An experimental study of extreme wave kinematics on opposing depth-varying currents

Xuyang Niu, Yuxiang Ma, Xiaozhou Ma, Guohai Dong, Yongbo Song

State Key Laboratory of Coastal and Offshore Engineering

Dalian University of Technology

Dalian, China

大连理工大学 DALIAN UNIVERSITY OF TECHNOLOGY

海岸和近海工程国家重点实验室 STATE KEY LABORATORY OF COASTAL AND OFFSHORE ENGINEERING

Contents

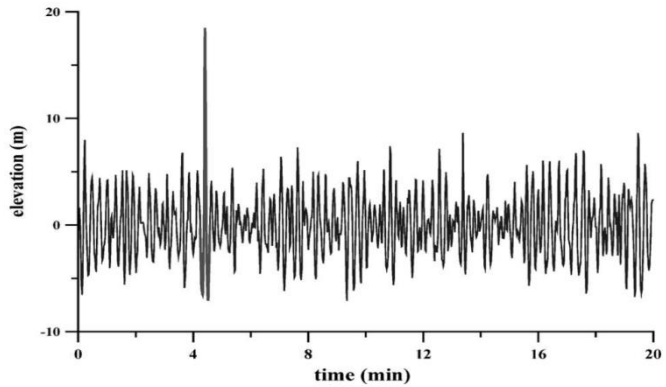
1. Introduction: Extreme wave

Extreme wave

Extraordinarily large wave

Damages of ships and ocean structures

Kinematics of extreme waves

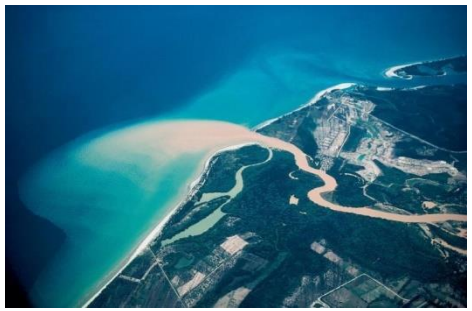


Extreme wave (New Year Wave, H_{max}/H_s=2.15)

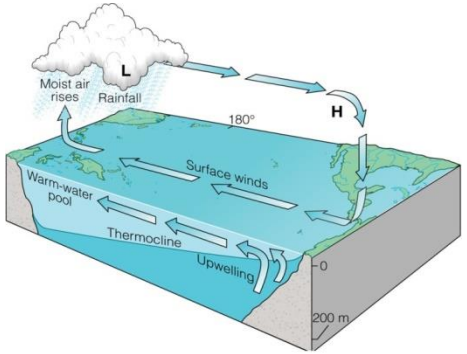
Photos of destructive extreme waves

1. Introduction: Depth-varying current

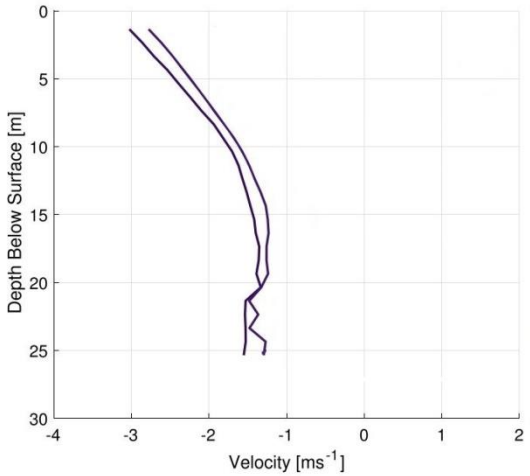
Waves are always coexisting with depth-varying currents



