

- 2016 5th OpenFOAM Korea User's Community Conference -

OpenFOAM을 이용한 파랑 중 선박의 부가저항 수치해석

2016. 9. 30

한국해양대학교 서성욱, 박선호



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Introduction

□ Research background

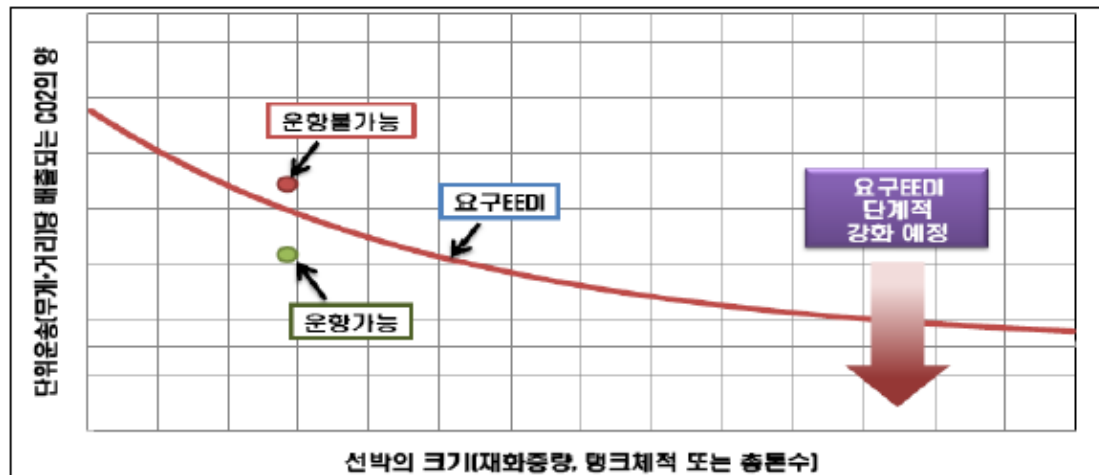
· 국제해사기구(IMO)으로부터 선박의 온실가스 방출을 규제하기 위한 EEDI 및 EEOI 도입

※ Energy Efficiency Design Index, EEDI : 선박제조 연비지수

Energy Efficiency Operator Indicator, EEOI : 선박운항 연비지표

- 온실가스 방출 대비 운항 효율을 향상시키기 위해 선박의 부가저항을 감소시키는 방법이 고려

- 실제 운항 상태에서의 정확한 선박의 부가저항 추정 필요



〈그림 2-45〉 EEDI 기준선

※ 출처 : 황태규. 2012. "선박에너지효율등급 도입에 따른 친환경-고효율 조선 요소부품 경쟁력 제고 전략"

Introduction

□ Research background

- 부가저항 : 선박이 실제 해상에서 운항하는 경우 바람이나 파랑에 의해 받는 저항

$$R_{added} = R_{total} - R_{calm}$$

R_{added} : 선박의 부가저항

R_{total} : 실제 해상에서 받는 선박의 전 저항

R_{calm} : 정수 중에서 받는 선박의 전 저항

□ Research objective

- OpenFOAM를 이용하여 파랑 중 선박의 부가저항 계산
- 5가지 규칙파랑에 대한 선박의 부가저항 및 2자유도(pitch & heave) 수치해석
- 2015 Tokyo CFD workshop 부가저항 모형실험 결과와 비교

Numerical modeling

□ Ship model and boundary conditions

- 3,600TEU KRISO Container Ship(KCS)를 선정
- blockMesh와 snappyHexMesh를 이용하여 격자 생성(370만개)

Table 1. Principal particulars of KCS model

	Full Scale	Model Scale
Scale ratio	1	1/37.9
Length (m)	230.0	6.0702
Breadth (m)	32.2	0.8498
Depth (m)	19.0	0.5015
Draft (m)	10.8	0.2850
Reynolds number	2.4×10^9	1.07×10^7
Froude number		0.261

