OpenFOAM을 이용한 규칙파 중 원형 기둥에서의 파랑 상호작용에 관한 수치해석

2016. 09. 30

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5th OKUCC

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□ Research background

- 해양 환경에서 파랑은 해양 구조물에 예기치 못한 손상을 초래할 수 있음
  - 설계단계에서 파랑하중과 소상파고(Wave run-up) 예측은 비용 및 안정성에서 매우 중요
  - 원형 실린더에 대한 소상파고는 물리적 또는 수치적으로 연구가 지속적으로 진행 중
- 전산유체역학에 대한 의존도가 지속적으로 증가하는 중
  - 물리수조를 이용한 모형실험 시 실제적인 파랑환경 재현 등에 어려움이 있음
  - 파랑과 구조물의 상호작용을 포함한 비선형성 거동을 예측하기 위해 전산유체역학을 사용

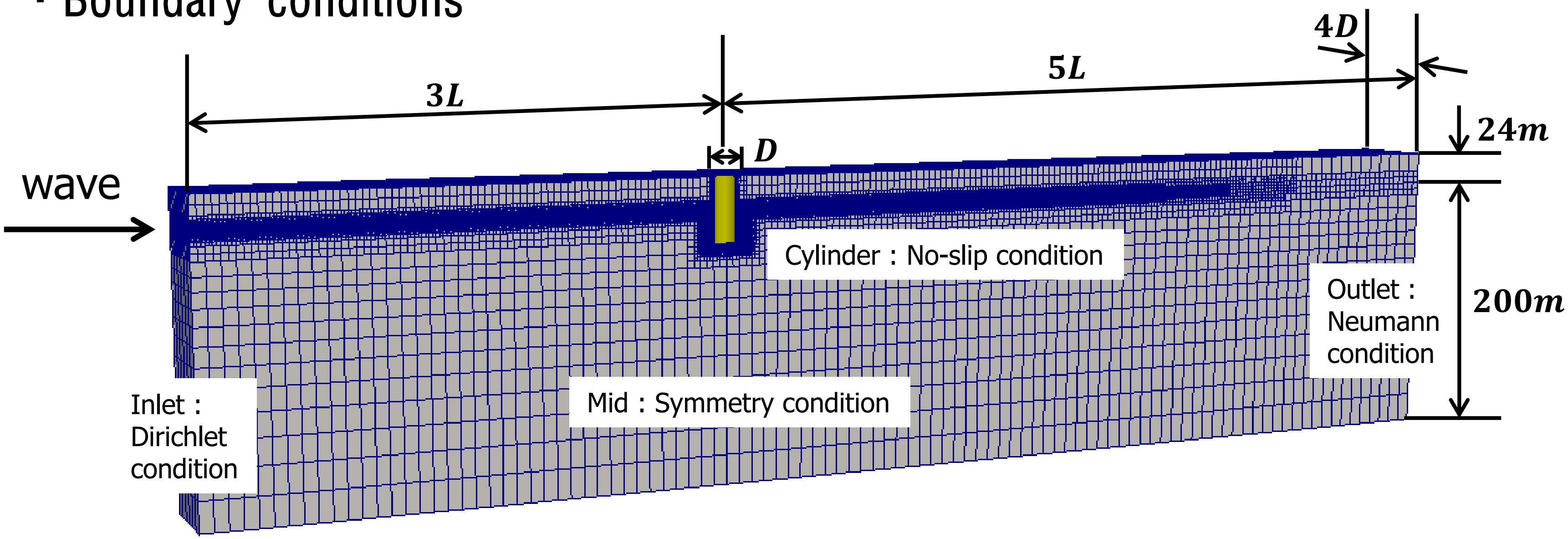
□ Objective

- 규칙파 중 원형 실린더 구조물에 발생하는 wave run-up 에 대한 수치적 해석
- 규칙파랑 재현을 통해 수치파랑수조의 수치기법 검증

Numerical modeling

□ Mesh generation & boundary conditions

- Mesh generation (Number of mesh : 3.1M)
  - blockMesh : Structured block mesh generation
  - snappyHexMesh : Automatic mesh generation
    → Unstructured hanging node mesh & cut cell mesh
- Boundary conditions



* L = wave length

* D = the diameter of the cylinder diameter (16m)

□ Numerical methods

- Turbulence model : RNG $k-\varepsilon$ model
- P-V coupling : PIMPLE (hybrid method between PISO and SIMPLE)
- Free surface : VOF (Volume Of Fluid)
- Convection term : second order differencing scheme (limitedLinear)
- Diffusion term : upwind scheme

