Colombia mar2019

VI CONGRESO INTERNACIONAL DE DISEÑO E INGENIERÍA NAVAL

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XXVI CONGRESO PANAMERICANO DE INGENIERÍA NAVAL, TRANSPORTE MARÍTIMO E INGENIERÍA PORTUARIA

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A Study on the Effect on Fatigue Damage due to Different Shipping Routes

Luis De Gracia*, Hitoi Tamaru**, Naoki Osawa*, Adan Vega***, Hector Ruiz*

*Graduate School of Engineering, Osaka University, Suita, Osaka, Japan

** Graduate School of Marine Science and Technology, Tokyo Maritime Science and Technology, Tokyo, Japan

***Zoartech Consulting, Panama City, Panama

大阪大学
OSAKA UNIVERSITY

Outline

- Background
- Objectives
- Case of study
- Wave Statistics
  - Weather routing algorithm
  - Wave direction distribution
- Statistical wave storm model
  - Wave scatter diagram
  - Stress distribution
- Fatigue assessment
- Conclusions / Future work

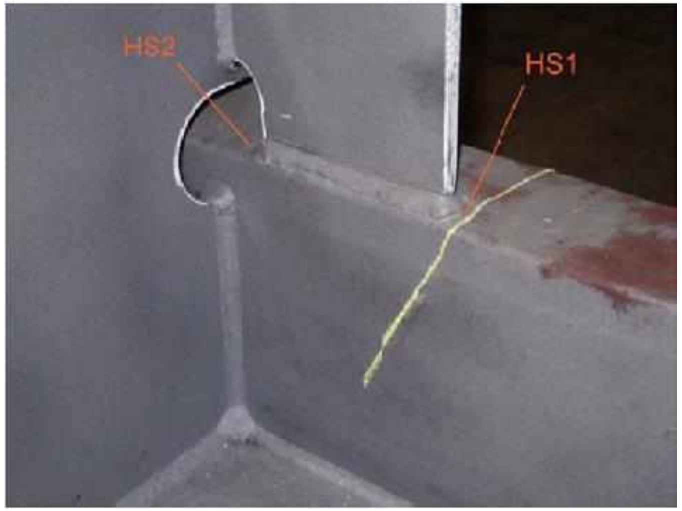
Background

Ship's size has been rapidly increased

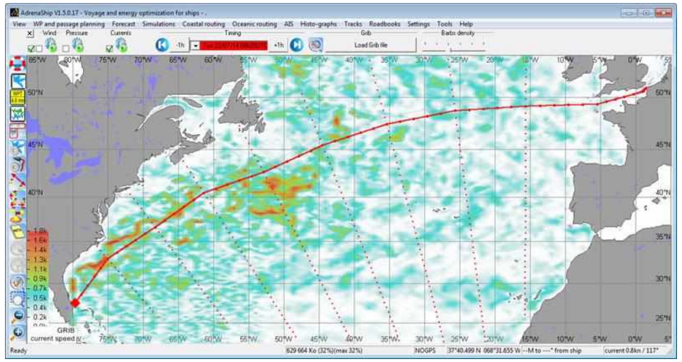
Premature fatigue failures are found in ship structural members.

Ship Energy Efficiency Management Plan (SEEMP)

Improve voyage planning.

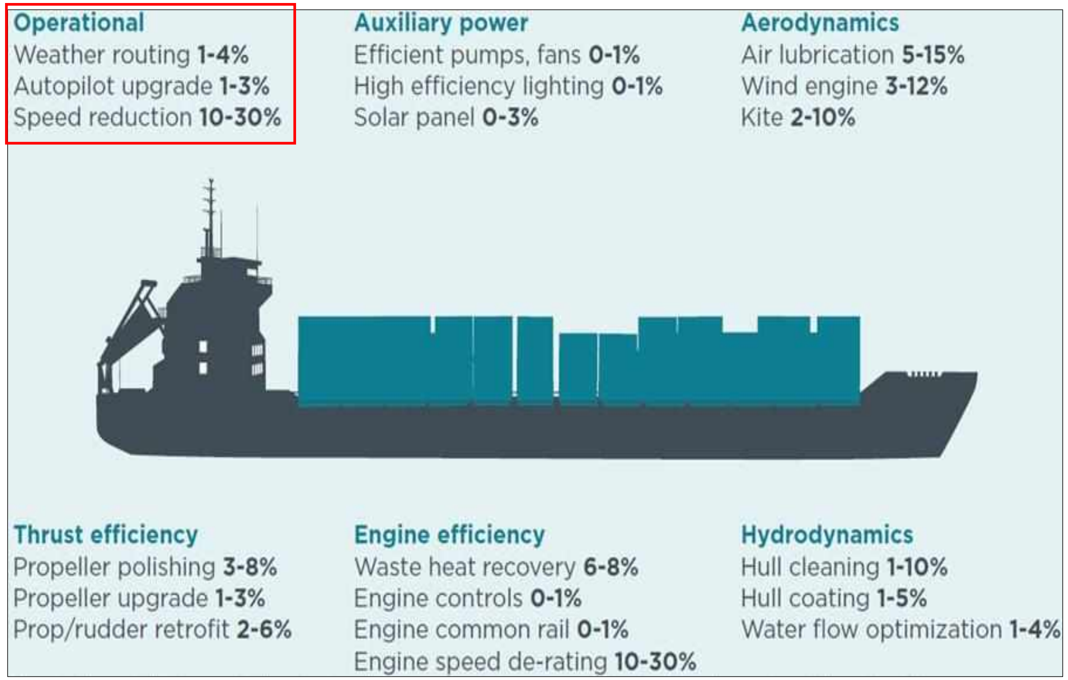


Fatigue crack at the side longitudinal of a Panamax container vessel (Adapted from Fricke et al. (2010)).