Currents around river mouth

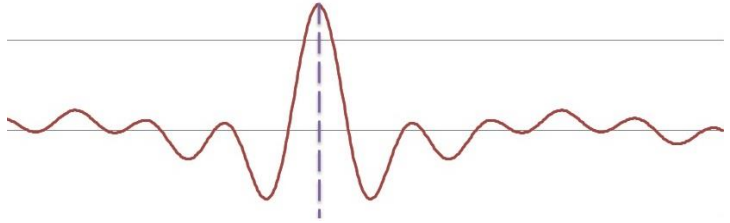


Currents generated by wind forcing



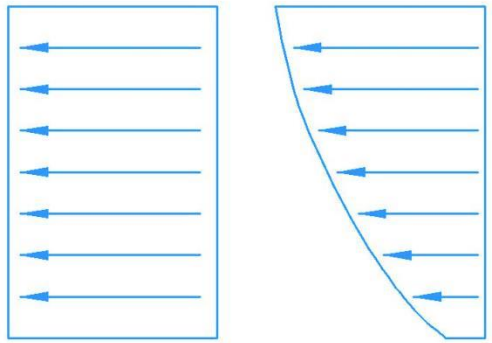
Depth-varying current

Profiles of velocity at Columbia River Mouth



Extreme waves

+

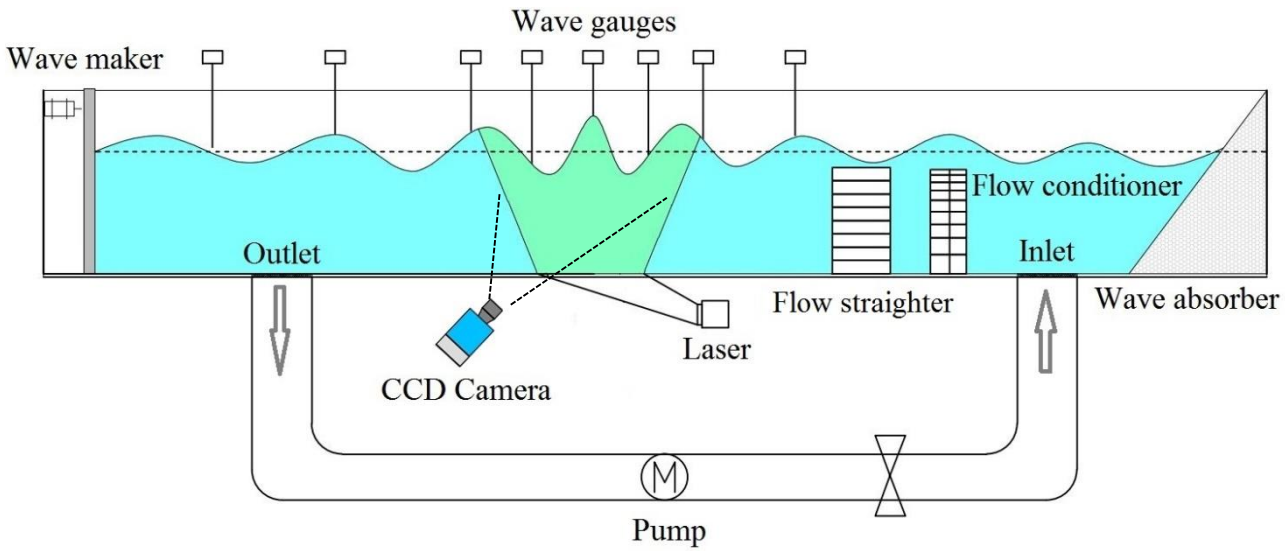


Opposing currents

→ Surface elevations

Wave kinematics

2. Experimental setup



Schematic of the experimental set-up

- Wave flume length: 20m
- Water depth: 0.4m

Wave generation:

- Piston-type wave maker

Currents generation:

- Controllable pump
- Flow conditioner
- Flow straighter

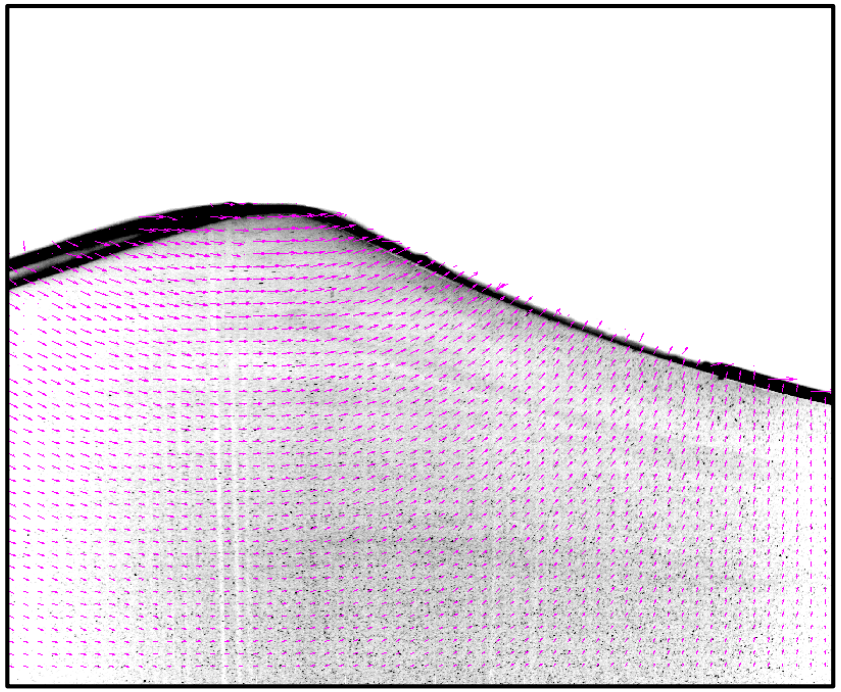
Surface elevation:

- Capacitance-type wave gauges

Velocity field:

- PIV system

2. Experimental setup



Velocity field measured by PIV system

PIV system

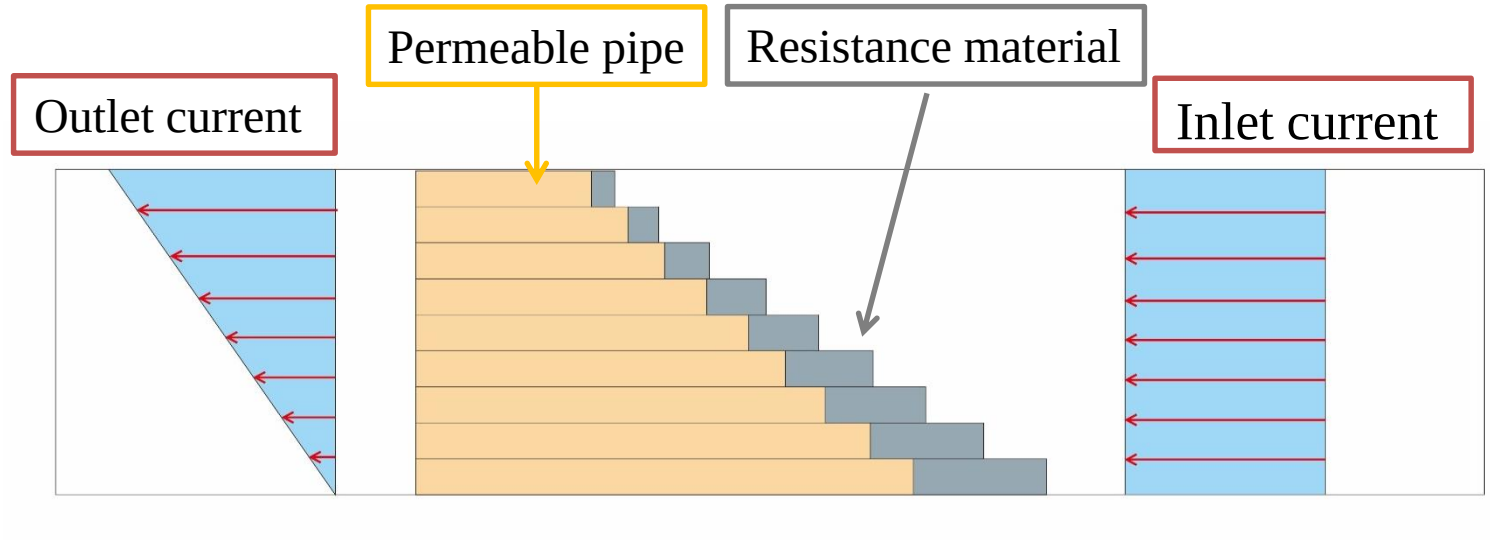
- Dual pulse Vlite-200 YAG laser
- CCD camera: 1340 × 1192 pixels
- Field of view 50 cm × 50 cm
- Interrogation window 64 × 64 pixels