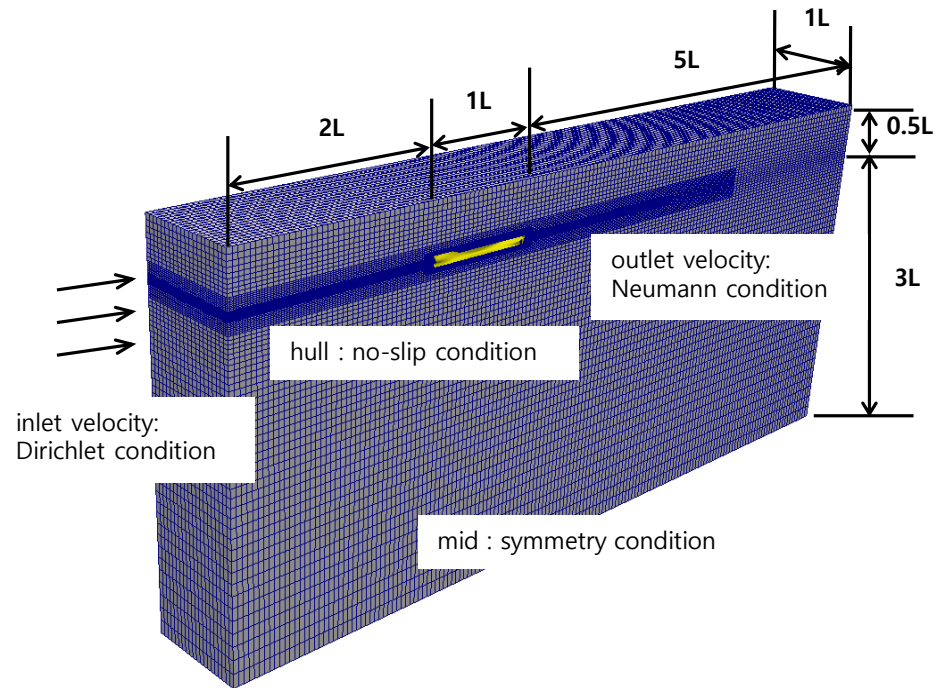


Fig. 1 Boundary conditions and domain size

Numerical modeling

□ Numerical methods

- Solver : interDyMFoam (2-phase flow, dynamic mesh)
- Dynamic module : Six-degree of freedom rigid body motion
- Free surface : VOF (Volume Of Fluid) method
- Wave generation : waves2Foam
- Turbulence model : k-w SST Model
- P-V coupling : PIMPLE (hybrid method between PISO and SIMPLE)
- Convection term : 2차 정확도 차분 (vanLeer)
- Diffusion term : 2차 정확도 중심 차분

Numerical modeling

□ Simulation conditions

- 선박의 2자유도(heave & pitch) 운동 해석
- 단파($\lambda/L=0.65$) ~ 장파($\lambda/L=1.95$) 5가지 규칙파랑으로 분류

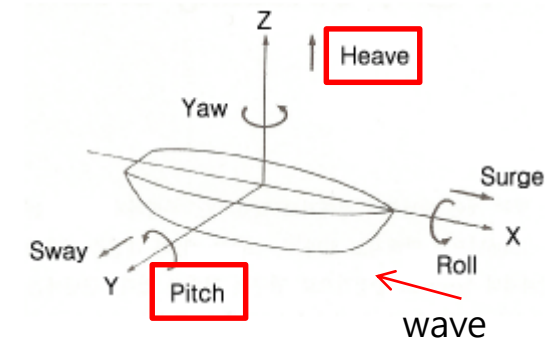


Table 2. Simulation conditions in calm water and in regular head waves

Case no.	Froude number	Wave steepness H/λ	Wave length λ/L_{pp}	Encounter frequency f_e (Hz)	Encounter period T_e (s)
0	0.261			no waves	
1	0.261	1/60	0.65	1.136	0.878
2	0.261	1/60	0.85	0.940	1.064
3	0.261	1/60	1.15	0.762	1.312
4	0.261	1/60	1.37	0.676	1.480
5	0.261	1/60	1.95	0.533	1.874

