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UMR CNRS 6143
Morphodynamique Continentale et Côtière
M2C
Université de Caen, Basse Normandie

1. Effect of cold on the rocks and soils
   Mechanical effects of freeze-thaw cycles

2. Influence of rheological parameters on the mechanical properties of geomaterials.
Movement of materials and the process of erosion.

3. Interaction of surface waves and turbulence with bottom and and suspended particles

Several wave flumes equipped with wave wakers

Interaction of solitons with sandy bottom in a shallow water resonator

Outline

1. Introduction.
2. Excitation of solitons in a shallow water resonator.
   2.1 Map of regimes
   2.2 Numerical simulation of soliton using Boussinesq equation
3. Interaction of solitons with sandy bottom.
   3.1 Evolution of sandy bottom profile
   3.2 Theoretical description
4. Segregation of particles under the action of solitons.
5. Conclusions.

1. Introduction.

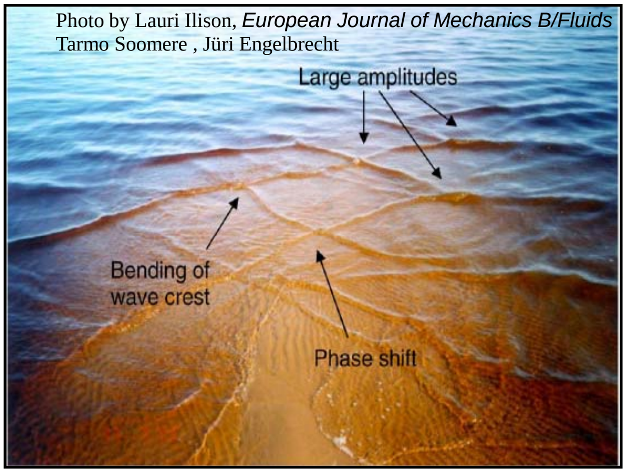
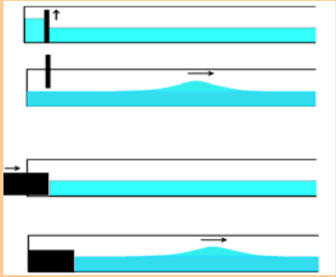


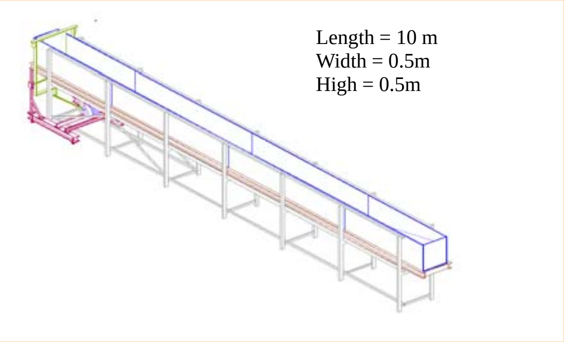
Photo by Lauri Ilison, *European Journal of Mechanics B/Fluids*
Tarmo Soomere , Jüri Engelbrecht



Hammack&Segur 1974
Olsen, Smith&Scott 1984
Kuwabara, Hasegawa&
Kono 1986

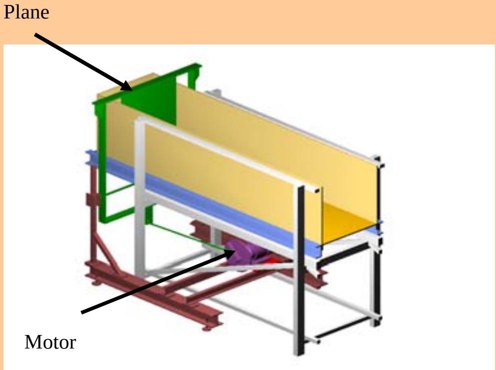
Maxworthy 1976
Weidman&Maxworthy 1978

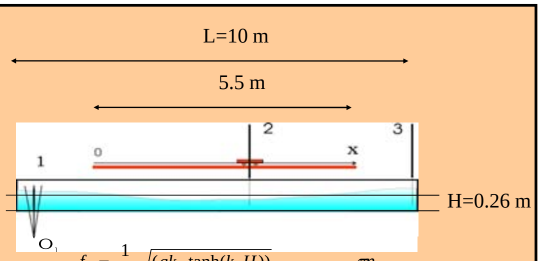
2. Excitation of solitons in a shallow water resonator.