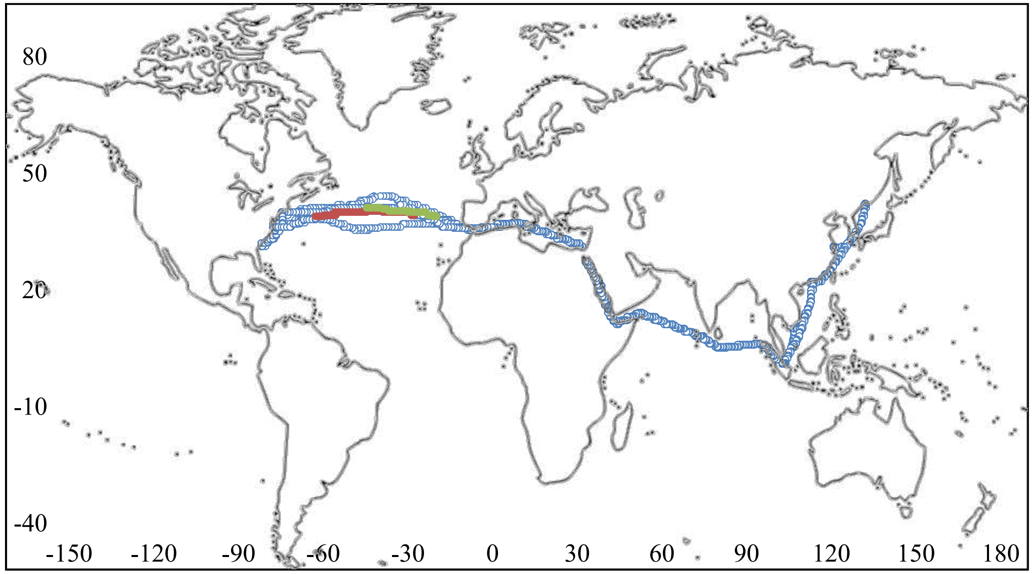


Adapted from: http://www.adrenaship.com/products/ocean-routing.html

Background



Potential fuel use and CO_2 reductions from various efficiency approaches for ships. International Council on Clean Transportation (ICCT, July 2013).



Usual operation route of the containerships

Ship operation based in weather routing becomes necessary

Objectives

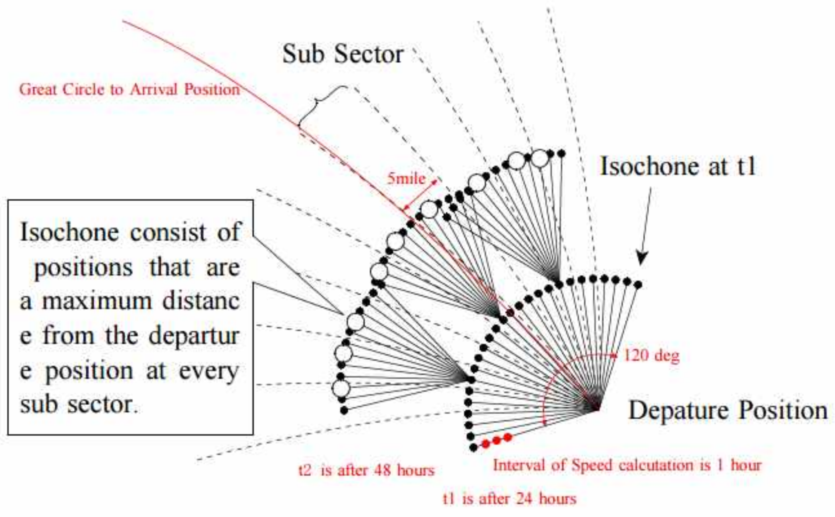
- Introduce an advanced practical method to generate wave load sequence for fatigue assessment of ship structural member, that can be applied to ship weather routing cases.

- Simulate wave load sequences experienced by a ship that sails in two different ocean routes.

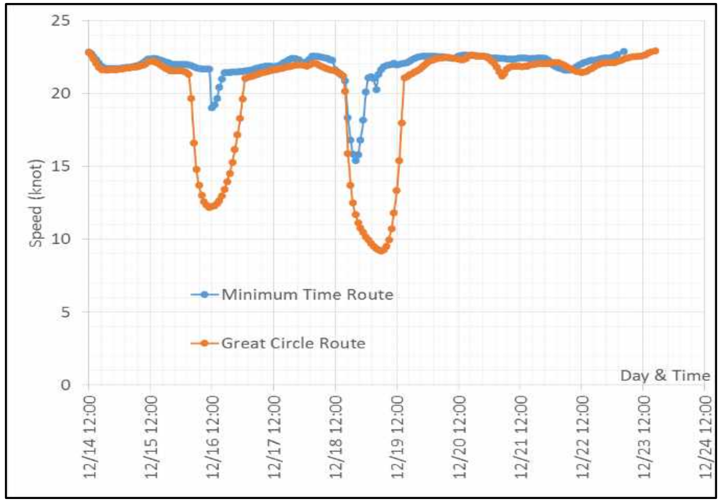
- Clarify the effect on the estimated fatigue damage of ship structural member, due to ships which follow weather routing.

Weather routing algorithm

- Maximize the safety and crew comfort
- Minimum fuel consumption
- Minimum time underway



Minimum time route algorithm.

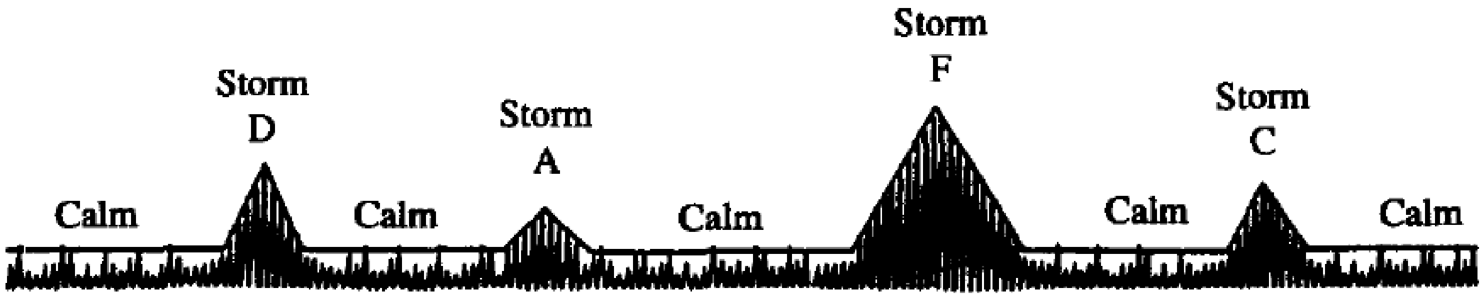


Time history of speed on minimum time route and great circle route on 14th Dep. 2003 from S.F. to Tokyo

The relationship between ship speed loss, relative heading angle and significant wave height is taken into account.

