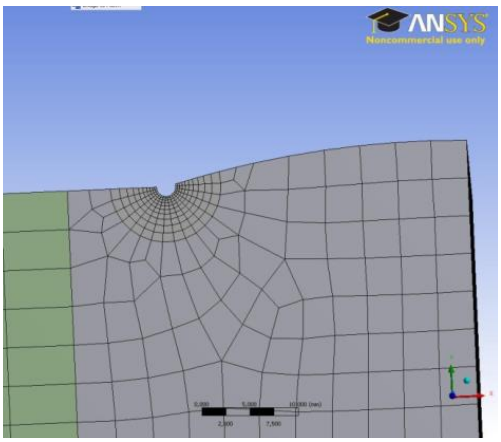
- Group a: weld shapes directly and randomly taken from actual specimens from GL tests of Part I
- Group b: Notch of weld raises proportionally to thickness
- Group c: Exact same weld geometry for all specimens
- Group d: Undercuts of radius r=1mm

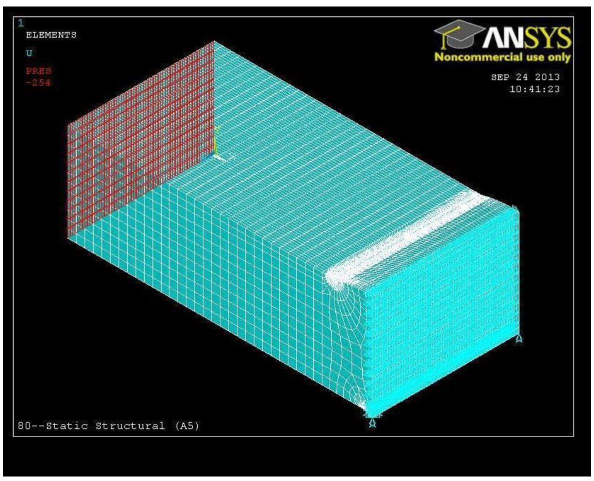





# Part III: Notch Stress Approach

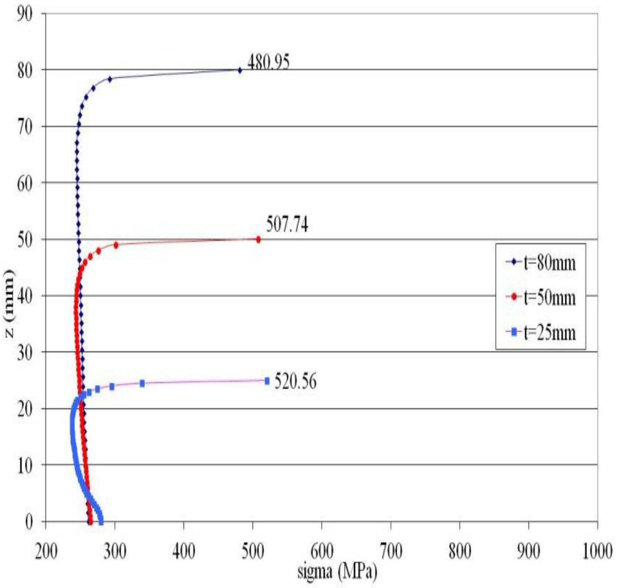
- High tensile steel material properties
- Nominal stress range $\Delta\sigma$=254N/mm$^2$
- Software used for modeling: ANSYS

