Study on scale effects on ship roll motion

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Objectives

➢ **Problems:**

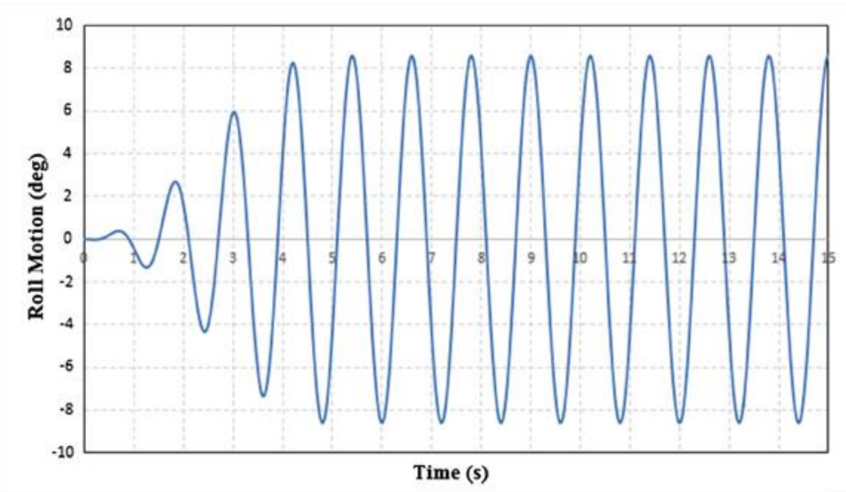
- Scale effects on roll motion is unclear
- Sea trial data of roll motion are scarce
- Exactly full-scale roll motion simulation

➢ **Solution:**

- Validate full-scale roll motion simulation
- Investigate scale effects through roll decay simulations
- Clarify scale effects through forced roll simulations

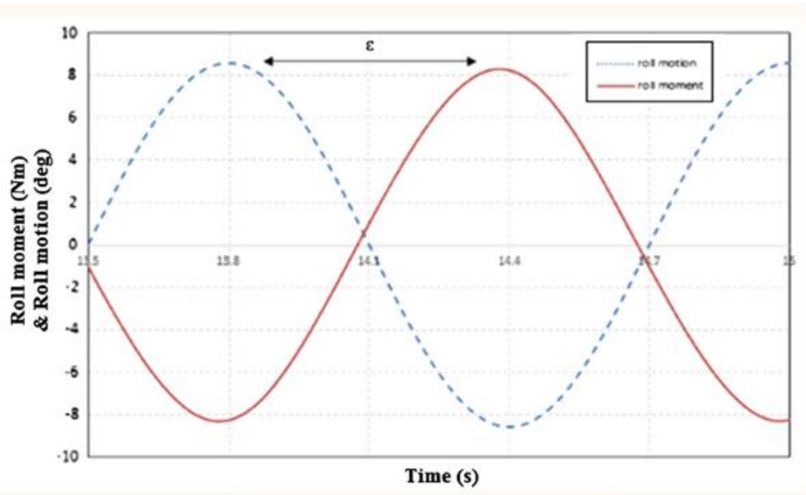
Methodology

- To validate full-scale roll motion simulation: compare numerical results with experimental results and sea trial data.
- Numerical method (using STAR-CCM+): roll decay motion and forced roll motion are simulated at model-scale and full-scale
- Roll damping coefficient calculation:



$$f(t)=\begin{cases}\frac{1}{2}\sin\left(\frac{1}{4}\times\frac{\pi}{T}\times t-\frac{1}{2}\pi\right)+\frac{1}{2} & (t<4T)\\ 1 & (t>4T)\end{cases}$$

$$b_{44}=\frac{M_0.\sin(\varepsilon)}{\phi_0\omega}$$



$$B_{44}=\frac{b_{44}}{\nabla\rho B^2}\sqrt{\frac{B}{2g}}$$

$$M_E=M_0.\sin(\omega t+\varepsilon)$$

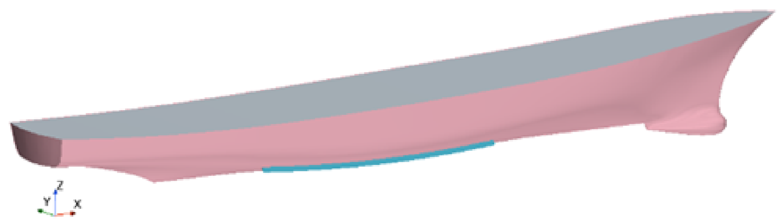
- Calculate roll damping components: frictional damping, bilge keel damping and others

