A Study of the Effect of Whipping on the Fatigue Life

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- Introduction to Whipping
- Fatigue Tests
- Advanced Numerical Simulations
- Simplified Fatigue Life Calculations
- Effect of Whipping on Fatigue Life
- Conclusion

1. Background

- Wave-induced Hull Girder Vibrations;
  - ✓<u>Whipping</u>: Transient vibration
  - ✓<u>Springing</u>: Quasi-resonant vibration
- Depends on;
  - ✓Hull form
  - ✓Speed
  - ✓Sea state
  - ✓Heading – Wave direction
  - ✓Mass and damping

1. Background

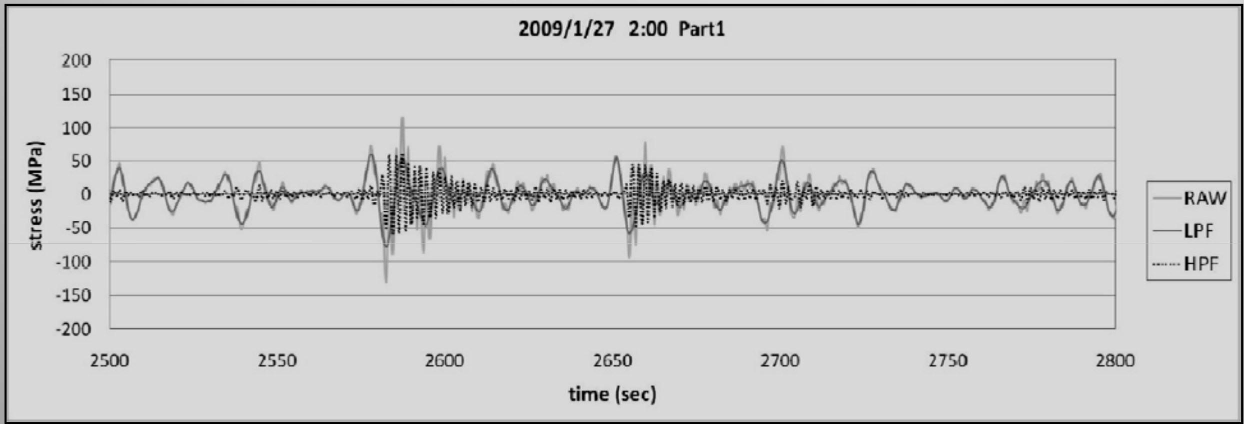
- Effects of Hull Girder Vibrations;
  - ✓ Fatigue life (Long-term)
  - ✓ Buckling and collapse (Short-term)
  - ✓ Brittle fracture (Short-term)
- Recently-raised Warnings;
  - ✓ Mainly against accelerated <u>fatigue damage</u>
  - ✓ Based on numerical simulations, scaled tank tests, in-service monitoring and simplified fatigue calculation method
  - ✓ Mainly from **Hydrodynamics** aspect

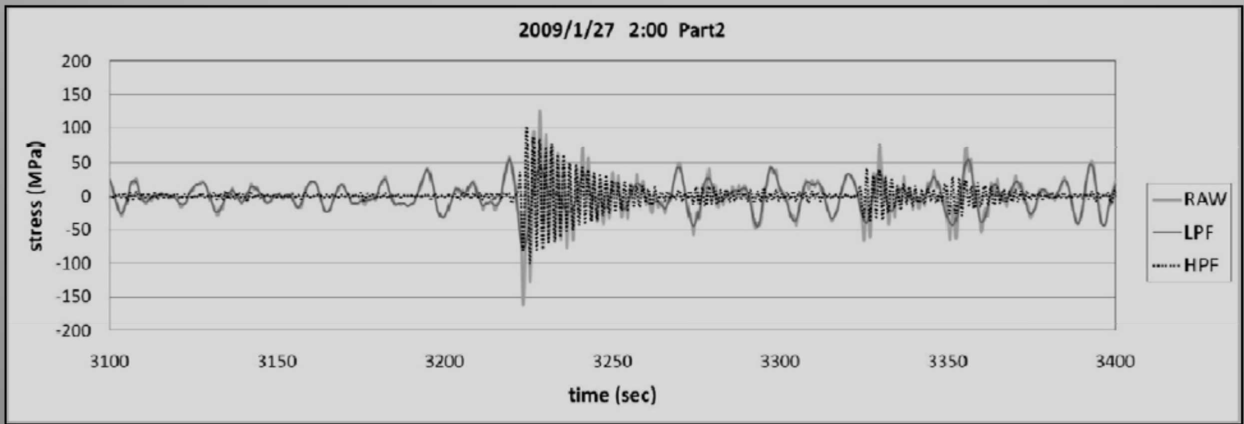
1. Background

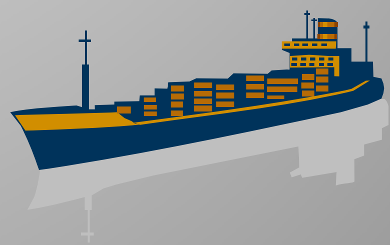
- Vibrations are not "**something new**";
  - ✓ Common throughout ship types & sizes
  - ✓ No frequent fatigue report to date
- Subject of present study;
  - ✓ Focused on effect of Whipping on fatigue
  - ✓ Review from **Strength** aspect
  - ✓ Based on in-service monitoring data, fatigue tests and advanced numerical simulations

2. Introduction to Whipping

- Actual Data of Whipping Stress;
  - ✓Monitored onboard large **Containerships**





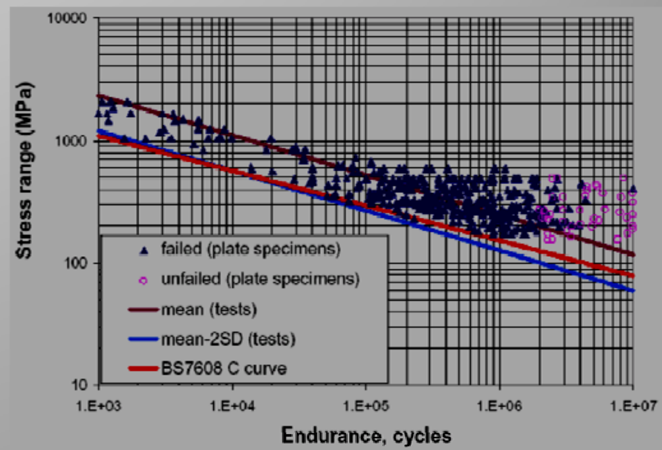


2. Introduction to Whipping

- **Features** of Monitored Whipping;
  - ✓5 times frequency of wave bending
  - ✓Diminution within 4 cycles of wave bending
  - ✓Smaller amplitude than wave bending in most cases
  - ✓Does not occur at all times even in rough sea condition
- **Less Effects** on **Oil Tanker**;
  - ✓Low speed, full hull form, small bow flare