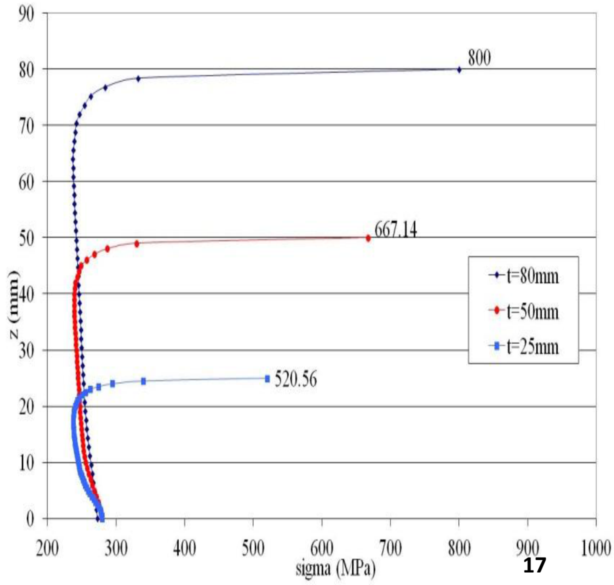


# Part III: Notch Stress Approach

**Results:** Max. Principal stress distribution at the relevant cross section at the weld toe, Groups a & b

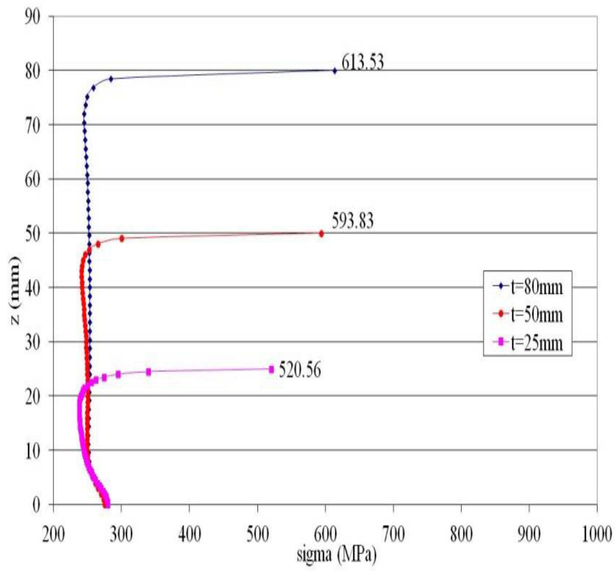


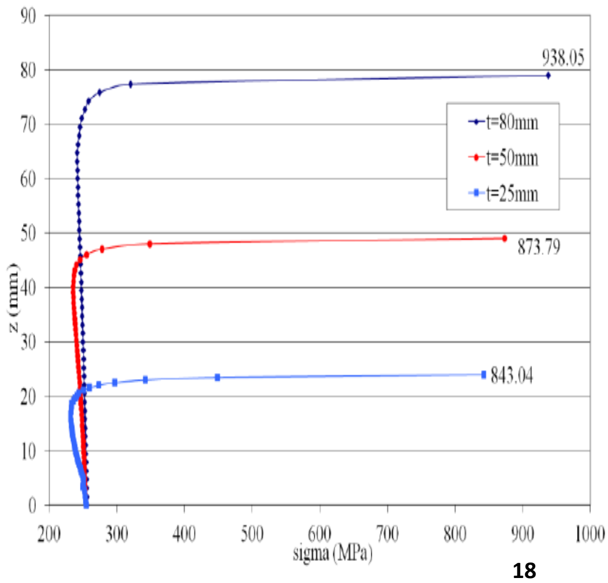






# Part III: Notch Stress Approach

**Results:** Max. Principal stress distribution at the relevant cross section at the weld toe, Groups c & d

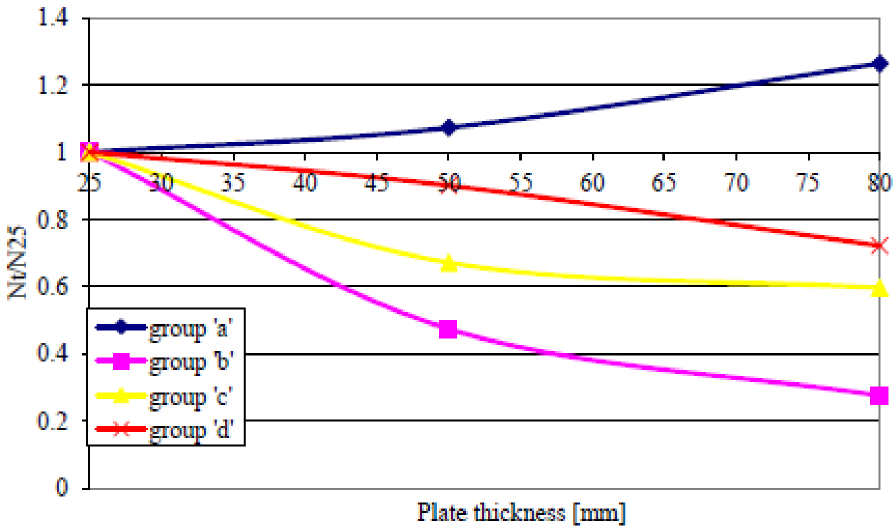


# Part III: Notch Stress Approach

**Results:** Thickness effect calculated by notch stress approach

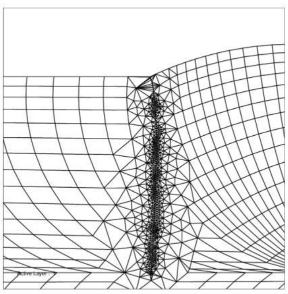