Wave parameter

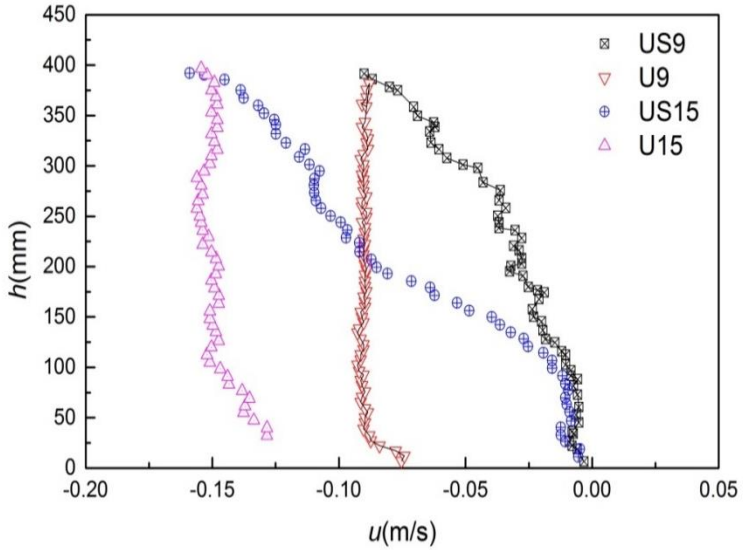
Wave case	***f*** **(Hz)**	**Components**	**Spectrum**	***A*****(cm)**
A3				3
A4	0.8-1.2	32	JONSWAP	4
A5				5

Extreme waves generated by dispersion focusing method

2. Experimental setup



Flow conditioner apparatus

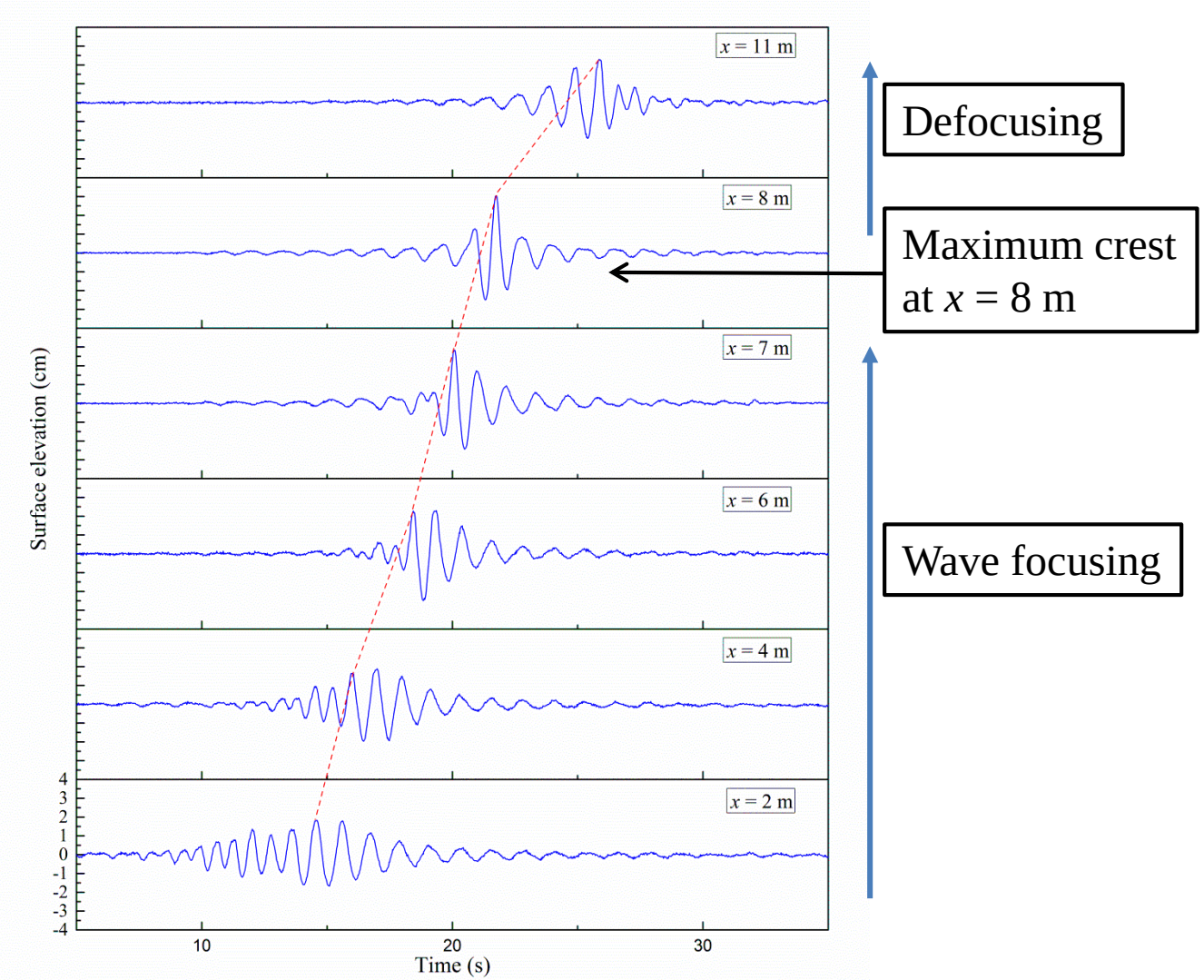


Velocity profiles of the currents

Current parameter

Current case	Surface velocity (m/s)	Current Shear (s^{-1})
Uniform current U9	-0.09	0
Shear current US9	-0.09	0.225
Uniform current U15	-0.15	0
Shear current US15	-0.15	0.375