3. Fatigue Tests

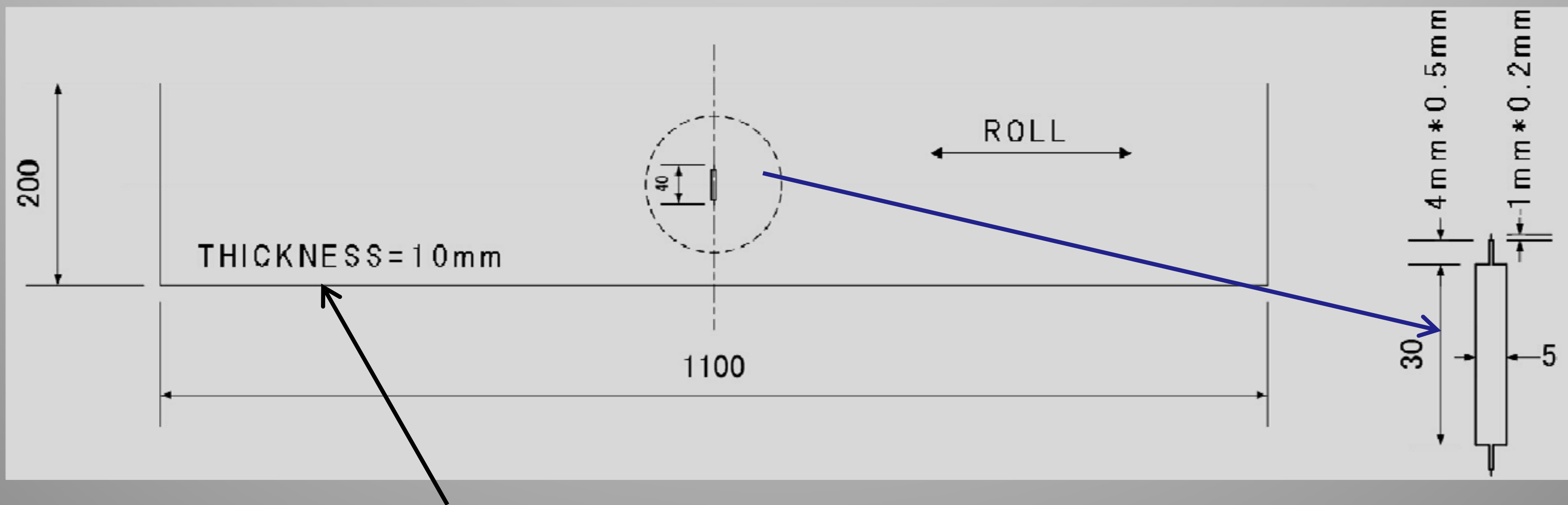
- Definition of Fatigue Life (Shipbuilding);
  - ✓ Not time to <u>initiate</u> microscopic crack
  - ✓ But time to <u>grow into</u> visually detectable crack in periodical close-up survey
- Depending on Weld Defects or Notches;
  - ✓ Varying in size & shape;
    - With as-weld specimens, a lot of fatigue tests are needed for statistical reason.



3. Fatigue Tests

➢ Fatigue Crack **Propagation** Tests;

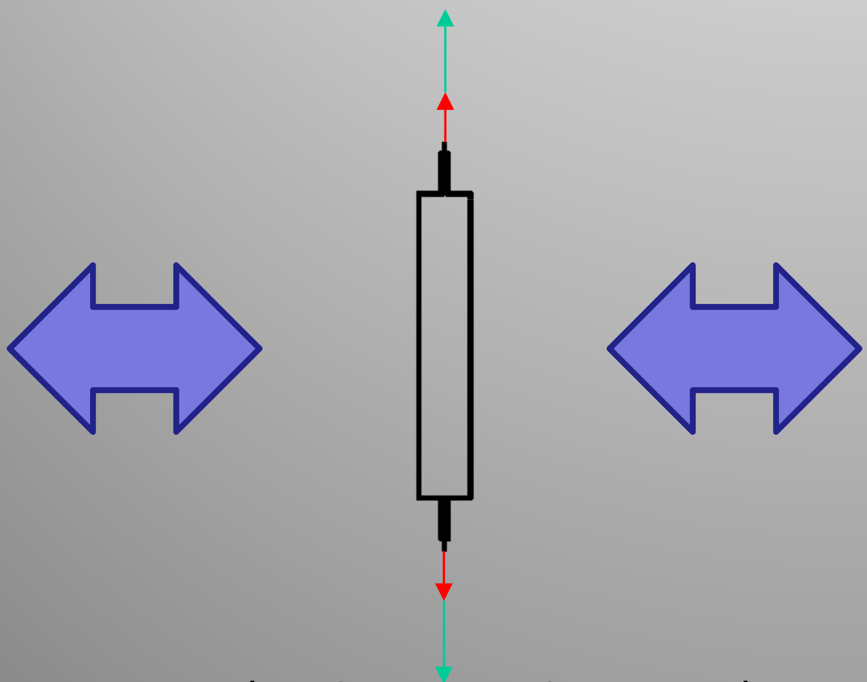
- ✓ To study effect of whipping on fatigue
- ✓ Flat bar specimen with center through-thickness notches (machined)



Base Steel Thickness: 13.5 mm or 12 mm

3. Fatigue Tests

- Definition of **fatigue life**;
  - ✓ Time (Stress cycle) to grow into 20 mm in fatigue crack length