$$N = N_D \left(\frac{\sigma_a}{\sigma_D}\right)^{-k}$$

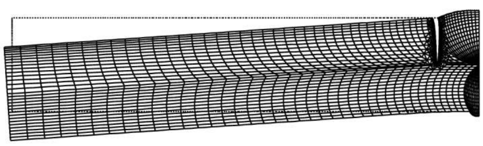





# Part III: Fracture Mechanics Approach

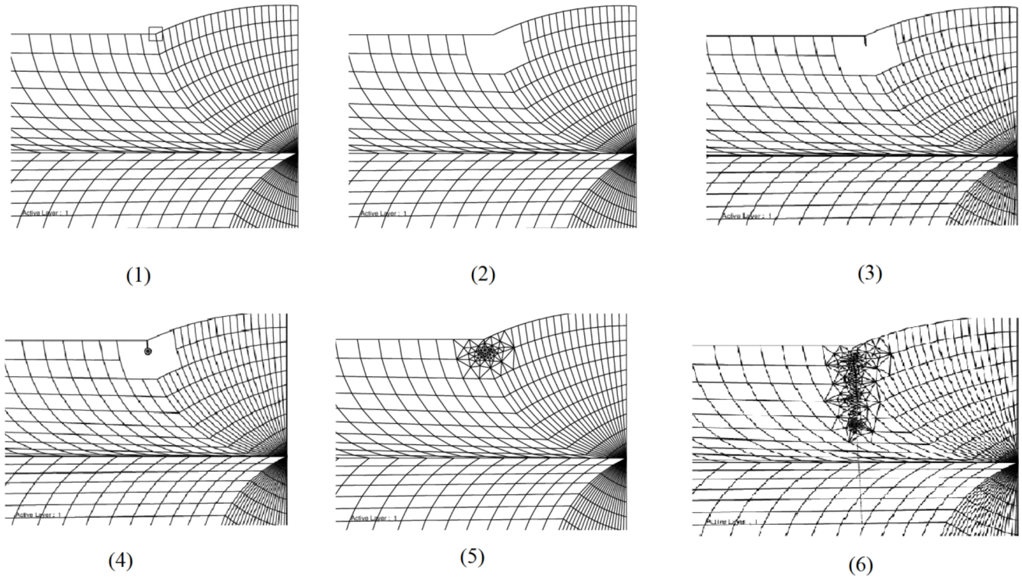
- Modeling of butt welds (25, 50 and 80mm) and simulation of crack propagation with software FRANC2D
- Calculation of Stress Intensity Factor (SIF)
- Evaluation of fatigue life using Paris equation
- Investigation of thickness effect





# Part III: Fracture Mechanics Approach

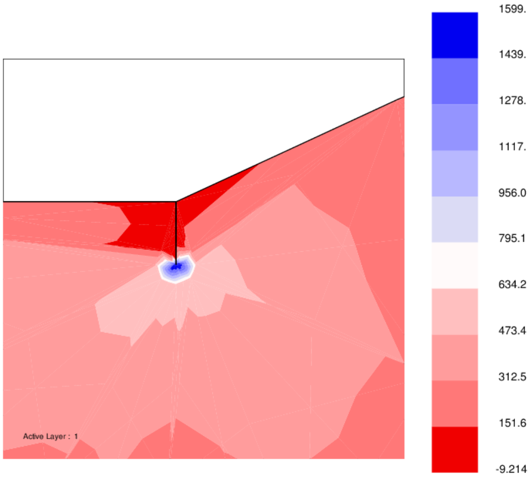
- Simulation of crack propagation with software FRANC2D