$$B_{44F}=\frac{b_{44F}}{\nabla\rho B^2}\sqrt{\frac{B}{2g}}\ ;\quad B_{44BK}=\frac{b_{44BK}}{\nabla\rho B^2}\sqrt{\frac{B}{2g}}$$

$$B_{44W}+B_{44E}+B_{44L}=B_{44}-B_{44F}-B_{44BK}$$

Simulation

a) Bettica model (full appendages)



b) DTMB 5512 model (hull with BK)

Fig. 1 Geometry of Bettica and DTMB

Parameters	Symbol	Unit	Bettica		DTMB	
			Ship	Model	Ship	Model
Scale factor	λ	-	1	20	1	46.6
Length between perpendiculars	L_{pp}	m	80	4.0	142	3.048
Breadth	B	m	12.2	0.61	19.06	0.409
Draught	d	m	3.2	0.16	6.15	0.132
Block coefficient	C_B	-	0.455	0.455	0.506	0.506
Mass	W	t	1399	0.174	8632	0.085
Metacentric height	GM	m	1.107	0.055	1.938	0.042

Setting parameters:

- ✓ VOF method
- ✓ Implicit unsteady RANSE
- ✓ Multiphase: water + air
- ✓ Overset mesh method
- ✓ Multiphase: water + air
- ✓ All y+ wall treatment
- ✓ SST k-ω turbulence model

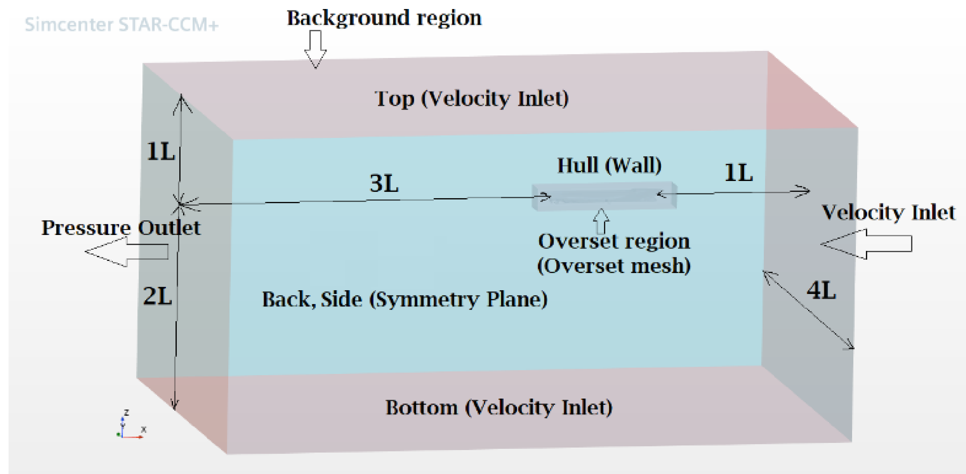


Fig. 2 Boundary conditions.