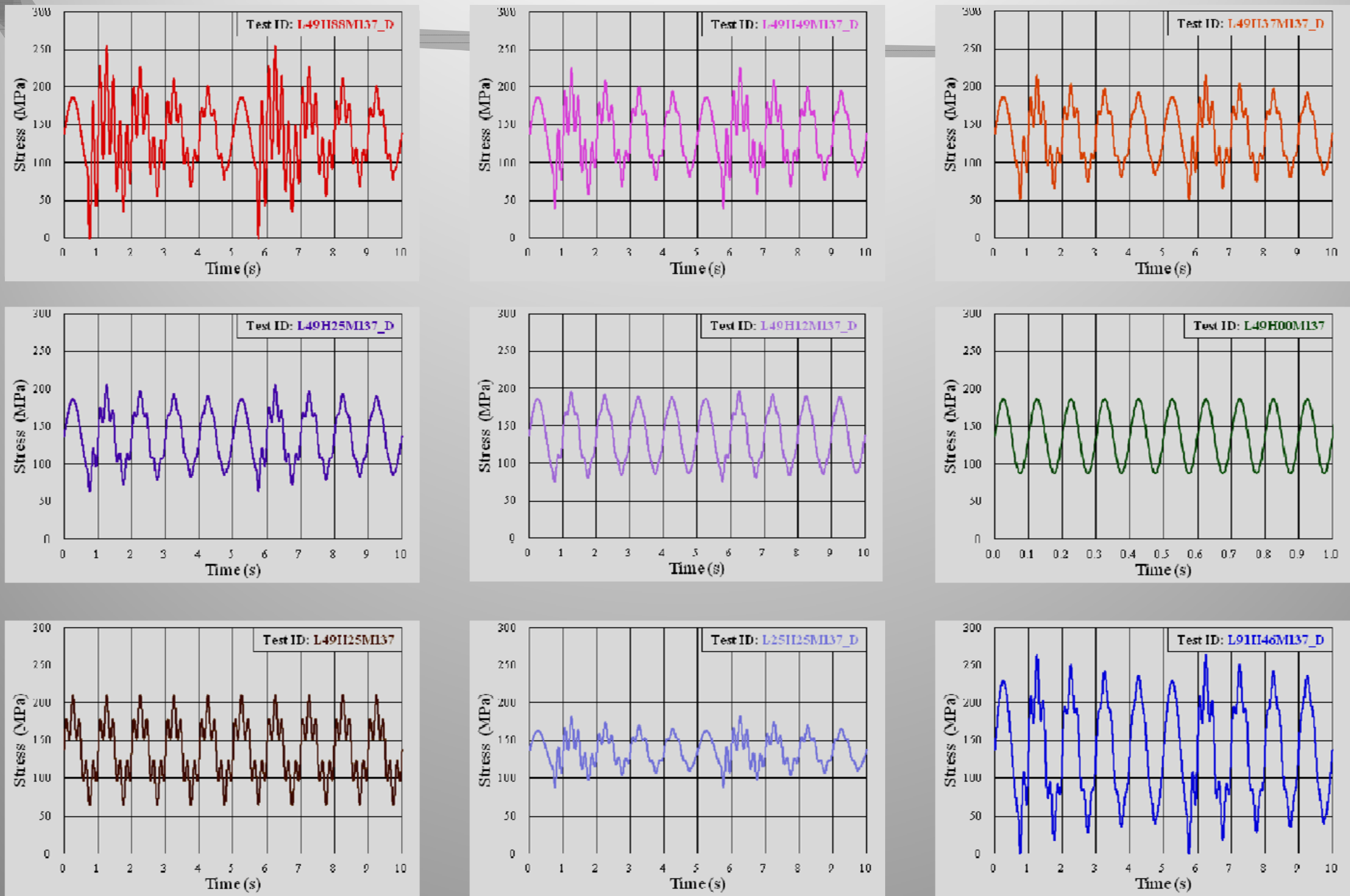
3. Fatigue Tests

- Applied Stress Cycles (Regular);
  - ✓ Low cycle represents wave bending
  - ✓ High cycle represents whipping
  - ✓ Cycle ratio of high to low: **0** or **5** (25)
  - ✓ Amplitude ratio of high to low: **0** ~ **1.8**
  - ✓ Damping: **0** or **0.1**
- Applied Stress Cycles (Irregular);
  - ✓ Low cycle: Semi-random
  - ✓ High cycle: Cycle ratio of **5** with damping

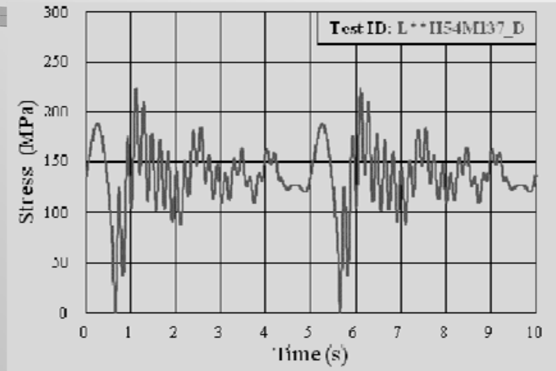
3. Fatigue Tests

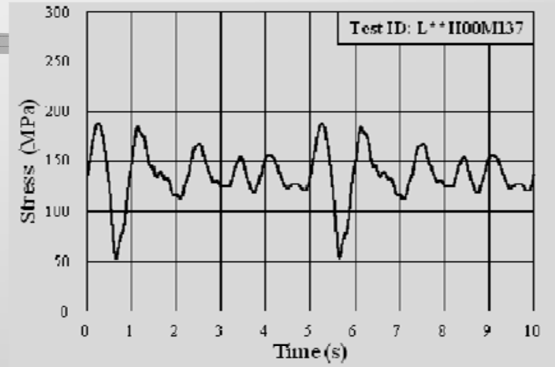
Test ID	Stress Amplitude (MPa)		Stress Ratio (H/L)	Cycle Ratio (H/L)	Mean Stress (MPa)	Damping
	Low Cycle	High Cycle				
L99H46M137_D	± 91.0	± 46.0	0.50	5	+ 137.2	Given
L49H88M137_D	± 49.0	± 88.2	1.80			
L49H49M137_D		± 49.0	1.00			
L49H37M137_D		± 37.0	0.76			
L49H25M137_D		± 25.0	0.51			
L49H12M137_D		± 12.0	0.24			
L25H25M137_D	± 25.0	± 25.0	1.00			
L**H54M137_D	Random	± 54.0	Random			
L**H00M137	Random	± 00.0	Random	0		None
L49H25M137	± 49.0	± 25.0	0.51	5		
L49H00M137		± 00.0	0.00	0		
L49H00M078		± 00.0			+ 078.4	
L49H25M078		± 24.5	0.51	25		
L49H10M078		± 09.8	0.20			
L59H00M078	± 58.8	± 00.0	0.00	0		