Length = 10 m
Width = 0.5m
High = 0.5m

Wave maker





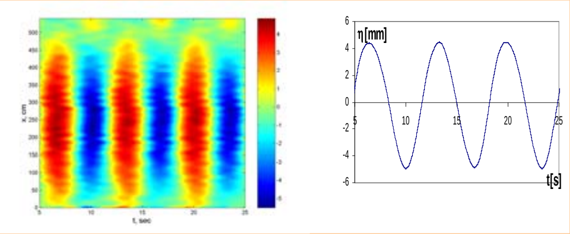
$$f_n = \frac{1}{2\pi}\sqrt{(gk_n \tanh(k_n H))} \qquad k_n = \frac{\pi n}{L}, n = 1,\ 2,\ 3,...$$

f_2 = 0.1654 Hz

1 – wave maker
2 – moveable transducer
3 – immovable transducer

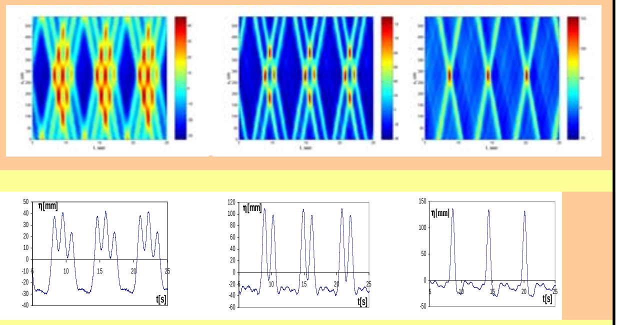
Small amplitudes of external excitation

(X-T) diagram Time series



$a_{ex} = 3cm,\ f_{ex} = 0.151Hz$

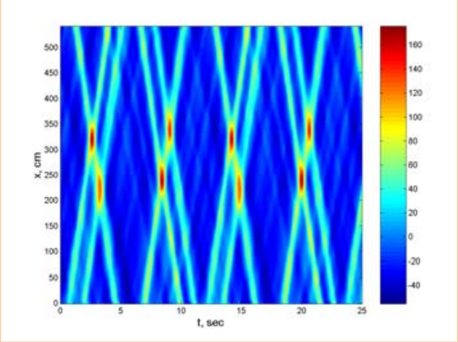
Large amplitude of external excitation



$a_{ex} = 11.5cm,\ f_{ex} = 0.158Hz$ $a_{ex} = 11.5cm,\ f_{ex} = 0.170Hz$ $a_{ex} = 11.5cm,\ f_{ex} = 0.177Hz$