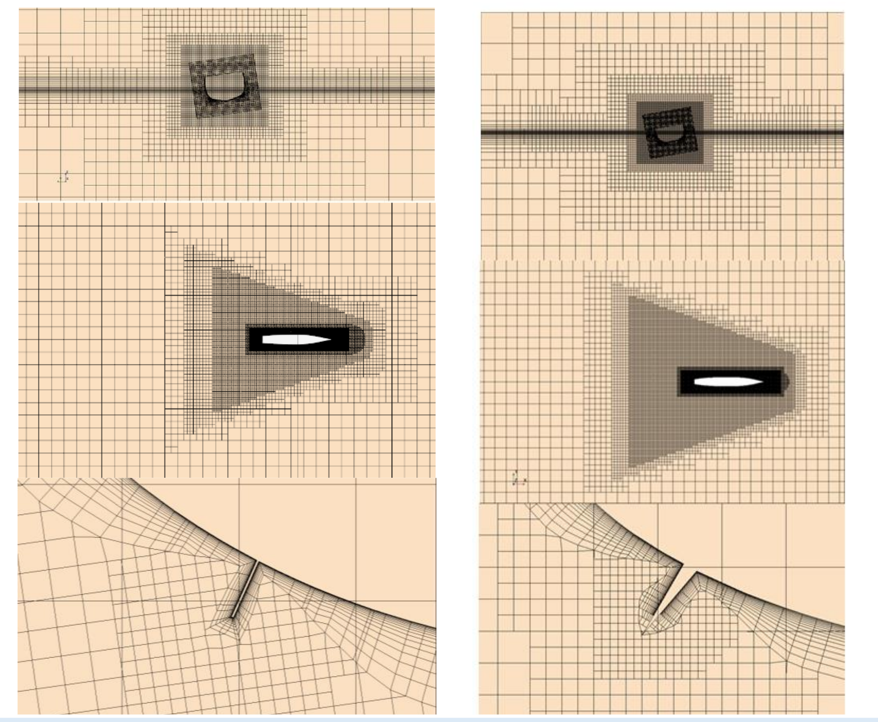


Fig. 3 Generated mesh of Bettica and DTMB

Results

Numerical simulation validation

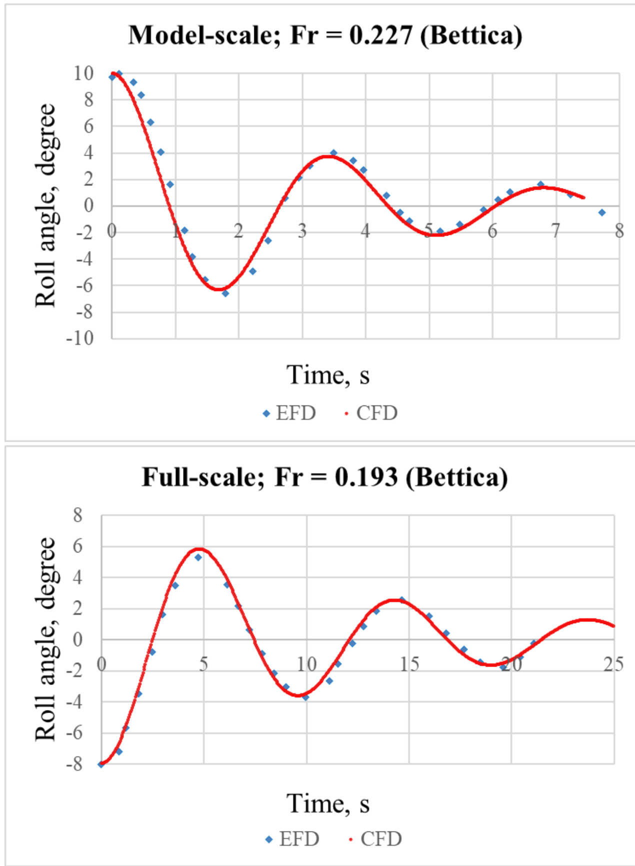


Fig. 4 The validation results of Bettica

- Wall y+ within 200 is suitable for full-scale roll motion simulation.
- Time step should meet the requirement that Courant number on the ship hull smaller than 1.
- The numerical simulation strategy can be used for predicting full-scale roll motion for other vessels, which lack experimental results.