☐ Computational conditions (27th ITTC OEC Benchmark study)

· Main particulars of single/four cylinders

Description	Symbol [unit]	Prototype	Single / four cylinder model (MOERI)
Diameter	$D[m]$	16	0.318
Draft	$T_d\ [m]$	24	0.477
Scale	Γ	-	1/50.31

· Incident wave conditions

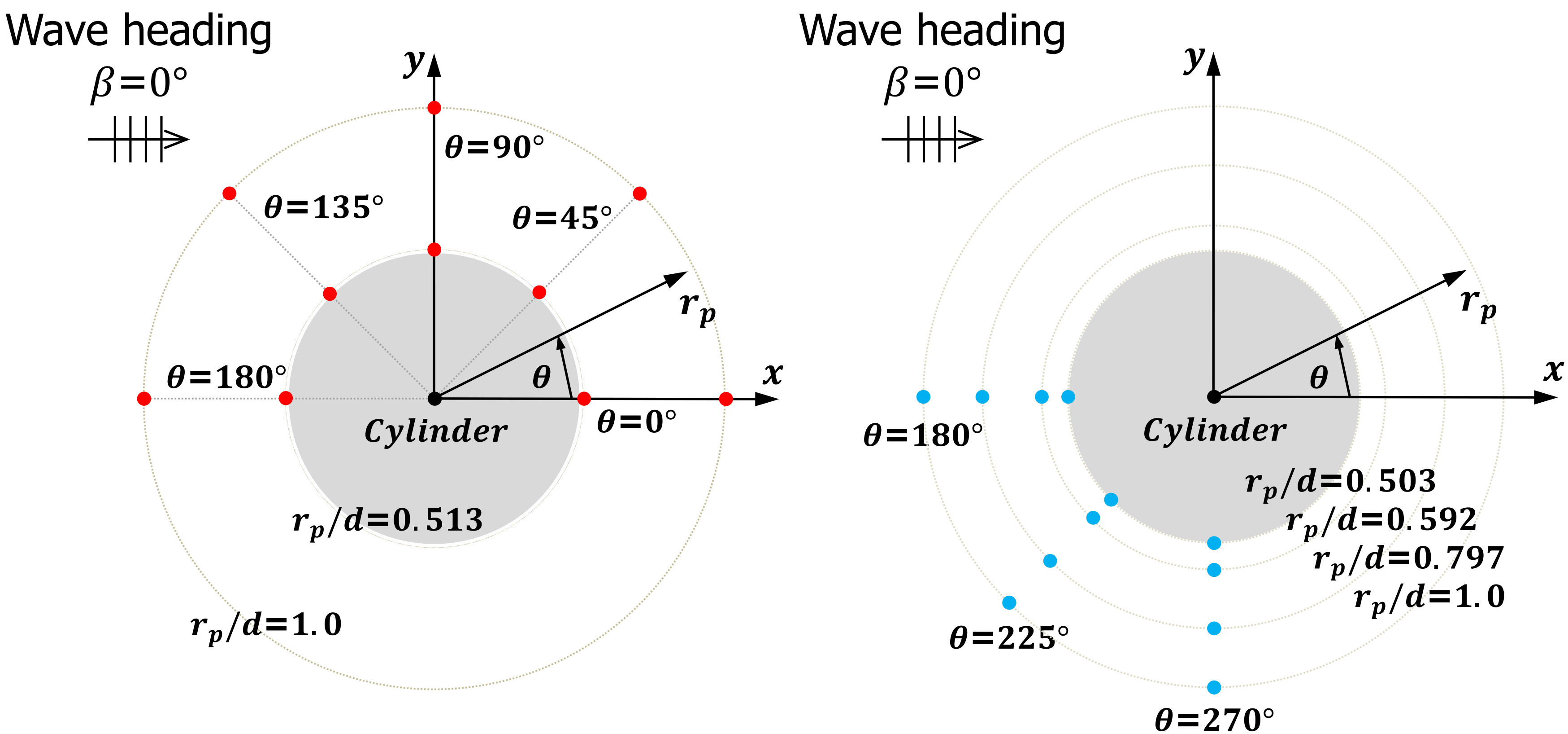
$T\ (s)$	H/L	k_0A	KC	k_0r	$L\ (m)$	D/L	$H\ (m)$	$A\ (m)$
7s	1/30	0.1	0.5003	0.657	76.44	0.21	2.548	1.274
9s		0.2	0.8270	0.398	126.36	0.13	4.212	2.106
15s		0.3	2.2973	0.143	351.00	0.046	11.700	5.850

