ICCE 2018

36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018

Baltimore, Maryland | July 30 – August 3, 2018

The State of the Art and Science of Coastal Engineering

Breaking Wave Detection with the Phase-Time Method (PTM) Revisited

FZK Forschungszentrum Küste

Dr.-Ing. Stefan Schimmels

Forschungszentrum Küste (FZK)
Leibniz University Hannover & Technical University Braunschweig, Germany

T-SAIL

Dan Liberzon, Assistant Professor

Technion - Israel Institute of Technology, Haifa, Israel

schimmels@fzk.uni-hannover.de; iberzon@technion.sc.il




Introduction

- Breaking waves are associated with high energy transfer rates and turbulence levels and can create tremendous loads when impacting on a structure.
- Understanding of the wave breaking process is of major interest in coastal and offshore engineering research.
- Point of breaking inception is important, e.g. for breaking wave impact studies, as well as the detection of breaking waves in a sea state for physical oceanography studies.
- Phase Time Method (PTM), proposed by Huang et al. (1992), was first applied by Zimmermann & Seymour (2002) for breaking wave detection in laboratory generated random deep water wave fields and later applied by Irschik et al. (2011) for determining the point of breaking inception in a flume.
- Results are promising, but threshold based approach still slightly ambiguous and lacks general validity.
- A new pattern detection approach to interpret PTM data for breaking wave detection will be proposed.

Huang, N. E., Long, S. R., Tung, C. C., Donelan, M. A., Yuan, Y., Lai, R. J., 1992. The local properties of ocean waves by the phasetime method, Geophysical Research Letters, 19(7), 685–688.
Irschik, K., Schimmels, S., Oumeraci, H., 2011. Breaking criteria for laboratory experiments based on the Phase-Time Method (PTM), Coastal Engineering Proceedings, 1(32), waves.6.
Zimmermann, C.-A., Seymour, R., 2002. Detection of breaking in a deep water wave record. Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 128, Issue 2, 72-78.

Phase Time Method (PTM) – theoretical background

- **Time variant (instantaneous) frequency and amplitude**

Time signal

$$\eta(t) = \sum_{n=0}^{\infty} a_n \cos(n\omega_0 t) + b_n \sin(n\omega_0 t)$$

Hilbert transform

$$v(t) = \sum_{n=0}^{\infty} a_n \sin(n\omega_0 t) - b_n \cos(n\omega_0 t)$$

Artificial signal

$$\Psi(t) = \eta(t) + i\, v(t)$$

phase

$$\Phi(t) = \arctan\left(\frac{\eta(t)}{v(t)}\right) = f_0 t + \Theta(t)$$

unwrap

frequency

amplitude

$$a(t) = |\Psi(t)|$$

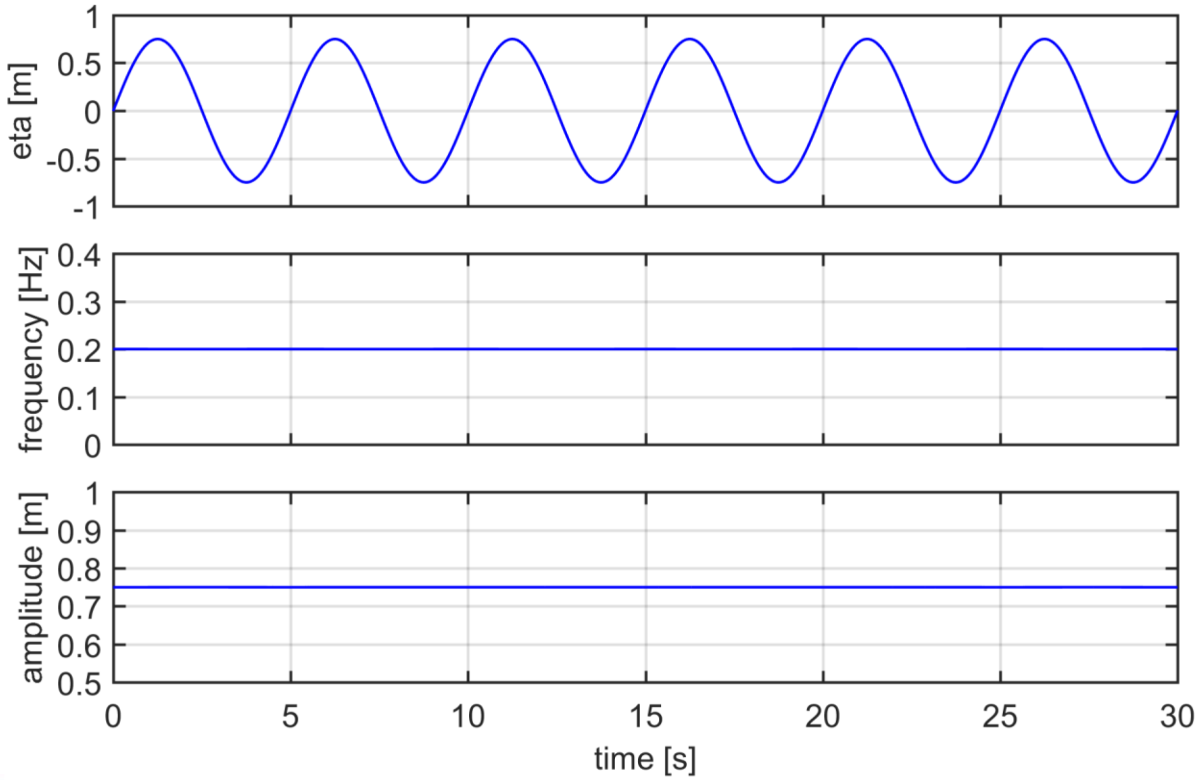
$$f(t) = \frac{\partial \Phi(t)}{\partial t} = f_0 + \frac{\partial \Theta(t)}{\partial t}$$

Phase Time Method (PTM) – theoretical background

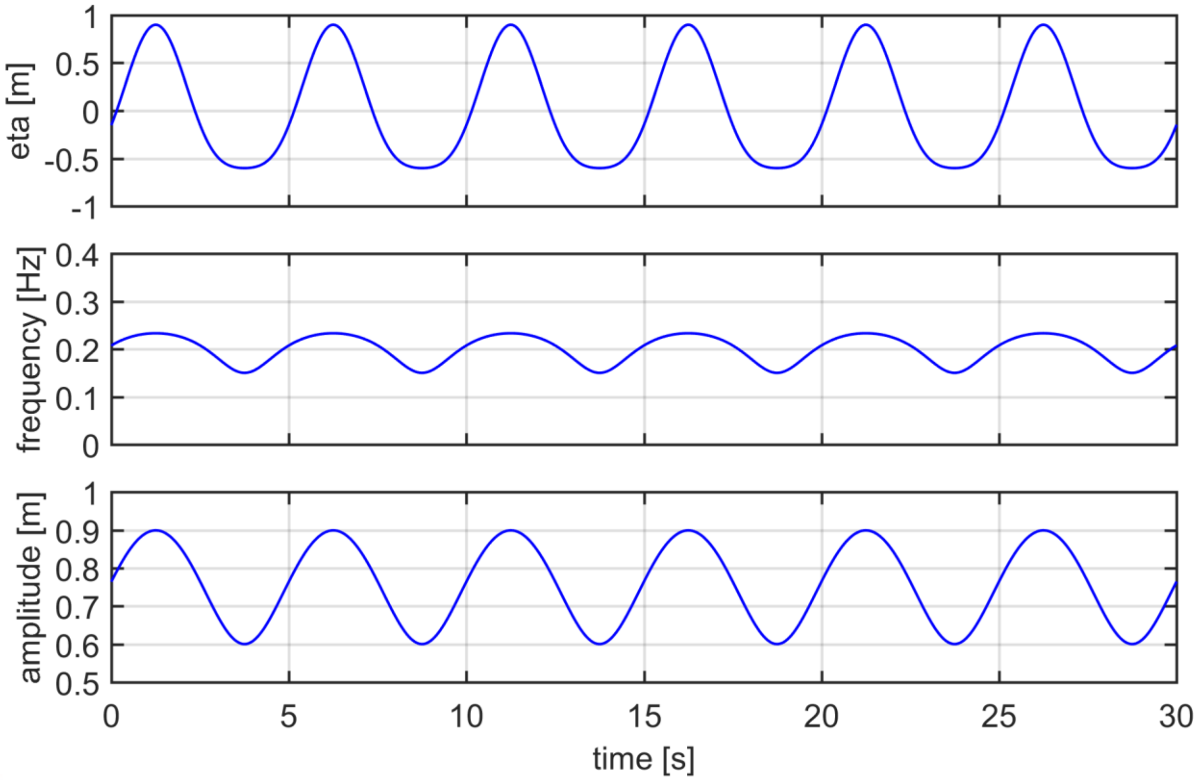
➢ **Example: 1st and 2nd order Stokes wave**