Statistical wave model: Storm Model

- The model assumes that oceanography phenomena can be divided into calm sea and storm conditions
- The calm sea is composed of time-independent values of Hs and crescendo/de-crescendo values of Hs for a storm
- The random sea states can be modelled with the random significant wave height Hs



Simplified random loading model for fatigue analysis of ship structural members.*

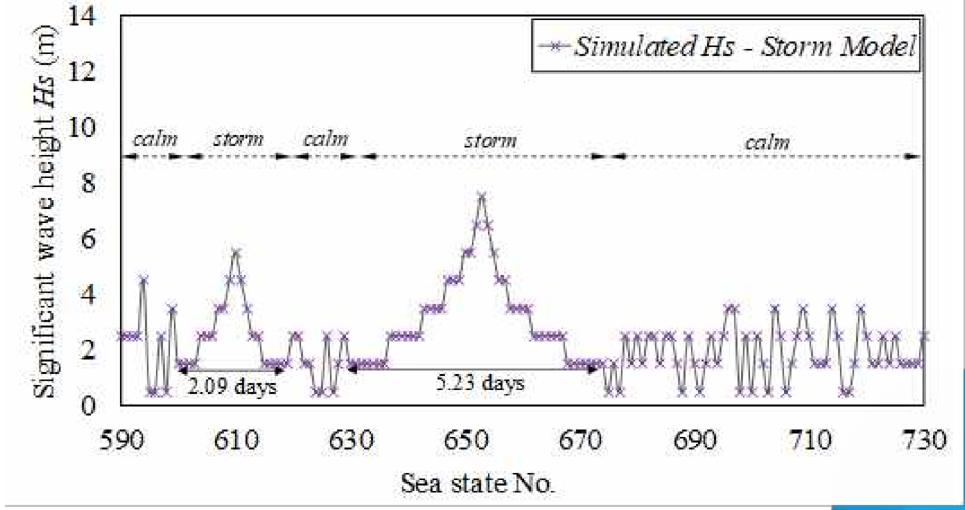
*Tomita, Y., Matoba, M., Kawabe, H.: Fatigue Crack Growth Behavior under Random Loading Model Simulating Real Encountered Wave Condition, Marine Structure, vol. 8, pp. 407-422 (1995).

Statistical wave model: Storm Model

- The variance of storm duration is considered

- The generation of Hs time history needs a storm profile
  - the probability density of the storm and calm sea;
  - the probability density of the Hs in a calm sea;
  - the probability density of the *i*-th storm class S(i); and
  - the Hs profile for each storm class n(Hs)i.

- The long-term distribution of Hs is assumed to follow the Weibull distribution



Significant wave height time history with variable storm duration generated by storm model simulation

Wave load and structural stress

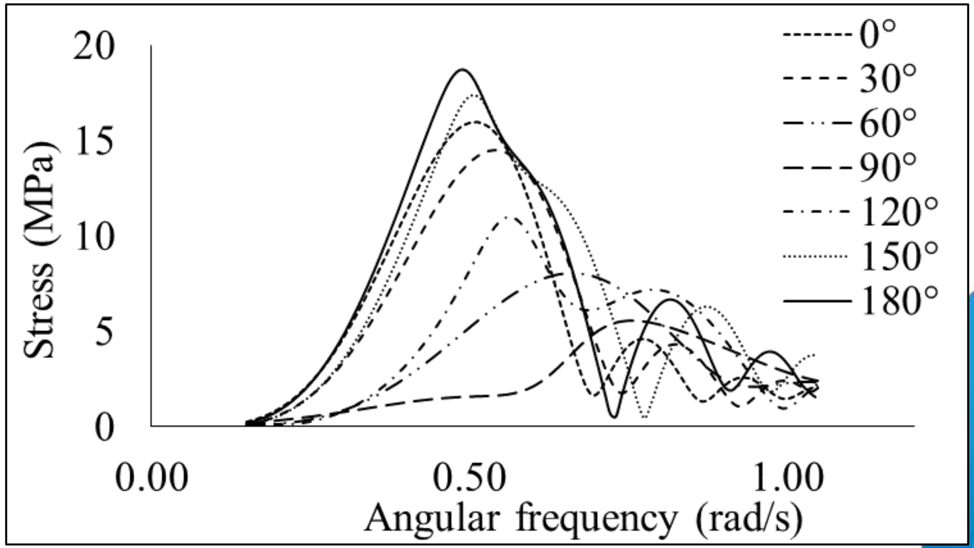
Wave spectrum

$$S(\omega|H_s, T_z) = \frac{4\pi^3 H_s^2}{T_z^4 \omega^5} exp\left[-\frac{1}{\pi}\left(\frac{\omega T_z}{2\pi}\right)^{-4}\right]$$

ISSC/ITTC Wave Spectrum

Transfer function

$$H_\sigma(\omega|U_0,\theta) = A_1 H_v(\omega|U_0,\theta) + A_2 H_h(\omega|U_0,\theta) + A_3 H_t(\omega|U_0,\theta) .$$



Target structural stress RAO

Structural stress response spectrum

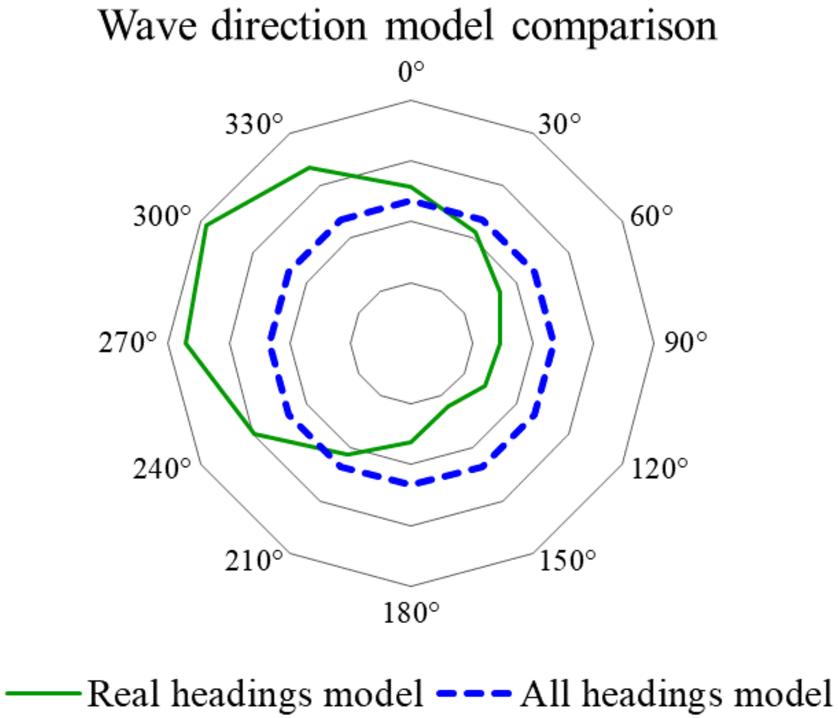
$$S_\sigma(\omega_e|U_0,\theta,H_s,T_z) = |H_\sigma(\omega_e|U_0,\theta)|^2 S(\omega_e|H_s,T_z),$$