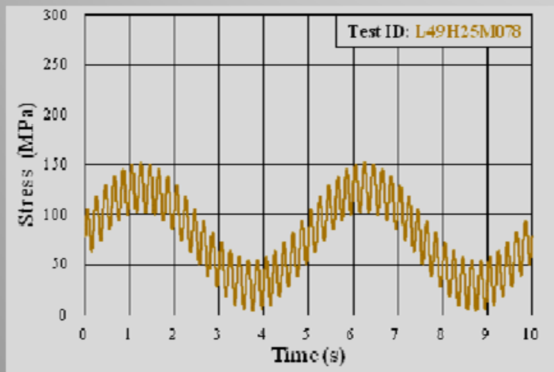
3. Fatigue Tests

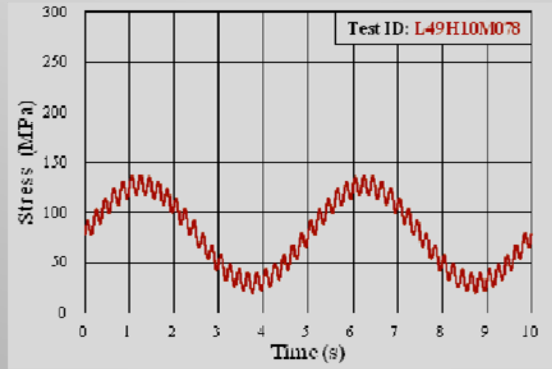


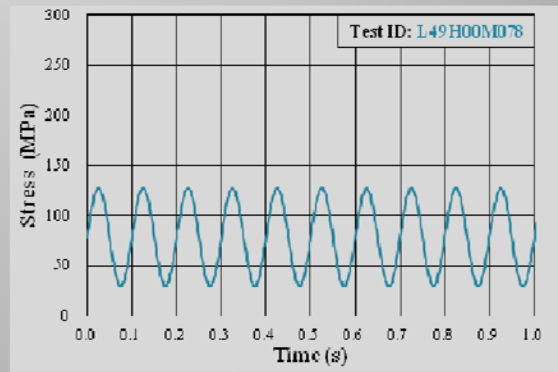
3. Fatigue Tests

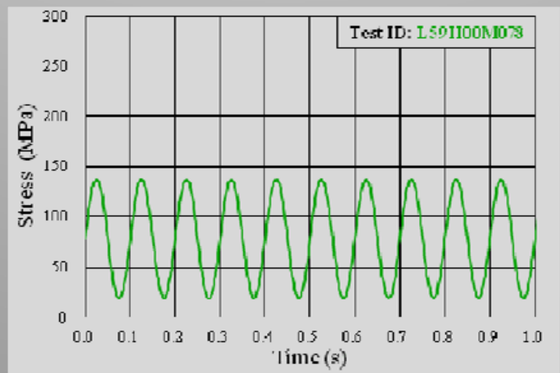