H = 1.5 m; T = 5 s; d = 5 m

Stokes 1st order

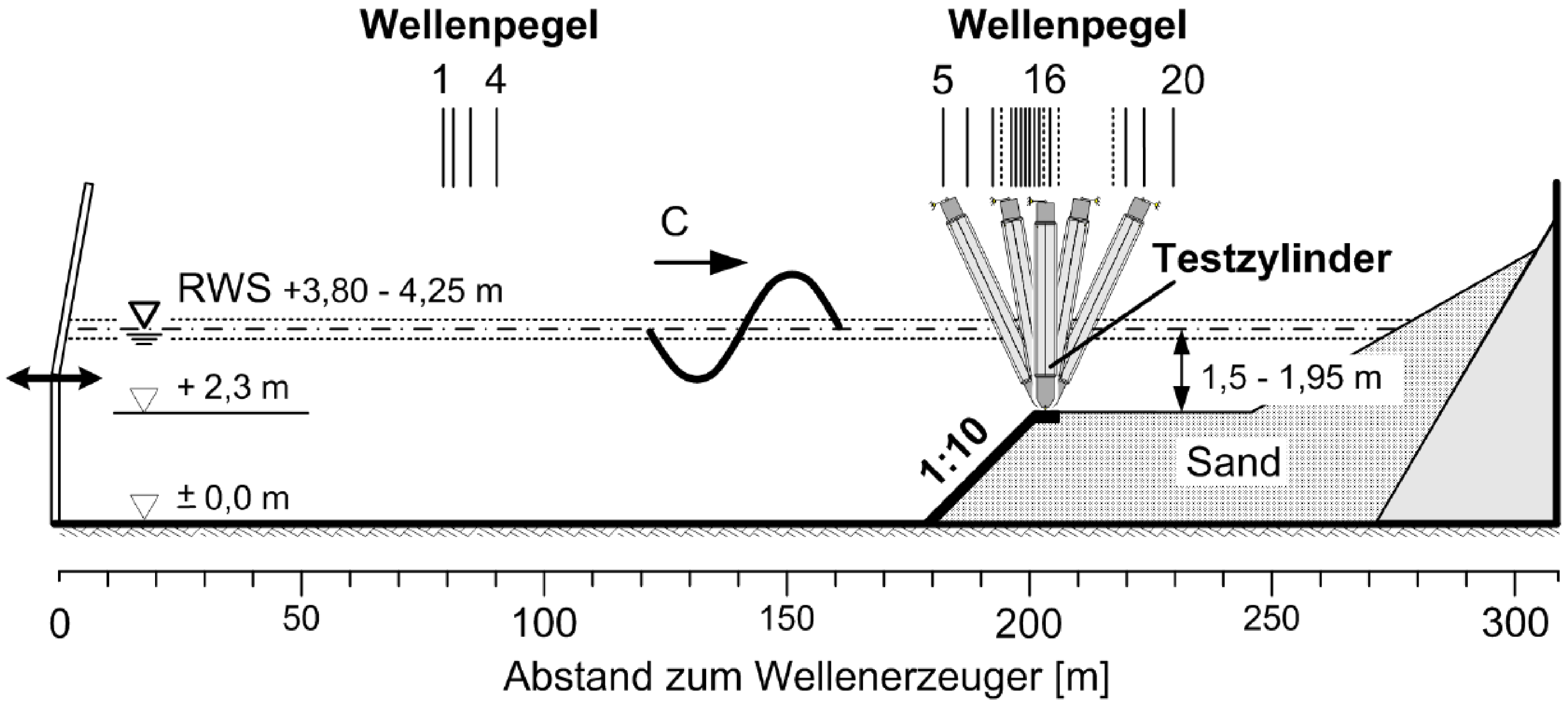


Stokes 2nd order



Phase Time Method (PTM) – theoretical background

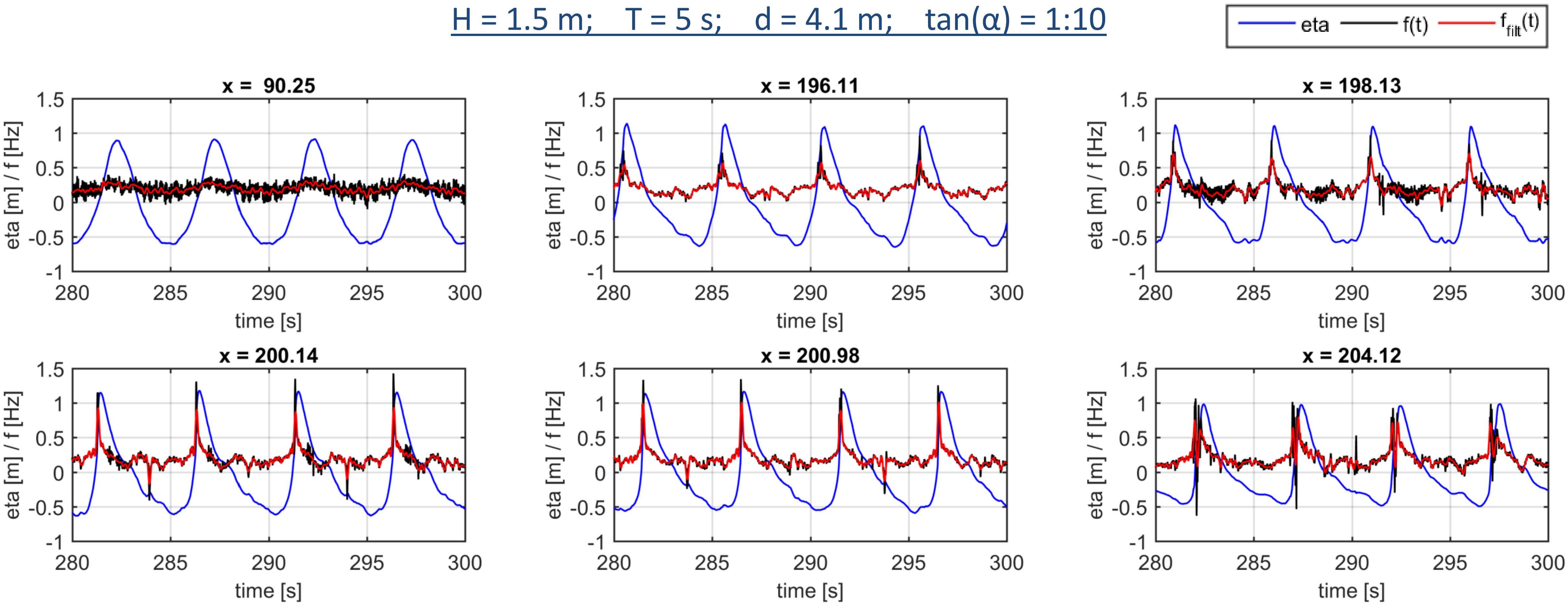
➢ **Example: Shoaling breaking wave – model set-up**



Phase Time Method (PTM) – theoretical background

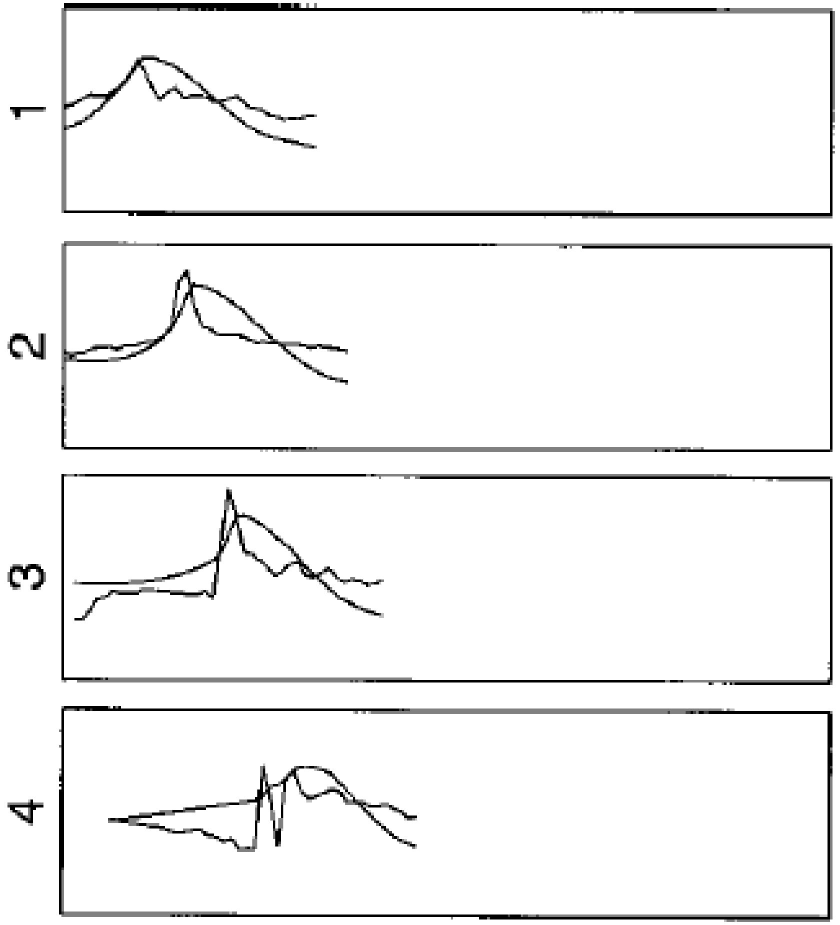
➢ **Example: Shoaling breaking wave – results**

