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Dependencies of Breaking Type, Breaking Criteria and Energy Dissipation on Amplitude-Phase Frequency Structure of Waves

Sergey Kuznetsov,

Yana Saprykina,

V.P.Zenkovich laboratory of the sea shelf and coasts, P.P.Shirshov Institute of Oceanology of the Russian Academy of Sciences, Moscow, Russia

saprykina@ocean.ru, kuznetsov@ocean.ru

Outline

1. Motivation – wave breaking affect on energy dissipation, sediment transport, extreme load on technical constructions. Breaking waves are asymmetrical, so nonlinear transformation features are important – amplitudes and phases of harmonics.

2. Two types of wave breaking criteria – both are empirical. 1 – what will be the the type of breaking; 2 – at what place the wave will break. Considering the nonlinearity we will explain the empirical criteria.

3. The conditions of 2 field and 3 laboratory experiments.

4. Nonlinear peculiarities of Spilling and Plunging breaking waves – dependencies on amplitudes and phases of higher harmonic.

5. “Nonlinear” dependencies of wave breaking position.

6. Frequency dependencies of wave energy dissipation on breaking type.

7. Conclusions – scenarios of wave transformation can explain many features of wave breaking process.

Motivation of amplitude-phase frequency structure studying

Wave energy dissipation

Kuznetsov, Saprykina, 2004: “The wave breaking changes the shape of wave spectrum to compensate processes of linear and non-linear wave transformation”

Sediment transport

$$q = \frac{1}{2} \cdot f_w \rho \left(\frac{\varepsilon_b}{tg\phi} \overline{u|u|^2} + \frac{\varepsilon_s}{W_s} \overline{u|u|^3} \right)$$

(Bailard, 1981)

*ξ(t,x)=a₁ (x)*cos(ωt-kx)+a₂ (x)*cos(2ωt-2kx+φ)*

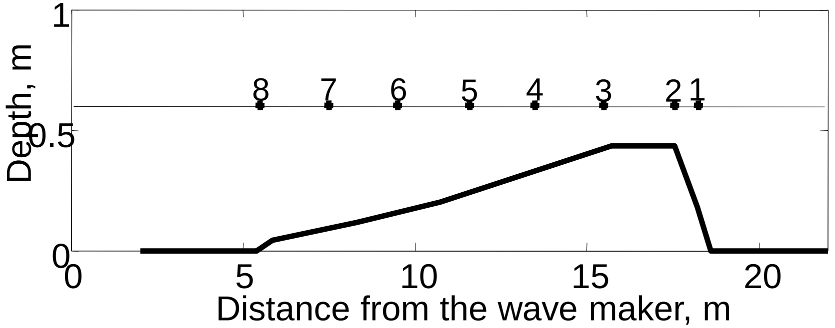
$$\overline{u|u|}^2 \approx u_1^2 u_2 \cos\varphi \qquad \overline{u|u|}^3 \approx u_1^3 u_2 \cos\varphi$$

(Stive, 1986) , q depends on a_1 and a_2 and φ.

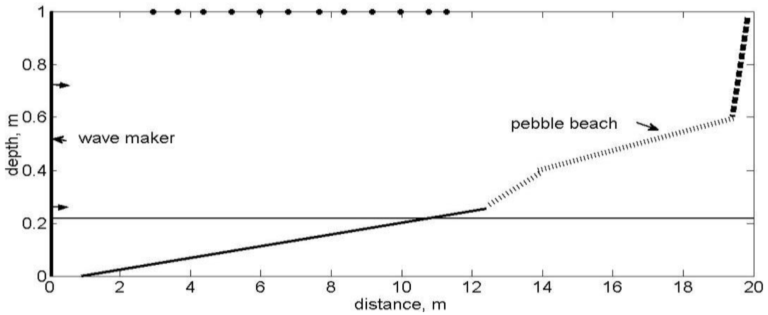
Extreme load on technical constructions strongly depend on type and position of wave breaking

3 laboratory experiments, the same results

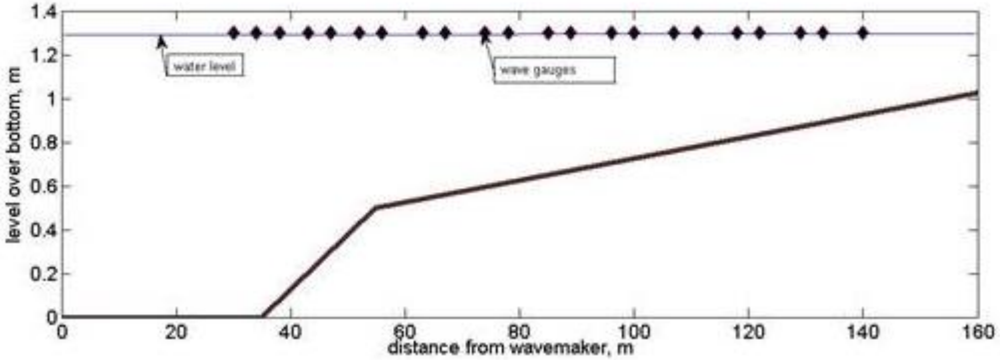
Research center “Sea Shores” Sochi, Russia, 2004, 8 capacitance type wave gauges, bottom slope 0.04.



