An Investigation on Ship Parametric Rolling Based on Time Domain Strip Theory

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Outline

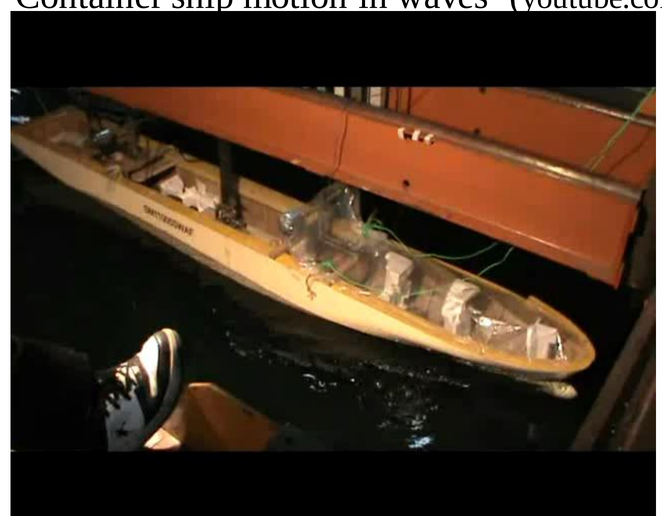
- A Brief Introduction on Ship Parametric Rolling
- An Enhanced Time Domain Strip Theory
- Numerical Simulation and Experiment Validation
- Summary

A Brief Introduction on Ship Parametric Rolling

The APL China incident,1998 (cargolaw.com)

Container ship motion in waves (youtube.com)

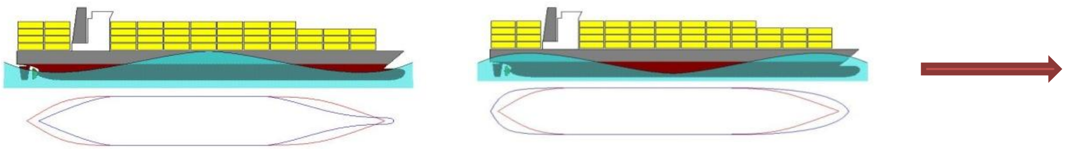
Cruise ship ***Voyager*** suffered from parametric rolling, 2005 (youtube.com)



Parametric rolling model test conducted at HEU

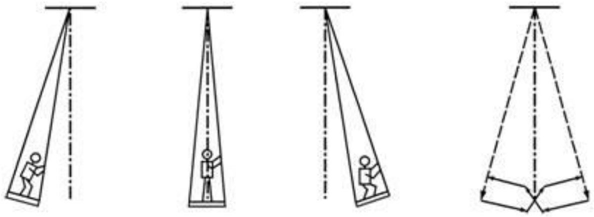
A Brief Introduction on Ship Parametric Rolling

Parametric rolling occurring for any ship having large righting arm variations between trough and crest condition.

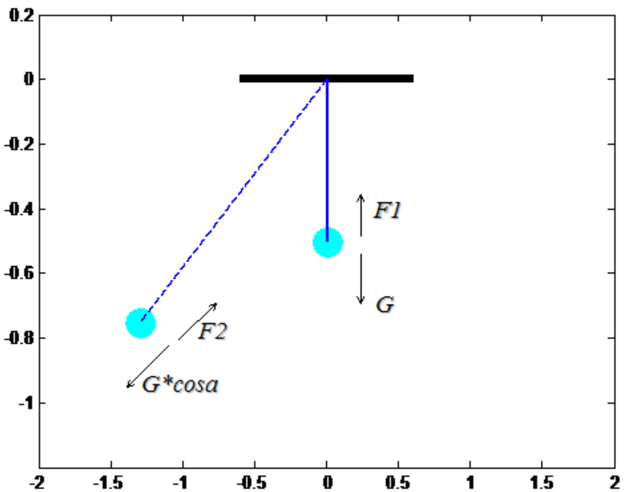


Ship on the wave crest and trough.(From STAB Webpage)