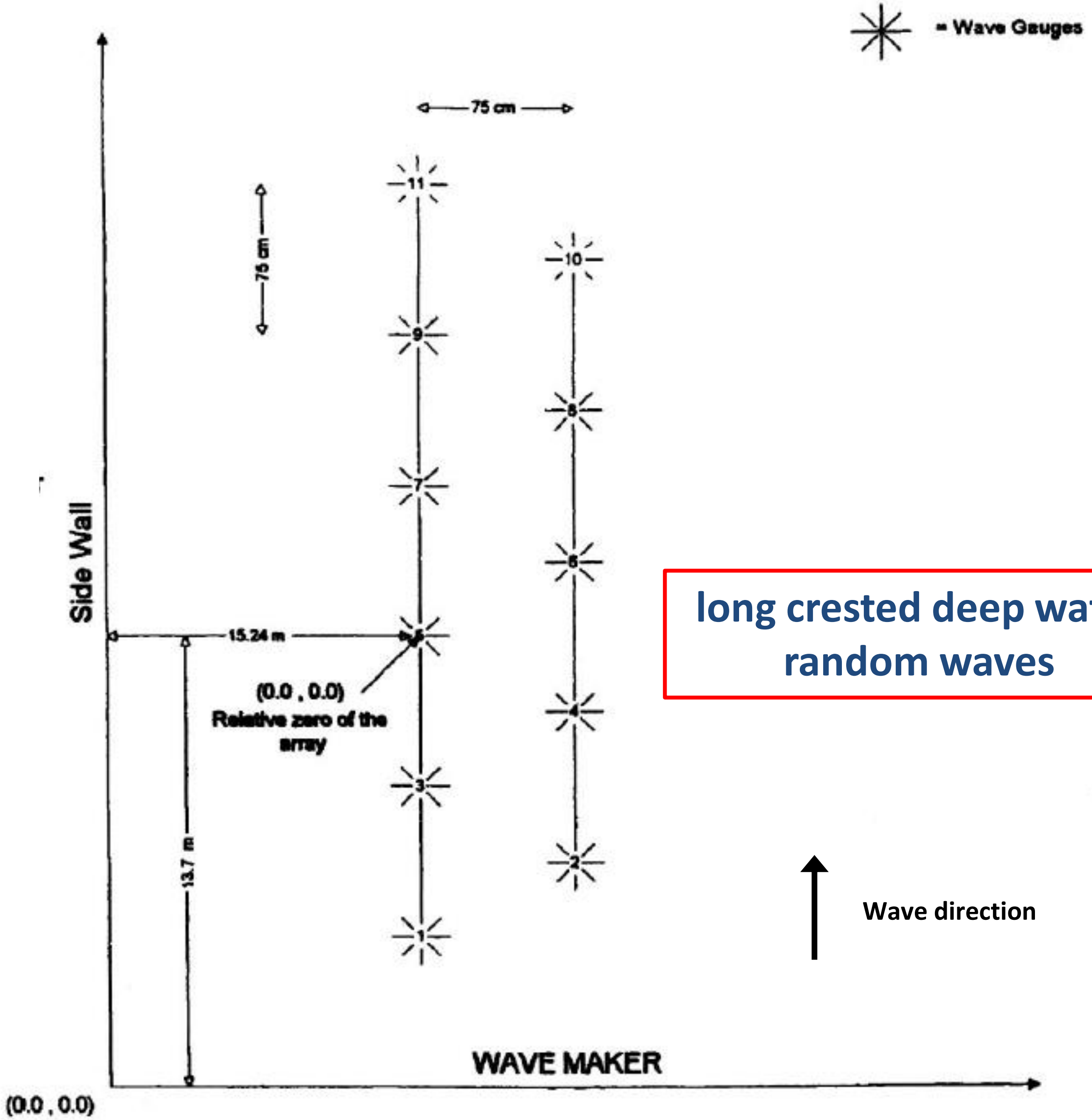
H = 1.5 m; T = 5 s; d = 4.1 m; tan(α) = 1:10



PTM breaking detection – origin

➢ Zimmermann & Seymour (2002)





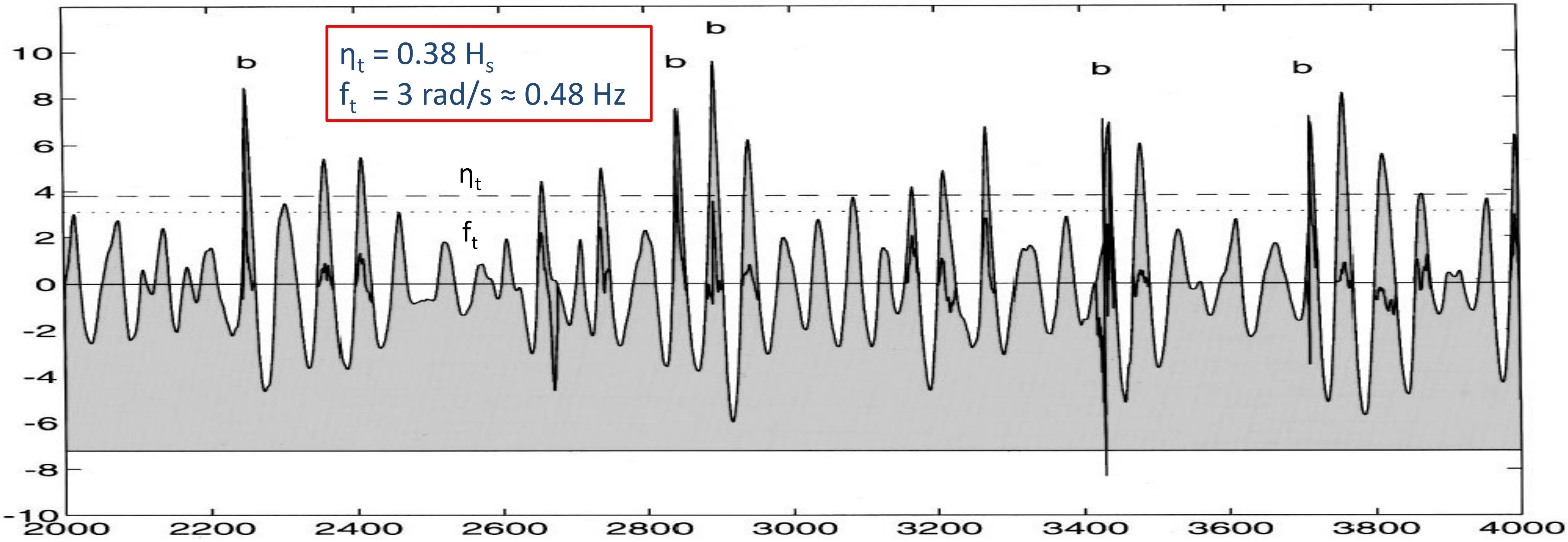
long crested deep water random waves

Wave direction

Zimmermann, C.-A., Seymour, R., 2002. Detection of breaking in a deep water wave record. Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 128, Issue 2, 72-78.

PTM breaking detection – origin

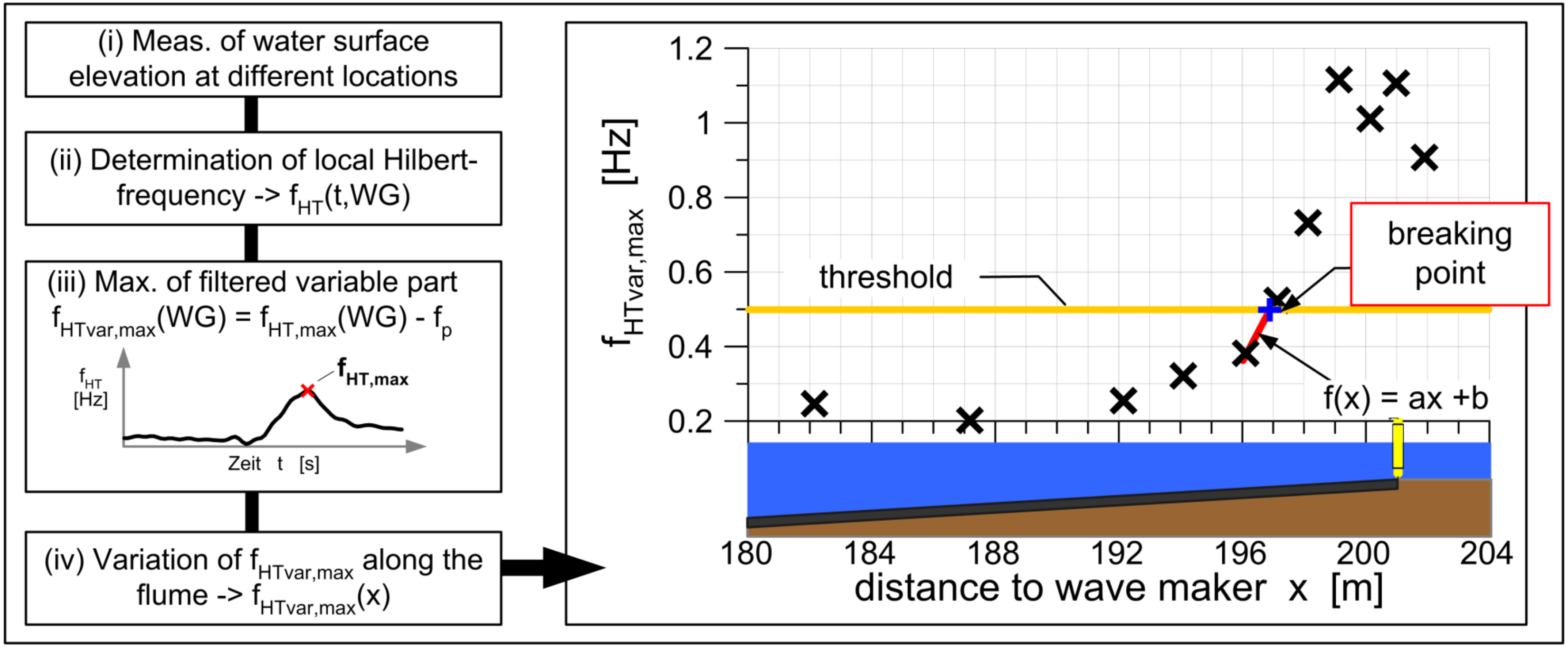
- **Zimmermann & Seymour (2002)**



Zimmermann, C.-A., Seymour, R., 2002. Detection of breaking in a deep water wave record. Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 128, Issue 2, 72-78.

