FOCUSING UNIDIRECTIONAL WAVE GROUPS ON FINITE WATER DEPTH WITH AND WITHOUT CURRENTS.

Dimitris Stagonas[1], Eugeny Buldakov[2] and Richard Simons[3]

Focused waves are often used in physical and numerical studies as a representative condition for extreme waves or as a mean to generate very steep and breaking waves at a desired location in space and time. A focused wave is in theory created when all the components in a transient wave group come in phase. In the past, linear wave theory and empirical iterative methodologies have been suggested in order to achieve the required phase and amplitude focusing. Nevertheless, their effectiveness decreases as the non-linearity of the wave group increases and thus the generation of very high focused waves was a challenging task. Here, an empirical iterative methodology is suggested which can focus waves of any height at a predetermined temporal and spatial location. The methodology has been successfully applied to wave groups travelling on still water but also on sheared currents and it has been implemented in both physical and numerical wave flumes. The results presented here refer to linear, weakly non-linear and strongly non-linear focused waves generated with a realistic target spectrum.

Keywords: Focused waves; extreme waves; waves on currents

INTRODUCTION

The constructive interference at a certain point in space and time of numerous wave components of varying frequency and amplitude results in the generation of a large focused wave. When simulating extreme hydrodynamic conditions in a laboratory facility, such a wave possesses comparative advantages. It is significantly higher and steeper than any other wave within the propagating wave group, it occurs at a predefined point in space and time, and it represents an event with a large return period which would take a long time to reproduce within a random wave sequence. As such it is often used in experimental investigations of wave loading on marine structures, serving as a representative of the largest wave occurring in a random sea. Other applications include study of the characteristics of deep water breaking waves and experimental generation of freak/rogue waves.

For the focusing of experimental unidirectional wave groups three main approaches can be identified. Rapp and Melville (1990), among others, used linear wave theory to choose the appropriate phases so as to achieve focusing at a preselected time and point in the flume. Chaplin (1996) was the first to propose a simple empirical method where through an iterative process the wave components were brought into phase. Later on, this method was extended by Schmittner et al. (2009) to include amplitude modification as well and more recently Fernandez et al. (2014) suggested a self-correcting method employing a potential flow solver. Shemer et al. (2007) computed the wave board signal required for the generation of a focused wave by backward integration of the Zakharov equation. For focusing wave groups in the presence of currents, Yao and Wu (2005) proposed an empirical method similar to that of Chaplin (1996) but they used an extended version of the linear dispersion relation which accounts for the presence of a constant sheared current.

Although effective for small amplitude waves, the efficiency of these methods reduces as the nonlinearity of the wave group increases. As a result, for increasing focused wave amplitudes, the focal point is shifted in both space and time and the quality of focusing reduces considerably. In addition, with some exceptions, these methods have been used with unrealistic target spectra.

The present work combines and adds to previous knowledge and proposes an improved methodology for focusing unidirectional wave groups. It is shown that this new methodology performs very well even for focusing very steep/nearly breaking waves propagating over both still water and currents.

METHODOLOGY

The control system of the wave board uses amplitudes and phases of individual spectral components as input parameters and applies linear theory for generating a desired wave group at

[1] Research associate, Department of Civil & Environmental Engineering UCL Gower Street LONDON, WC1E 6BT UK, d.stagonas@ucl.ac.uk

[2] Lecturer, Department of Civil & Environmental Engineering UCL Gower Street LONDON, WC1E 6BT UK, e.buldakov@ucl.ac.uk

[3] Professor, Department of Civil & Environmental Engineering UCL Gower Street LONDON, WC1E 6BT UK, r.r.simons@ucl.ac.uk

specified time and position. However, it does not produce satisfactory results in the case of large amplitude waves and for waves on currents. We apply an iterative procedure for generating wave groups of a prescribed spectrum (target spectrum) for waves of large amplitudes and waves on currents. The main distinction of the proposed methodology from previous iterative methods of wave generation is using a linearised spectrum as a target, which is the natural choice since the full spectrum of a nonlinear wave group is uniquely defined by its linear component. Given a desired target spectrum and focusing point and time, the empirical methodology suggested here consists of the following steps:

- The target spectrum is used as the initial input of the control system.
- For the same amplitude spectrum four wave groups are generated with constant phase shifts of 0 (crest focussed wave), π (trough focused wave), $\pi/2$ and $3\pi/2$ (positive and negative slope focussed waves).
- Surface elevation for each wave is measured at the focus point and the linear part of the spectrum is extracted using a suitable linear combination of four measured spectra. A similar approach for separation of harmonics is performed in e.g. Orszaghova et al. (2014).
- The linearised output spectrum is compared with the target spectrum and a corrected input spectrum is calculated as:

$$\begin{aligned} a_{in}^{1} &= a_{in}^{0} \times a_{tgt} / a_{out}^{0} \\ \phi_{in}^{1} &= \phi_{in}^{0} - (\phi_{tgt} - \phi_{out}^{0}) \end{aligned} \tag{1}$$

- The procedure is applied iteratively until the linear wave components at the focusing point have come into phase and the measured linearised spectrum coincides with the target spectrum to the desired accuracy, see Fig. 1.

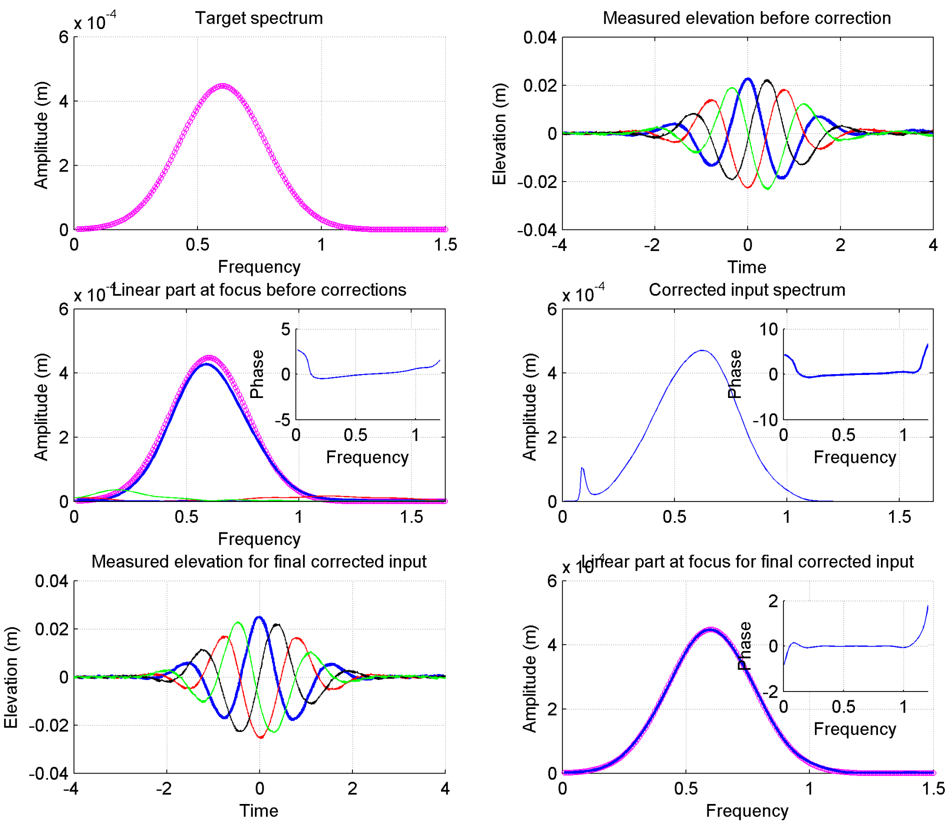

Figure 1: Example inputs and outputs for the steps of the suggested methodology. For this example the linear sum of the amplitudes at focus is 2.5cm.

Tests for the experimental results presented below were conducted in a 20m x 1.2m x 1m wave flume with a water depth of 0.5m. The flume is equipped with two wave-makers located at each end of the facility; when waves are generated from one wave-maker the other acts as an active absorber. For the results presented here, a Gaussian target spectrum is used, with peak frequency f_{peak}=0.6Hz, 154 components, f_{min}= 0.078Hz and, f_{max}=1. 42Hz, focused at 8.4m from the wave board with a focus time of 64sec.