Numerical modeling

□ Wave generating method

- 소스코드가 공개된 waves2Foam 사용(Jacobsen et al., 2012)
- Generating zone과 Damping zone을 사용하여 파랑의 생성과 소멸을 표현
- 2차 stokes 파 이론을 적용

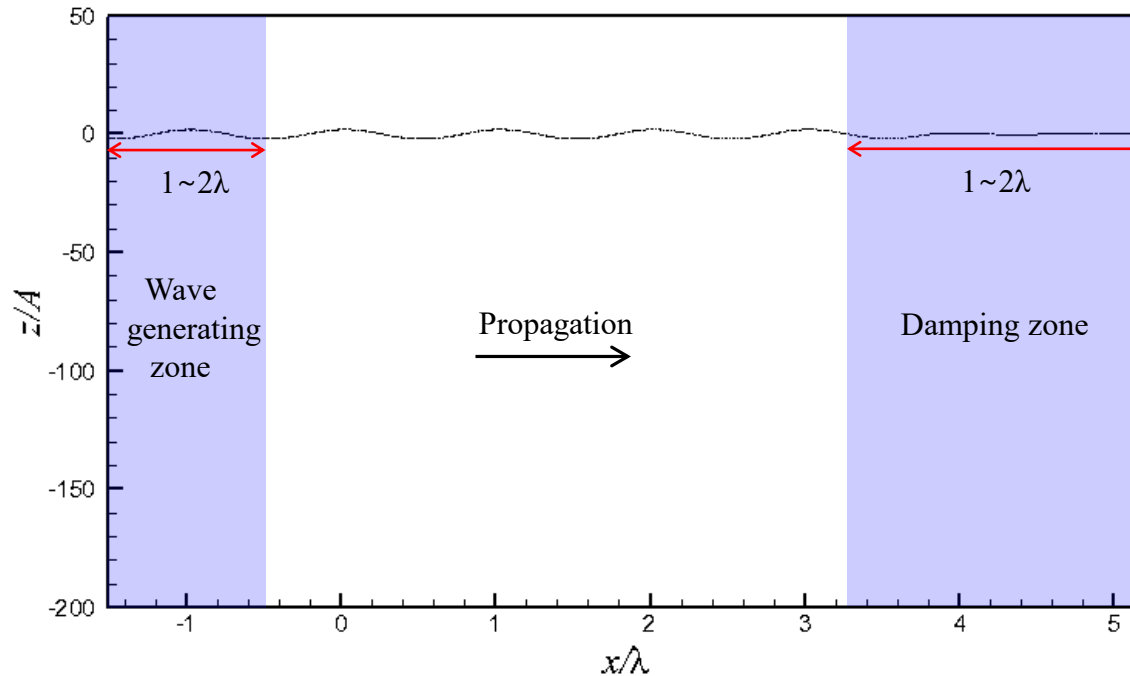


Fig. 2 Simulation domain used for wave generating zone and damping zone

Results

□ Ship resistance, sinkage and trim in calm water

Table 3. Result in calm water

Case 0	$C_T (\times 10^{-3})$	sinkage/ $L_{pp} (\times 10^{-3})$	trim (deg)
EFD	3.835	-2.074	-0.1646
Present	4.018	-1.989	-0.1676
Error (% EFD)	-4.757	4.216	-1.845