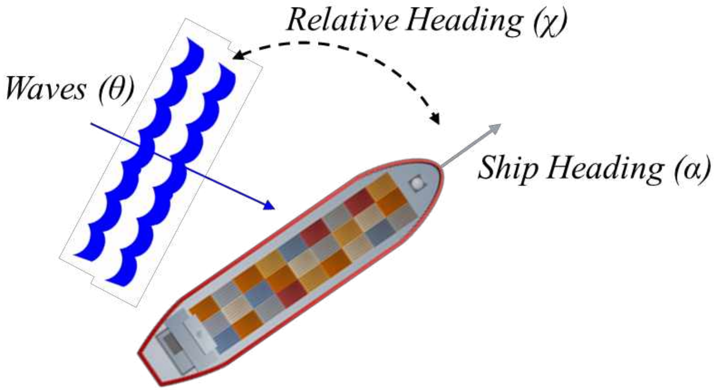
Sea state $S(\omega|H_s, T_z)$ with a forward speed U and heading angle θ

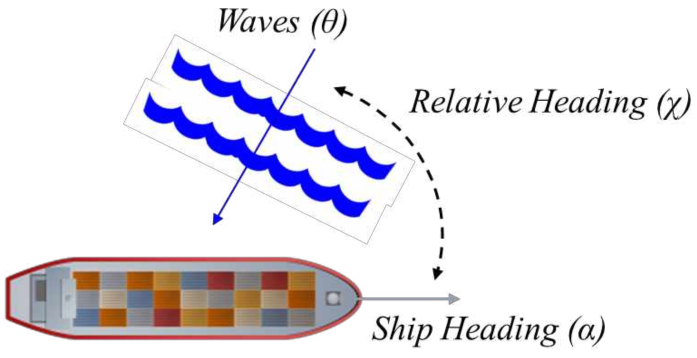
ω_e is the encountered wave frequency and the encountered wave spectrum $S(\omega_e)$

A_1, A_2, and A_3 are the structural stress caused by a unit amplitude vertical bending, horizontal bending, and torsion