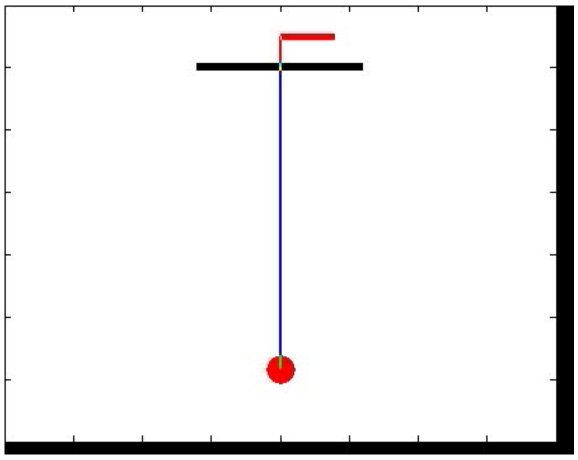
$$\overline{GM} = \frac{I}{\nabla}$$



Swing model



Physical explain of parametric excitation



The motion of the pendulum

Disturbance frequency equals to two times the natural frequency

A Brief Introduction on Ship Parametric Rolling

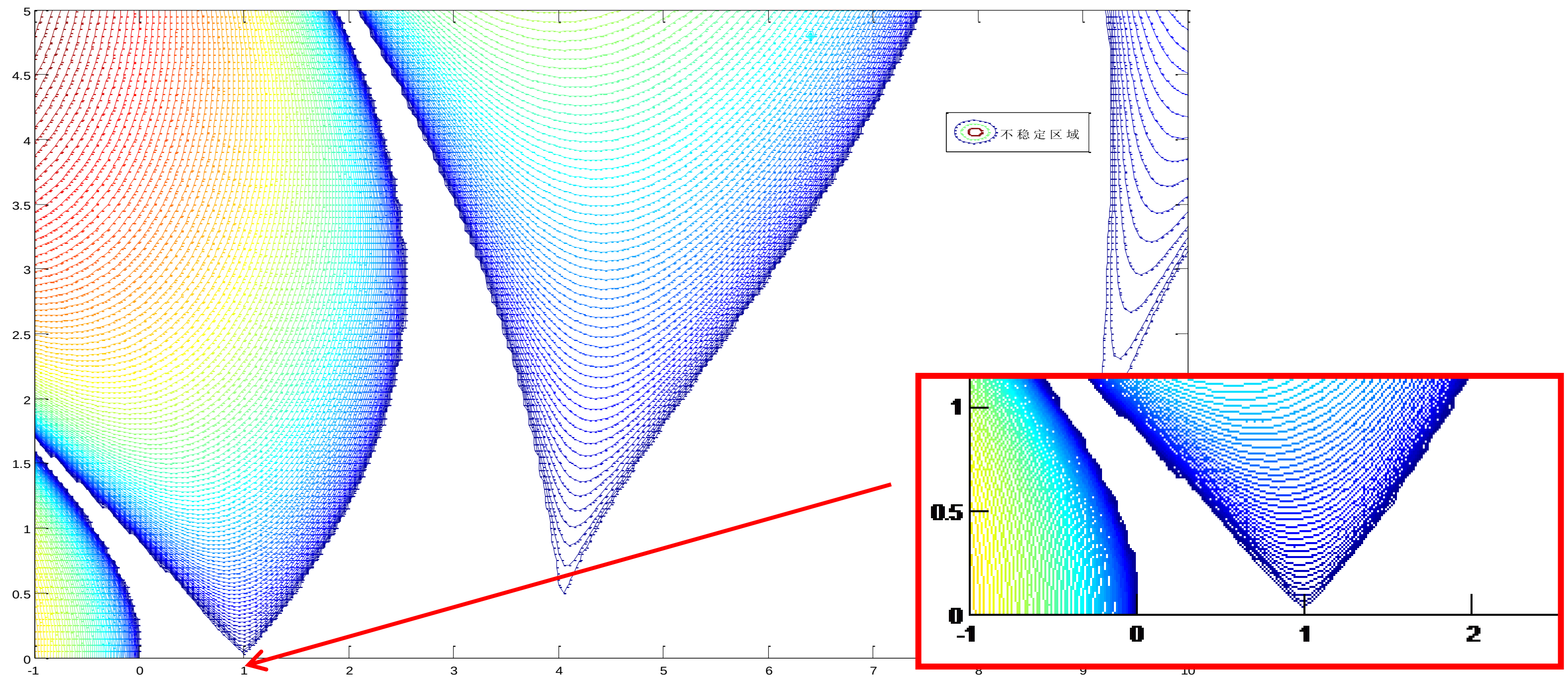
$$\ddot{\phi} + \cancel{\dot{\phi}} + ({\omega^2}_m + {\omega^2}_D \cos(\omega_e t)) \cdot \phi = 0$$

Mathieu Equation

ω_m The natural frequency ω_D Amplitude of the disturbance

ω_e The encounter frequency

ω_D



$\dfrac{\omega_e}{2\omega_m}$

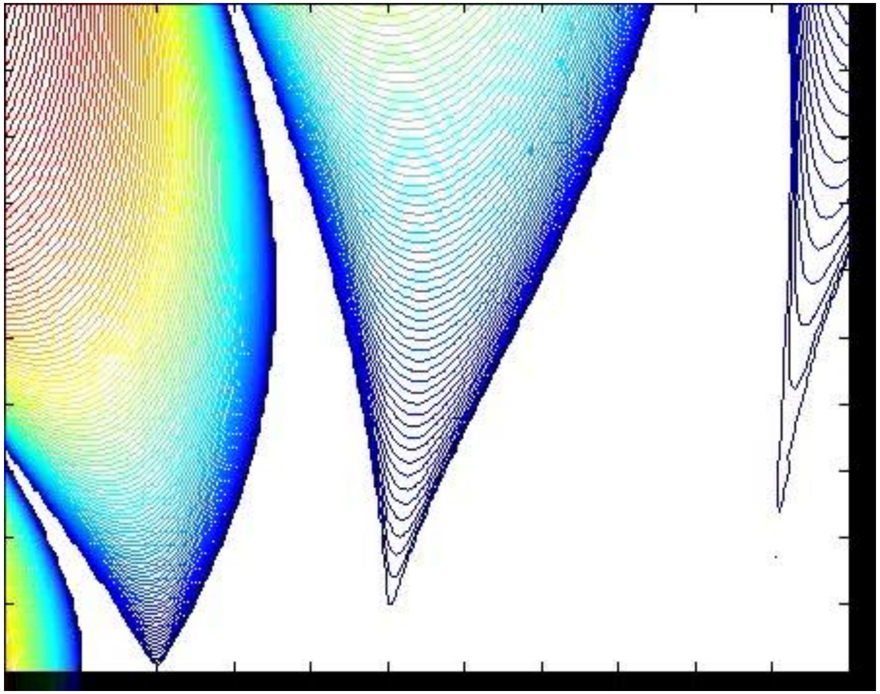
Unstable domain (shaded area)