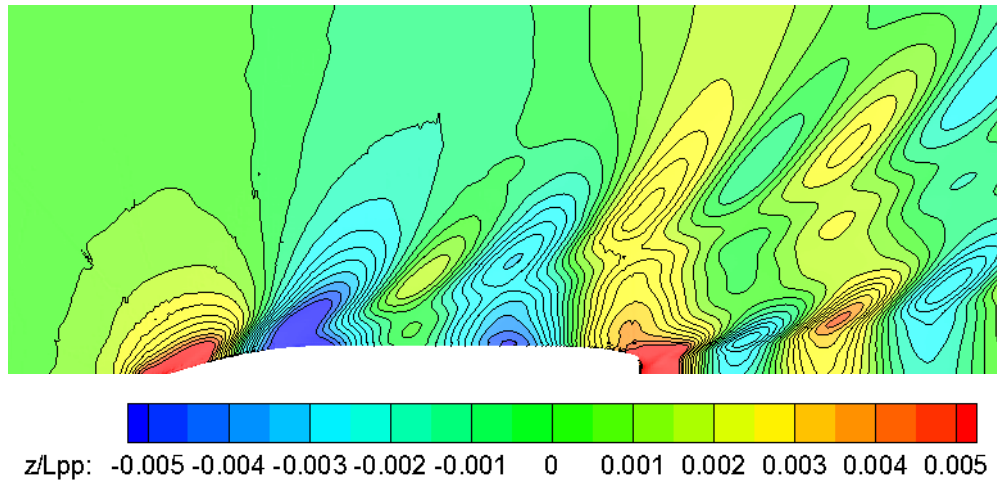


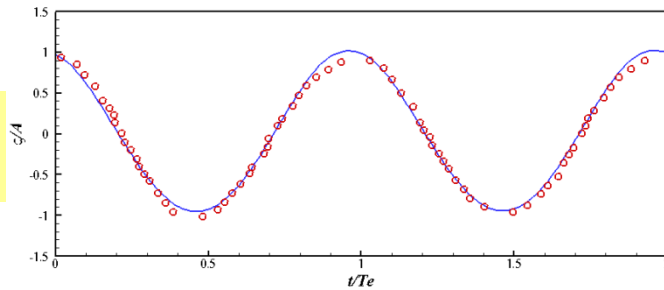
Fig. 3 Wave pattern around the KCS in calm water

Results

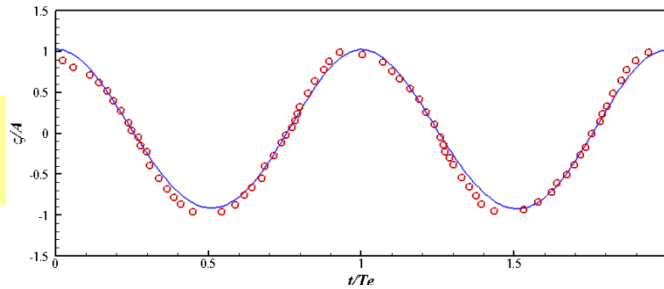
□ Wave generation

- 파랑 생성 결과를 실험결과와 비교
- Red symbol : analytic solution
- Blue line : present

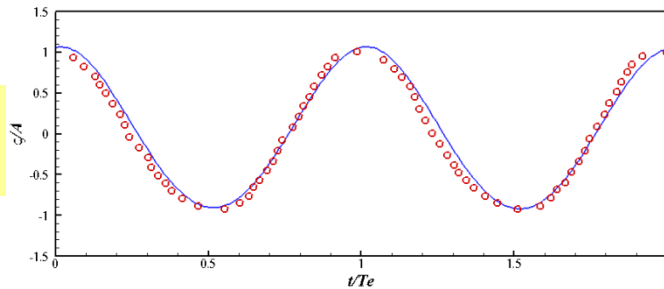
Case 1
($\lambda/L=0.65$)