Three pumps placed in parallel are used to recirculate the flow which discharges vertically into the wave flume. The inlet and the outlet are located 1m in front of each wave-maker and both inline and opposing currents can be generated. A purposely built wire structure was used to condition and profile the flow, which resulted in the successful generation of sheared currents. Fig. 2 shows profile measurements made using an ADV located 1m from the inlet (in red) and at 8.4m from the wave board (in blue). For each location profile measurements were taken for surface flow velocities of 0.2m/s, 0.4m/s and 0.6m/s. For each location profile measurements were taken for surface flow velocities of 0.2m/s, 0.4m/s and 0.6m/s and tests were conducted with waves in still water and waves on in-line currents.

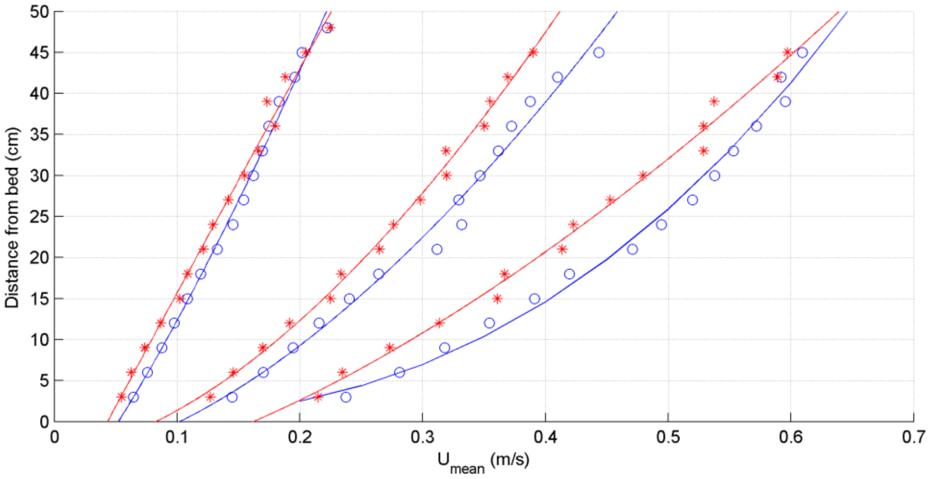

Figure 2: Flow velocity profiles at a. 1m from the inlet (red lines and *) and b. 8.4m from the wave-maker (blue lines and o) and 4.4m from a. In each subplot and starting from the left profiles correspond to surface flow velocities of 0.2m/s, 0.4m/s and 0.6m/s.

RESULTS

Fig. 3. presents the measured surface elevation at focus, for three focused waves with A_{linear}=0.025m, A_{linear}=0.05m and A_{linear}=0.09m travelling over still water; A_{linear} is the linear sum of all target components at the focal point. The third case corresponds to a nearly breaking wave and thus it is considered as the most strongly non-linear wave tested.

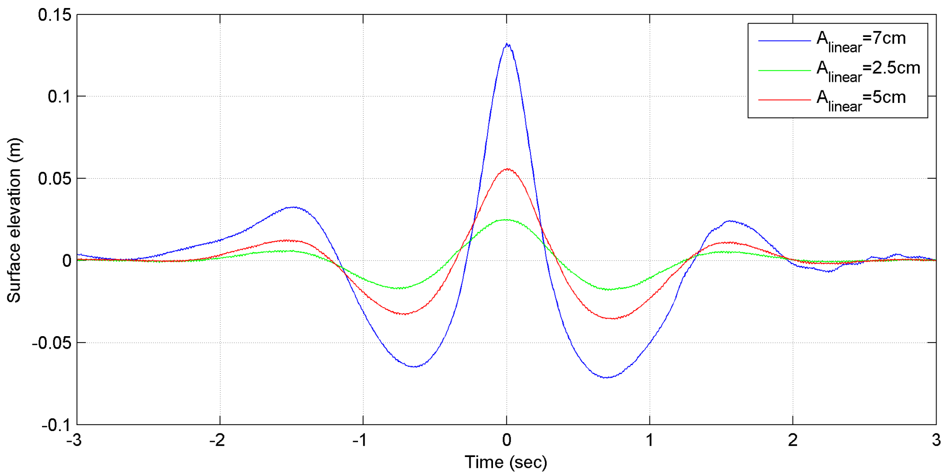

Figure 3: Surface elevation measurements at the focusing point, for waves travelling on still water

The spectra and phases corresponding to the waves of Fig. 3 are shown in Fig. 4. The normalised with A_{linear}, amplitudes of the extracted linear part are presented (black line) along with normalised amplitudes for the 2^{nd} sum and difference (red and green lines) and the higher than 2^{nd} harmonics (blue line). A very good agreement between the target (magenta o) and the linear part of the measured spectrum is seen and only for the strongly non-linear wave noticeable discrepancies appear at the higher frequency side. In the same time, nearly all the components of the linear part are in phase at the focusing location but as with the amplitudes and only for the limiting non-breaking case a weaker control over the phases of the higher frequencies is observed, lower panel of Fig. 4.