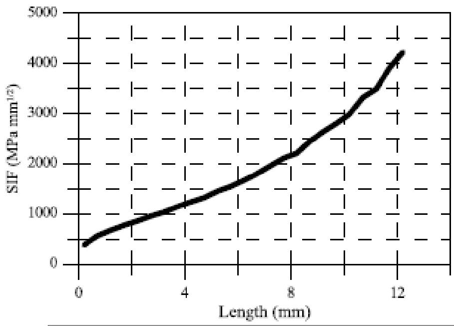


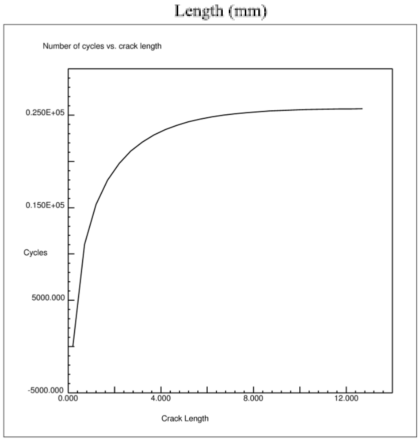



# Part III: Fracture Mechanics Approach

- **Results:**

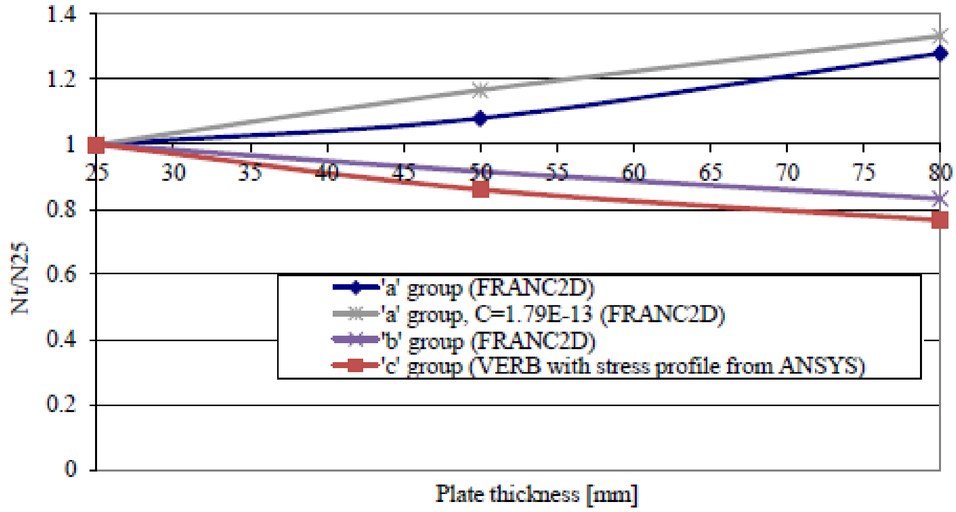


## Part III: Fracture Mechanics Approach

- **Results:** plate thickness effect for a, b and c groups of specimens from fracture mechanics approach






## OVERALL CONCLUSIONS

**Part I**

- The fatigue performance of YP47 is proved to be good
- No clear picture of thickness effect in test results

**Part II**

- Obtained value for parameter C lower than the recommended

**Part III**

- Great dependency of the value of notch stress on the geometry of the weld
- Possible explanation for Part I

## RECOMMENDATIONS FOR FUTURE WORK

- Further consideration of misalignments for the evaluation of test results
- Further investigation of parameter C since the obtained result shows a significant difference to the recommended one
- Studying of the impact of residual stresses in SIF calculation
- Application of more advanced formulas than Paris equation (e.g. Bilinear law, NASGRO etc)
- Similar investigation for components made of different material (e.g. different steel alloys, titanium alloys)
- Similar investigation for different weld types (e.g. cruciform fillet welded joints etc)