Wave load and structural stress



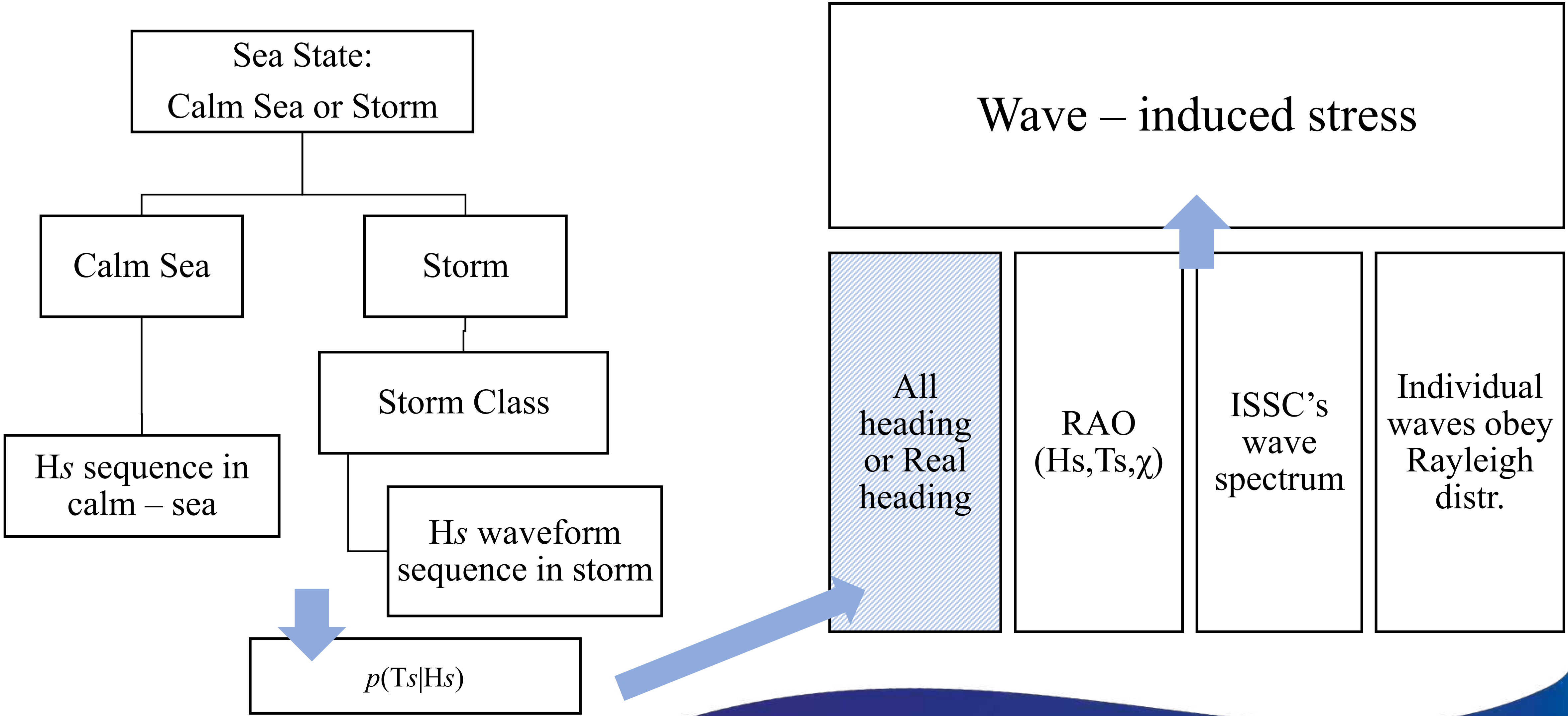




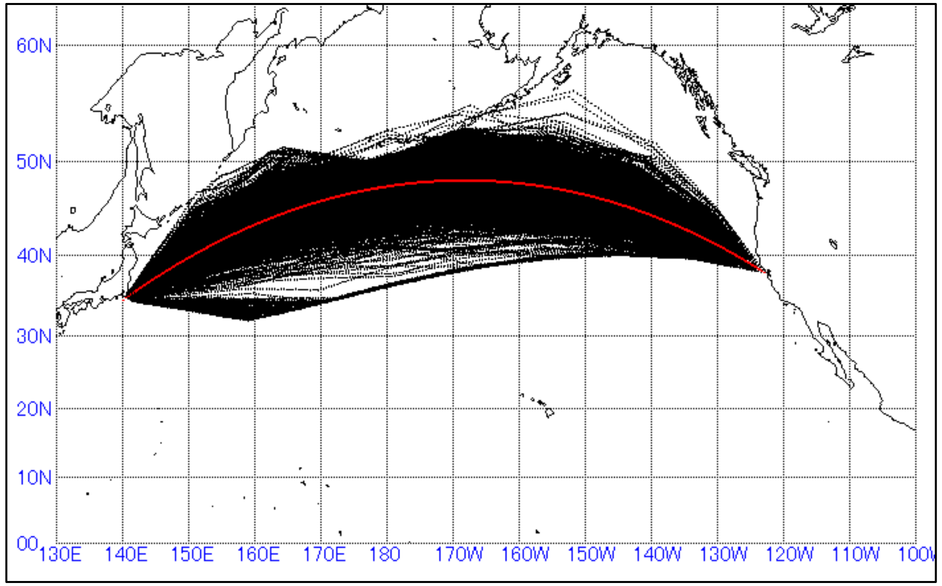
Relative Angle $\chi = \sigma - \theta$

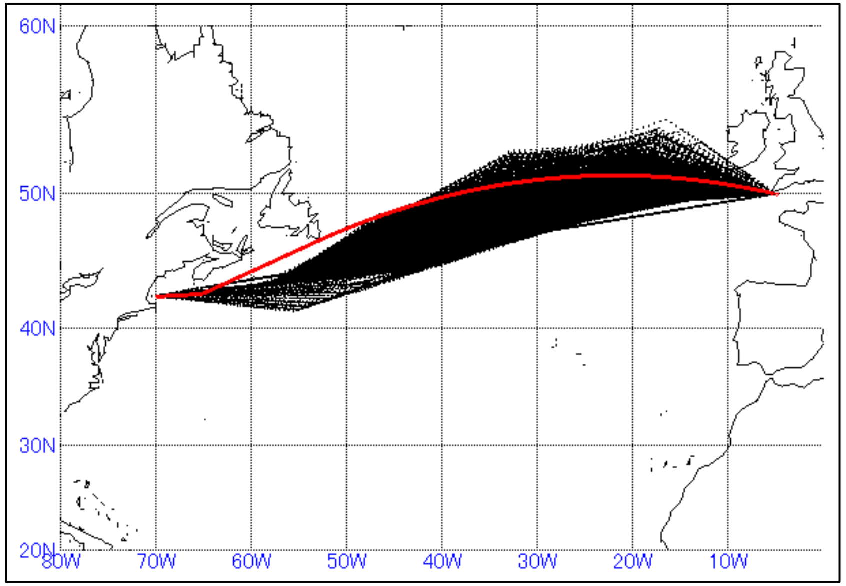
Θ is chosen by random selection considering $wave\ direction\ occurrence\ probability$

Wave load history generation



Case of Study





North Pacific Ocean:

- Japan - United States route

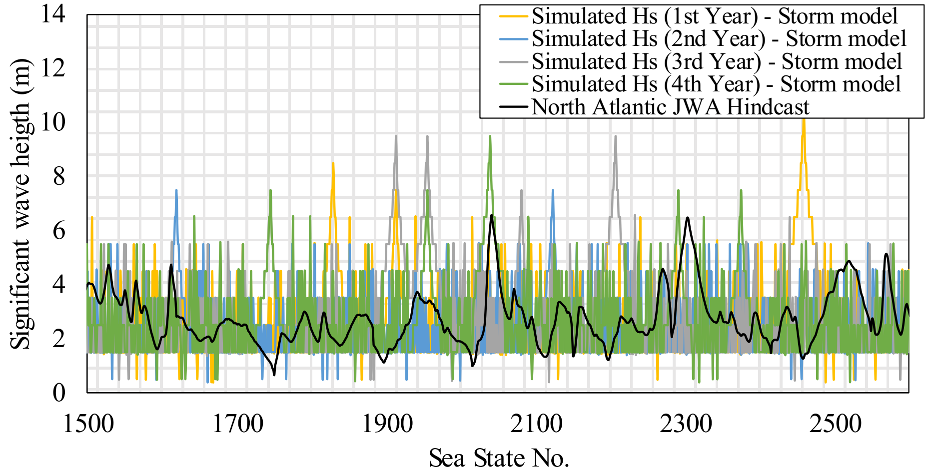
North Atlantic Ocean:

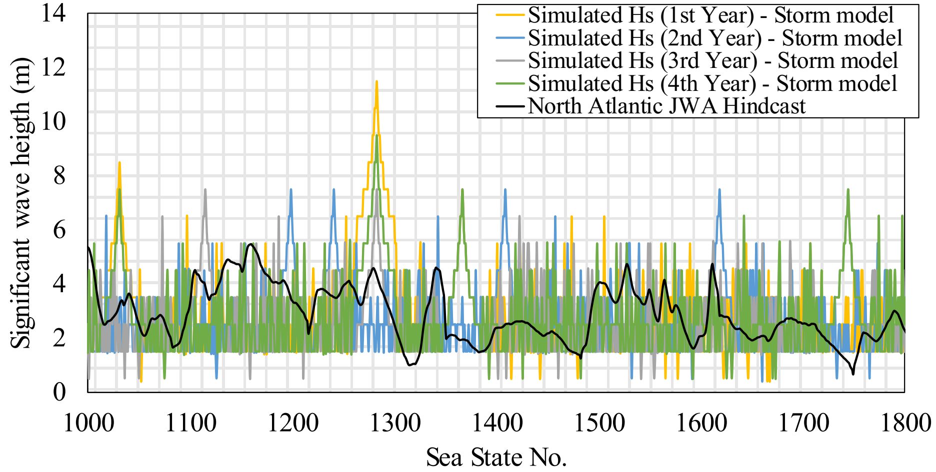
- United States – Europe route

January 1st, 2000 – December 31st, 2010.
Japan Weather Association (JWA) hindcast data