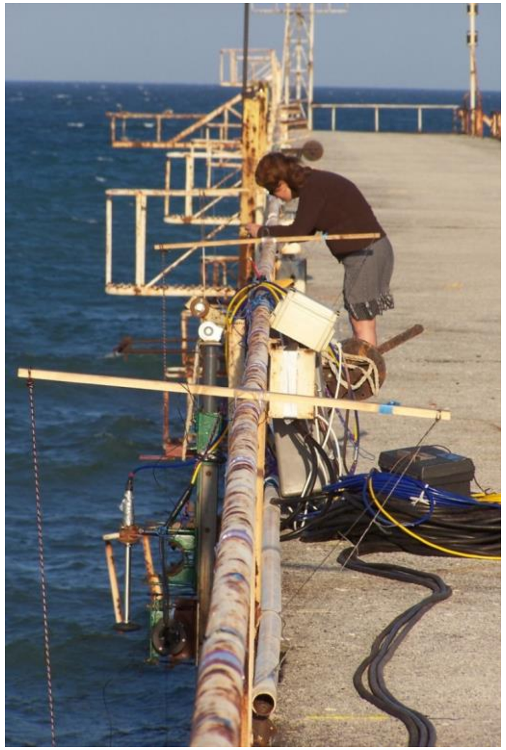
Research center “Sea Shores” Sochi, Russia, 2013,
pseudo monochromatic waves;
bottom slopes 0.043 and 0.022; 15 capacity type wave gauges.



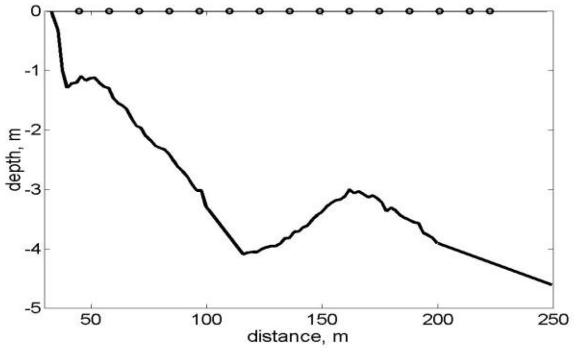
Tainan Hydraulics Laboratory, Taiwan, 2015, bottom slope 0.005; 15 capacity type wave gauges.



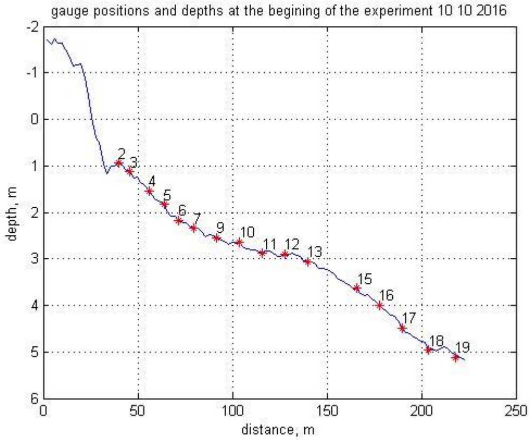
2 field experiments, the same results

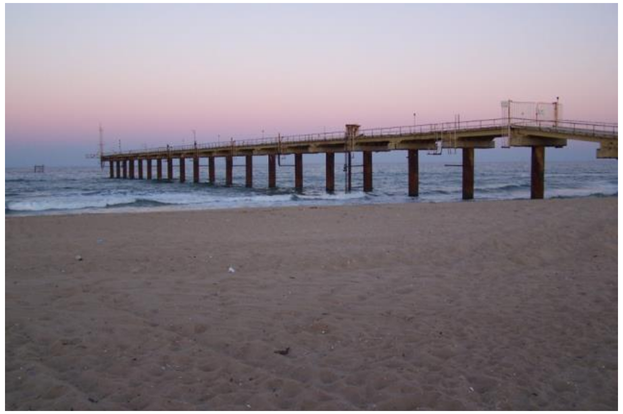


“Shkorpilovtsy –2007”, Bulgaria, Black Sea, 15 wire wave gauges, barred sandy bottom, mean slope 0.025



“Shkorpilovtsy –2016”, Bulgaria, Black Sea, 22 wire wave gauges, mean bottom slope 0.02





Wave breaking criteria

How find out the breaking type?

$$\chi = \frac{a_0 \omega_0}{g\,\mathrm{tg}^2 \beta}; \qquad \omega_0 = 2\pi f \qquad \text{(Galvin, 1972; Guza, Inman, 1975)}$$

$\chi > 33$

spilling

$2.5 < \chi < 33$

plunging

Where the waves break?