3. Results and Discussion

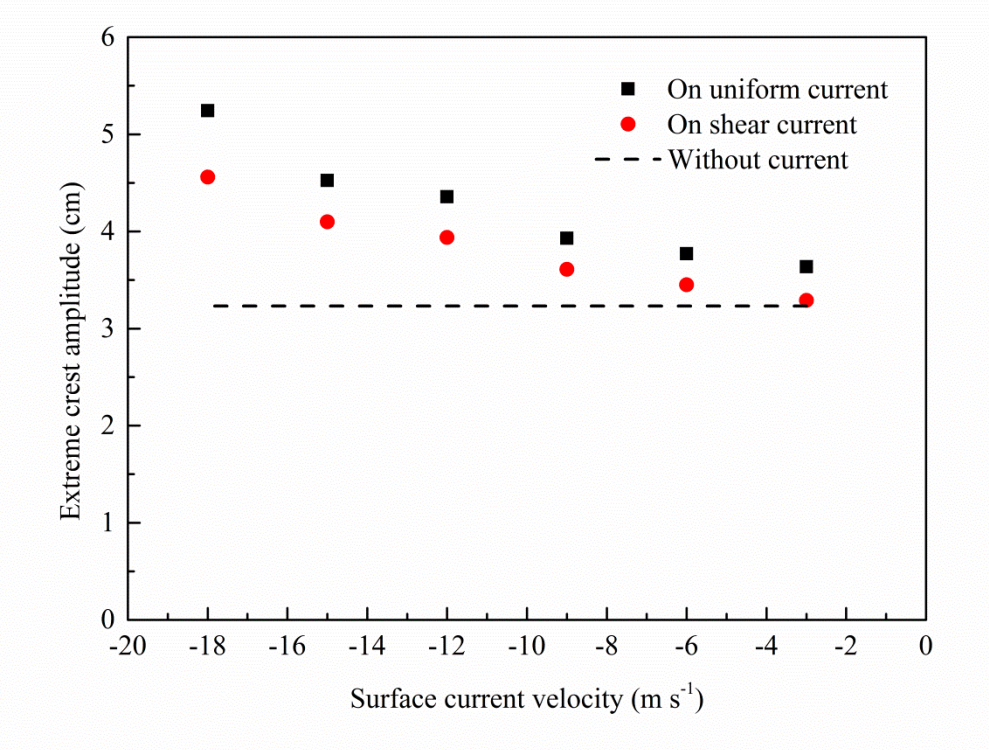


The evolution of surface elevation without current

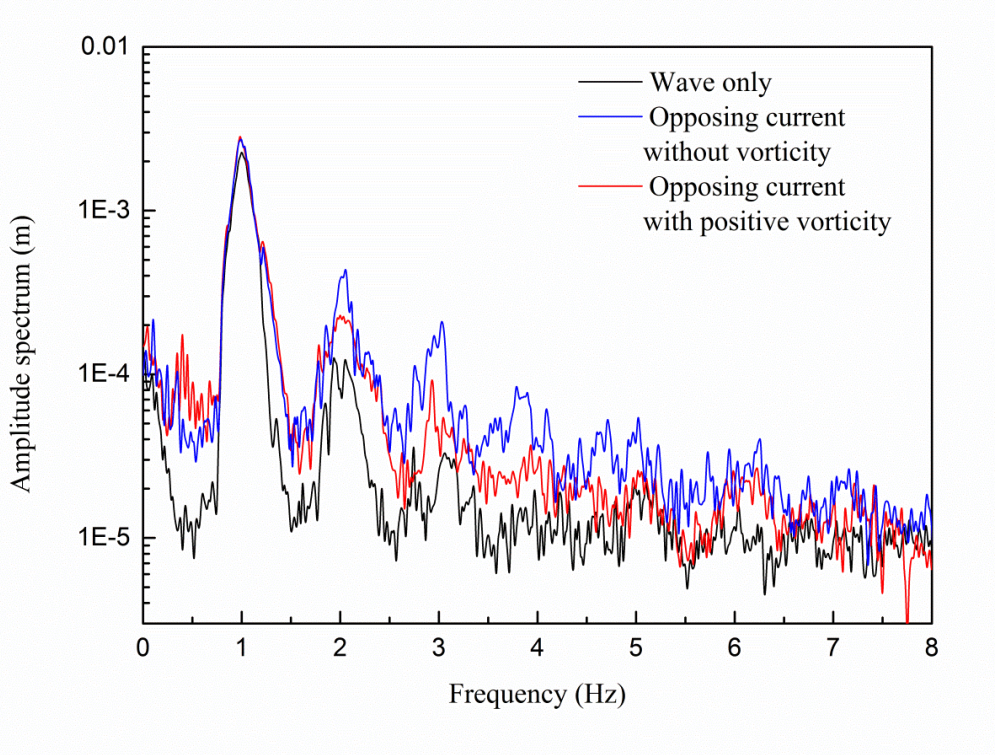
The video of the extreme wave crest

3. Results and Discussion

Extreme wave elevation and spectrum



Maximum wave crests on currents



Amplitude spectrum on currents

3. Results and Discussion

Models to depict the kinematics below extreme wave crests

- Linear model $u^{tot}(z)=\sum_{i=1}^{N}u_i^{(1)}(z)$

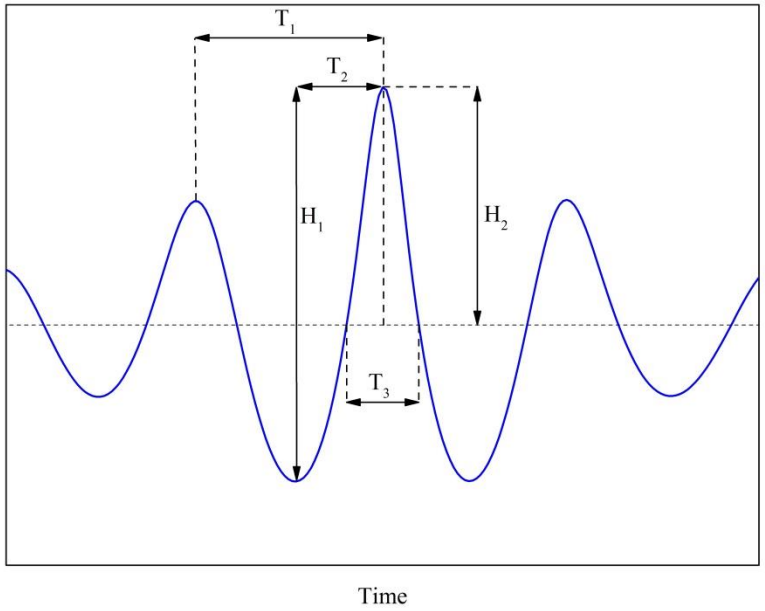
- Second-order irregular model