A Brief Introduction on Ship Parametric Rolling

$$\ddot{\phi}+2\delta\dot{\phi}+({\omega^2}_m+{\omega^2}_D\cos(\omega_e t))\cdot\phi=0$$

ω_m The natural frequency ω_D Amplitude of the disturbance

ω_e The encounter frequency



The unstable domain vary with different roll damping level

A Brief Introduction on Ship Parametric Rolling

Factors affecting the accuracy of numerical simulation:

- Parameters contributed to righting arm variations
  - Waves
  - Unsteady motion coupling

- The exact roll damping model
  - Waves
  - Unsteady motion coupling

- Large amplitude hydrodynamics model

An Enhanced Time Domain Strip Theory

Motion Equation:

$$A\ddot{\eta} = F^D(t) + F^R(t) + F^I(t) + F^S(t) + F^v$$

F^R	Radiation Force
F^D	Diffraction Force
F^I	Wave excitation force
F^s	Restoring Force
F^v	Viscous force

An Enhanced Time Domain Strip Theory

Time domain radiation force:

$$F^{R}_{jk}(t) = -\mu_{jk}\ddot{\eta}_k(t) - b_{jk}\dot{\eta}_k(t) - c_{jk}\eta_k(t) - \int_0^t K_{jk}(t-\tau)\dot{\eta}_k(\tau)d\tau$$

Cummins (1962)

$$\begin{cases} \nabla^2\varphi_k, \nabla^2\psi_k = 0 \\ \varphi_k, \psi_k = 0 \quad (on\ S_F) \\ \dfrac{\partial\varphi_k}{\partial n} = n_k \quad (on\ S_0) \\ \dfrac{\partial\psi_k}{\partial n} = m_k \quad (on\ S_0) \\ \nabla\varphi_k, \nabla\psi_k \to 0 \quad (r \to \infty) \end{cases}$$

$$\begin{cases} \nabla^2\overline{\chi}_k = 0 \\ [(\dfrac{\partial}{\partial t} - U\dfrac{\partial}{\partial x})^2 + g\dfrac{\partial}{\partial z}](\overline{\chi}_k + \psi_k) = 0 \quad (on\ S_F) \\ \dfrac{\partial\overline{\chi}_k}{\partial n} = 0 \quad (on\ S_0) \\ \overline{\chi}_k\Big|_{t=0} = 0 \quad \dfrac{\partial\overline{\chi}_k}{\partial t}\Big|_{t=0} = -g\dfrac{\partial\varphi_k}{\partial z} \quad (on\ S_F) \end{cases}$$

$$\begin{cases} \mu_{jk} = \rho\iint_{S_0}\varphi_k n_j ds \\ b_{jk} = \rho\{\iint_{S_0}\psi_k n_j ds - \iint_{S_0}\varphi_k m_j ds\} \\ c_{jk} = -\rho\iint_{S_0}\psi_k n_j ds \\ K_{jk}(t) = \rho\{\iint_{S_0}\dfrac{\partial}{\partial t}\overline{\chi}_k(p,t)n_j ds - \iint_{S_0}\overline{\chi}_k(p,t)m_j ds\} \end{cases}$$

Liapis (1986)

Bradley, 1987

$$b_{jk} \equiv 0$$

X

$$b_{jk} \equiv 0 \qquad j = k$$

$$b_{35} = -b_{53} = U\mu_{33}$$

$$b_{26} = -b_{62} = -U\mu_{22}$$

Frequency domain radiation force:

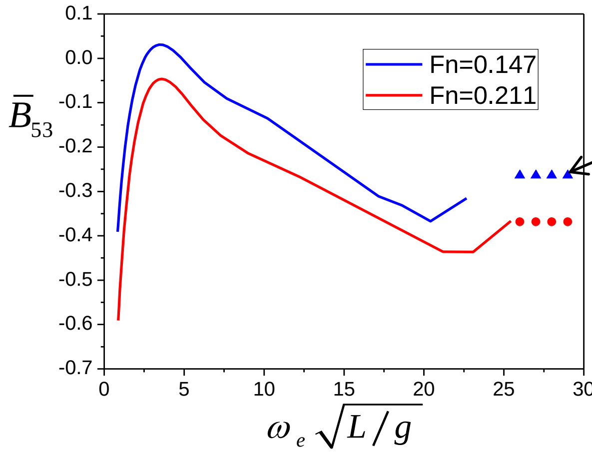
$$F_{jk}(t) = \mathrm{Re}\{e^{i\omega_e t}[\omega_e^2 A_{jk} - i\omega_e B_{jk}]\}$$

$$K_{jk}(\tau) = \frac{2}{\pi}\int_0^\infty (B_{jk}(\omega_e) - b_{jk})\cos\omega_e\tau d\omega_e$$