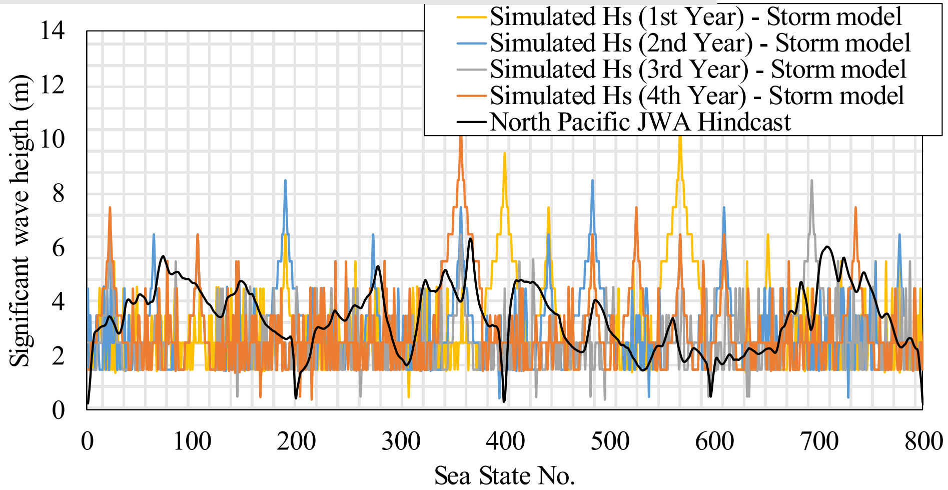
Wave statistics

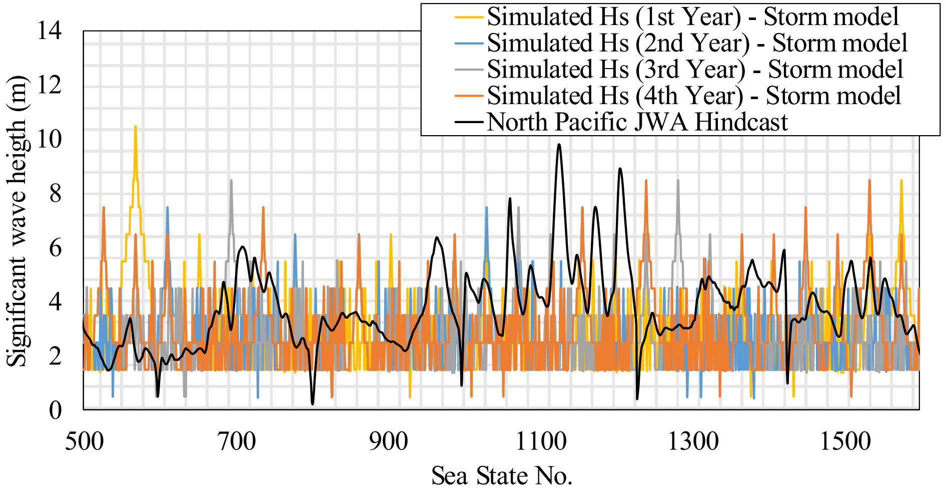
North Atlantic



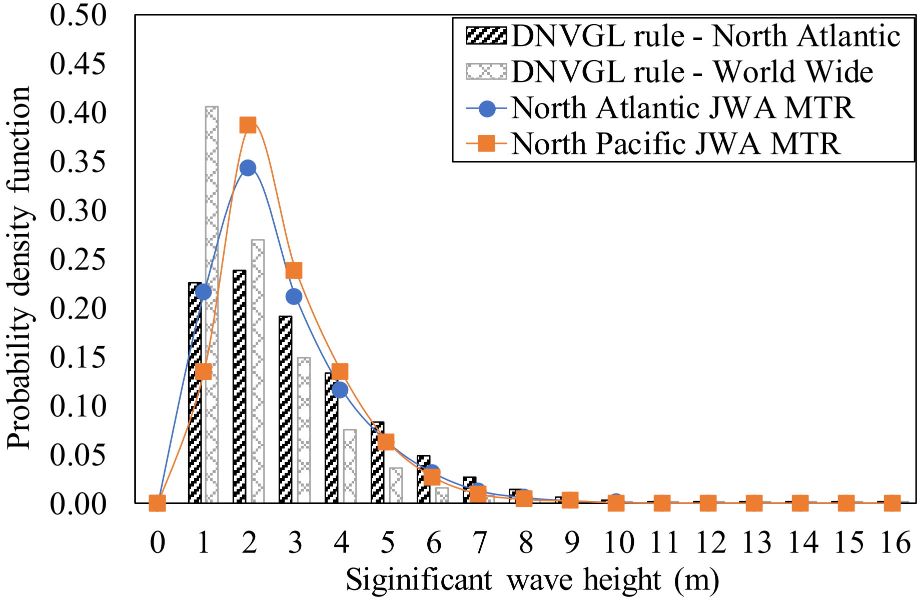


North Pacific





Wave statistics



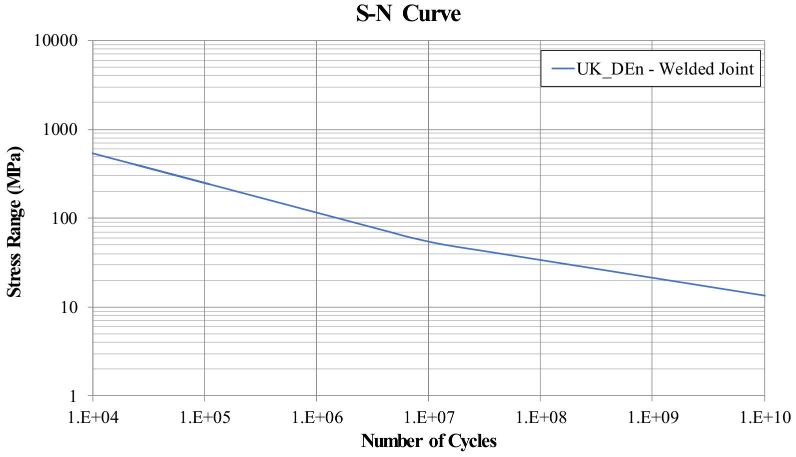
Statistic of Hs	North Atlantic JWA Hindcast		North Atlantic Storm Model	
	Mean	Std	Mean	Std
First moment E[Hs]	2.68	1.46	2.75	1.39

Statistic of Hs	North Pacific JWA Hindcast		North Pacific Storm Model	
	Mean	Std	Mean	Std
First moment E[Hs]	2.74	1.33	2.85	1.32

The first moment statistics can be estimated with good accuracy.