$$u^{tot}(z)=\sum_{i=1}^{N}u_i^{(1)}(z)+\sum_{i=1}^{N}\sum_{j=1}^{N}u_{i,j}^{(2,sum)}(z)+\sum_{i=1}^{N}\sum_{j=1}^{N}u_{i,j}^{(2,diff)}(z)$$

- Characteristic parameters model

$$u^{tot}(z)=u_c^{(1)}(z)+u_c^{(2)}(z)+\cdots+u_c^{(5)}(z)$$

Model	Height	Period
A	H_1	T_1
B (Grue's method*)	H_1	$2*T_2$
C	$2*H_2$	$2*T_3$

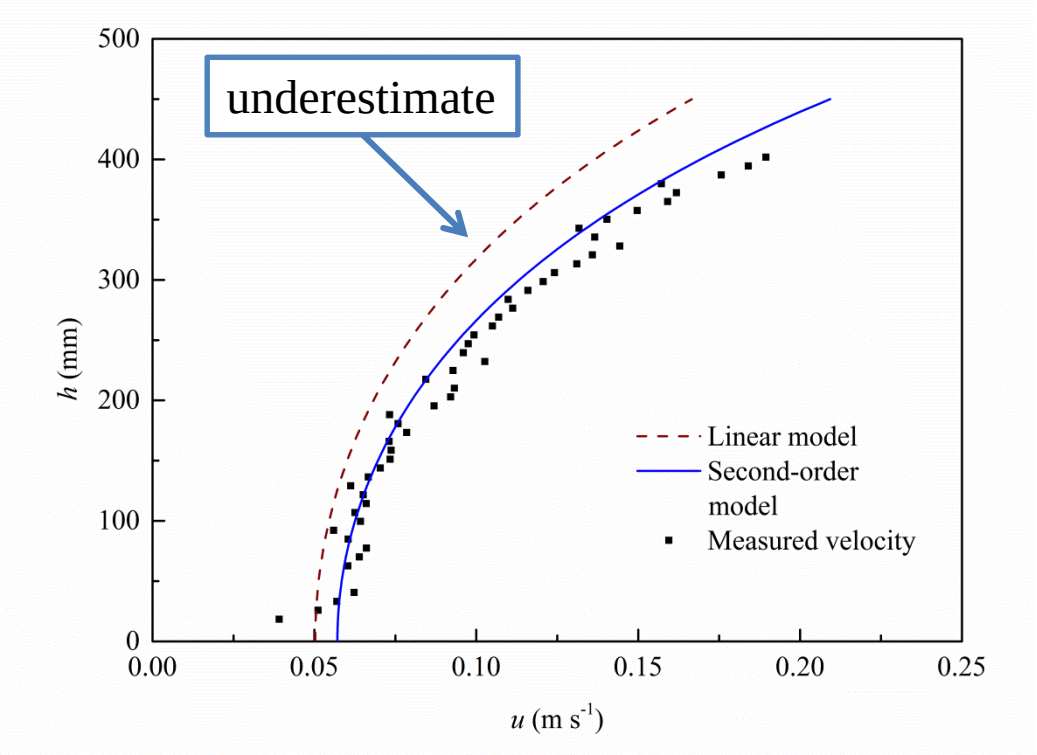


Definition of characteristic parameters

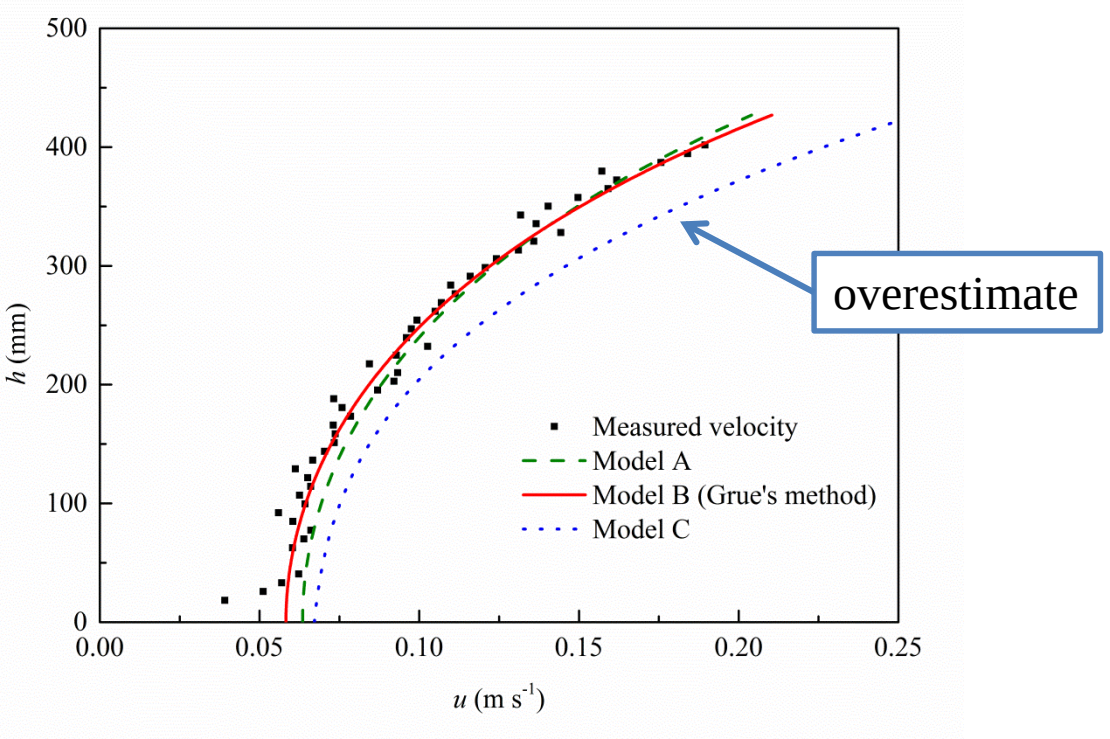
*Grue, J., Clamond, D., Huseby, M. and Jensen, A., 2003. Kinematics of extreme waves in deep water. Applied Ocean Research, 25(6): 355-366