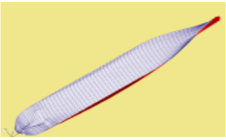
Kramers-Kronig relation(Cummins,1962,Ogilvie,1964)

Some corrections for b_{jk} term

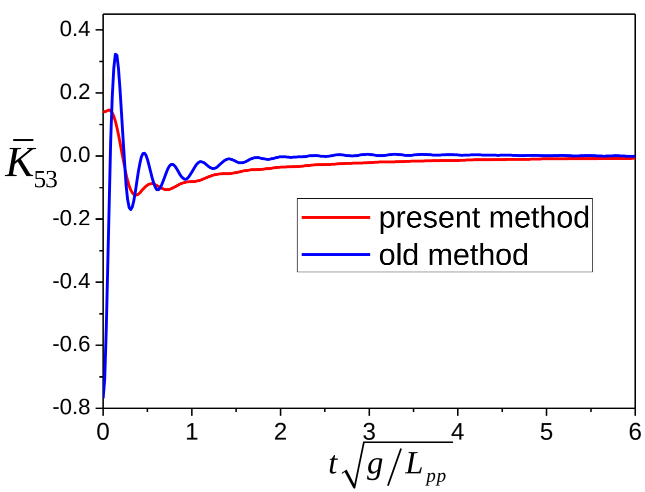
$$K_{jk}(\tau) = \frac{2}{\pi}\int_0^\infty (B_{jk}(\omega_e) - b_{jk})\cos\omega_e\tau d\omega_e$$

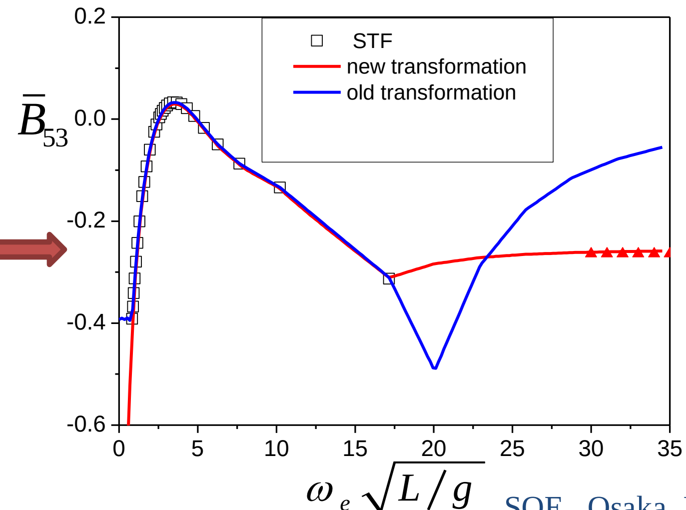


$$b_{53} = -U\mu_{33}$$



$$b_{jk} = \lim_{\omega\to\infty} B_{jk}(\omega_e) \qquad j \neq k$$





The derivation of c_{plus} term

Time unvarying linear system

Time domain method

Frequency domain method

$$B_{jk}(\omega)=\frac{2}{\pi}P.V.\int_0^{\infty}\frac{\omega_1^2}{\omega_1^2-\omega^2}[\mu_{jk}-A_{jk}(\omega_1)]d\omega_1$$

$$\mu_{jk}-A_{jk}(\omega)=-\frac{2}{\pi}P.V.\int_0^{\infty}\frac{B_{jk}(\omega_1)}{\omega_1^2-\omega^2}d\omega_1$$

$$j,k=1\cdots6$$

Kramers-Kronig relation(Cummins,1962,Ogilvie,1964)

$U=0$

$U\neq0$

S.T.F is not a complete Theory to handle ship motion with forward speed (zero speed approximation)

The derivation of c_{plus} term

$$A_{55} = A_{55}^0 + \frac{U^2}{\omega_e^2} A_{33}^0 = \mu_{55} - \frac{1}{\omega_e^2} c_{55} - \frac{1}{\omega_e} \int_0^\infty K [\ldots] \omega_e \tau d\tau$$

$$B_{55} = B_{55}^0 + \frac{U^2}{\omega_e^2} B_{33}^0 = b_{55} + \int_0^\infty K_{55}(\tau) \cos \omega_e \tau d [\ldots]$$