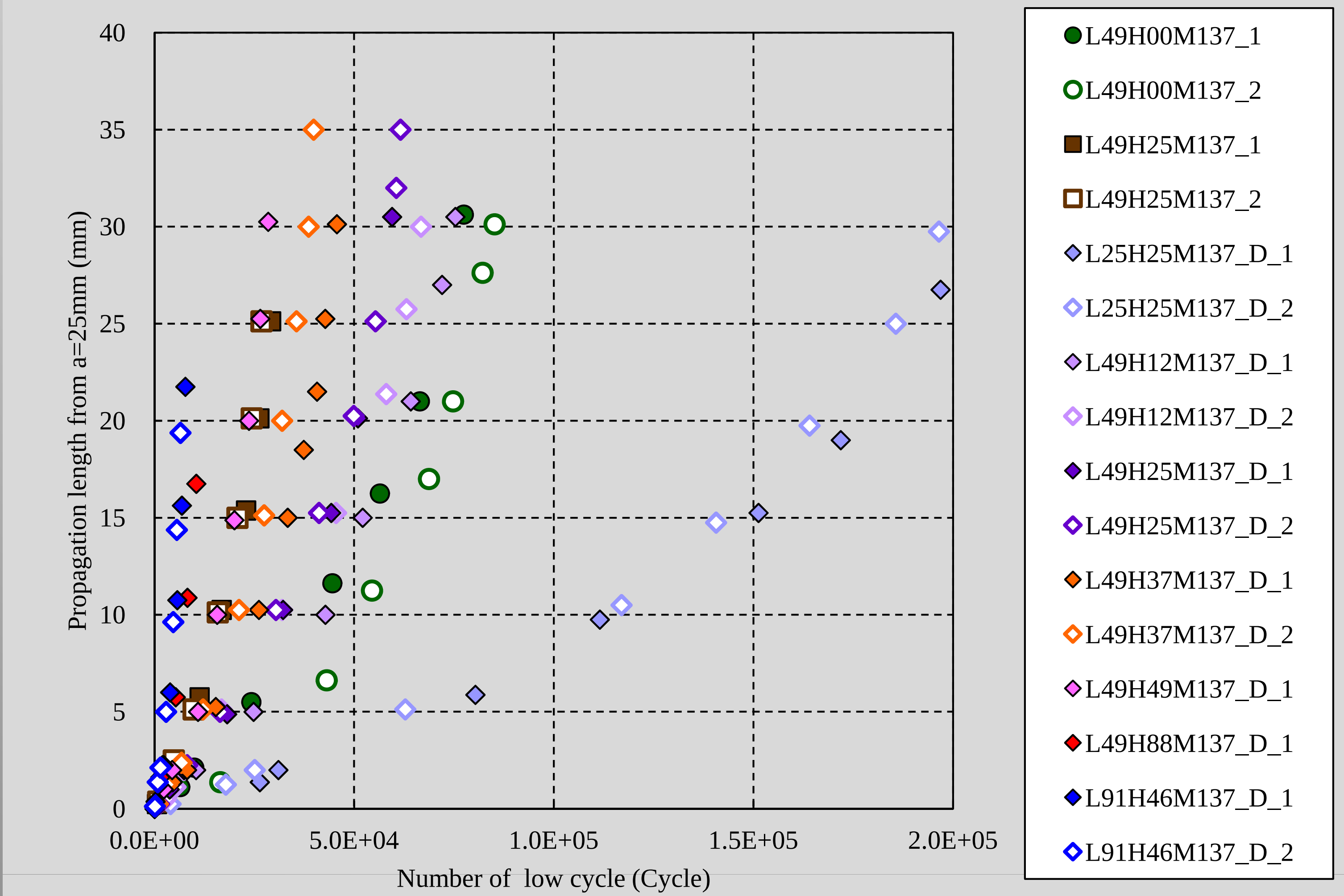








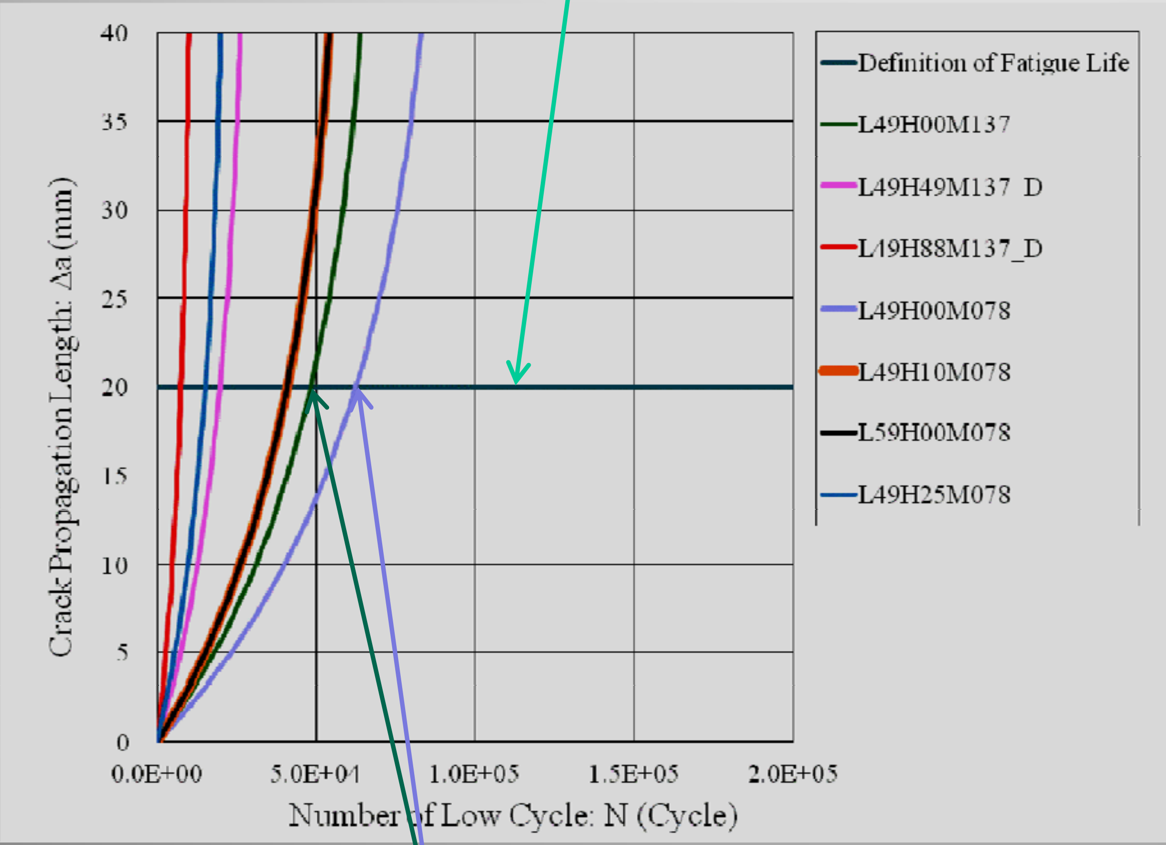
3. Fatigue Tests



Propagation of Fatigue Crack is stable because initial notches are machined.