PTM breaking detection – origin

➢ **Irschik et al. (2011)**

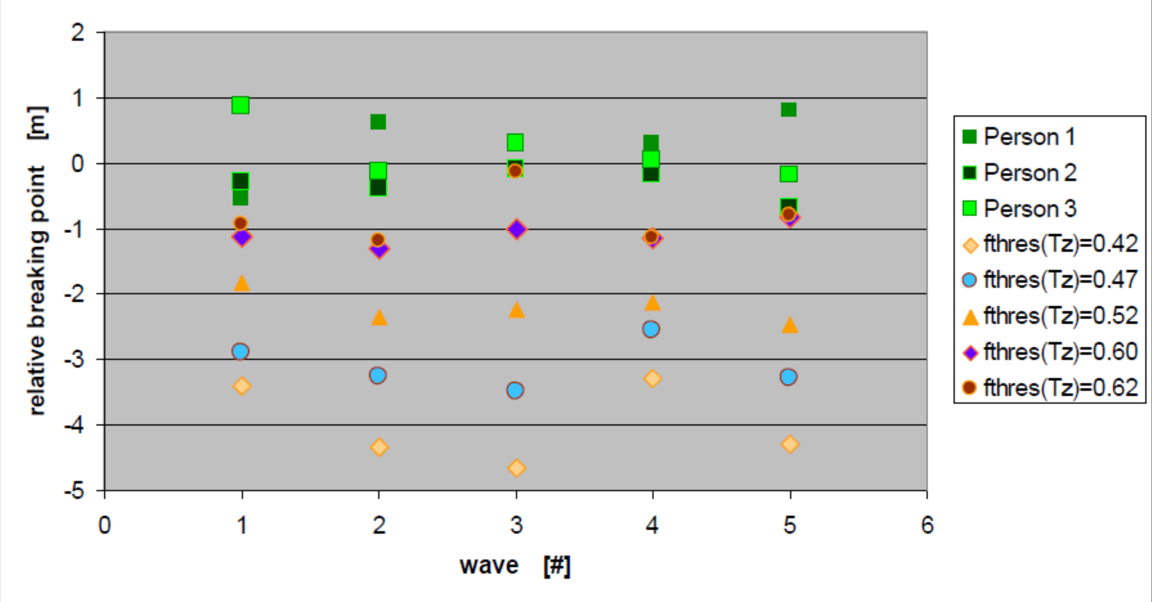


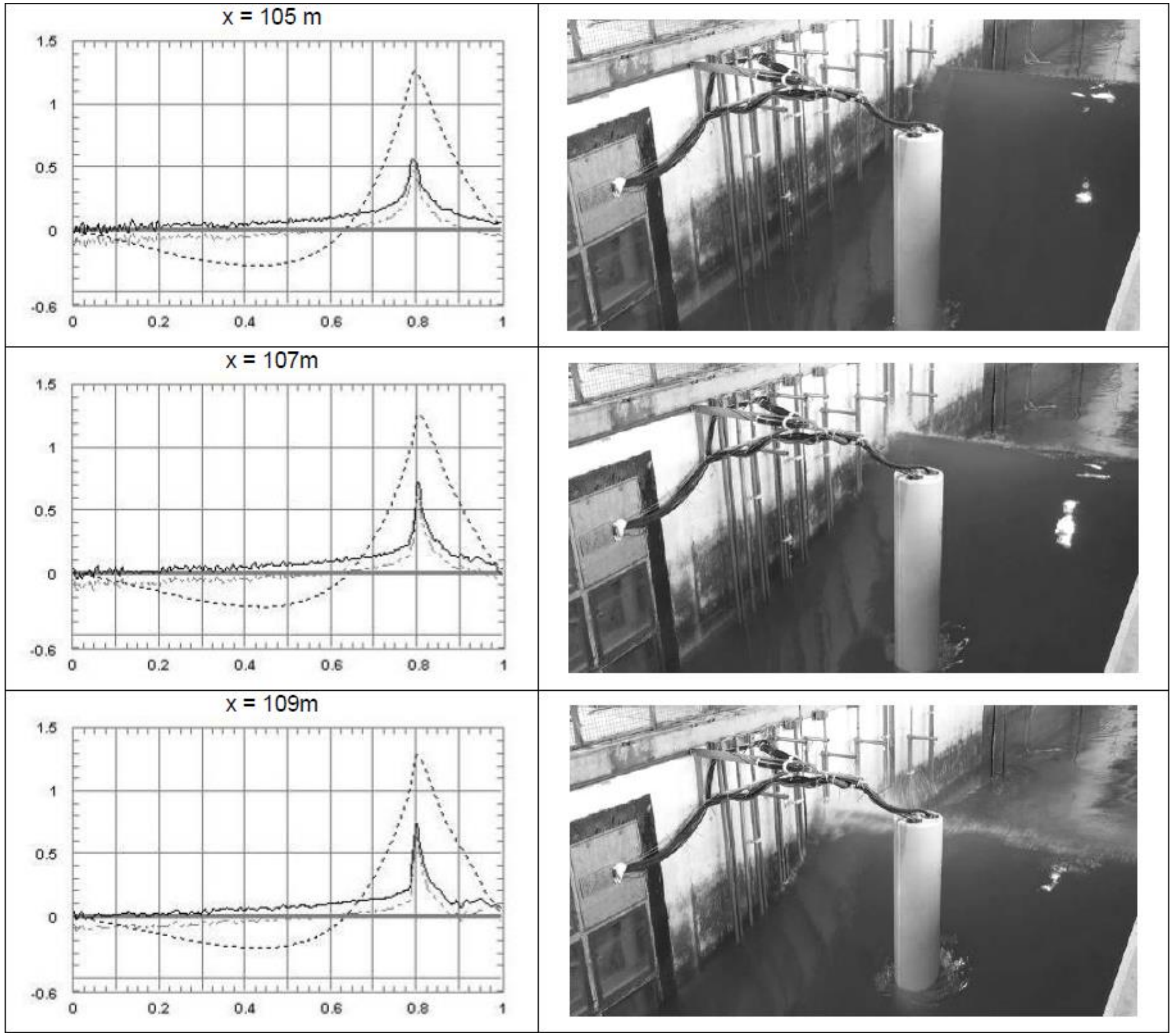
Irschik, K., Schimmels, S., Oumeraci, H., 2011. Breaking criteria for laboratory experiments based on the Phase-Time Method (PTM), Coastal Engineering Proceedings, 1(32), waves.6.

PTM breaking detection – origin

➢ Irschik et al. (2011)

- focused wave packages (no need for η_t)
- $f_t \approx 0.6 - 0.7$ Hz
- also applicable to shoaling breaking waves