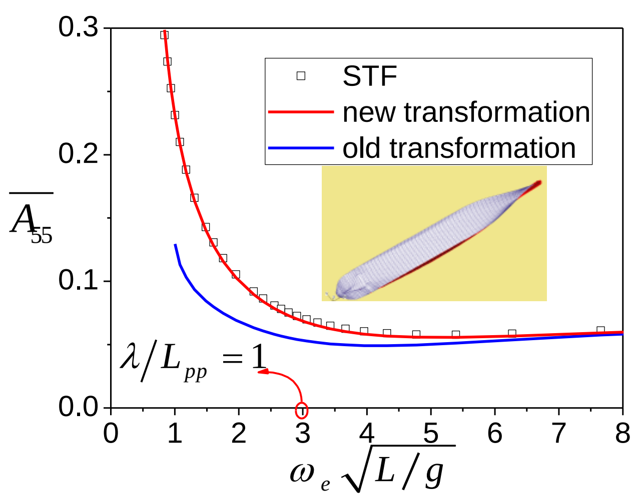
$\overline{C}_{55} = c_{55} + c_{plus}$

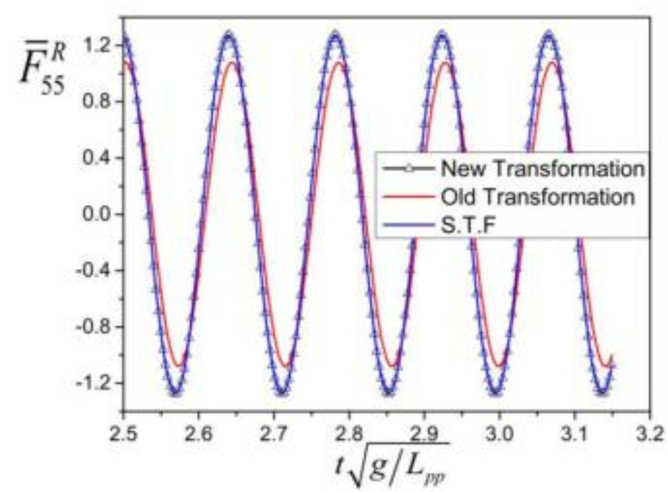
$$c_{plus} = -\frac{2U^2}{\pi} \int_0^\infty \frac{B_{33}(\omega_1)}{\omega_1^2} d\omega_1$$

A_{jk} B_{jk} By S.T.F → K_{ij}

Physical model distortion

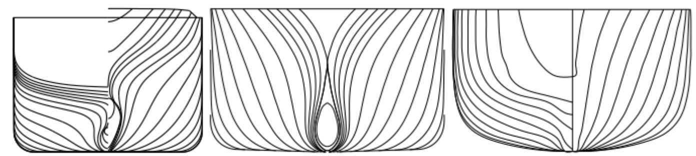
Modification





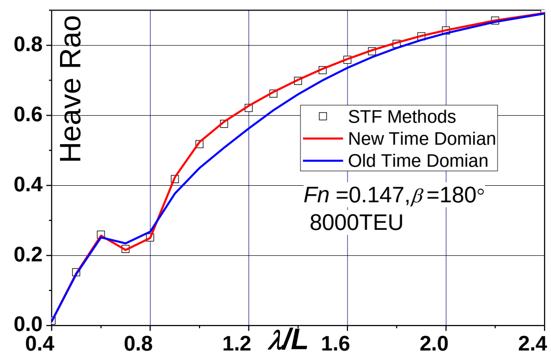
Validation

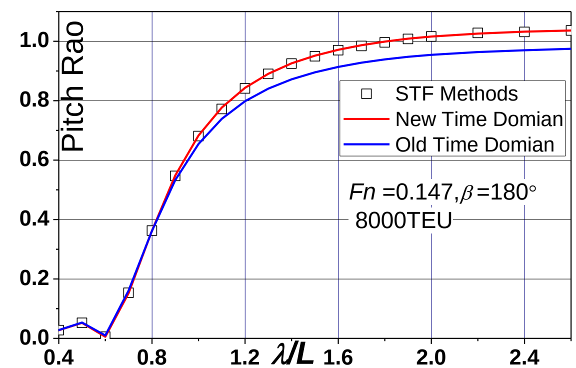
	8000TEU	S175	Warship (model)
Lpp(m)	319.92	175	6.157
B(m)	42.80	25.4	0.654
T(m)	13.00	9.5	0.207
▽(m3)	114067	24140	0.4022
CB	0.6408	0.572	
Kyy`	$0.25L_{pp}$	$0.24L_{pp}$	$0.25L_{pp}$