· Grid sizes

Grid system	$L/\Delta x$	$H/\Delta z$	$\Delta x/\Delta z$	$T/\Delta t$	Turbulence model
Coarse	101(1.25m)	3(1.25m)	1	1000	RNG $k-\varepsilon$
Medium	202(0.626m)	7(0.625m)			
Fine	404(0.313m)	13(0.313m)			

□ Computational conditions

- Locations of wave probes around circular cylinders

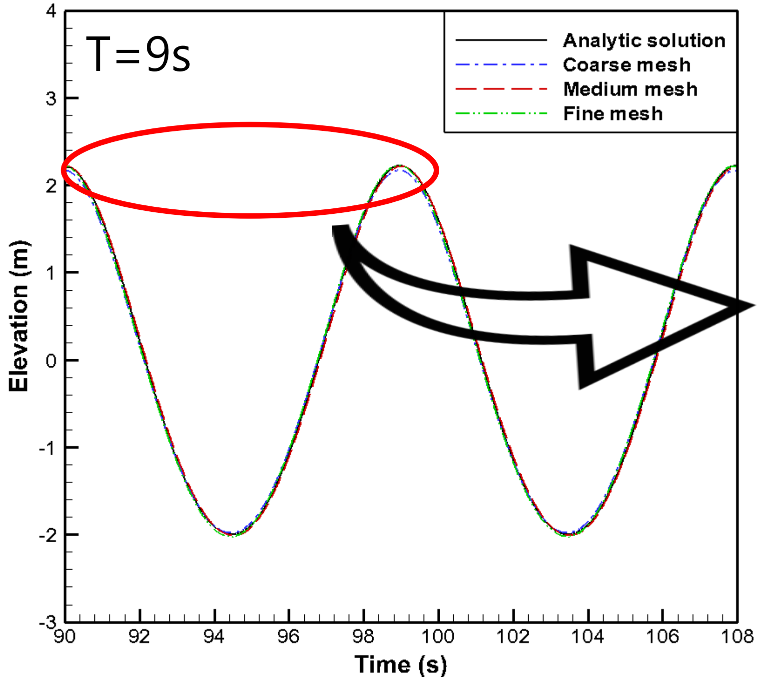


(a) Single circular cylinder (b) Two / four circular cylinders

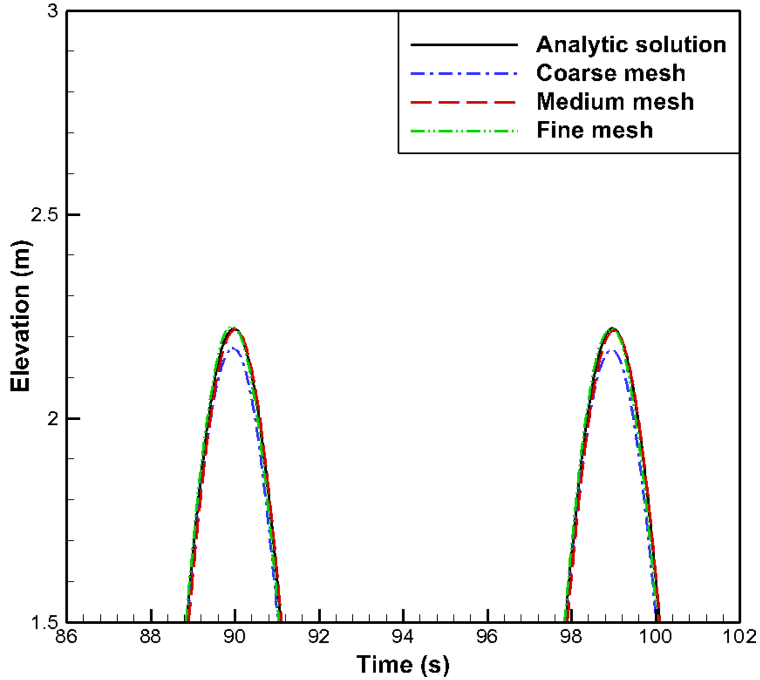
Numerical validations

□ Validations for wave propagation for stokes 2nd order wave theory

- Grid convergence (probed at the center point of the cylinder)
  - At least the medium mesh should be considered