- At point where $h_S = \gamma H;$

$\gamma = 0.4 \div 1.2;$

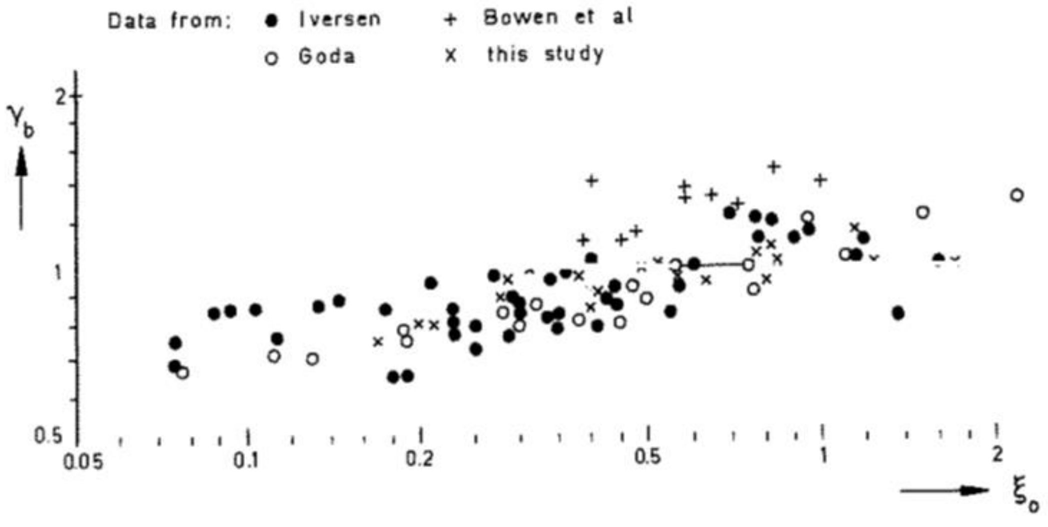
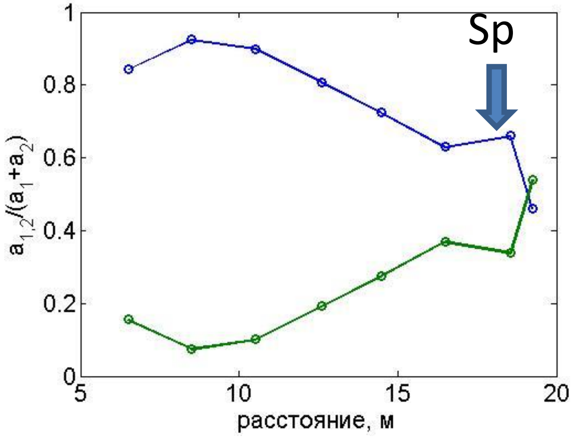


Fig. 2.6 - Breaker height-to-depth ratio.

$$\xi_0 = \tan\beta\sqrt{\frac{L_0}{H_0}}$$

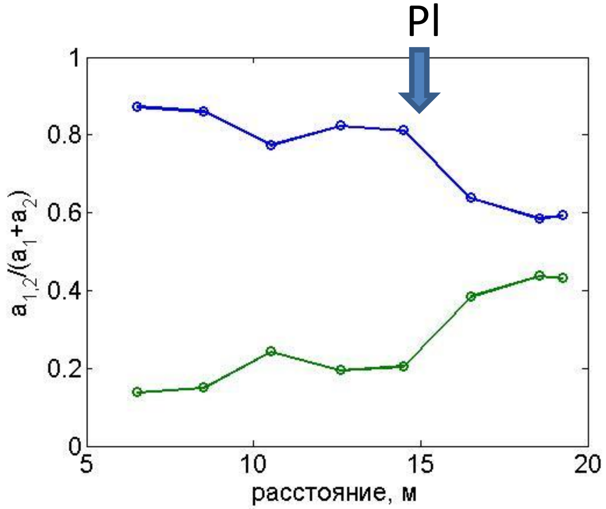
(J.A. Battjes, doctoral thesis , 1974)

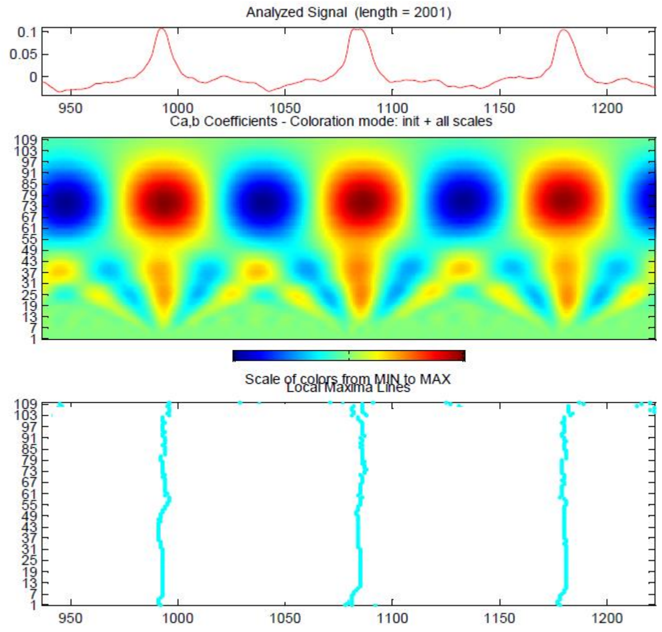
Amplitudes and phases of harmonics of Spilling and Plunging breaking waves,
laboratory experiment Sochi 2014