$F_n = 0.147$

8000TEU

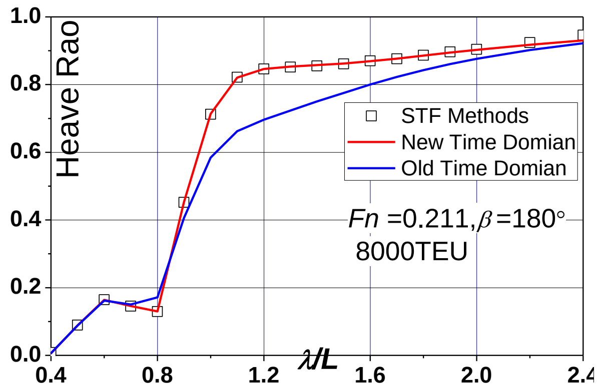


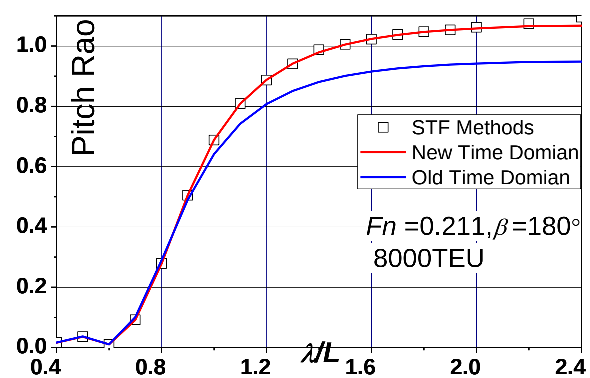


Here, radiation forces are represented by IRF in time domain

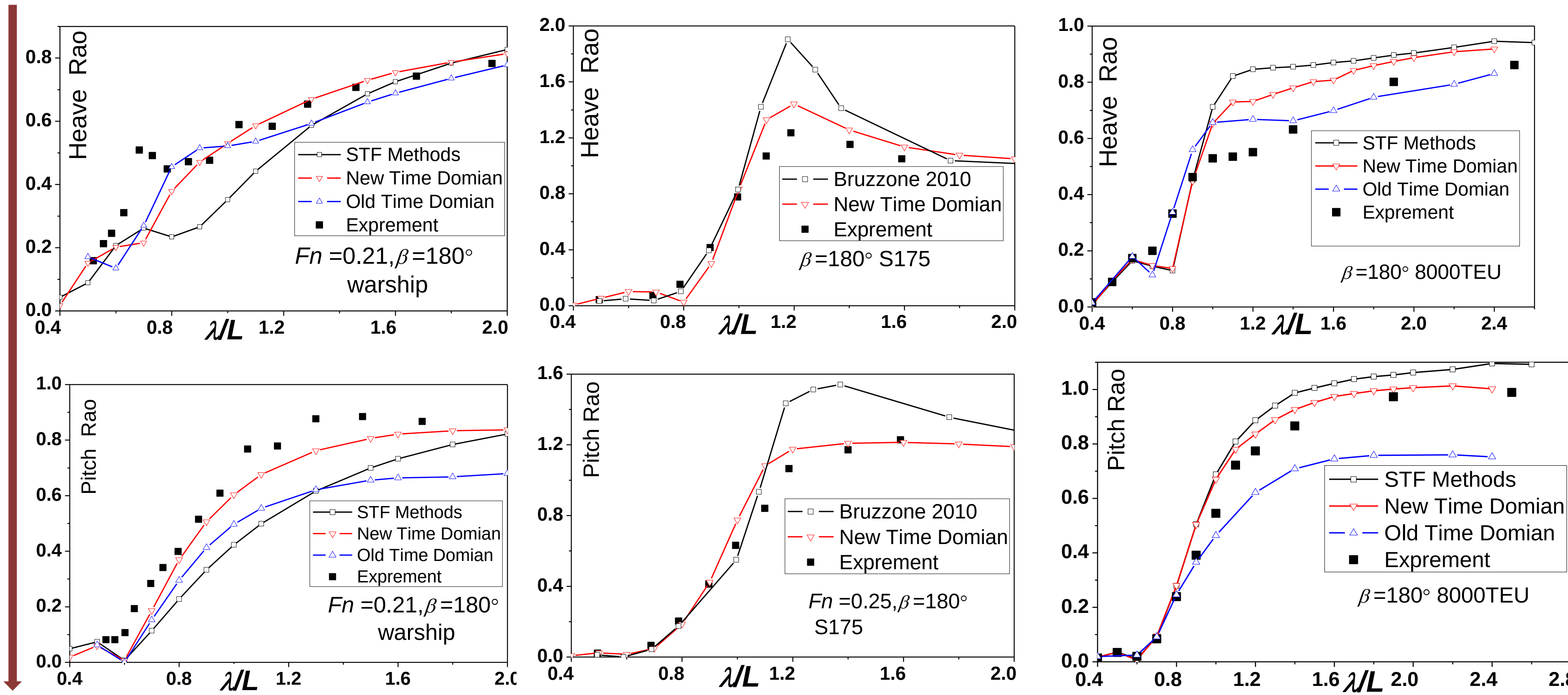
$F_n = 0.211$

8000TEU

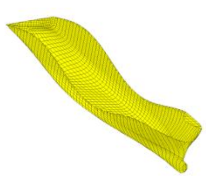




An Enhanced Time Domain Strip Theory

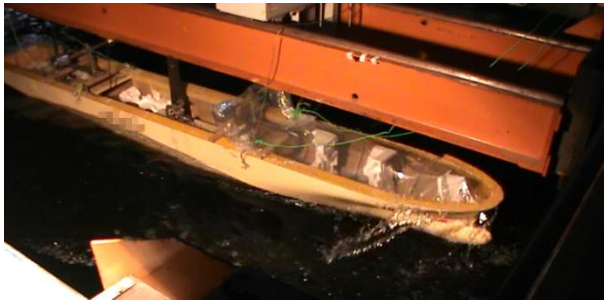


Warship **S175** **8000TEU**

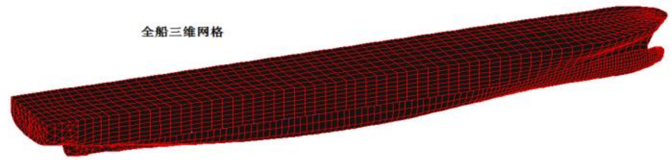


F-K forces calculated on instantaneous wet surface

Numerical Simulation and Experiment Validation