(a) Time series of the wave elevation

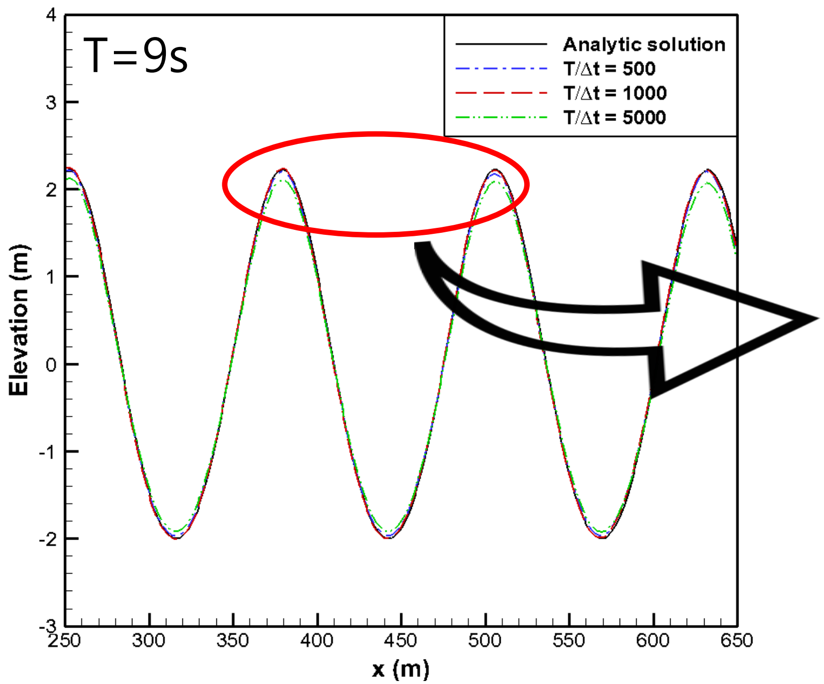


(b) Enlarge two consecutive crests

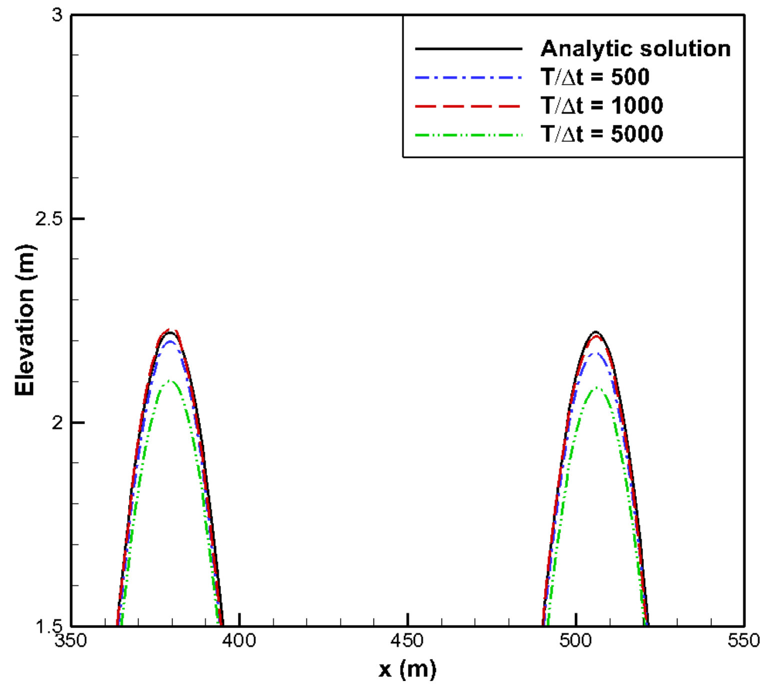
Numerical validations

☐ Validations for wave propagation for stokes 2nd order wave theory

- Time steps per one wave period (simulation time=12 periods)
  - One wave period is resolved by 1,000 time steps