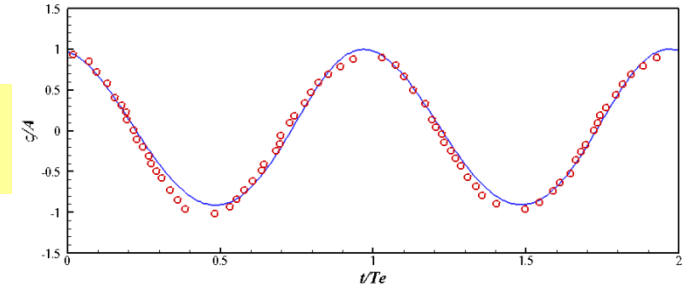
Case 2
($\lambda/L=0.85$)



Case 3
($\lambda/L=1.15$)



Case 4
($\lambda/L=1.37$)



Case 5
($\lambda/L=1.95$)

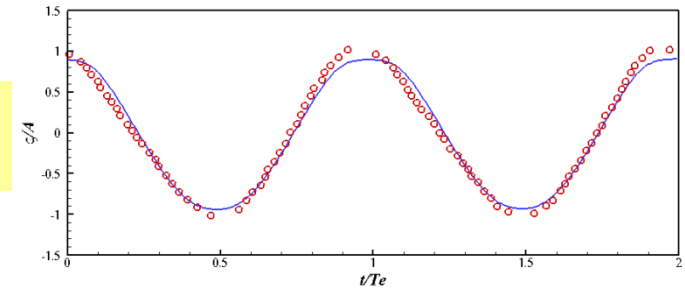


Table 4. The 1st harmonic wave amplitude in different wave conditions

Case	1	2	3	4	5
EFD ($L=6.07\text{m}$)	5.132	6.409	10.152	12.300	16.114
Present ($L=6.07\text{m}$)	4.883	6.226	10.033	12.169	15.452
Error (% EFD)	4.846	2.849	1.167	1.068	4.109

Results

□ Total resistance, heave & pitch motion in waves

$$\text{added resistance} : \sigma_{aw} = \frac{F_{x,wave} - F_{x,calm}}{\rho g \zeta_{I1} B_{WL}^2 / L_{PP}} \quad \text{heave} : TF_3 = \frac{x_{31}}{\zeta_{I1}} \quad \text{pitch} : TF_5 = \frac{x_{51}}{\zeta_{I1} k}$$

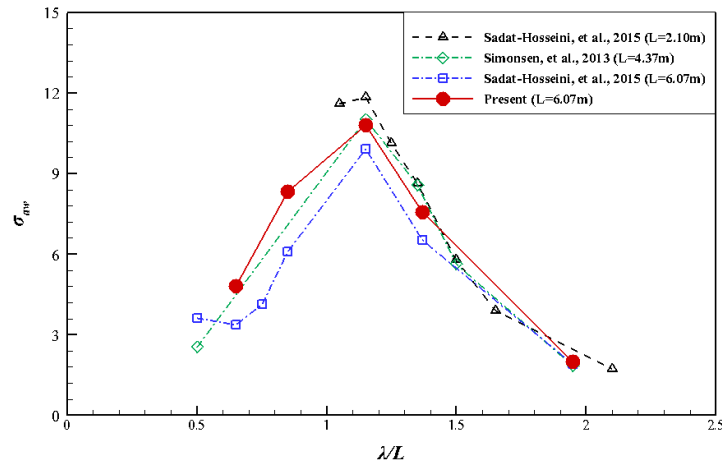
Table 7. Results of C_T , added resistance, TF_3 and TF_5 in difference wave conditions

$C_T (\times 10^3)$						σ_{aw} (added resistance)					
Case	1	2	3	4	5	Case	1	2	3	4	5
EFD (L=6.07m)	4.127	4.622	7.078	6.977	5.421	EFD (L=6.07m)	3.386	6.102	9.911	6.512	1.909
Present (L=6.07m)	4.379	5.036	7.451	7.559	5.514	Present (L=6.07m)	4.803	8.320	10.807	7.577	1.986
Error(%)	-6.120	-8.944	-5.271	-8.335	-1.725	Error(%)	-41.853	-36.353	-9.042	-16.348	-4.039