Scale effects on roll decay motion

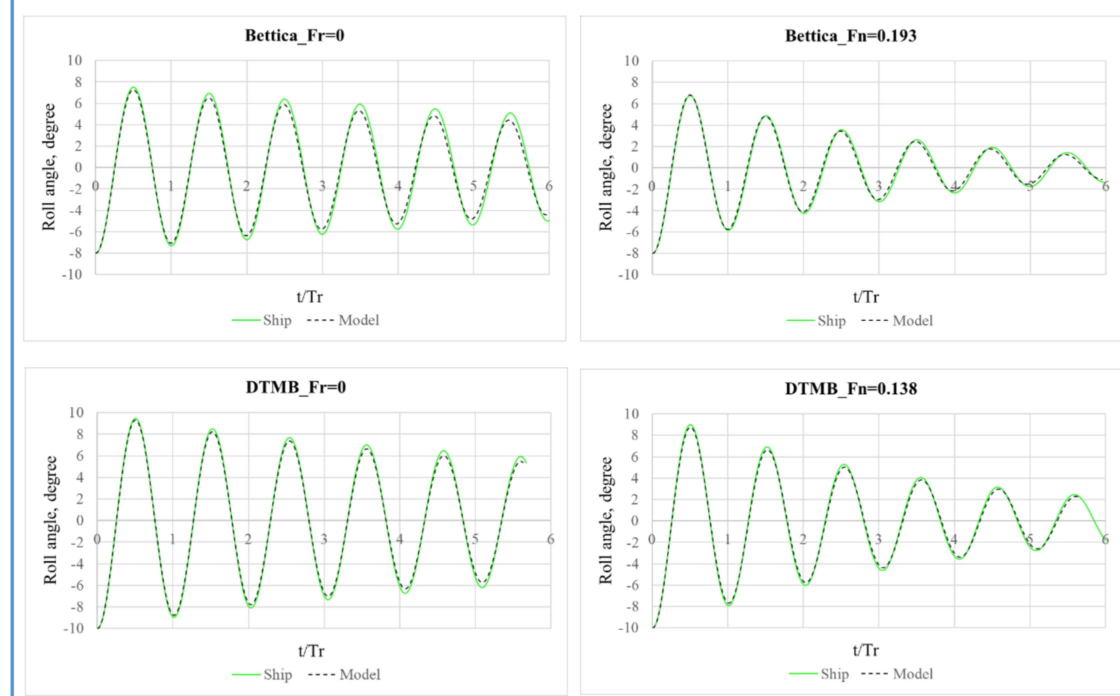


Fig. 5 Roll decay curves

- It is important to ensure the correlation between model-scale and full-scale in numerical simulation.
- There are difference in roll amplitudes between the model-scale and full-scale of two vessels.
- The scale effects are observed larger in the case of zero forward speed, while it is not significant at high forward speed.
- At this stage, the scale effects on roll motion can be only seen through the difference in roll amplitude.

Forced roll simulation

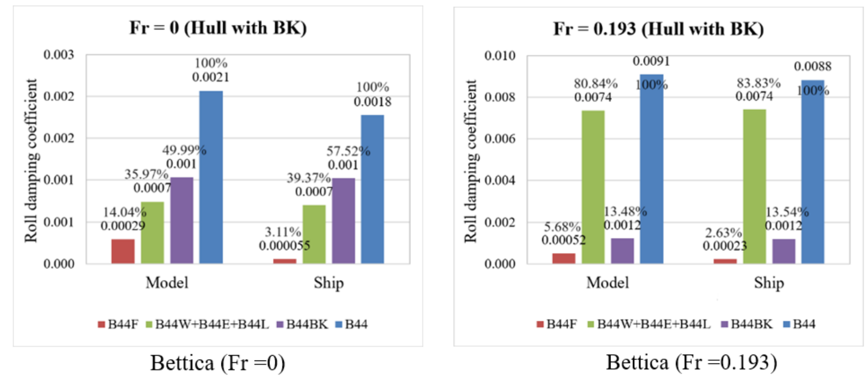


Fig. 6 Roll damping coefficients (Full BK height)

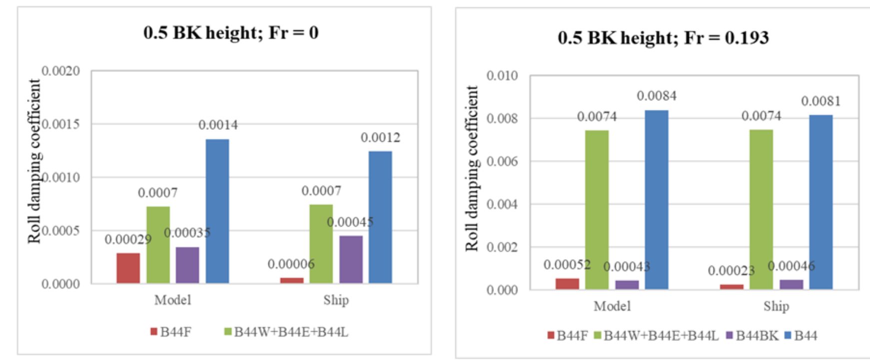


Fig. 7 Roll damping coefficients (0.5 BK height)