(a) Wave elevation along the x-coordinate

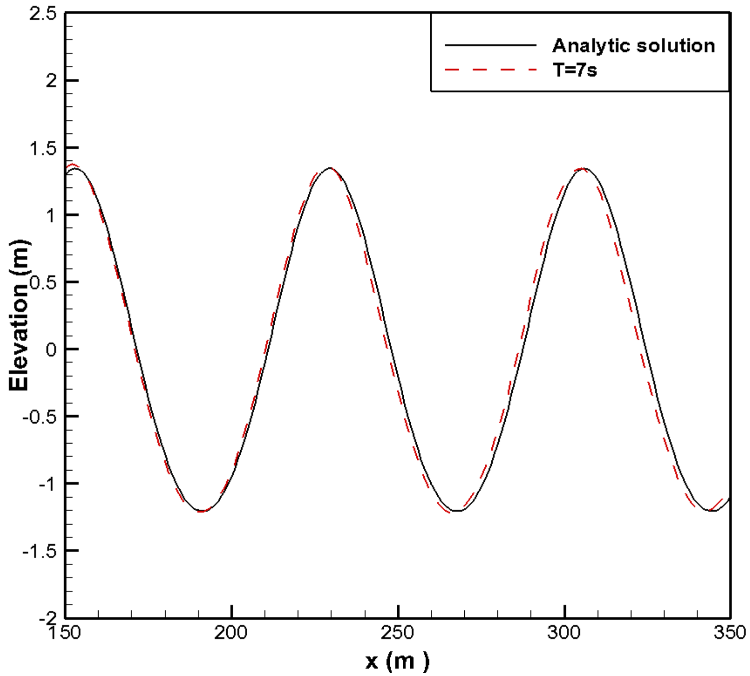


(b) Enlarge two consecutive crest

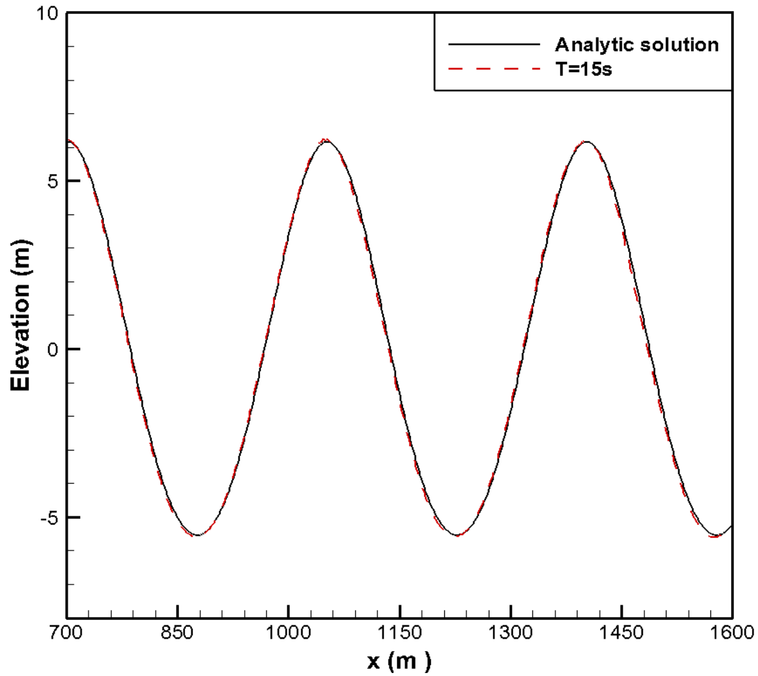
Numerical validations

☐ Validations for wave propagation for stokes 2nd order wave theory

- Wave period = 7s and 15s with fine mesh and medium mesh, respectively
- Wave elevation at the computational zone



(a) Wave period = 7s



(b) Wave period = 15s

□ RAOs and QTFs of surface elevations and wave forces

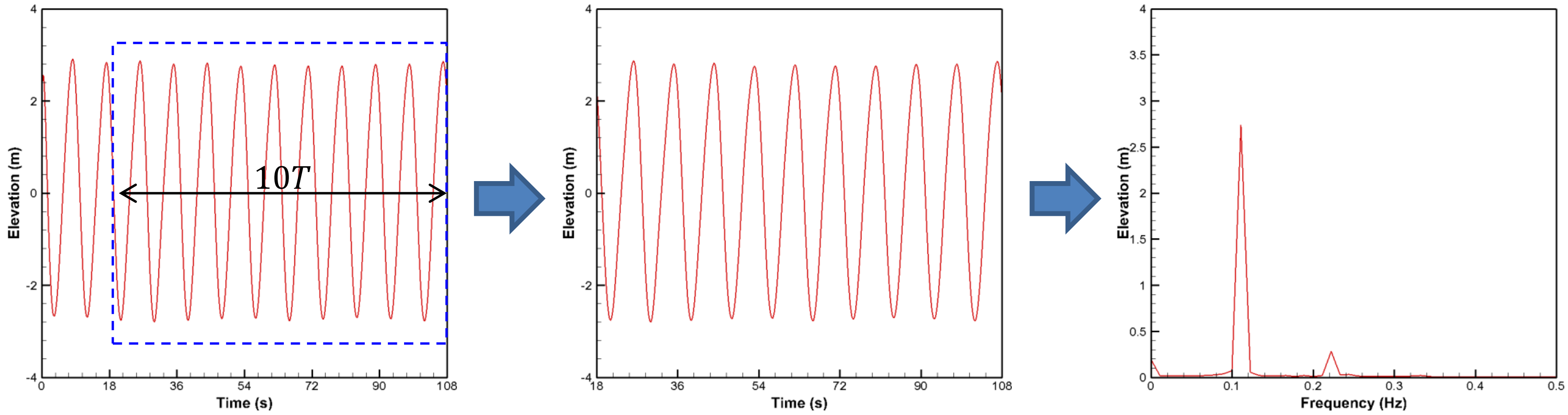
- Analysis method
  - $RAO = A^{(1)}/A_0$
  - $QTF = A^{(2)} * r/A_0^2$