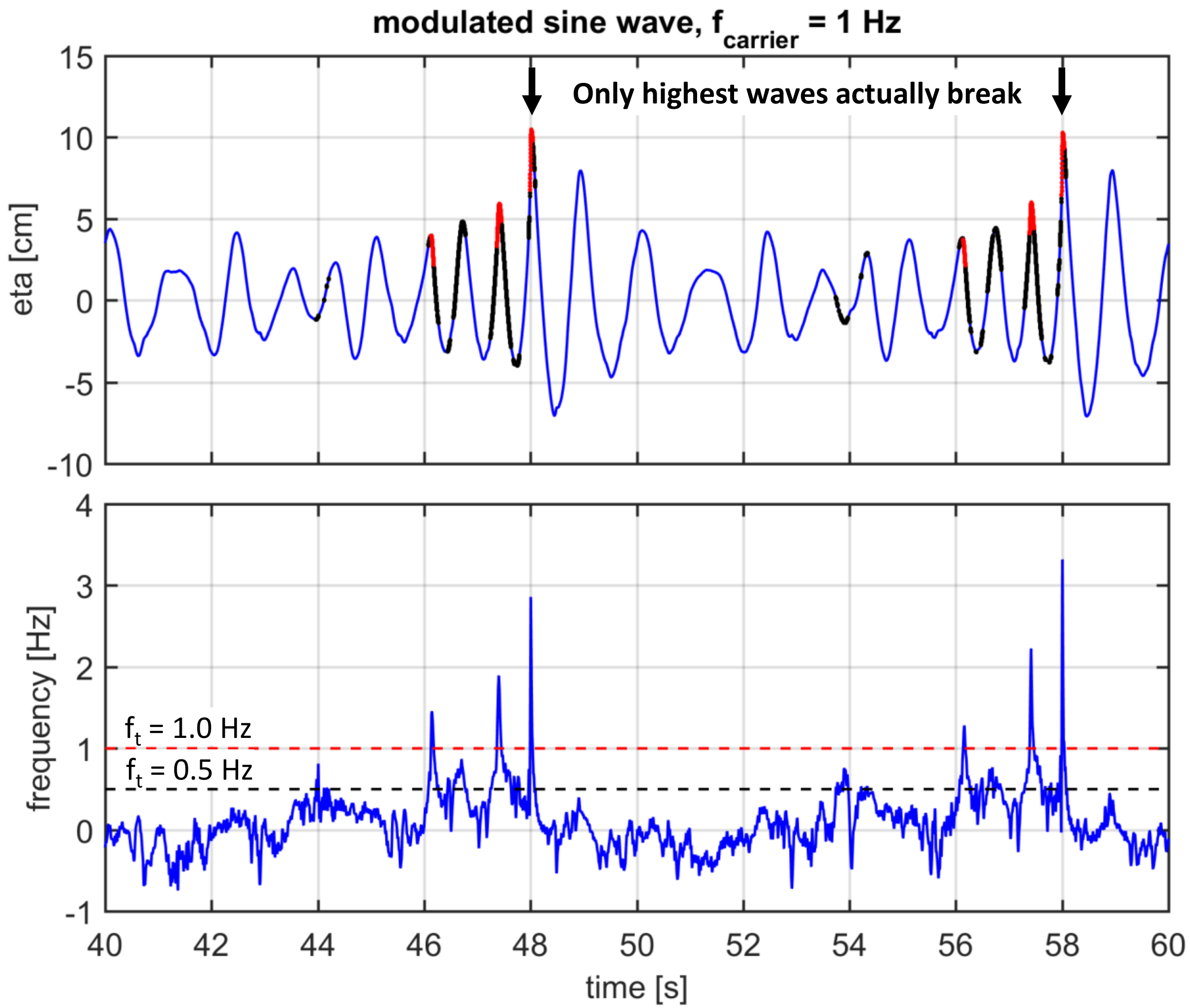
Irschik, K., Schimmels, S., Oumeraci, H., 2011. Breaking criteria for laboratory experiments based on the Phase-Time Method (PTM), Coastal Engineering Proceedings, 1(32), waves.6.

PTM breaking detection – origin

➢ Conclusions

- Threshold based approach works well for the detection of point of incipient breaking for focused wave groups and regular waves on a slope. (However, still ambiguity of “exact” threshold, f_t)
- For breaking wave detection in a random wave field (identification of breaking waves in a time series) difficulty in determination of f_0 and general difficulty in definition of f_t . Suggested values are far too low for very steep non-breaking waves.

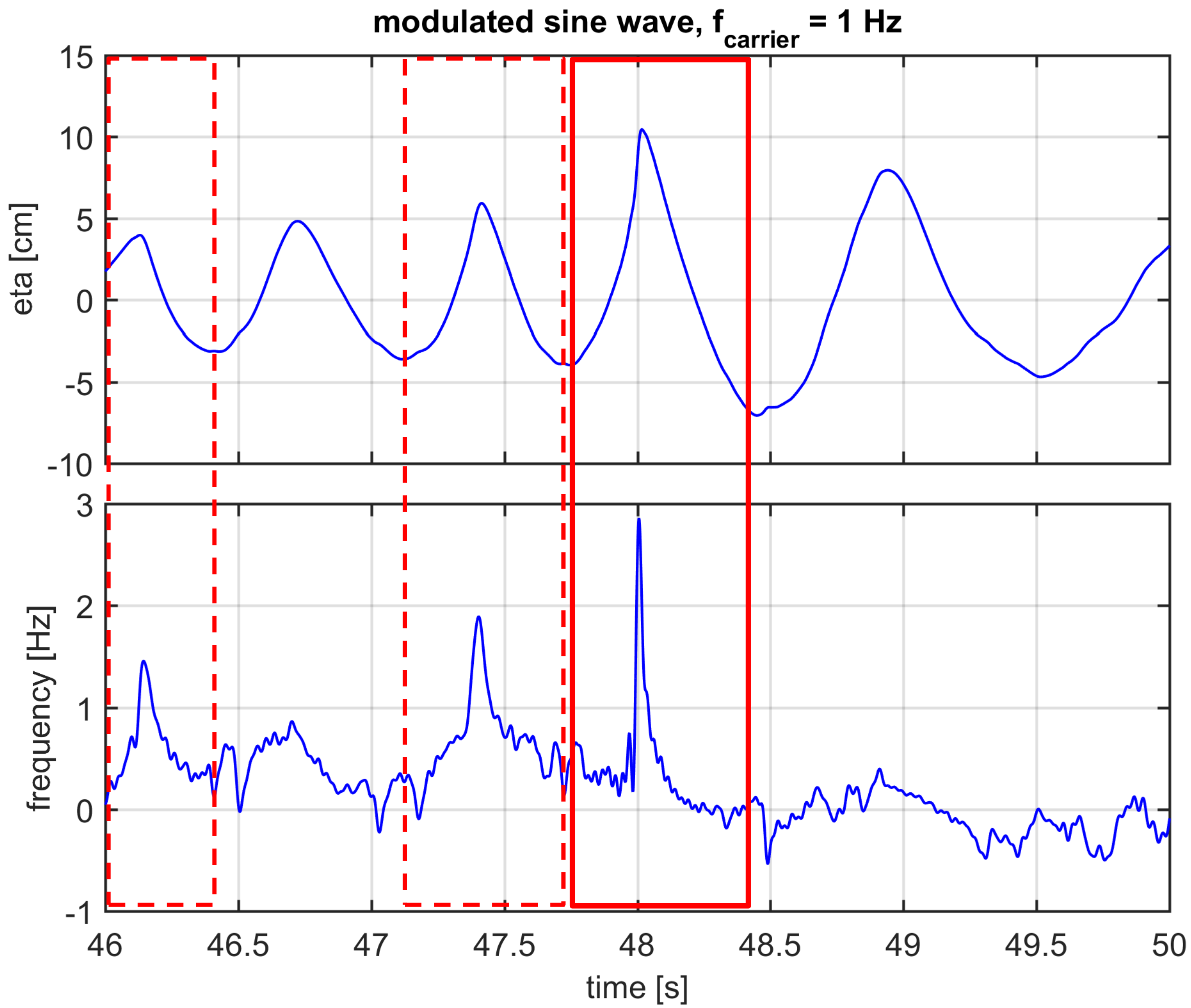
===> New approach → Pattern detection



Breaking wave detection with PTM revisited

➢ Introduction

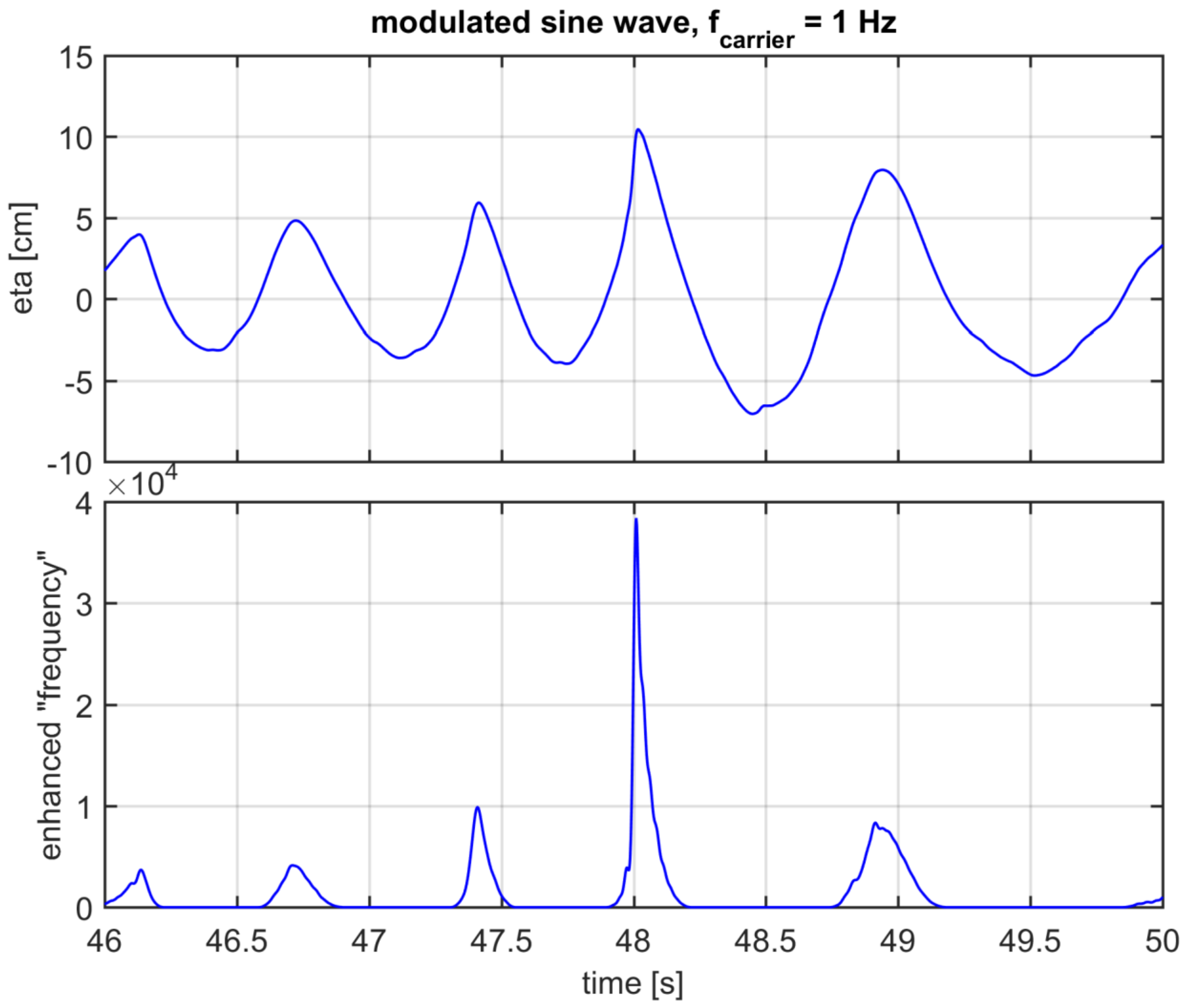
- Breaking waves show a typical pattern in the instantaneous frequency with a very quick rise of frequency followed by a rapid, smooth decay.
- Steep but non-breaking waves also have high inst. frequency (due to high nonlinearity), but do not show this pattern.
- Breaking waves can be detected by finding the typical pattern in frequency signal.
- Typical pattern always occurs at front of wave crest due to formation of the "bulge", i.e. frequency signal can be enhanced to improve pattern detection.