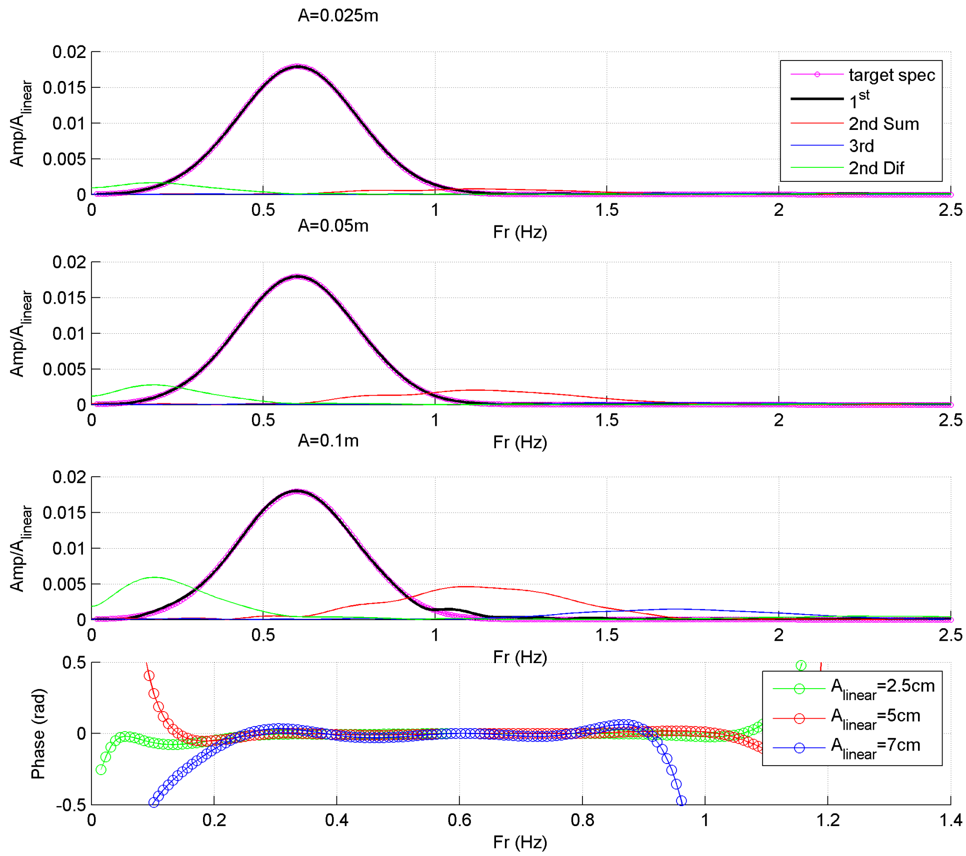

Figure 4: Starting from the top, measured spectra for A_{linear}=0.025m, A_{linear}=0.05m and A_{linear}=0.09m. For every case, the first and higher orders are plotted normalised with A_{linear}, while the phases of the linear part are shown in the bottom panel.

The methodology was also applied to generate focused waves with the same target spectrum but over in-line sheared currents. At this point it should be noted that as the waves pass through the conditioner and mainly over the inlet they lose a part of their energy. As the discharge increases the losses increase as well and as a result the size of the higher limiting non-breaking cases that can be generated is restricted.

Fig. 5, summarises the results for three focused waves with A_{linear}=0.025m, A_{linear}=0.05m and A_{linear}=0.07m, propagating over a sheared current with surface velocity of 0.2m/s. Once again, nearly all first order components are in phase at focus and a very good agreement is seen between the target and the measured spectrum. Nevertheless, for the highest waves generated the control over the amplitudes and phases at focus gets weaker and the quality of the final result deteriorates. It should, however, be highlighted that for all cases and even for the strongest current tested here (0.6m/s) the aim for a focusing point at 8.4m and a focus time of 64sec is always achieved.