3. Results and Discussion

Horizontal velocities without current



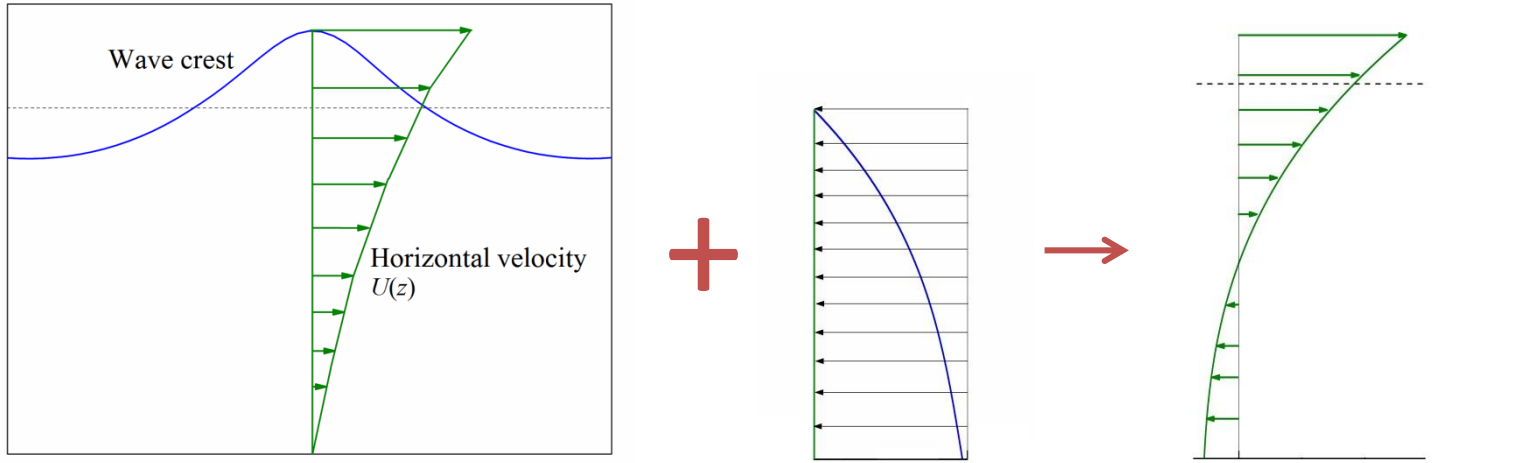
Horizontal velocities below extreme wave. (measured velocity, linear and second order model)



Horizontal velocities below extreme wave. (measured velocity and characteristic parameters model)