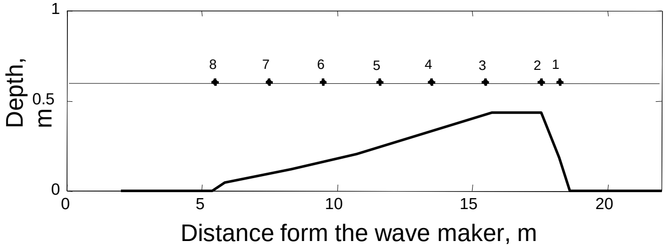


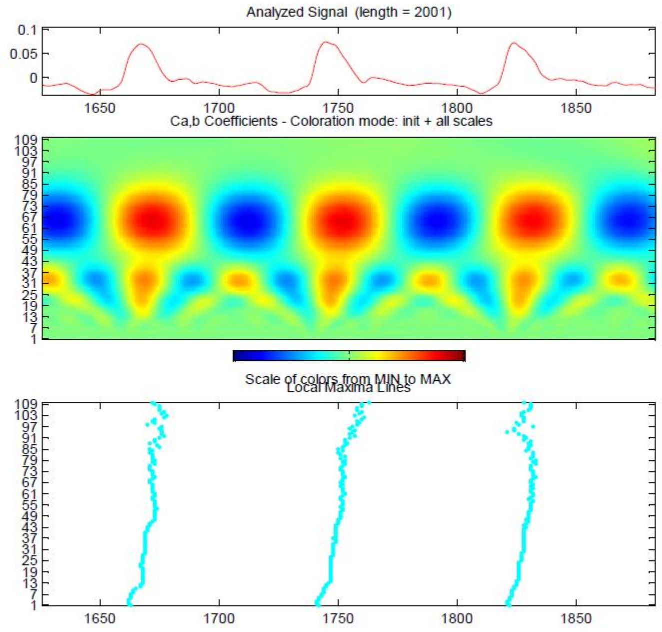
Run 48, **Sp** at 18 m, wave period 2.3 c