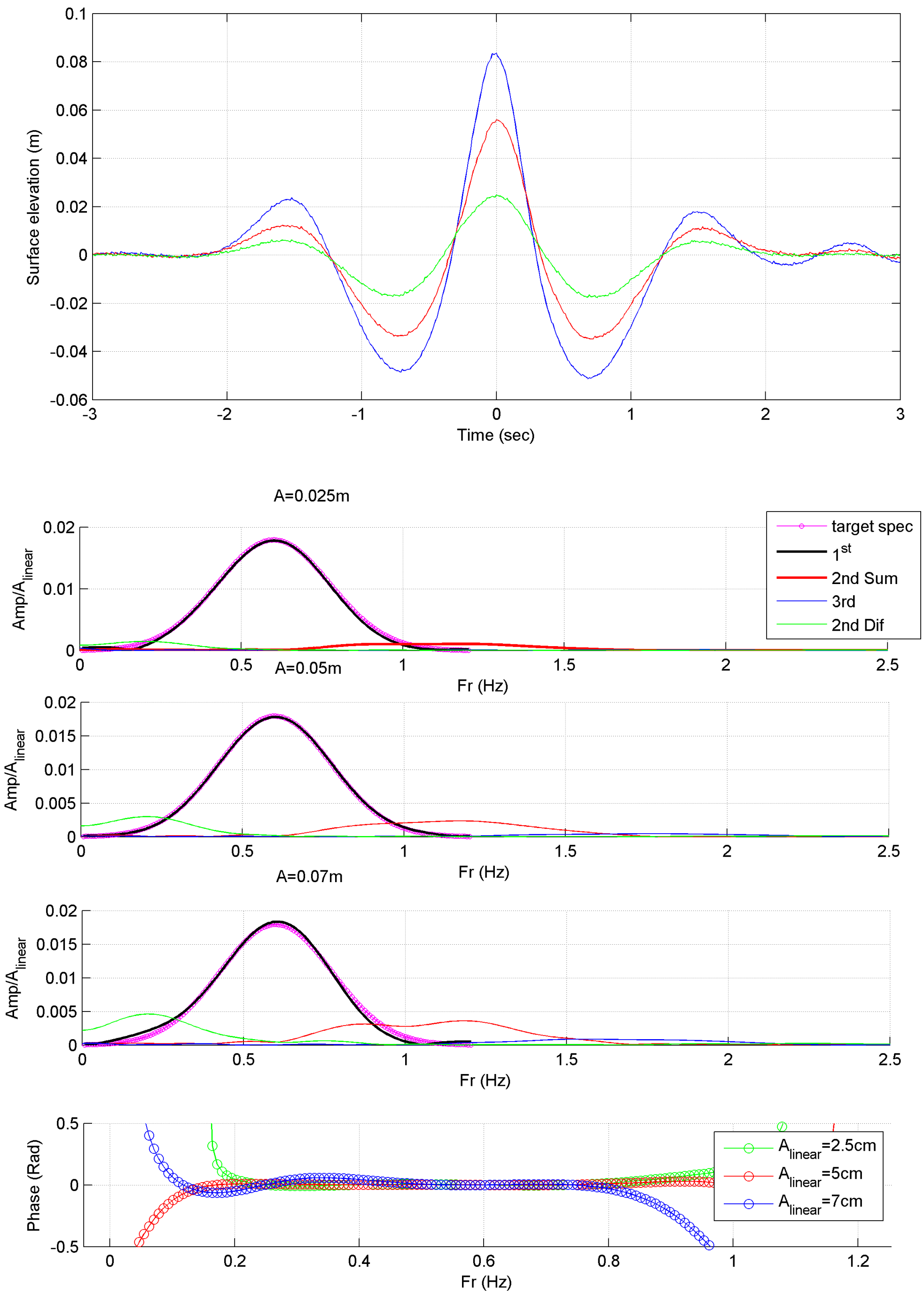

Figure 5: Starting from the top, measured surface elevation, spectra and phases at focus for A_{linear}=0.025m (green line), A_{linear}=0.05m (red line) and A_{linear}=0.07m (blue line). The focused waves illustrated were propagated on an in-line shear current with a surface flow velocity of 0.2m/s, see also Fig. 2.