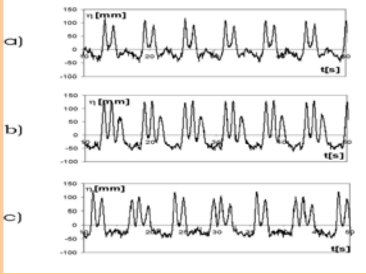
$f_2 = 0.1654\ Hz$

(X-T) diagram for period doubling



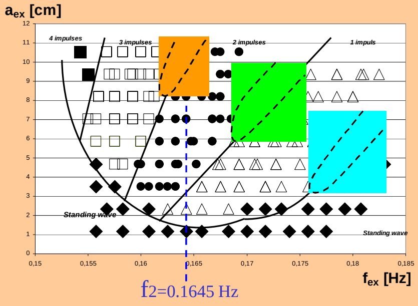
$a_{ex} = 13.5cm,\ f_{ex} = 0.177Hz$

Multi – stability

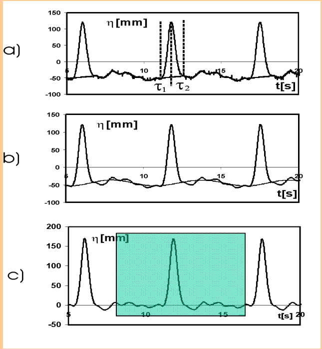


$a_{ex} = 13.5cm,\ f_{ex} = 0.1645Hz$

2.1 Map of regimes



Partition of (f_{ex}, a_{ex}) plane into regions with different nonlinear waves. In the regions eliminating by dash lines different types of regimes are observed for different initial conditions.

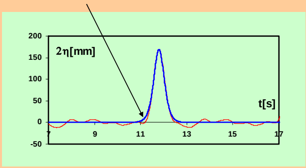


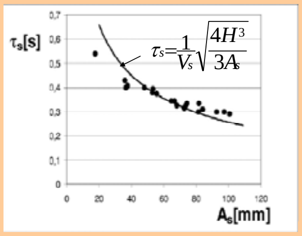
Linear approximation of time series after pic cutting

Signal after filtering

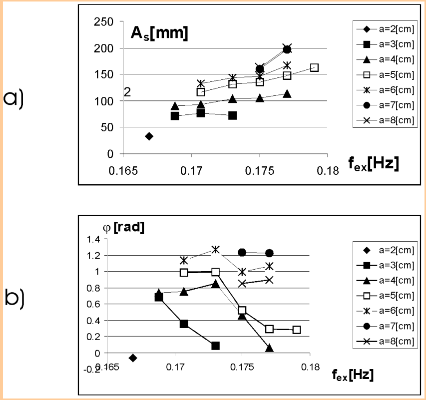
Sequence of solitons

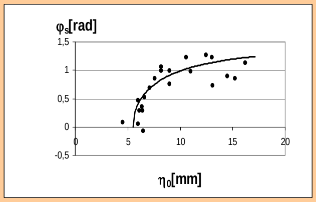
$$\eta(\xi)=A_s\cosh^{-2}\left(\sqrt{\frac{3A_s}{4H^3}}(x-Vt)\right)$$

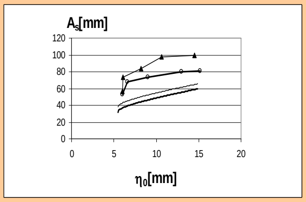




$$\tau_s=\frac{1}{V_s}\sqrt{\frac{4H^3}{3A_s}}$$







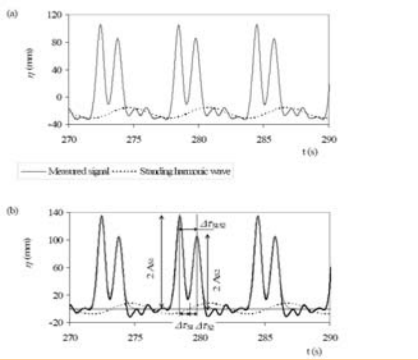
- Gorshkov, Ostrovsky and Papko (1979)
  Ostrovsky and Potapov (1999):
Studies for solitons of electromagnetic waves in resonators (section of an LC line excited by sinusoidal voltage)

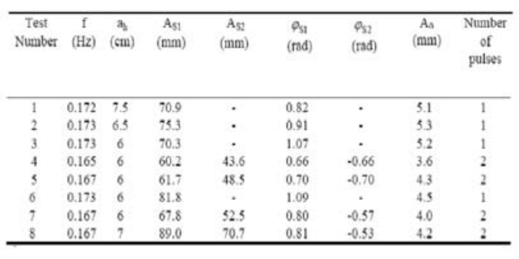
- Analogy with the solitons of electromagnetic waves
→ Equations for the amplitude and phase of the soliton

$$\frac{dE_s}{dt}=\frac{3}{2}\frac{\omega\eta_0}{H}E_s\cos\varphi_s-\delta E_s$$

$$\frac{d\varphi_s}{dt}=\frac{\sqrt{gH}}{2}\frac{A_s k}{H}-\frac{3}{2}\eta_0 k\sqrt{\frac{g}{d}}\sin\varphi_s-\Delta$$