Run 49, **Pl** at 16 m, wave period 2 c



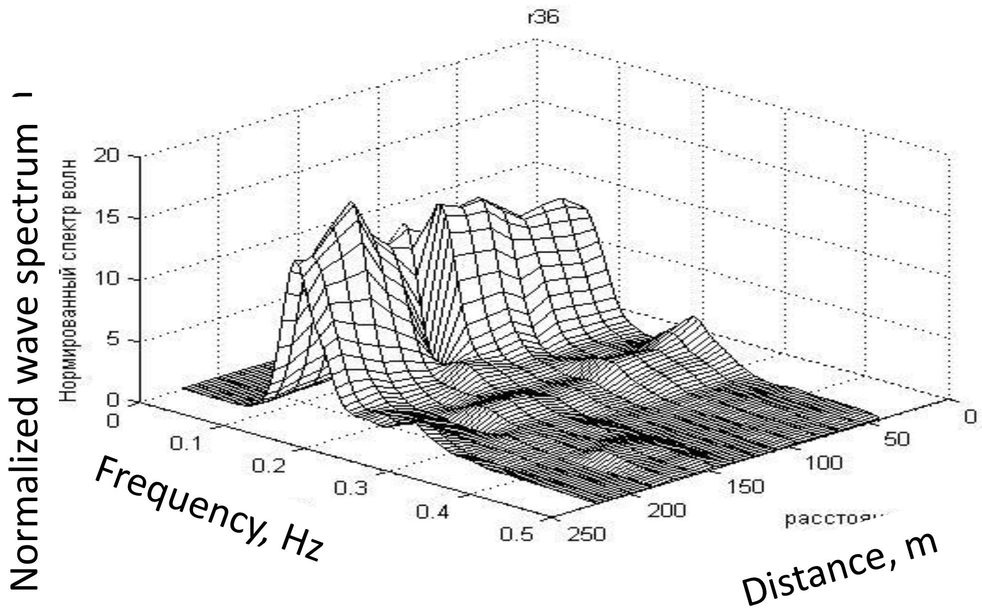


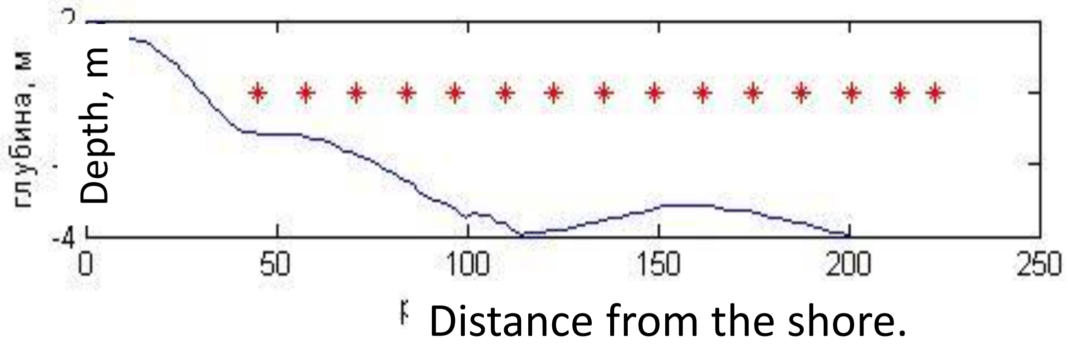


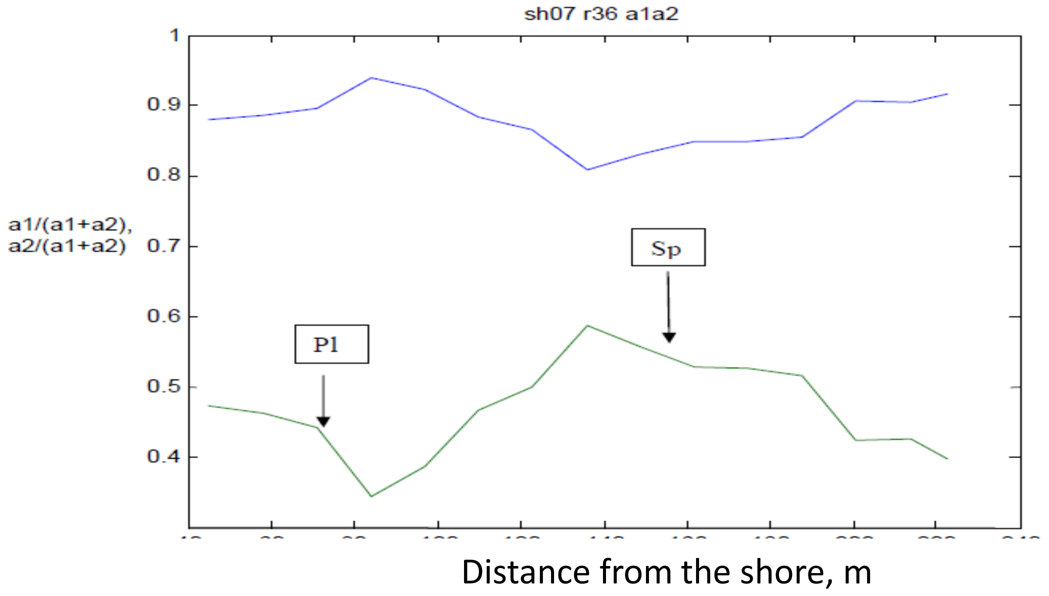


Field experiment “Shkorpilovtsy 2007”