Fatigue assessment

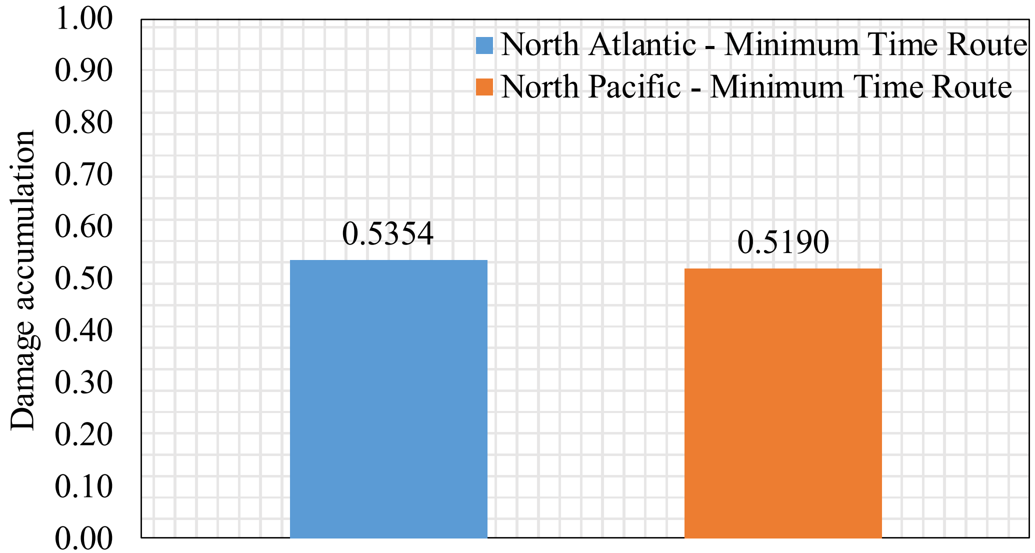
S-N Cumulative fatigue damage



Nominal design S-N curves (UK-DEn)

$$D_{10yr} = \sum_{i=1}^{S} \left(\frac{n_i}{N_i} \right)$$

Mean Fatigue Damage Comparison - UK DeN / D curve		
Route	North Atlantic Storm Model - MTR	North Pacific Storm Model - MTR
$D_{10YR\text{-}mean}$	0.5354	0.5190
L_{fmean} (year)	18.68	19.27

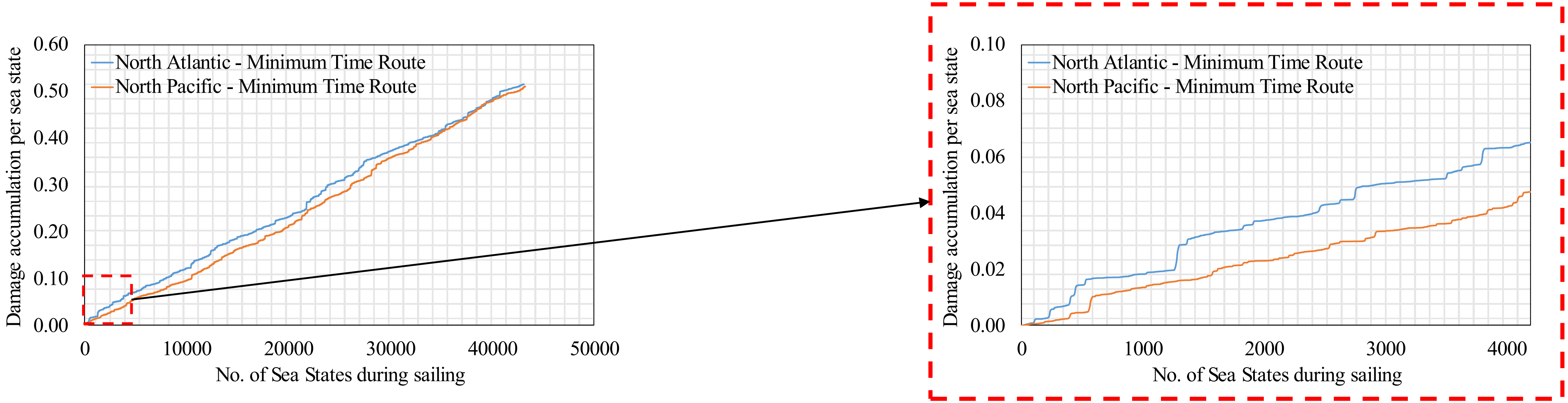


S: number of blocks, ni: number of cycles of stress range in the i-th block, and Ni: fatigue life corresponding to the stress range in the i-th block taken from the S-N curve.

Fatigue assessment

S-N Cumulative fatigue damage

Route	S-N Fatigue Damage	
	Mean	**STD**
North Atlantic	0.2715	0.1518
North Pacific	0.2471	0.1521



Fatigue assessment

Crack propagation

Fatigue crack propagation conditions:
- The crack growth law based on modified Dugdale model.
- Stress intensity factor of a surface crack by WES2805.
- Material properties determined by SR219. Mean stress assumed to be zero.

$$\frac{da}{dN} = C\left(\Delta K_{eff}\right)^{m} \frac{\left[1-\left(\frac{\left(\Delta K_{eff}\right)_{th}}{\Delta K_{eff}}\right)^{2}\right]}{\left[1-\left(\frac{\Delta K_{max}}{\eta}\right)^{2}\right]}, \quad \Delta K_{eff} = \left(K_{max} - K_{open}\right),$$

Material Parameters [SR219]