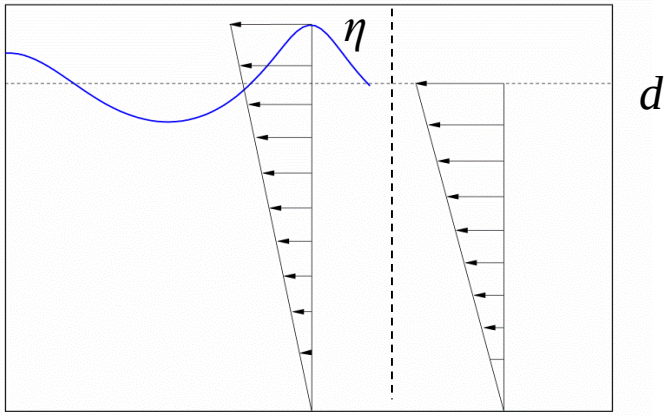
3. Results and Discussion

Doppler-shifted solutions on currents



Horizontal velocity below wave crest Opposing current Doppler-shifted velocity

Coordinate transformation



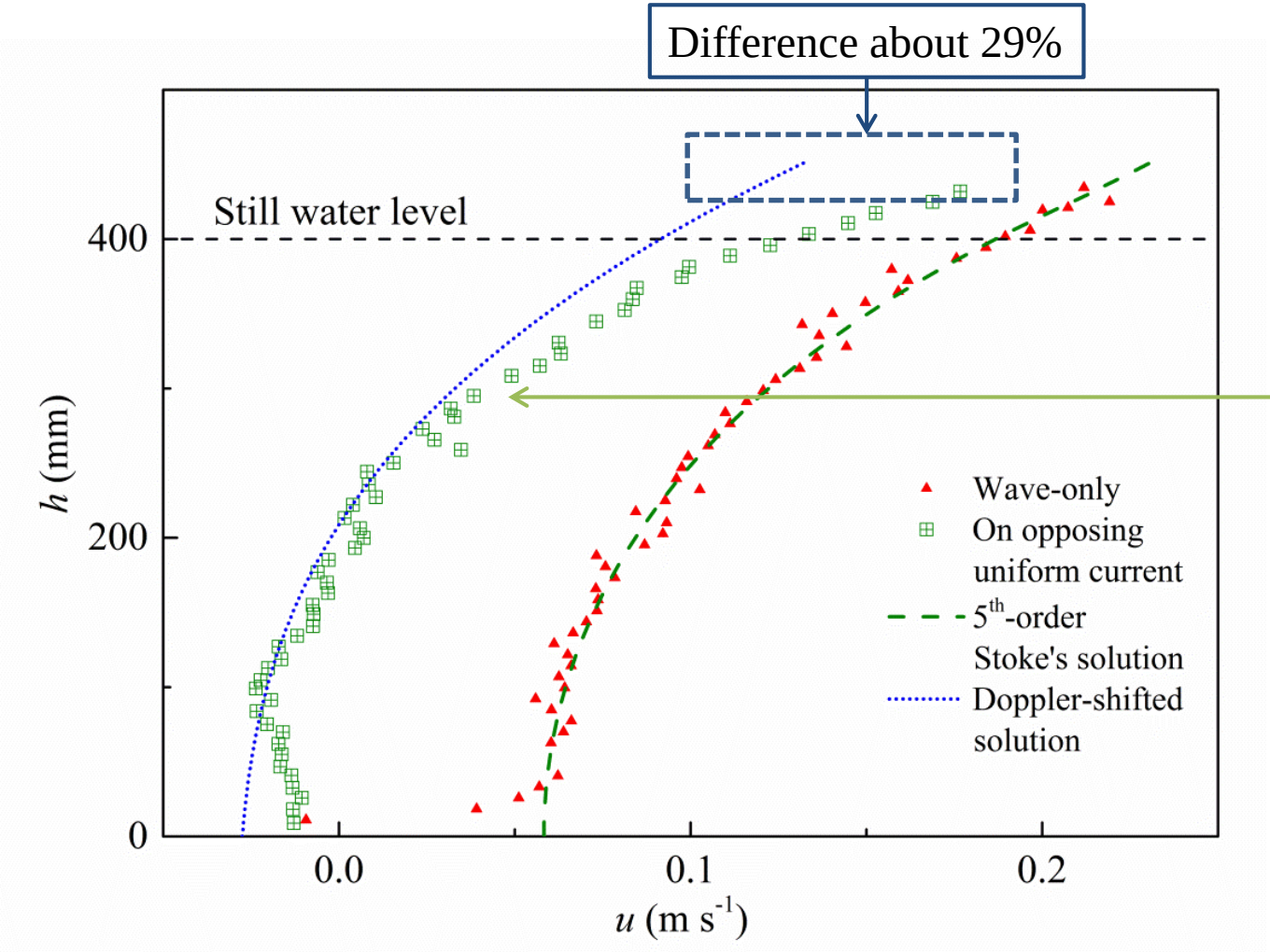
Stretched velocity Current velocity

Stretching method

$$U'(z) = \frac{U(z)*d}{\eta + d}$$

3. Results and Discussion

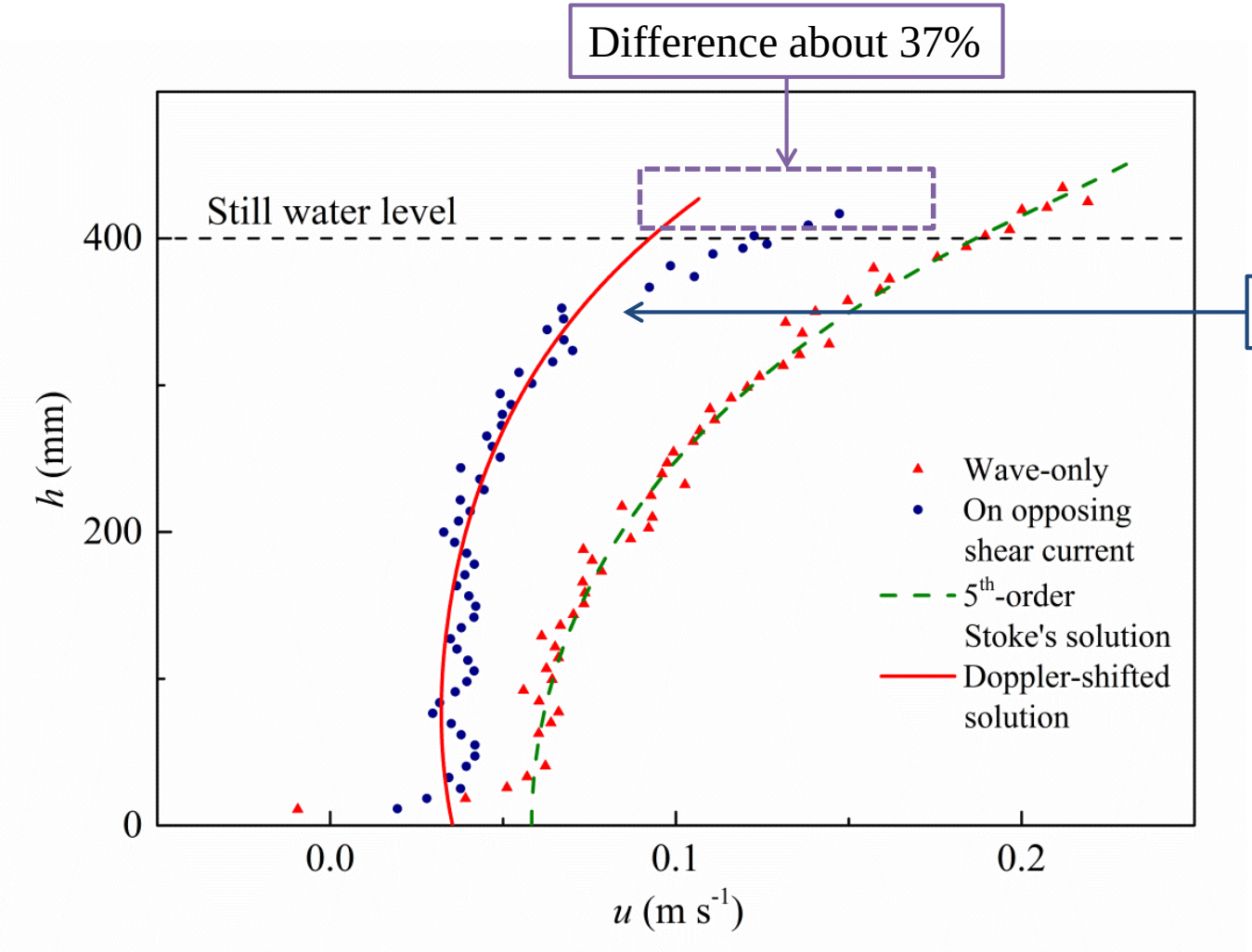
Horizontal velocities on opposing uniform current