Run 36



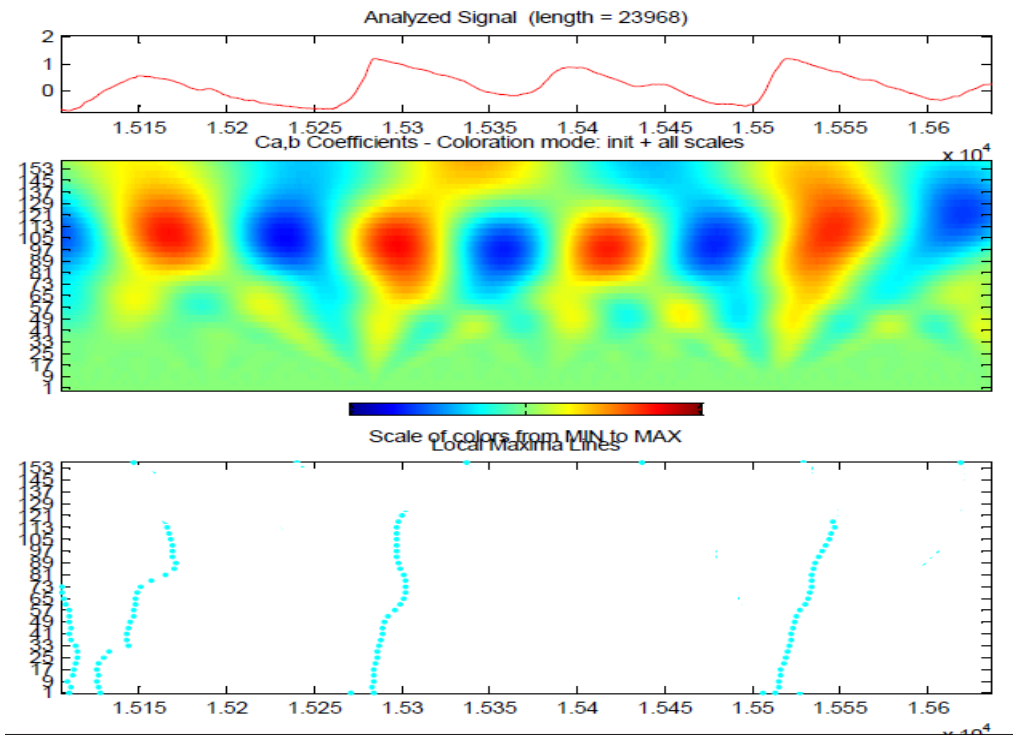




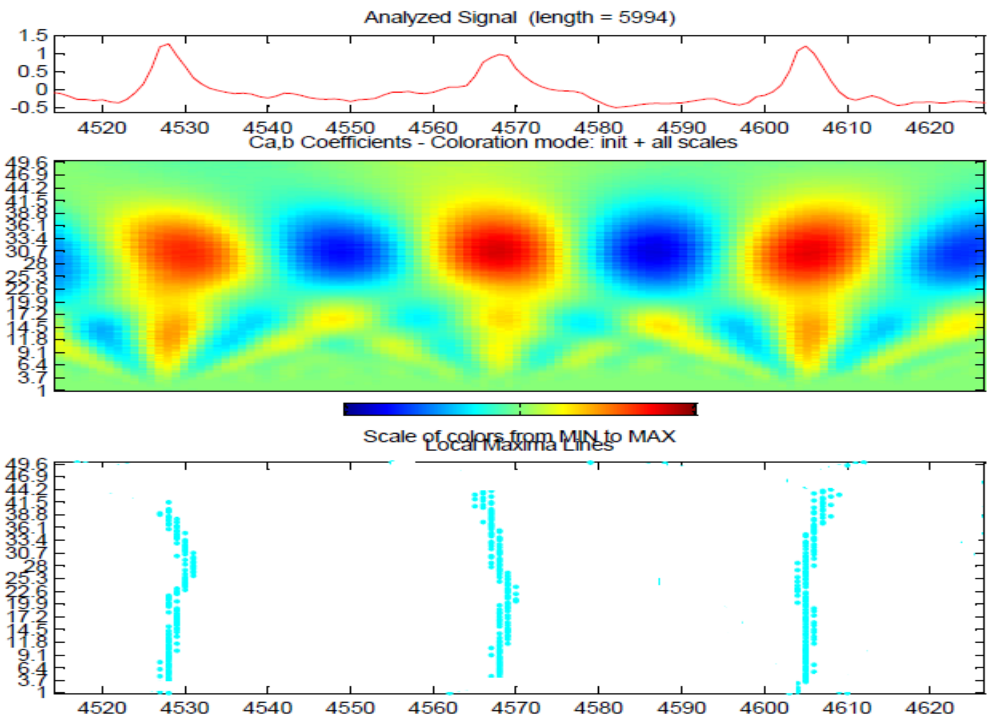
Evolution of first and second harmonic amplitudes. Run 36. Tp=7.5 c, Hs=1.08 m. Swell fronts parallel to shore line. Plunging at 70 m, Spilling at 155 m.

Asymmetry of breaking waves, field experiment "Shkorpilovtsy 2007"

Pl, Run 36, distance 70 m from the shore

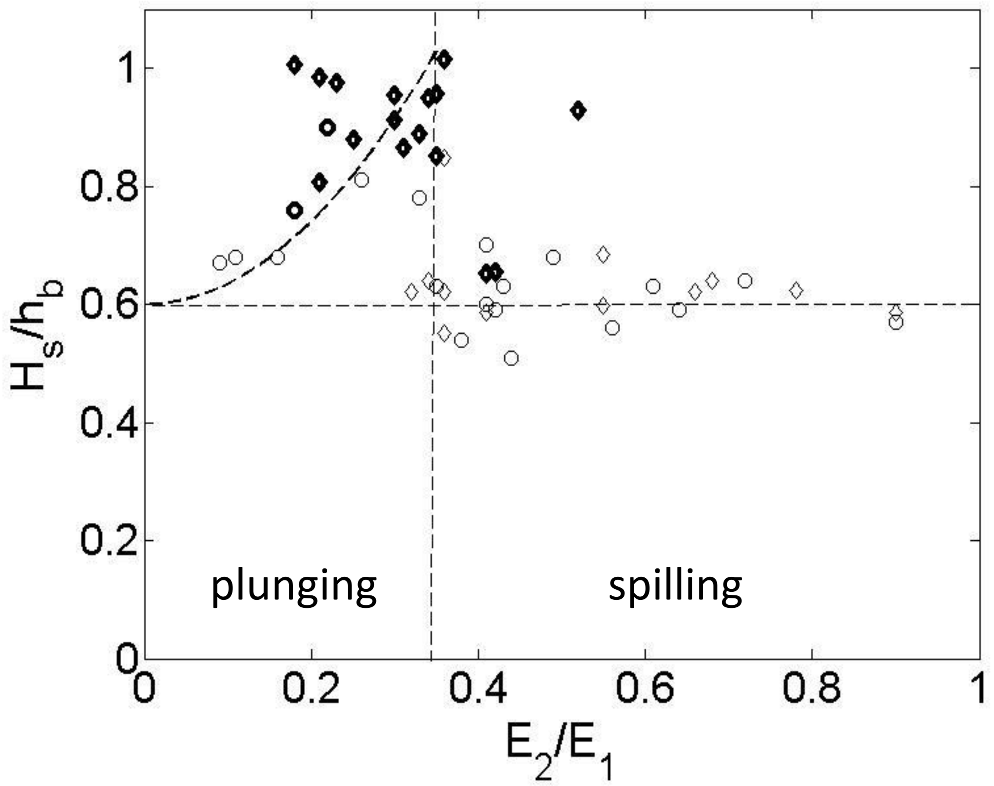


Sp, Run 36, distance 160 m from the shore



“Nonlinear” dependencies of wave breaking position.