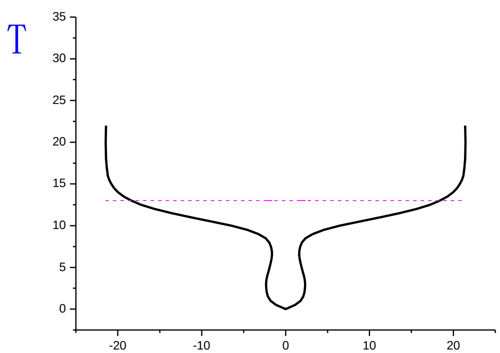


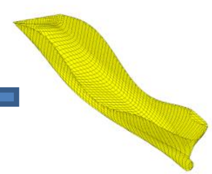
HEU Model Test



8000TEU Container Ship

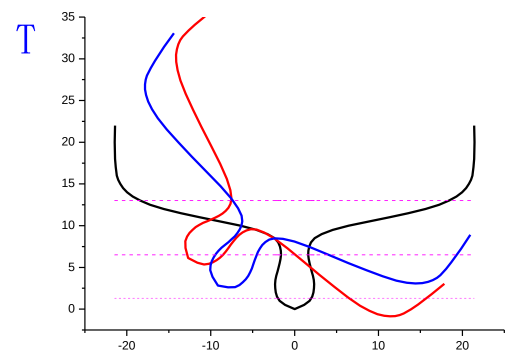
Numerical model 1:

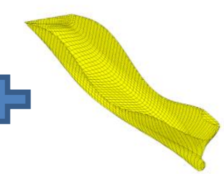




Linear radiation/diffraction force Body-exact F-K force

Numerical model 2:



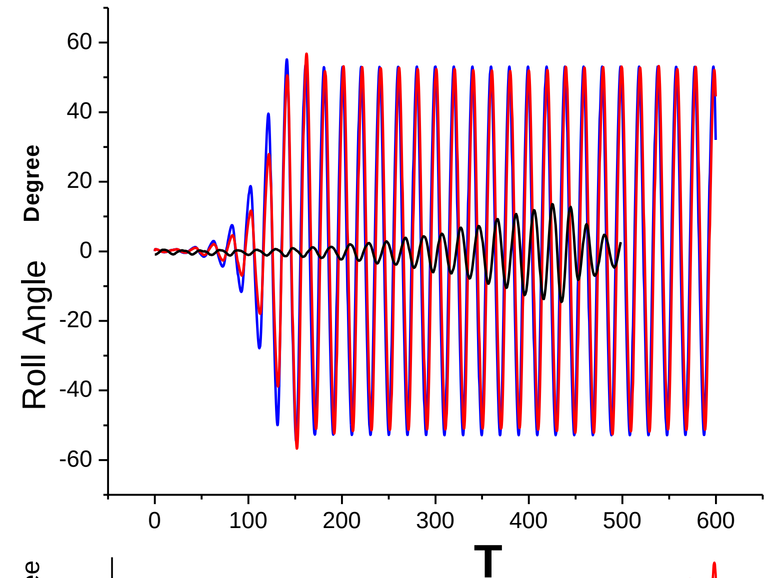


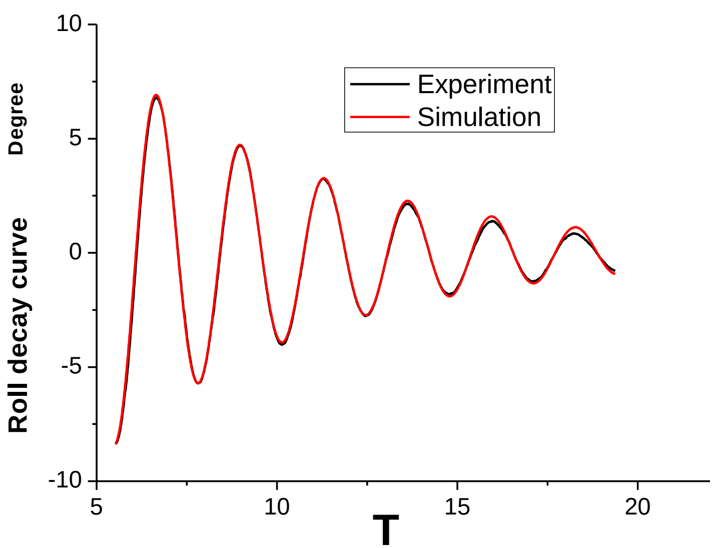
Body-exact radiation/diffraction force Body-exact F-K force

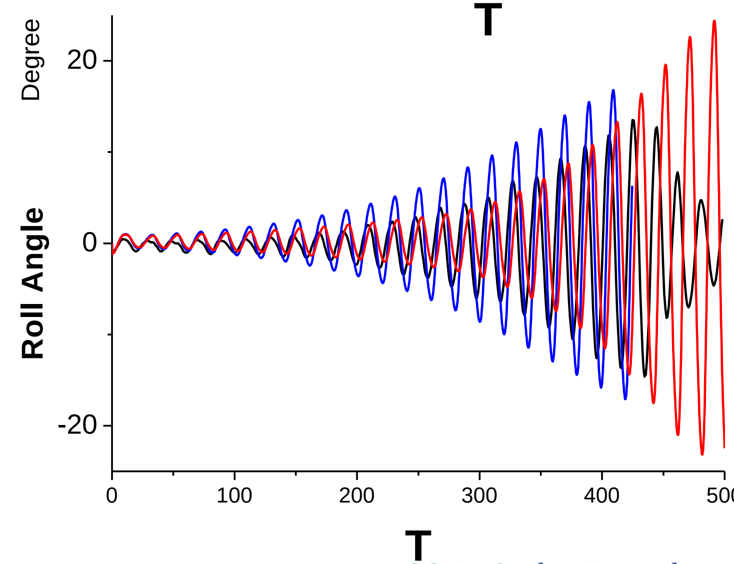
Numerical Simulation and Experiment Validation