Finally, the methodology suggested above has also been implemented on two numerical wave flumes and results were equally good as for the physical experiments, Fig. 6.

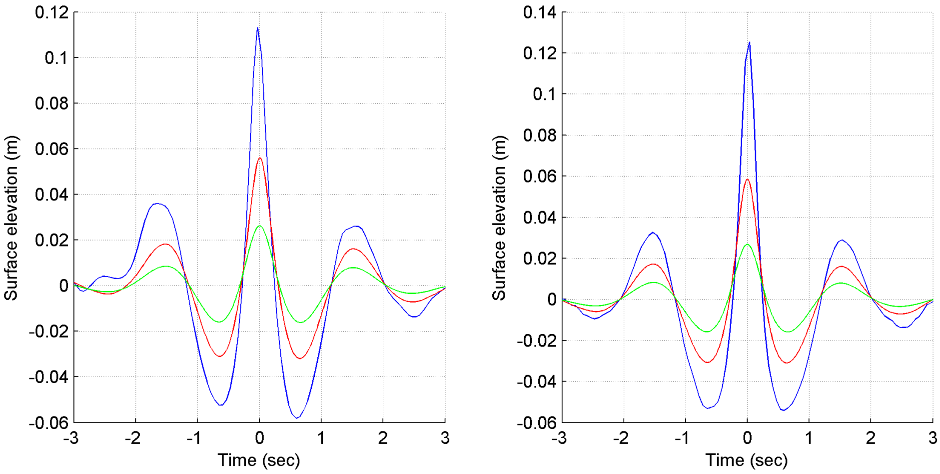

Figure 6: Focused waves generated with the suggested methodology in a CFD (on the left, courtesy of Mr. Thomas Vyzikas) and a Boussinesq (on the right, courtesy of Prof. Th. Karambas) numerical wave flume without currents. Here, target spectrum: PM with f_{peak} = 0.6Hz, focus point: 7.8m, focus time: 64sec, and water depth: 0.5m. As for the physical experiments, green line: linear case, red line: weakly non-linear case and blue line: strongly non-linear case.

CONCLUSIONS

This paper proposes an improved methodology for focusing unidirectional wave groups. Results presented illustrate that it performs well for linear, weakly non-linear and strongly non-linear wave groups propagating over still water of finite depth as well as over currents, and it can be applied on both physical and numerical wave flumes. This work is part of a larger project, involving UCL, University of Oxford and University of Bath, which looks at survivability aspects of tidal and wave energy converters subject to extreme wave and current conditions. As such, the generation of focused waves with realistic target spectra is considered as an additional advantage of the proposed methodology.

ACKNOWLEDGMENTS

This work is supported by the EPSRC SuperGen UKCMER marine energy research consortium, through grant EP/J010316/1

REFERENCES

Chaplin J.R. (1996). On frequency-focusing unidirectional waves. *International Journal of Offshore and Polar Engineering*, Vol. 6, No 2, 131-137.

Fernández H., Sriramb V., Schimmels S. and Oumeraci H. (2014) Extreme wave generation using self-correcting method — Revisited, *Coastal Engineering* 93 (2014) 15–31

Orszaghova J., Taylor P.H., Borthwick A.G.I. and Raby A.C. (2014). Importance of second-order wave generation for focused wave group run-up and overtopping. *Coastal Engineering* 94, 63-79.

Rapp R.J. and Melville W.K. (1990). Laboratory measurements of deep water breaking waves. *Philos. Trans. R. Soc. London. Ser A* 331, 735-800.

Schmittner C., Kosleck S., Henning J. (2009) A phase-amplitude iteration scheme for the optimization of deterministic wave sequences *Proceedings of the 28th International Conference on Offshore Mechanics and Artic Engineering*.

Shemer L., Goulitski K. and Kit E. (2007). Evolution of wide-spectrum unidirectional wave groups in a tank: an experimental and numerical study. *European Journal of Mechanics B/Fluids*, Vol. 26, 193-219.

Yao A. and Wu C.H. (2005). Incipient breaking of unsteady waves on sheared currents. *Physics of Fluids*, Vol. 17, 082104-1 - 082104-10.