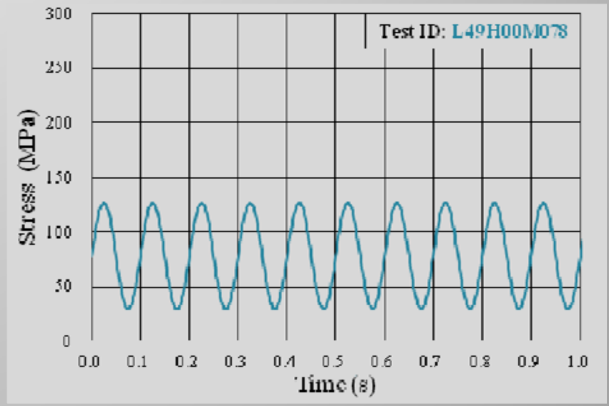
3. Fatigue Tests

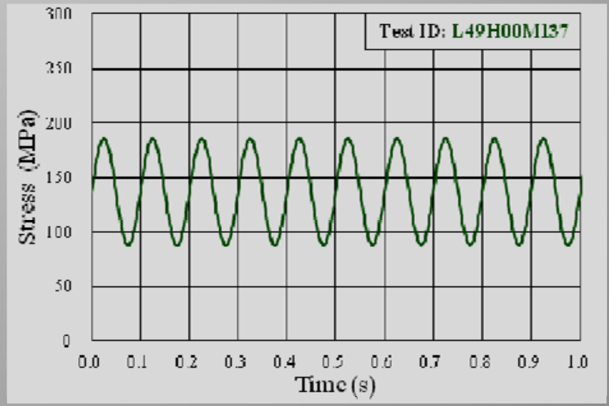
Equivalent Initiation of Fatigue Crack



Fitted Curves

Base steel plate of 13.5 mm

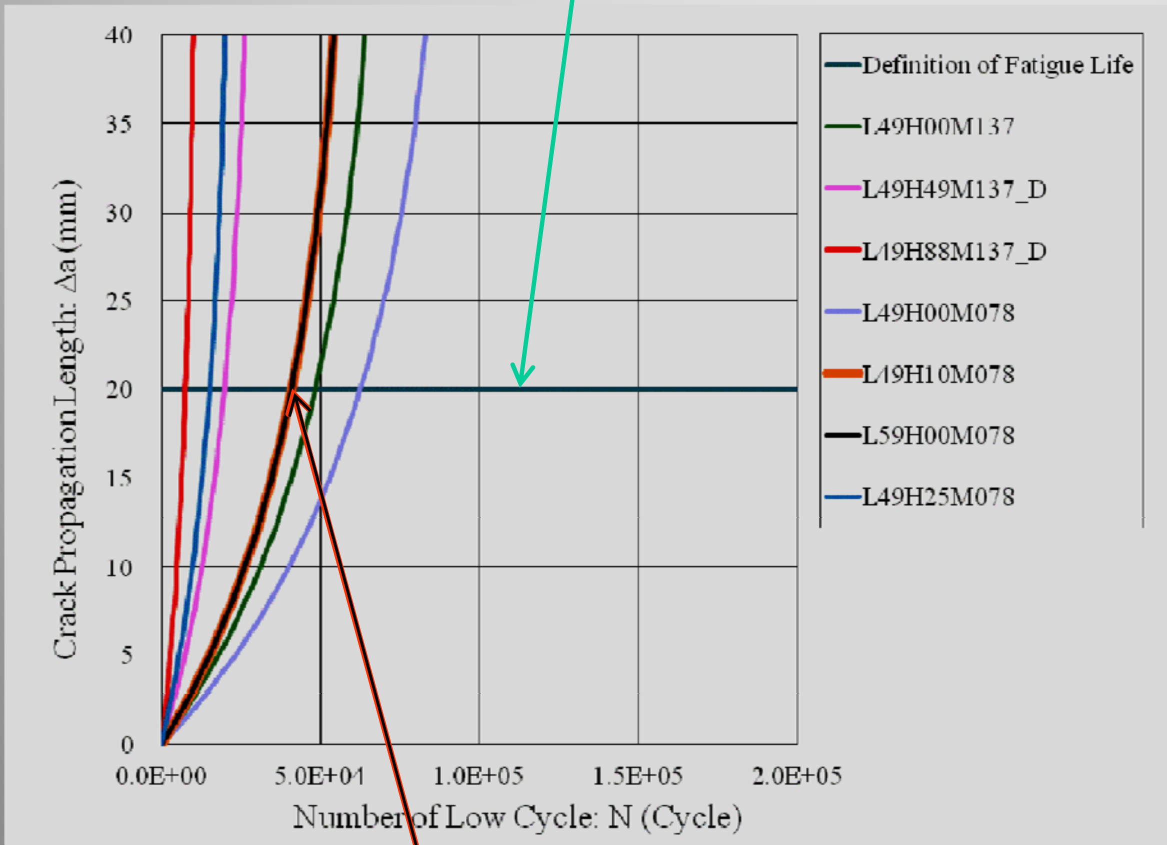




L49H00M137 - **L49H00M078** : Difference in mean stress

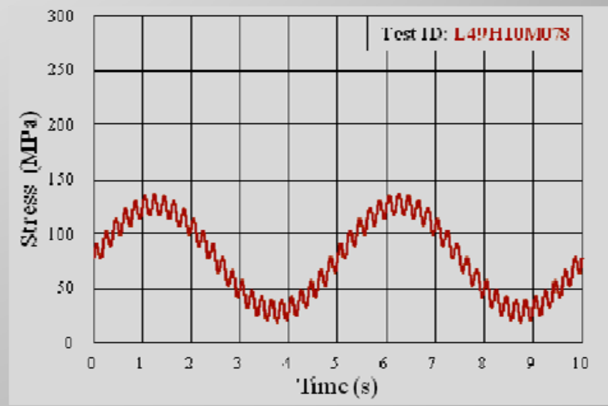
3. Fatigue Tests

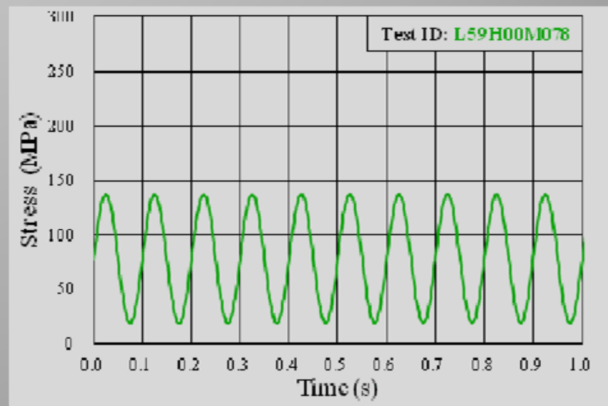
Equivalent Initiation of Fatigue Crack



Fitted Curves

Base steel plate of 13.5 mm

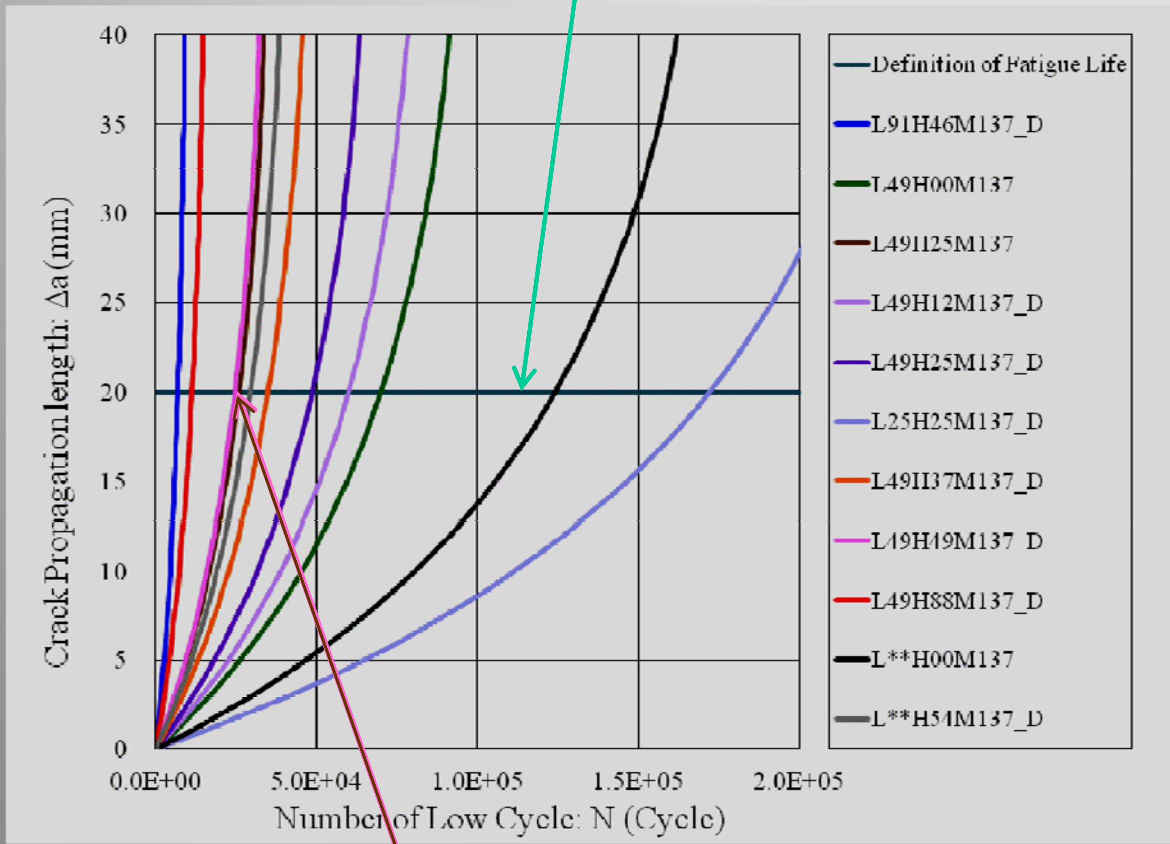




L49H10M078 - **L59H00M078** : Representation by envelope cycles

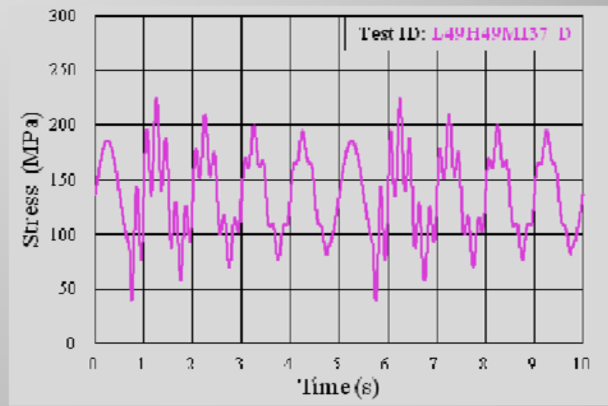