Breaking wave detection with PTM revisited

➢ Methodology

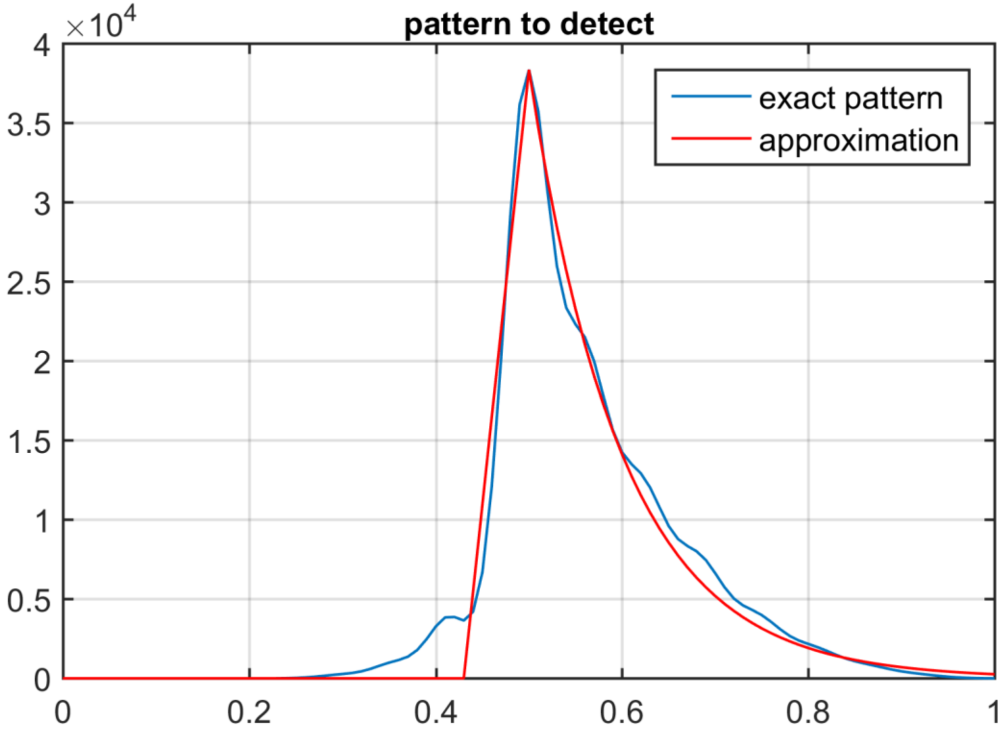
- Determine f(t) from η(t)
- Set f(t) = 0 where η(t) < 0 (wave trough)
- Multiply f(t) with $\eta^2(t)$ ==> $f_{enh.}(t) = f(t) \cdot \eta^2(t)$
- Use Wavelet analysis to find pattern in $f_{enh.}(t)$

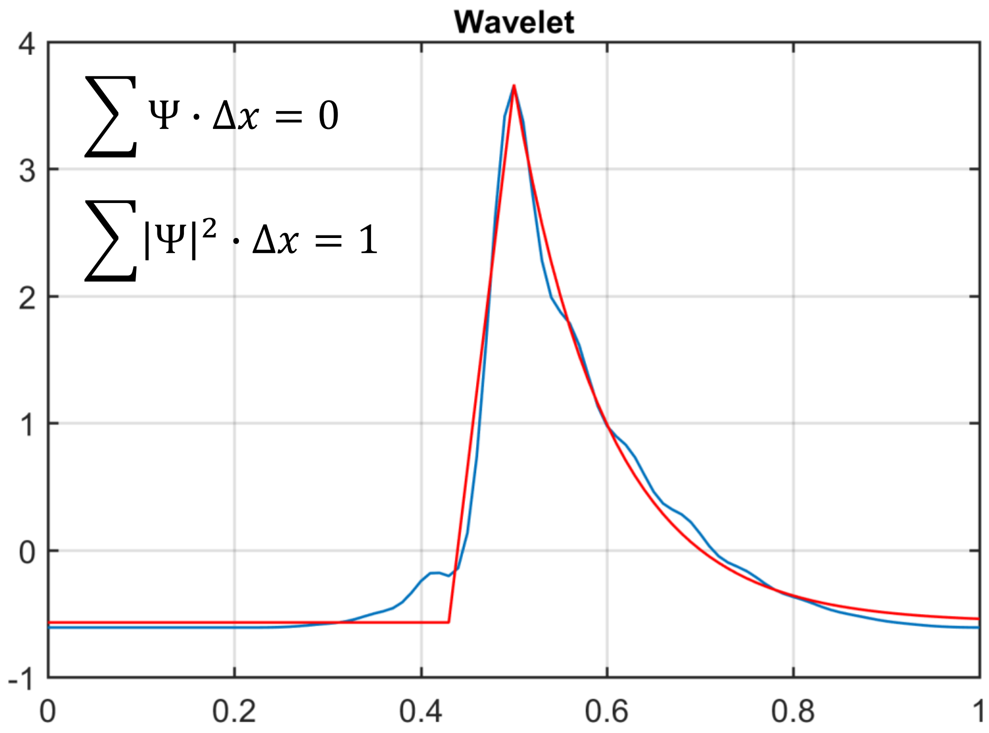


Breaking wave detection with PTM revisited

➢ From pattern to Wavelet

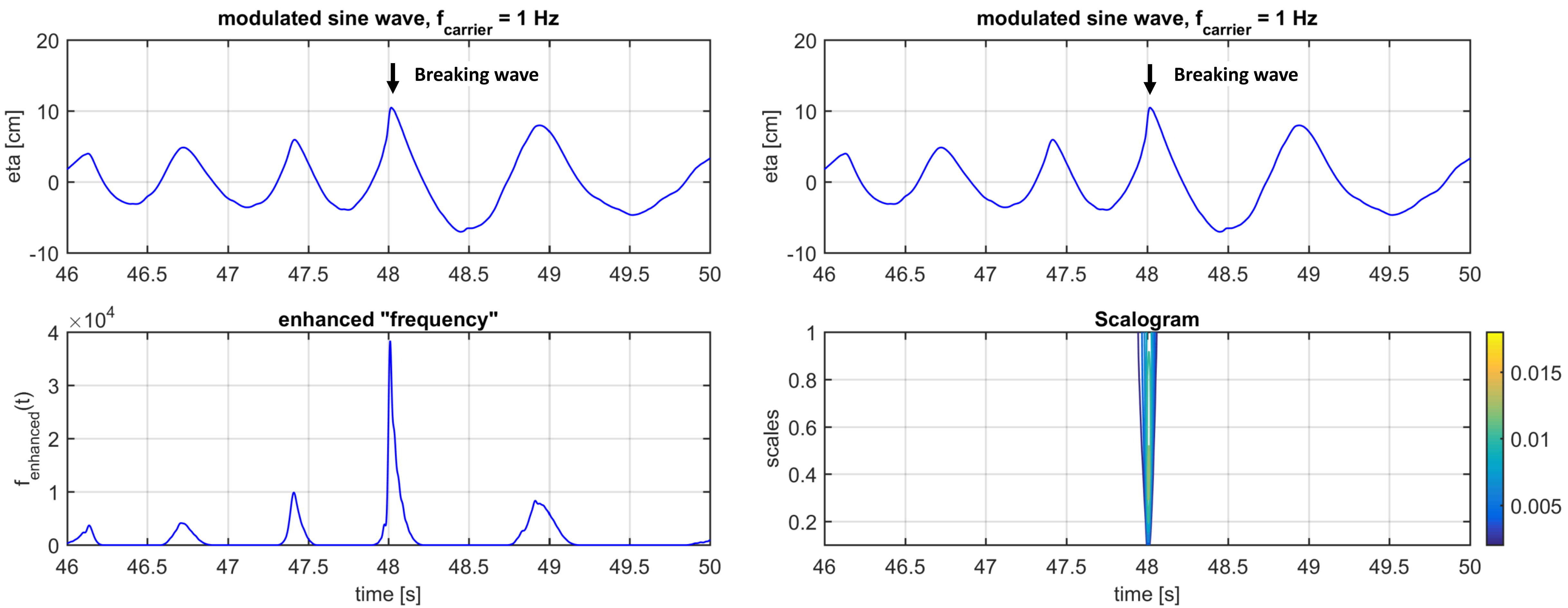
- The pattern to detect is arbitrary as long as it approximates the shape to be detected.
- Maximum should be centered for well defined detection.