$\lambda / L = 1.04 \quad H / \lambda = 1/40 \quad Fn = 0.2$

Experiment
Linear(R/D)+Nonlinear(FK)
Nonlinear(R/D)+Nonlinear(FK)



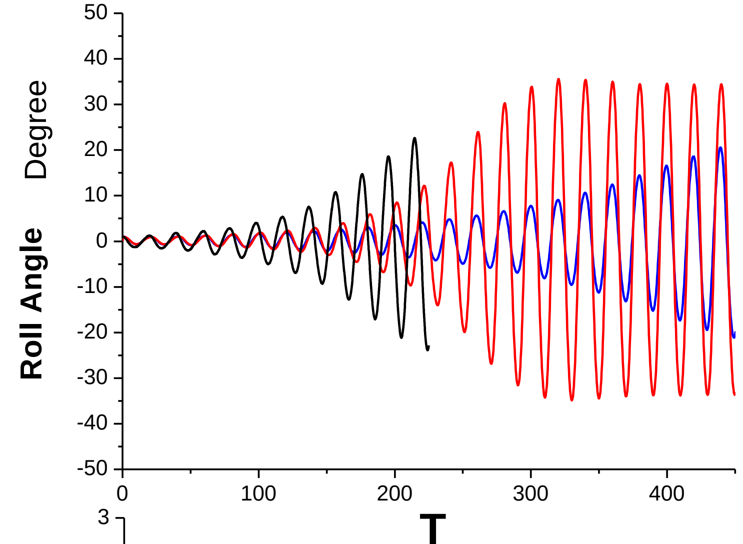


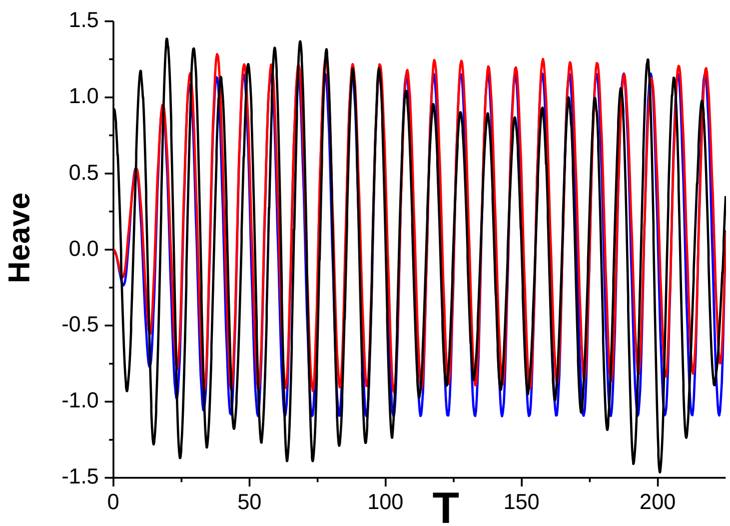


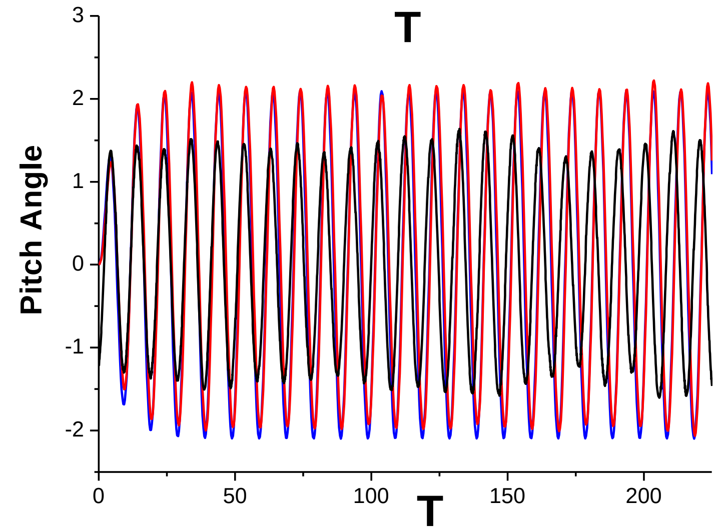
Numerical Simulation and Experiment Validation

$\lambda / L = 0.78 \quad H / \lambda = 1/40 \quad Fn = 0.1$

Experiment
Linear(R/D)+Nonlinear(FK)
Nonlinear(R/D)+Nonlinear(FK)







Conclusion

◆Roll damping is very important on final steady roll amplitude

◆ Motion coupling may affect the developing of parametric rolling

Further work

◆Body-exact time domain hydrodynamics solver

◆ Methods to ascertain roll damping at large roll amplitude

◆Efficient ways to evaluate parametric rolling in irregular waves