Breaking index depends on relative size of energy of second nonlinear harmonic

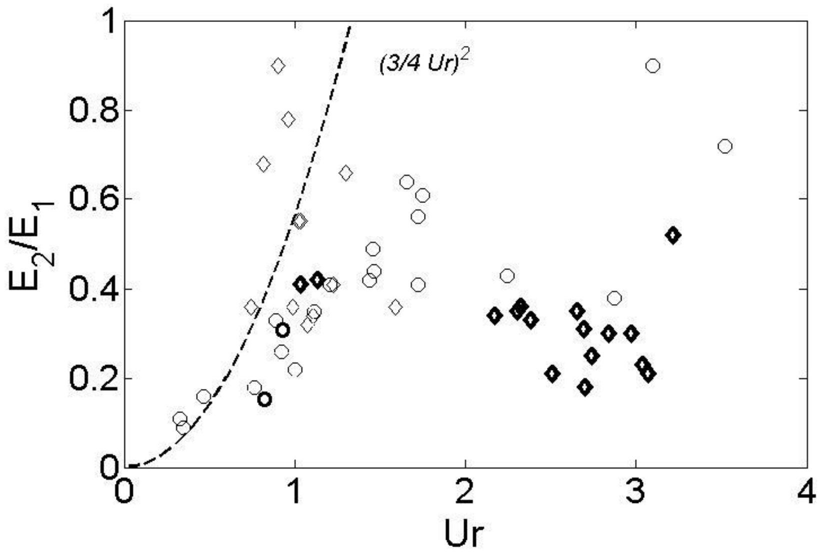


An increase of γ is characteristic of waves in which the amplitude of the second harmonic (E_2/E_1) is approximately less that 0.35 : **$\gamma = Hs/h_b = 0.6 + 3.5(E_2/E_1)^2$.**
For waves with (E_2/E_1) >0. 35%, γ does not increase and has approximately uniform distribution with respect to its mean value of **0.6.**

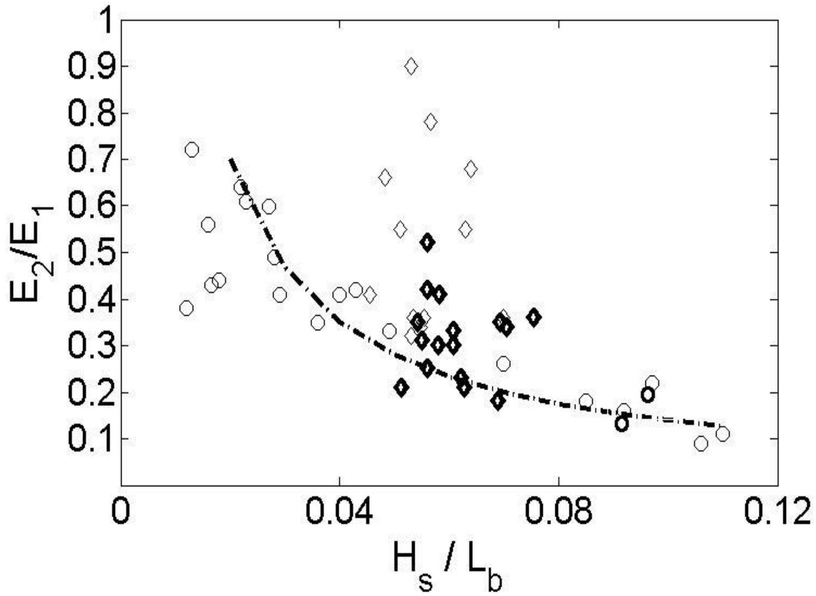
Dependence of relative energy of second harmonic on Ursell number and wave steepness at breaking point

$$\frac{a_2}{a_1} \approx \frac{3}{4}\frac{ak}{(kh)^3} = \frac{3}{4}\,\mathrm{Ur},$$

$kh \rightarrow 0$:



The size of the maximum relative energy of the second harmonic for wave transformation above an inclined bottom can be predicted from the steepness of waves



For small Ursell numbers (Ur < 1), the relative energy of the second nonlinear harmonic in the experimental data corresponds well to weakly nonlinear dispersive Stokes waves and can be determined by formula. These waves break predominantly by spilling.

With an increase in the Ursell number and, accordingly, an increase in the influence of nonlinearity, the relative share of energy of the second harmonic is not described by relation. Such waves break predominantly by plunging.