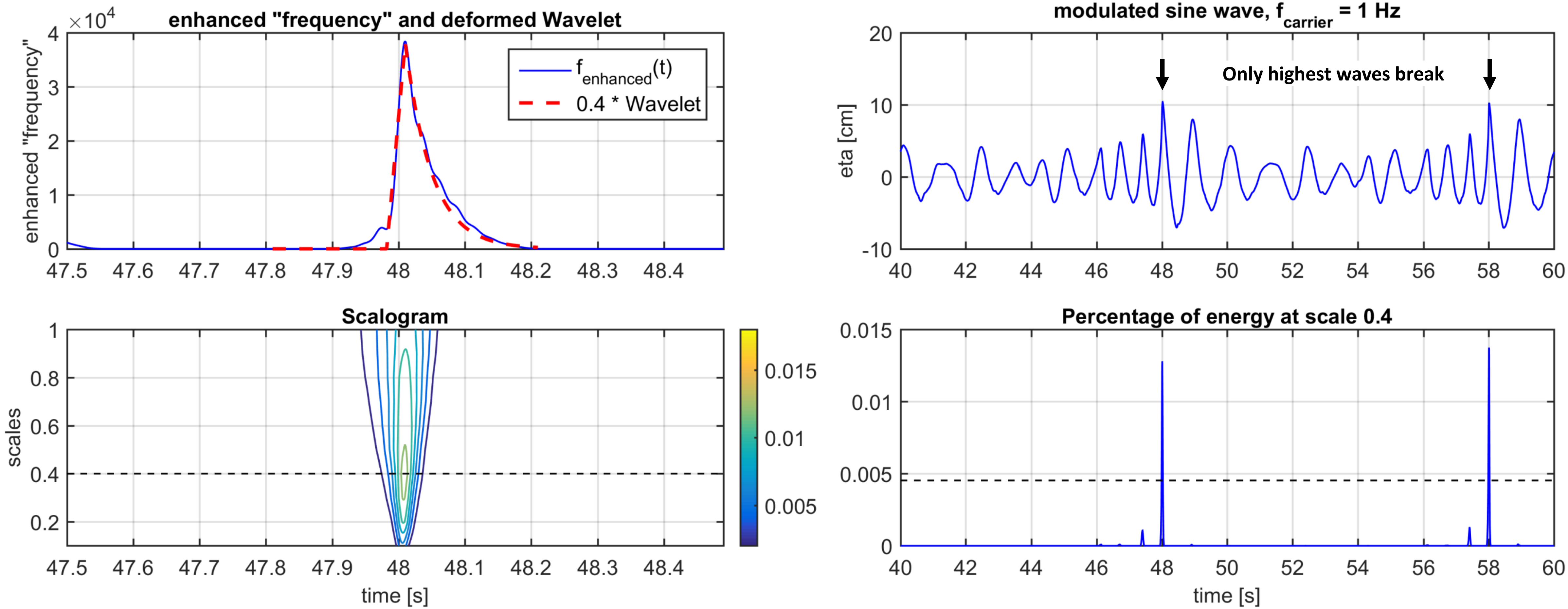
Breaking wave detection with PTM revisited

➢ **Pattern detection with Wavelet analysis 1/3**



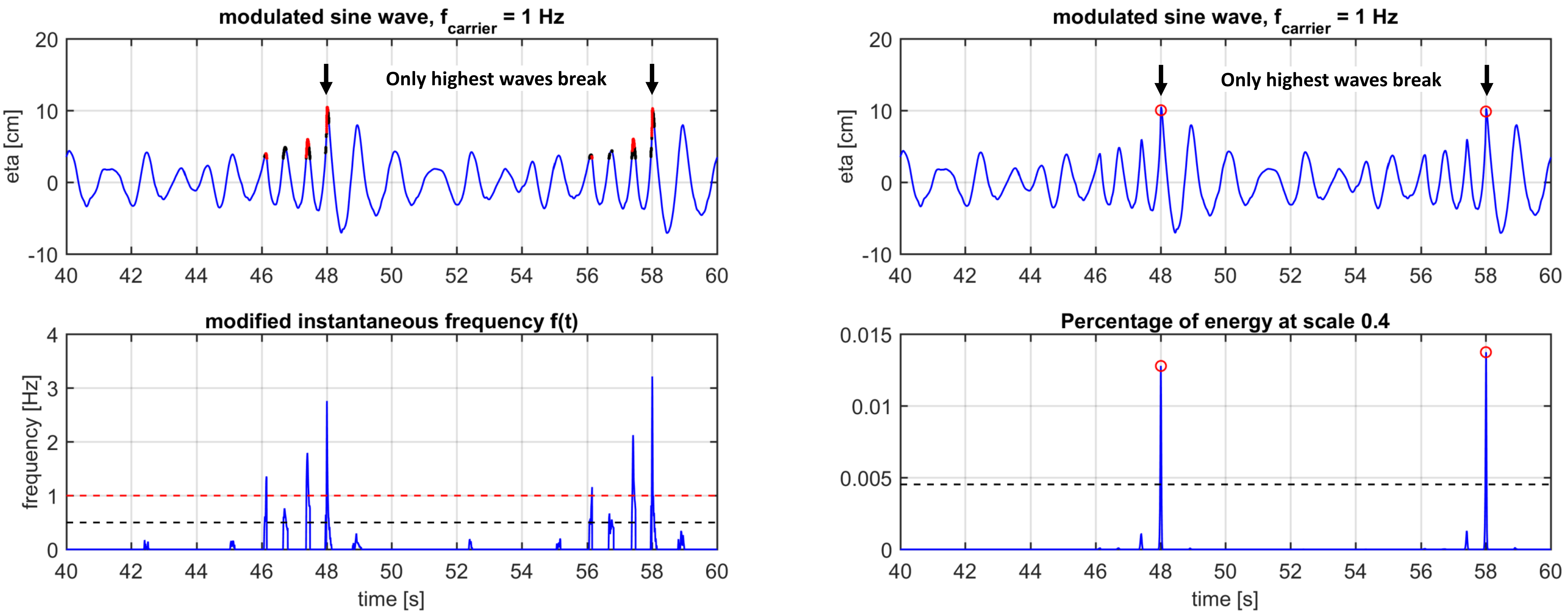
Breaking wave detection with PTM revisited

➢ Pattern detection with Wavelet analysis 2/3



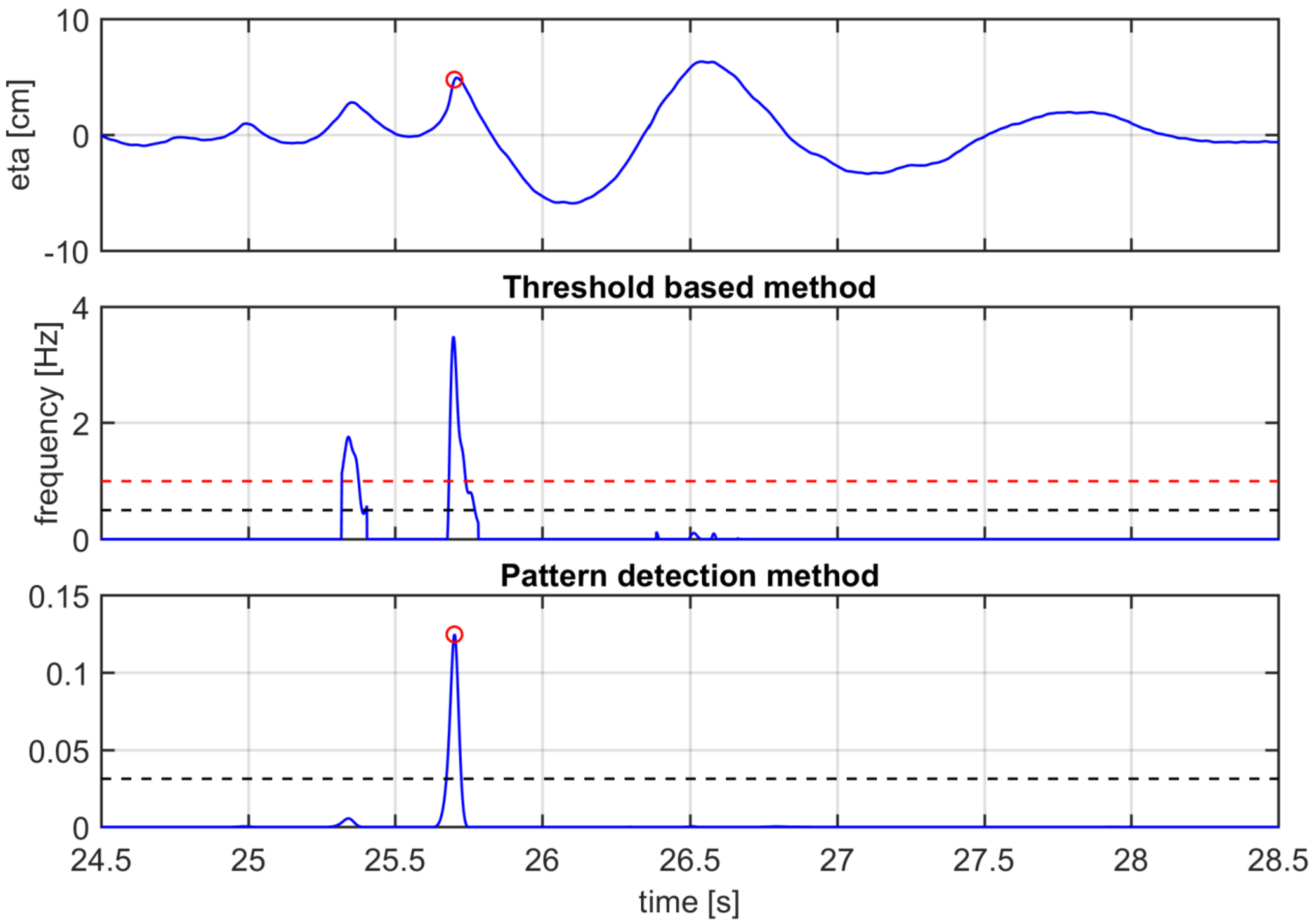
Breaking wave detection with PTM revisited