C = 2.60E-11

m = 2.75

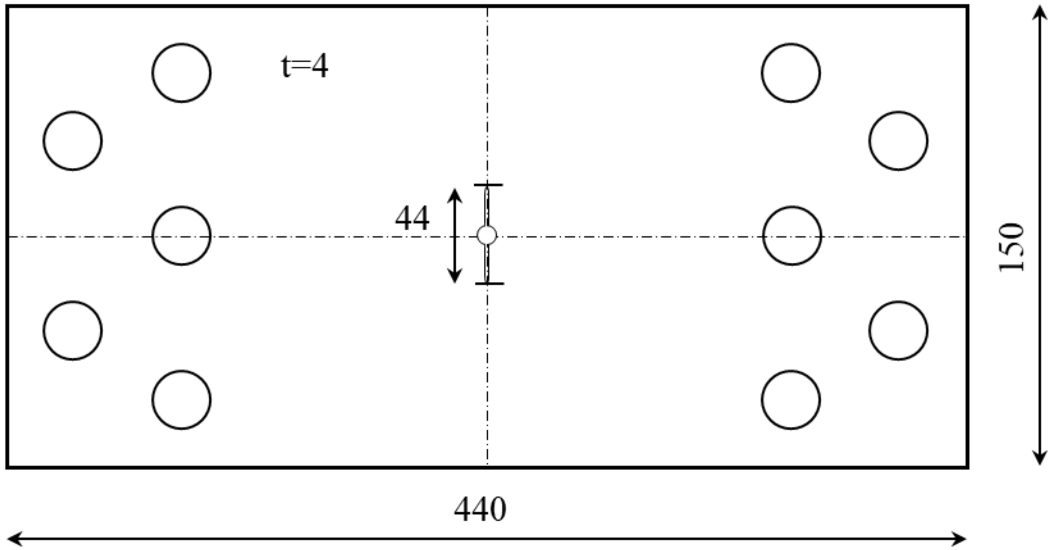
$\eta = 590\ MPa \cdot m^{1/2}$

$(\Delta K_{eff})_{th} = 2.00\ MPa \cdot m^{1/2}$.

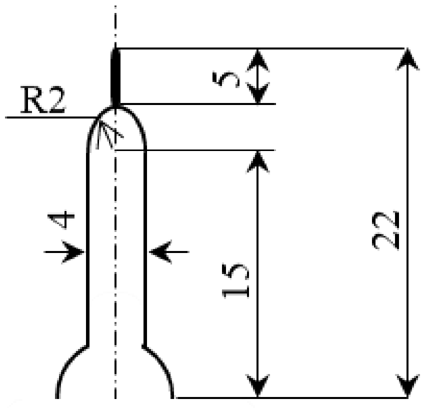
where, a is the half crack length or crack depth, C,m material constants, C4 is the threshold of the effective SIF, it is equal to zero, C5 is cyclic fracture toughness, Kmax and K(Sx) are SIF at Smax and SIF at applied load Sx, Smax and Smin are the maximum and minimum applied load, Kop opening stress intensity factor, ΔKeff.th effective threshold stress intensity factor range.

Fatigue assessment

Crack propagation



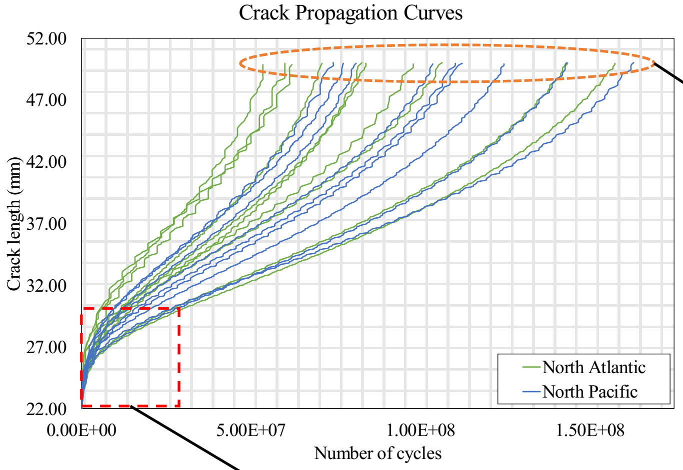
Specimen with notch crack in the center with initial notch height 4mm [unit: mm] from SR219 (1996).



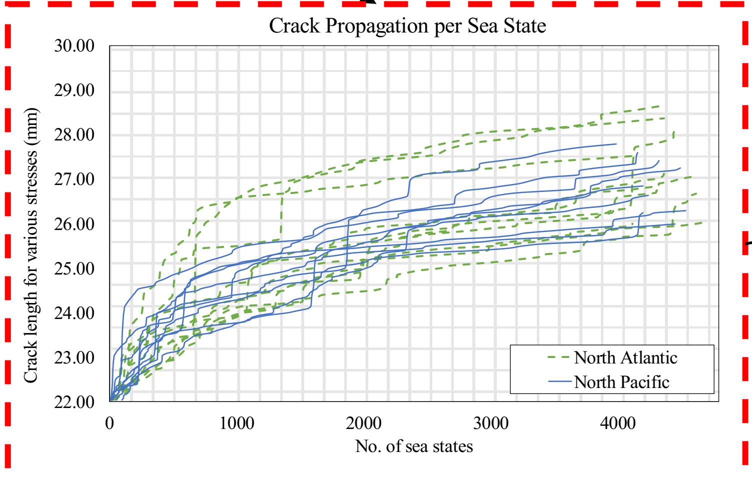
Initial Crack Conditions	
a	22 mm
c	22 mm
t	4 mm

Fatigue assessment

Crack propagation



Route	S-N fatigue life	Fatigue life	
	Mean	Mean	STD
North Atlantic	18.68	20.43	7.43
North Pacific	19.27	25.77	7.22



Route	Crack propagation in 1-Year[mm]	
	Mean	STD
North Atlantic	27.24	0.87
North Pacific	26.78	0.68

Ongoing work

- **Probabilistic Model of Whipping Occurrence**

- Examine the effect of the intermittently superimposed stress sequence and establish a stochastic model for whipping's frequency.

- Estimate the fatigue lives for welded joints subjected to intermittently whipping superimposed loads, including fatigue testing.

Acknowledgment

The authors would like to acknowledge:

- Dr. Kuniaki Matsuura for providing Japan Weather Association (JWA) hindcast data.

- Dr. Tomohei Kobayashi from Kawasaki Heavy Industry (KHI) for his valuable discussions and comments on FASTRAN II.

Conclusions

Storm model can be adapted to the stresses sequence generation of wave random loading for ships that follows weather routing.

The statistics properties of the cumulative damage based on S-N based fatigue assessment shows that a difference of at least 10% could be expected when the ship sails in the North Atlantic compared to that sailing in the North Pacific, under the condition chosen.

The effect of the difference in weather routing on SN-based fatigue assessment is smaller, compare to the difference in estimated propagation fatigue lives (is at least 30% under the condition chosen).

It is necessary to consider the effect of whipping/springing vibrations in the wave load sequences model.

Thank you for your kind attention!

Questions or comments?

Contact Information

Luis De Gracia

Luis_De_Gracia@naoe.eng.osaka-u.ac.jp

www.researchgate.net/profile/Luis_De_Gracia2

Osaka University
2-1 Yamadaoka, Suita, Osaka 565-0871
Japan

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Additional Material