$E_2/E_1 = 0.014/(H_s/L_b)$

$E_2/E_1 < 0.35$

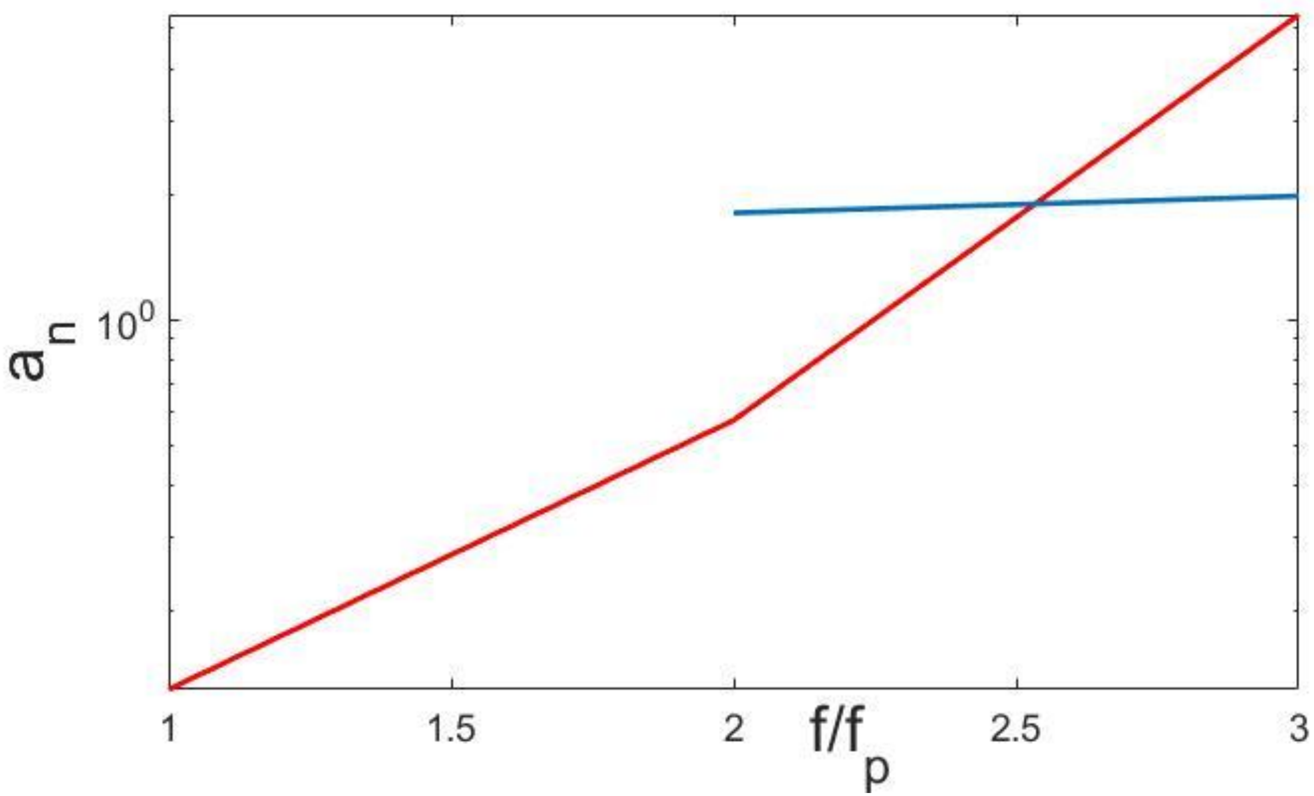
Frequency dependencies of wave energy dissipation on breaking type

$$\frac{dA_p}{dx} = -\beta_2 \frac{h_x}{h} A_p - i2g(F_p^+ + F_p^-) \boxed{-\alpha_n A_p}$$

$$\alpha_n = \frac{(S(x_{start} + \Delta x)_{calc} - S(x_{start} + \Delta x)_{meas})}{S(x_{start})_{meas} \times (2\Delta x)}$$

(Madsen, Sorensen, 1993; Eldeberky, Battjes,

Dissipation - difference between modelled (without dissipation) and measured spectra normalized on measured spectra on 3 gauge



Conclusions

Plunging breaking waves – “saw-tooth” type waves with steep forward front, symmetrical on horizontal axis, second nonlinear harmonics are shifted forward and it amplitude is relatively small .

Spilling breaking waves – waves with sharp and high crest and flat trough , symmetrical on vertical axis, second nonlinear harmonics are in phase with first one and it amplitude is relatively high.

If the relative share of the energy of the second nonlinear harmonic is more than 35%, then the breaking index varies insignificantly and can be taken as equal to 0.6. It corresponds to predominate breaking as the spilling type.

If the relative energy of the second nonlinear harmonic is less than 35%, then the breaking index is larger than 0.6 and will increase with an increase in the share of the energy in the frequency range of the second harmonic. It corresponds to waves breaking predominantly by plunging type.

Empirical dependences for calculating the breaking index using the share of energy of the second nonlinear harmonic and the biphase are suggested.

According Bailard 's formula and taking in account the undertow, phase-frequency structure of breaking explains the empirical fact that Plunging breaking waves wash out the beaches, then Spilling breaking waves restore the beaches.