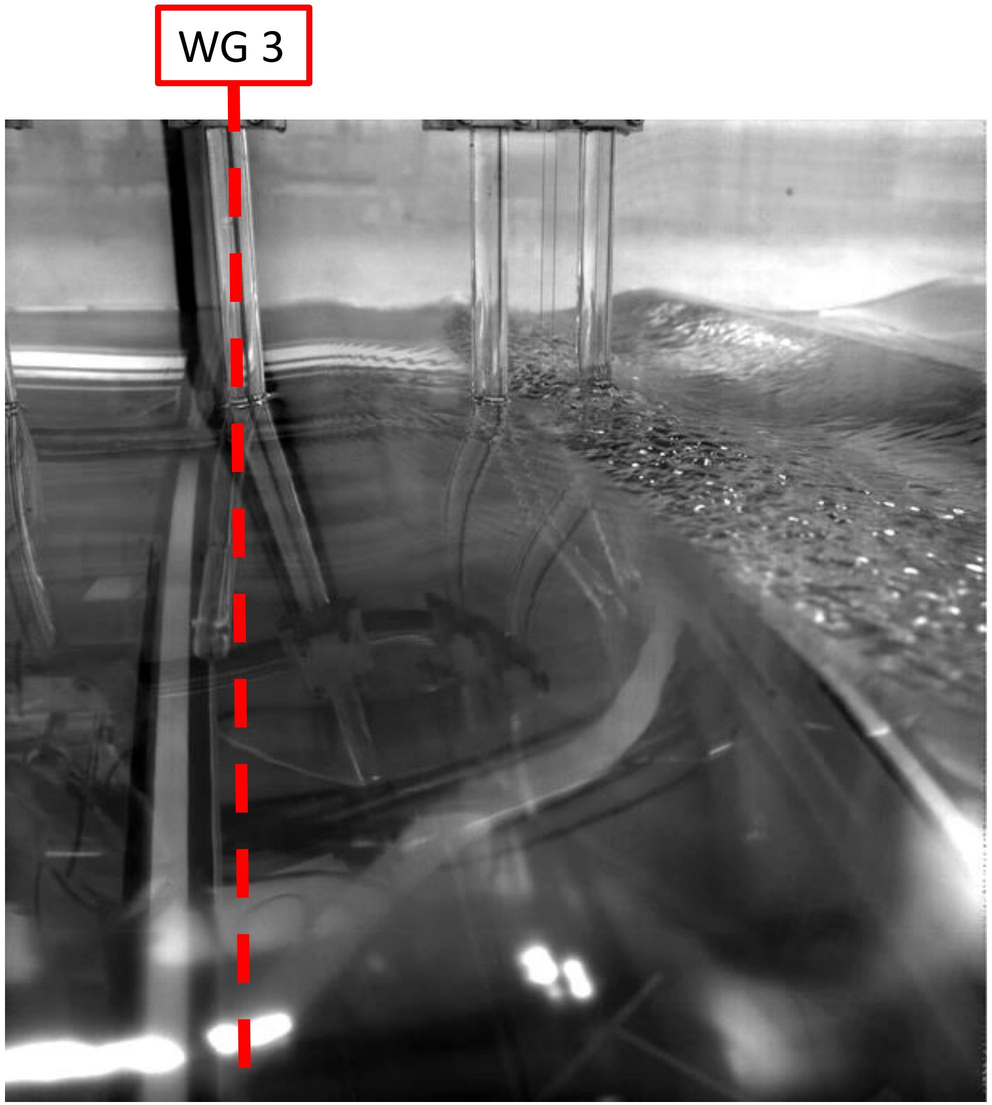
➢ Pattern detection with Wavelet analysis 3/3



Breaking wave detection with PTM revisited

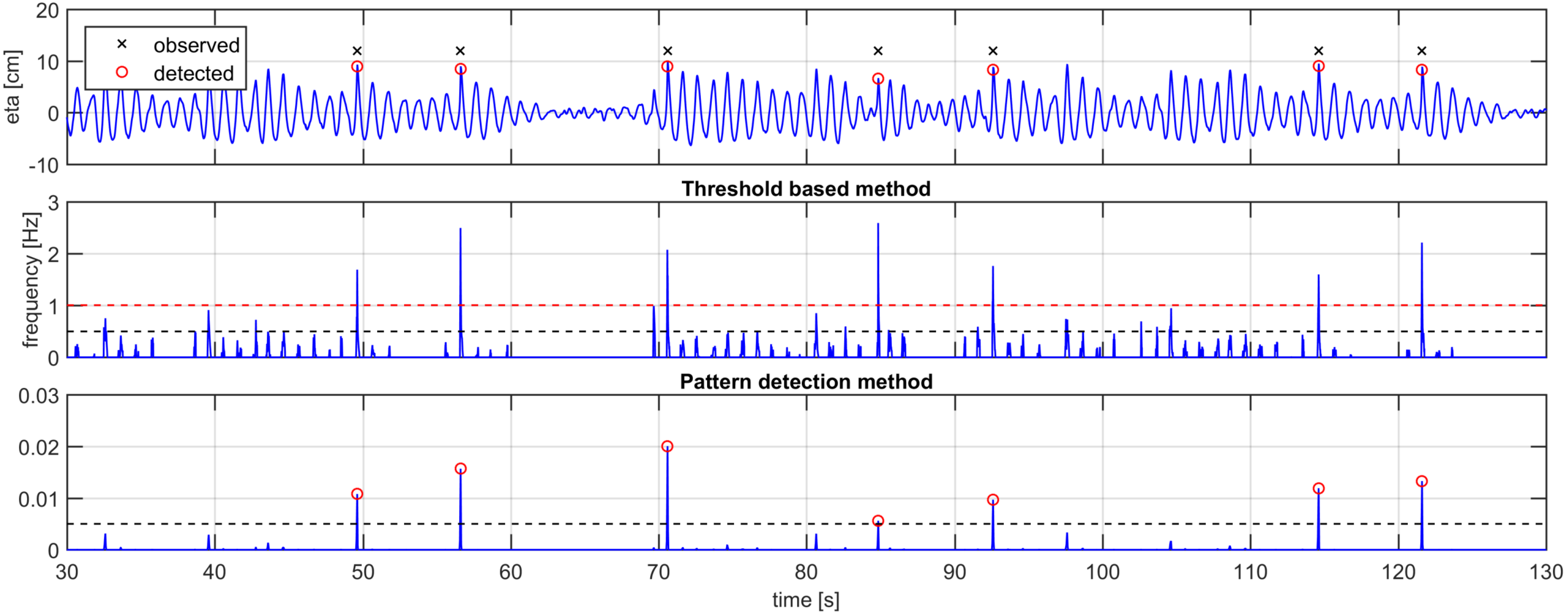
➢ **Validation example 1**





Breaking wave detection with PTM revisited

➢ Validation example 2



Conclusions

- PTM provides instantaneous frequency f(t) (and amplitude) of a time signal.
- The frequency signal can be used to detect breaking waves as f(t) increases at the wave crest front.
- Threshold based method can be used to determine point of incipient breaking, but difficulty in defining mean frequency f_0 to be subtracted from f(t) for random waves and slight ambiguity in definition of threshold f_t.
- Very steep but non-breaking waves also show high f(t) (due to high nonlinearity), i.e. threshold based method will overestimate number of breaking events.
- A typical pattern with a very quick rise of frequency followed by a rapid, smooth decay was found in f(t) for breaking waves and the new suggested method based on detection of this pattern was shown to work well for different examples where threshold based method would have failed.
- Further research is needed to check general validity of the new approach and to further investigate different patterns and their potential link to different breaker types and stages of breaking.

ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

Breaking Wave Detection with the Phase-Time Method (PTM) Revisited

Dr.-Ing. Stefan Schimmels
Forschungszentrum Küste (FZK)
Leibniz University Hannover & Technical University Braunschweig, Germany

Dan Liberzon, Assistant Professor
Technion - Israel Institute of Technology, Haifa, Israel

schimmels@fzk.uni-hannover.de; iberzon@technion.sc.il