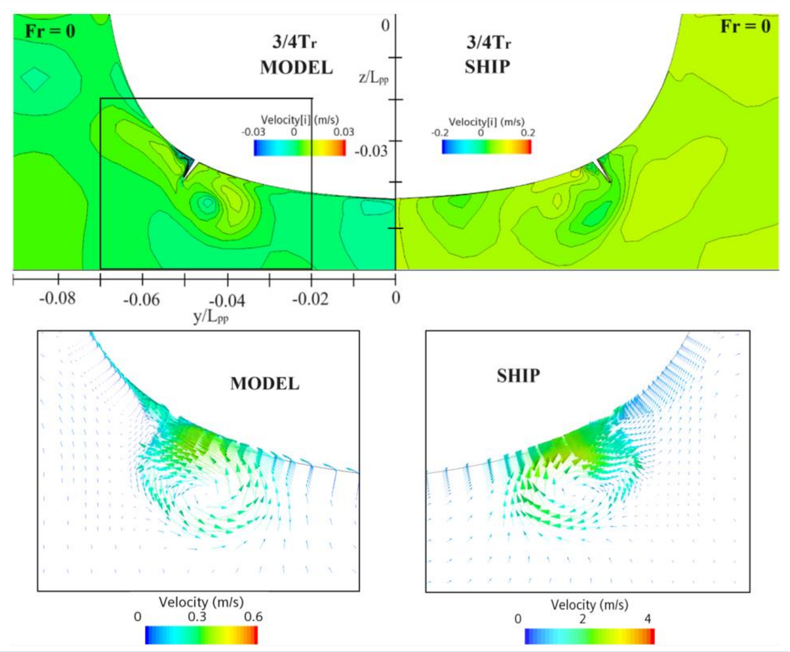


Fig. 8 Velocity field of DTMB (Full BK height)

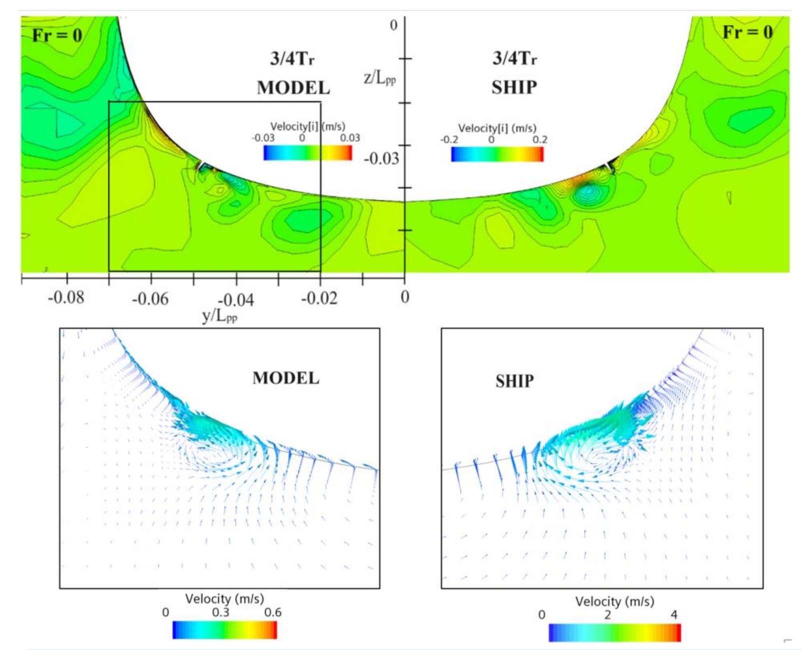


Fig. 9 Velocity field of DTMB (0.5 BK height)

- The percentage of frictional component is larger in model-scale and in the case of zero forward speed. The full-scale ship generates a smaller total roll damping coefficient compared to model-scale.
- When the height of bilge keel is smaller than the boundary layer thickness, bilge keel component is also affected by the scale effects.
- Scale effects on bilge keel component are larger in the case of zero forward speed and increase with the decrease of BK height.

Conclusions

- Scale effects on roll decay motion are larger in the case of zero forward speed, while it is not significant at high forward speed.
- Frictional damping component is affected by the scale effects. The percentage of frictional component is larger in model-scale and in the case of zero forward speed.
- When the height of bilge keel is too small, bilge keel component is also affected by the scale effects.