3. Fatigue Tests

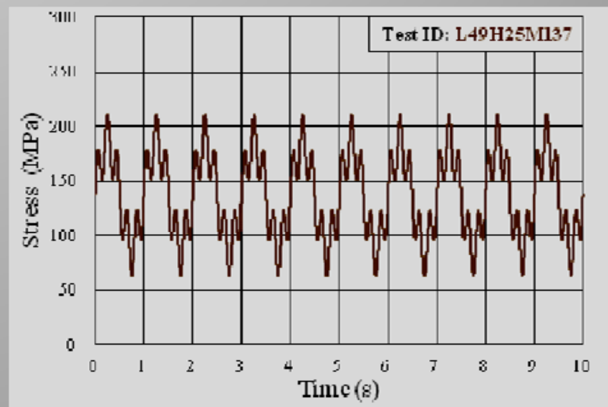
Equivalent Initiation of Fatigue Crack



Fitted Curves

Base steel plate of 12.0 mm



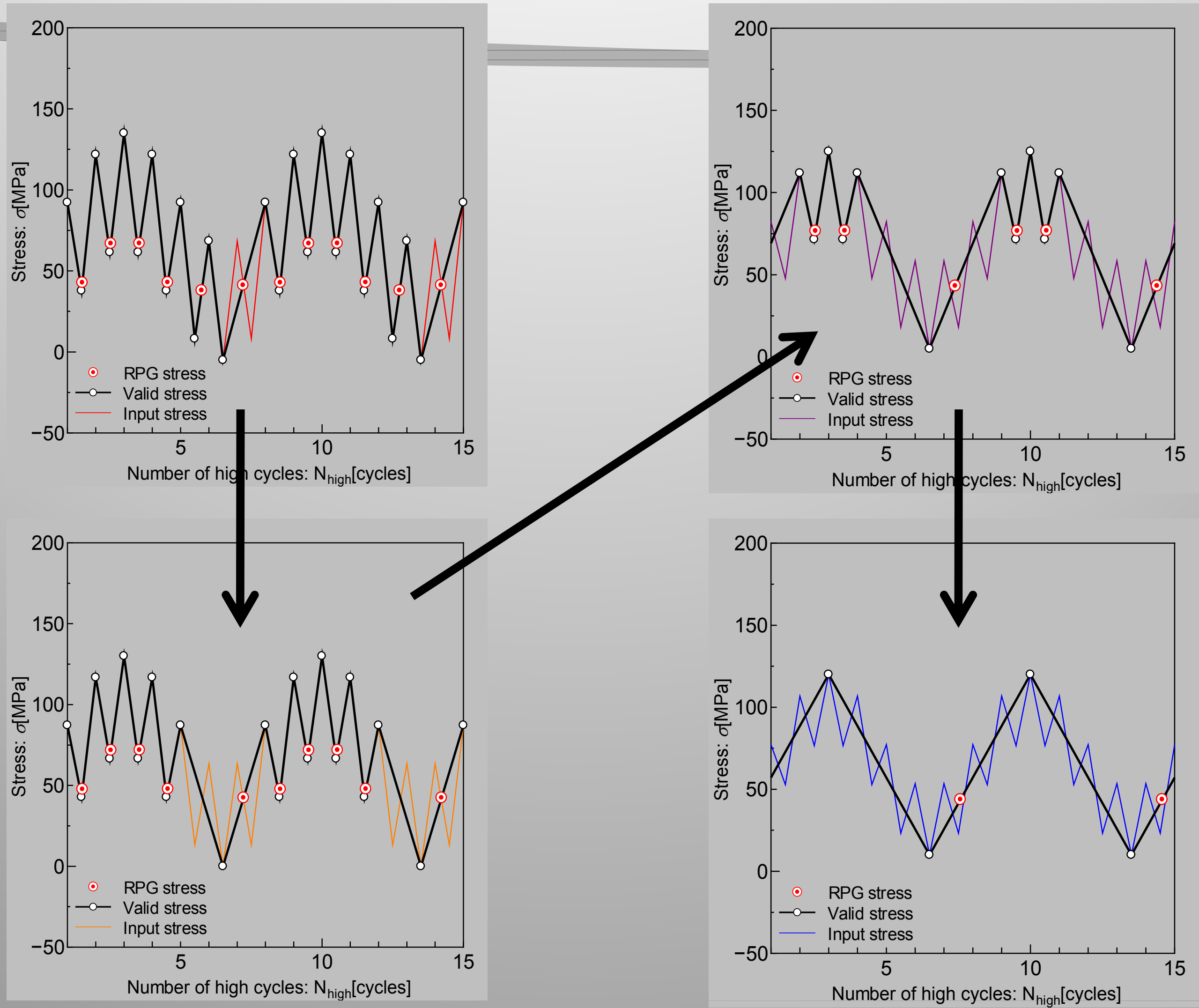


L49H25M137 - **L49H49M137_D**: Representation by average stress

4. Advanced Numerical Simulations

- FLARP Code;
  - ✓ Based on advanced fracture mechanics approach applying load criterion;
    - RPG (Re-tensile Plastic zone Generating)
  - ✓ Control parameter of extraction of loading history effective in driving fatigue crack propagation;
    - Critical value of plastic energy in the microscopic vicinity of a fatigue crack