$A^{(n)}$ = the nth harmonic amplitudes of the disturbed elevation

A_0 = the 1st harmonic amplitude of the incident(undisturbed) wave

r = the radius of the cylinder

- The Experimental data was from Sun et al., (2016)

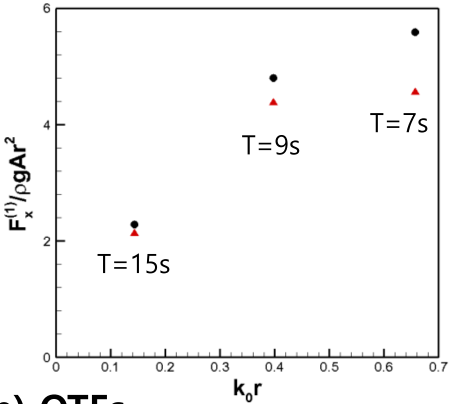


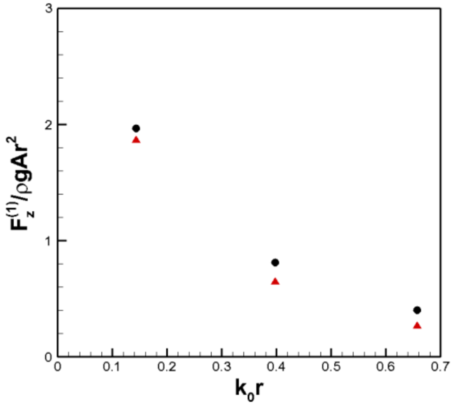
(a) Choose an usable time window (b) spectral analysis by a Fast Fourier Transform (FFT)

☐ RAOs and QTFs of surface elevations and wave forces at $H/L = 1/30$

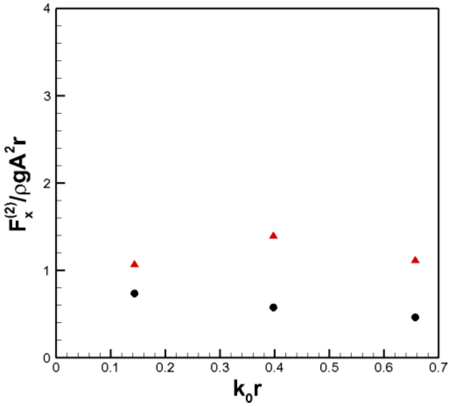
- RAOs and QTFs of wave forces for 3 different periods