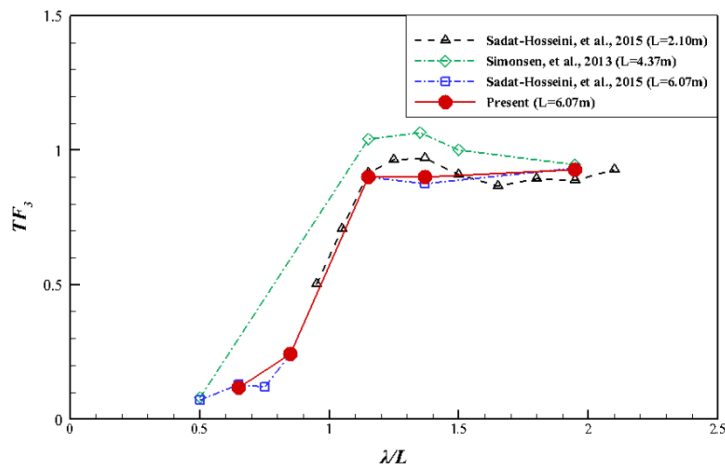
TF_3 (heave)						TF_5 (pitch)					
Case	1	2	3	4	5	Case	1	2	3	4	5
EFD (L=6.07m)	0.130	0.241	0.899	0.875	0.933	EFD (L=6.07m)	0.017	0.146	0.748	0.966	1.119
Present (L=6.07m)	0.117	0.242	0.901	0.899	0.928	Present (L=6.07m)	0.010	0.225	0.724	0.971	1.113
Error(%)	9.936	-0.446	-0.242	-2.760	0.571	Error(%)	42.000	-53.573	3.294	-0.578	0.610

Results

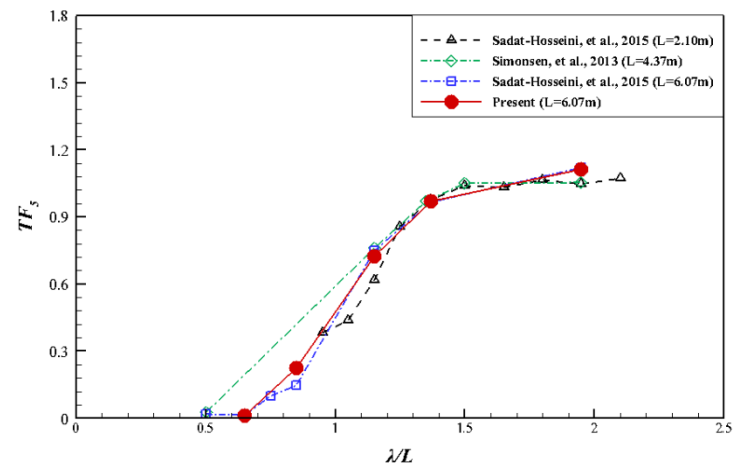
□ Total resistance, heave & pitch motion in waves



added resistance



heave motion



pitch motion

Conclusion and discussion

□ 결론

- OpenFOAM을 활용하여 파랑 중 선박의 부가저항과 2자유도 운동 수치해석
 - 파랑은 모든 경우에 대해 실험결과와 대부분 비슷하게 생성
 - 단파영역(Case 1~2)의 부가저항 최대 오차는 41%, pitch 운동 최대 오차는 53%
 - Heave 운동은 모든 파랑에 대해 10%이내의 오차 발생
 - ☞ 향후, 단파영역에서의 만족할 수 있는 오차 범위 내의 추가적인 부가저항 계산 결과 검증 예정

□ 향후 계획

- 격자에 대한 부가저항 및 운동응답 불확실성 해석 및 검증
- 여러 선형에 대한 추가적인 부가저항 계산 검증 수행

THANK YOU
Q&A