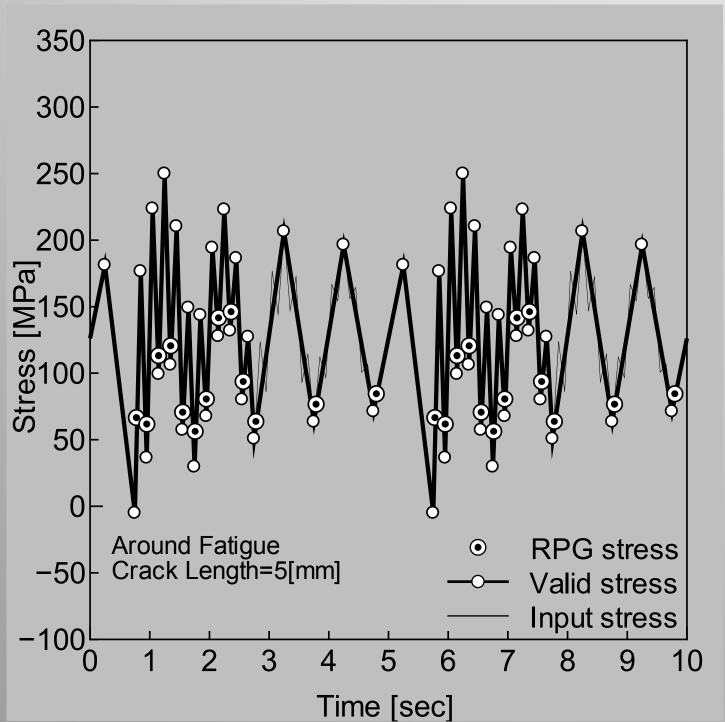
4. Advanced Numerical Simulations

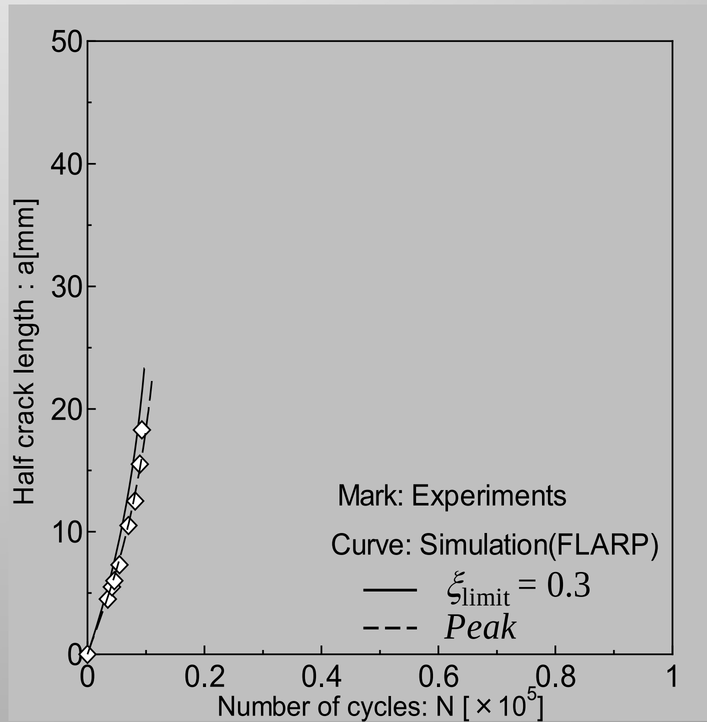


Skipping of actual stress cycles based on RPG load criterion

4. Advanced Numerical Simulations

Numerical simulation of L49H88M137_D





- Effective Duration of High Cycles;
  - ✓ Almost 2 of 5 low cycles

5. Simplified Fatigue Life Calculations

- Equivalent Pulsating Stress Ranges;
  - ✓ Extracted by Rainflow counting
- S-N Curve;
  - ✓ Derived from actual fatigue tests
- Calculated **Traditional** Damage Factors;

Test ID 13.5 mm Series	Damage Factor (Calculated) **D**	Actual Ratio (Fatigue Test) **Ra**	Overestimation Rate **D / Ra**
L49H00M137	**1.00**	**1.00**	**1.00**
L49H88M137_D	10.86	6.47	1.68
L49I149M137_D	4.58	2.45	1.87
L49I100M078	**1.00**	**1.00**	**1.00**
L49H25M078	7.08	4.14	1.71
L49H10M078	2.35	1.53	1.54

Tend to overestimate effect of high cycles

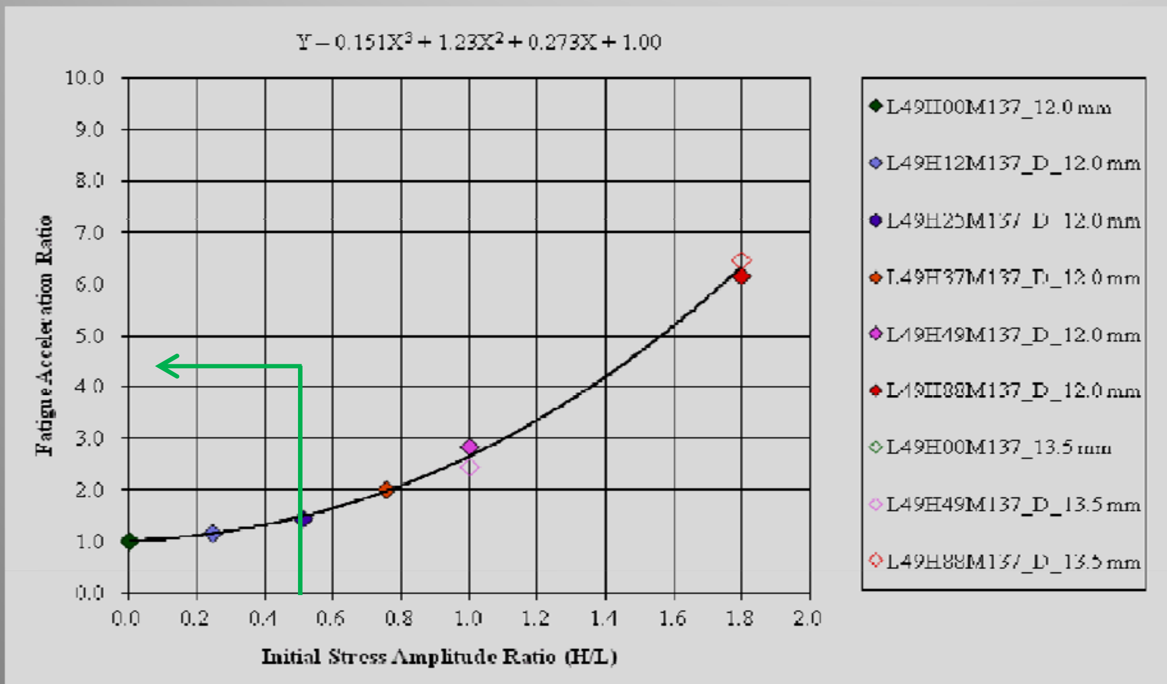
Fatigue can lead to errors & accidents and reduced productivity.

5. Effect of Whipping on Fatigue Life

- Majority of Initial Whipping Stress;
  - ✓ Smaller than wave bending stress
- Effect of Such Whipping Stress Cycles;
  - ✓ Not number of high cycles
  - ✓ But average stress amplitude;
    - 0.5 * initial whipping stress amplitude
- Majority of Whipping;
  - ✓ Represented by increased stress amplitude of wave bending stress cycles of low freq.

5. Effect of Whipping on Fatigue Life

- Fatigue Damage Acceleration Rates;
  - ✓ Given majority of amplitude ratios of <u>high</u> cycle to <u>low</u> cycle < 0.5;
  - ✓ Measured Acceleration rates: 1.0 ~ 1.5



Acceleration rates;

Close relationship between **amplitude ratio** of <u>high</u> cycle to <u>low</u> cycle

5. Effect of Whipping on Fatigue Life

- Fatigue Damage Acceleration Rates;
  - ✓ Whipping of **Containership** in rough sea;
    - Not at all times
    - Fatigue damage acceleration rate <u>throughout</u> **Containership's** lifetime: Substantially less than 1.5
  - ✓ Effect of whipping on Oil tankers;
    - Fatigue damage acceleration rate <u>throughout</u> **Oil Tanker's** lifetime: Less than **Containership** ~ 1.0

5. Effect of Whipping on Fatigue Life

- Fatigue Life of Ships;
  - ✓ In world-wide operation;
    - Around 2 times as long as that of ships to be operated in North Atlantic throughout her lifetime
  - ✓ Effect of whipping on **CSR Oil Tankers**;
    - North Atlantic trade: < 5 % of total
    - Any **Oil Tanker** needs not be operated in North Atlantic throughout her lifetime
  - ✓ Margin of 2.0 well covers rate of 1.5

6. Conclusion

- Actual whipping data monitored onboard large containerships were studied.
- A series of fatigue crack propagation tests were performed to simulate whipping and obtain fatigue damage acceleration ratios.
- Advanced numerical simulations and simplified fatigue life calculations of fatigue crack propagation tests were made to study the underlying mechanism and factors in question from **strength** aspect.

6. Conclusion

- The results of studies suggest that the effect of whipping on fatigue life of containerships is limited.
- Based on the qualitative comparison with containerships, the effect of whipping on fatigue life of oil tankers is more limited.
- While the effect of whipping on the fatigue life of ships should not be neglected, no overreaction is needed.

Thank you for your attention.