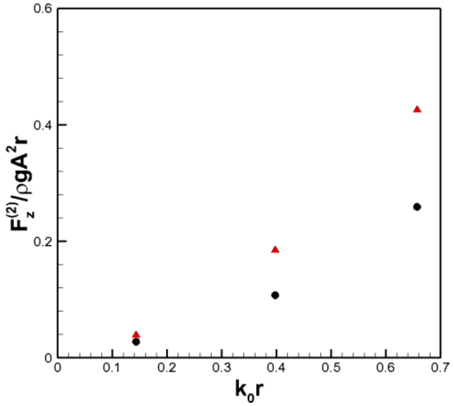
(a) RAOs





(b) QTFs





-Horizontal force

-Vertical force

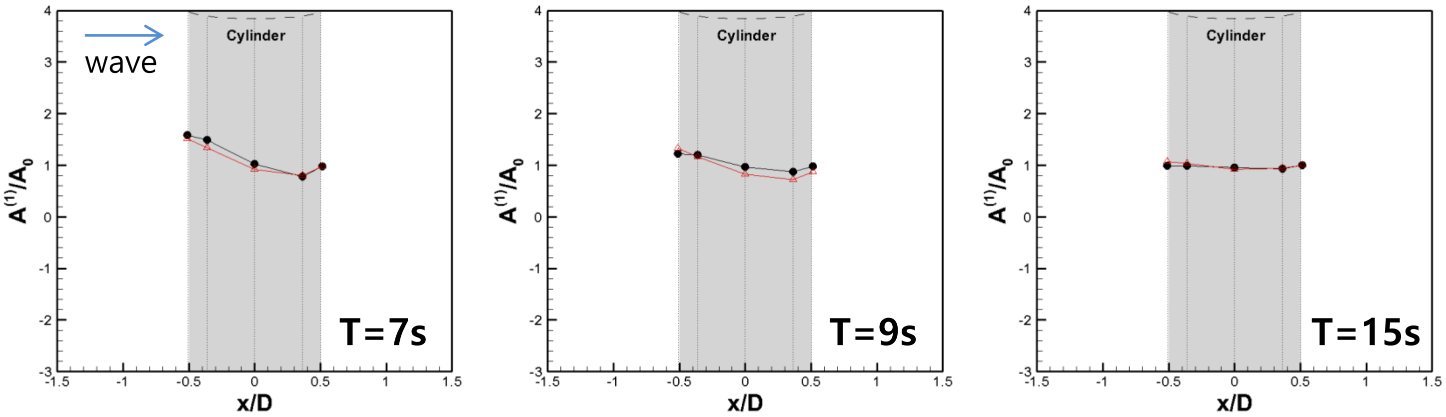
- $F^{(1)} = Force^{(1)}/\rho gAr^2$
- $F^{(2)} = Force^{(2)}/\rho gA^2r$
- ρ : *density*
- g : *gravity*
- A : A_0
- r : *the radius of the cylinder*

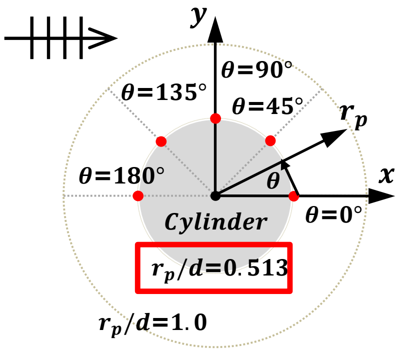
Results and discussion

☐ RAOs and QTFs of surface elevations and wave forces at $H/L = 1/30$

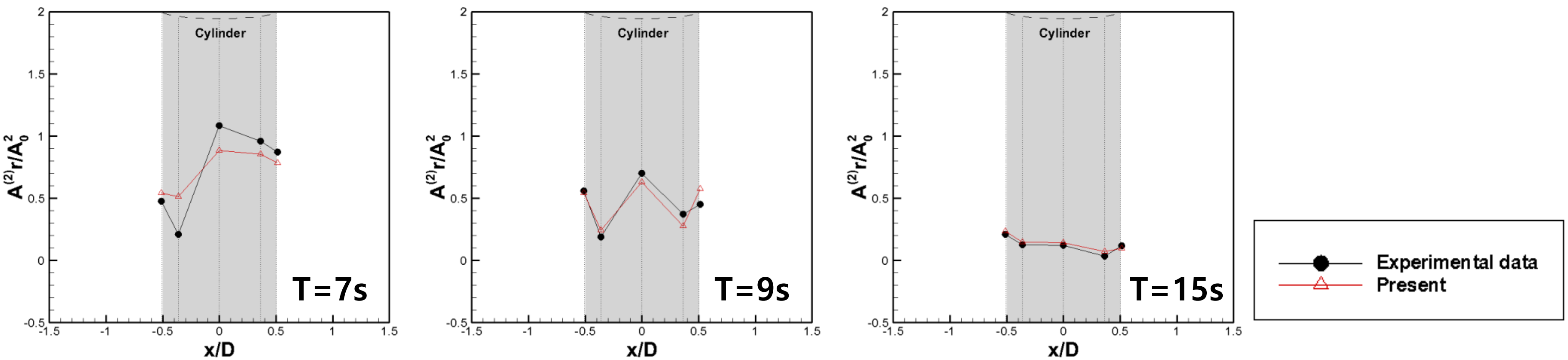
- RAOs and QTFs of surface elevations for 3 different periods