Horizontal velocities below extreme wave crests on depth-uniform current *Us* = -9 cm/s , d*U*/d*z* = 0

3. Results and Discussion

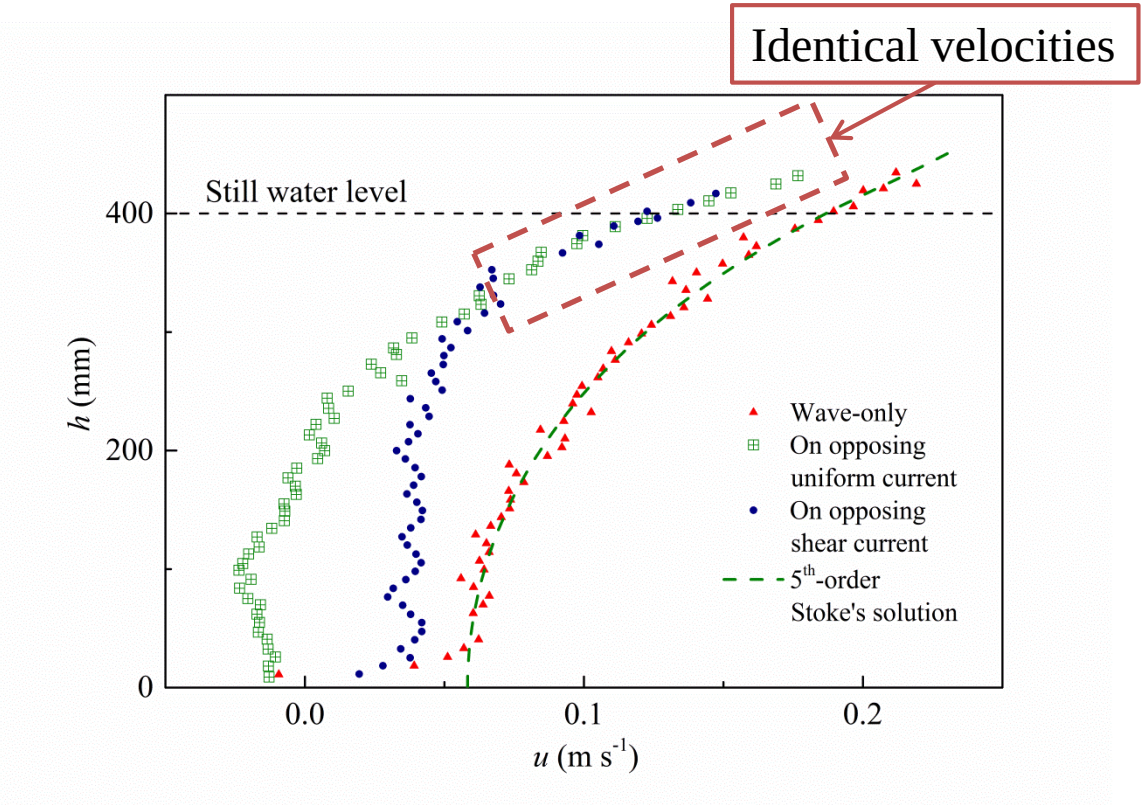
Horizontal velocities on opposing shear current



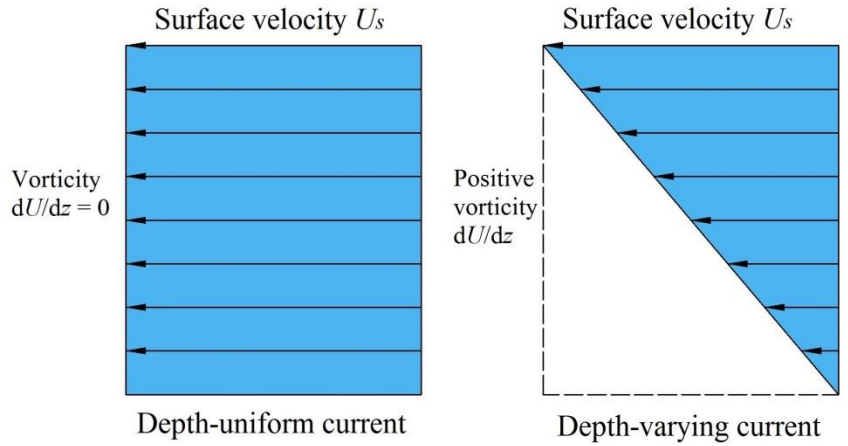
Horizontal velocities below extreme wave crests on depth-varying current *Us* = -9 cm/s , d*U*/d*z* = 0.225

3. Results and Discussion

Horizontal velocities on opposing currents



Horizontal velocities below extreme wave crests on depth-uniform and depth-varying currents



depth-uniform current Us = -9 cm/s , dU/dz = 0
depth-varying current Us = -9 cm/s , dU/dz = 0.225

4. Conclusion

- Adverse currents increase the heights of extreme wave crests
- 5^{th}-order Stokes solution based on Grue's method fits well with measured kinematics without current.
- The influence of shear currents on extreme waves is far more than linear correction.
- The velocity near the surface hardly depends on the vorticity in the water

Thank you for your attention

E-mail：niuxuyang@mail.dlut.edu.cn

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海岸和近海工程国家重点实验室
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