(a) RAOs





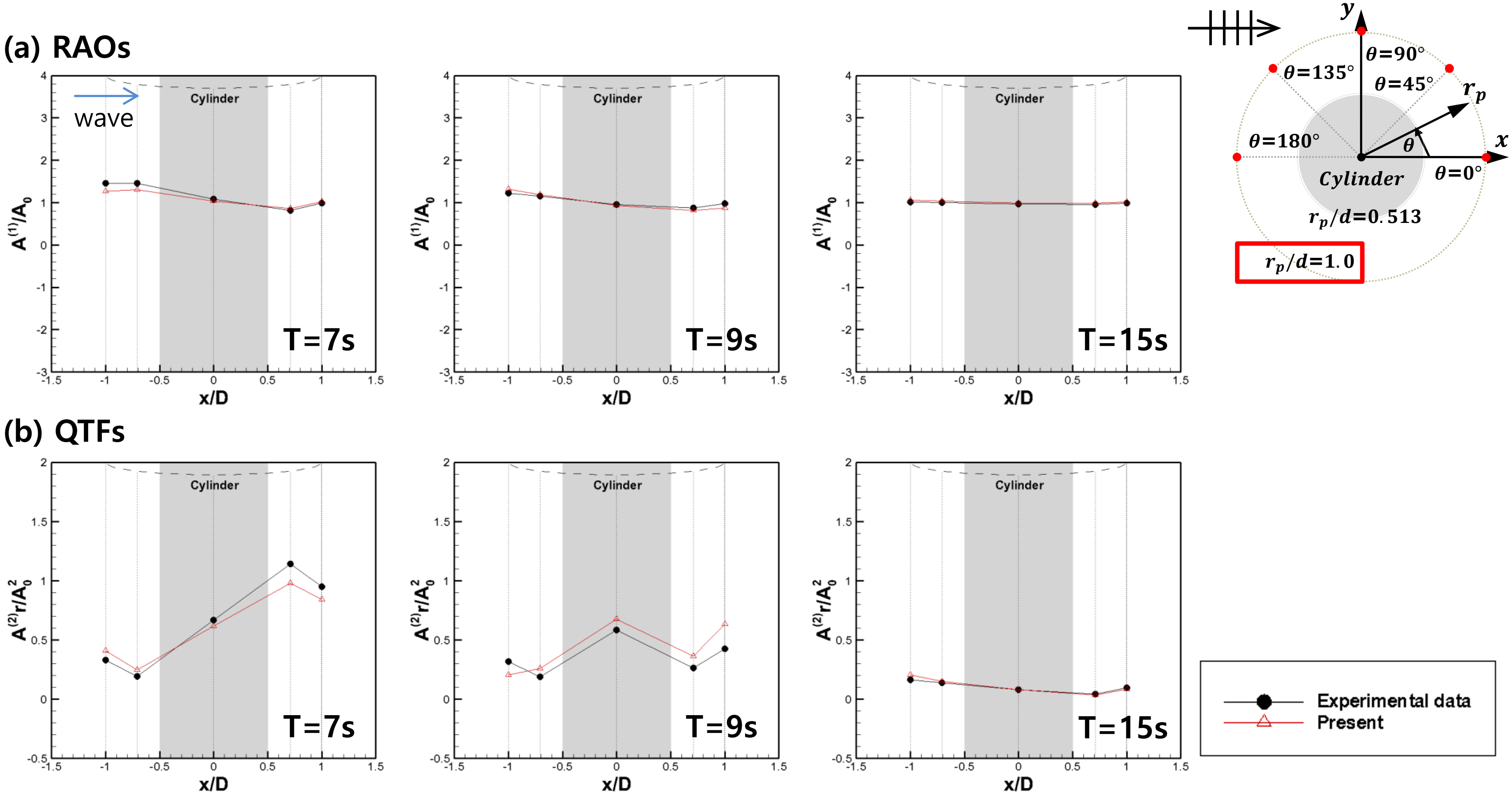
(b) QTFs



Results and discussion

☐ RAOs and QTFs of surface elevations and wave forces at $H/L = 1/30$

- RAOs and QTFs of surface elevations for 3 different periods



Conclusions

□ 규칙파랑 생성 및 검증

- 파 경사가 H/L=1/30 일 때, 최소 medium 격자 사이즈를 사용
- 추후 높은 경사도를 가지는 파에 대한 파랑 생성 검증이 필요

□ 파랑 구조물 상호 작용

- 소상파고와 파랑하중의 1차 조화성분은 실험 값과 대체적으로 비슷한 경향을 보임 (최대오차 12.6%)
  → 파수(k_o)가 커질수록 실린더 정면에서의 소상파고 및 수평하중은 증가, 수직하중은 감소
- 소상파고의 2차 조화성분은 실험 파수가 커질 수록 오차 범위가 커짐 (최대오차 147.9%)
- 관성력이 지배적인 KC<2 인 파랑 조건에서도 높은 주파수의 파 산란효과가 약하게 나타남

□ 향후 연구 계획

- 다양한 파랑 환경에 대해 수직 실린더와 파랑의 상호작용 검증
- 고정된 반 잠수식 구조물에 대한 파랑의 상호작용 분석을 통해 air-gap 예측

THANK YOU

Q&A