$E_s=\int_{-\infty}^{+\infty}\eta_s^2dx\sim A_s^{3/2}$ δ: dissipation of the soliton

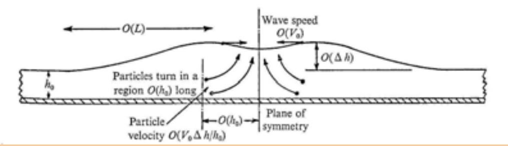




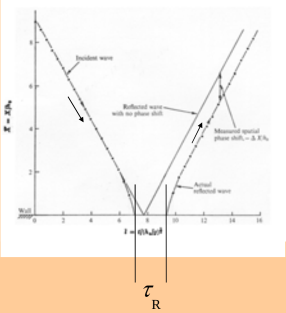
Test Number	f (Hz)	a_h (cm)	A_{S1} (mm)	A_{S2} (mm)	φ_{S1} (rad)	φ_{S2} (rad)	A_n (mm)	Number of pulses
1	0.172	7.5	70.9	-	0.82	-	5.1	1
2	0.173	6.5	75.3	-	0.91	-	5.3	1
3	0.173	6	70.3	-	1.07	-	5.2	1
4	0.165	6	60.2	43.6	0.66	-0.66	3.6	2
5	0.167	6	61.7	48.5	0.70	-0.70	4.3	2
6	0.173	6	81.8	-	1.09	-	4.5	1
7	0.167	6	67.8	52.5	0.80	-0.57	4.0	2
8	0.167	7	89.0	70.7	0.81	-0.53	4.2	2

Comparaison with results of Maxworthy

Maxworty T. Experiments on collision between solitary waves. J.Fluid Mech. 1976.

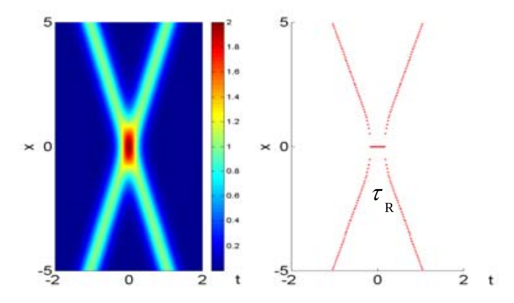


Maxworthy, 1976



τ_R - time of residence

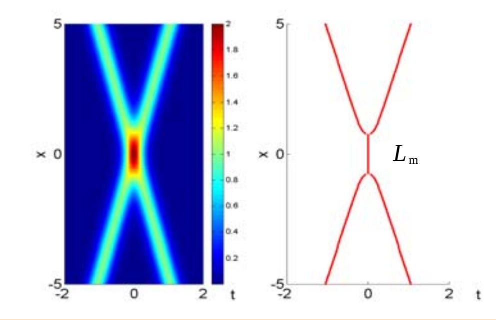
Processing of spatio-temporal diagram



snap shorts (Maxworthy)

τ_R - time of residence

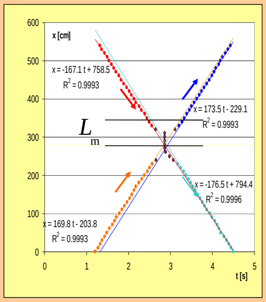
Processing of spatio-temporal diagram



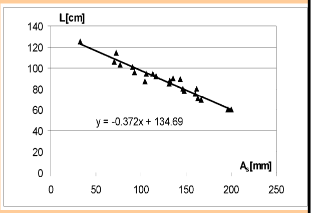
time series (our experiment)

L_m - length of merging

Our results



Dependance of length of merging on amplitude of soliton



L_m - length of merging

2.2 Numerical simulation of soiliton using Boussinesq equation.

Boussinesq approximation for nonlinear waves of free surface in shallow water (η :displacement of surface, ν: horizontal velocity)

$$\boxed{\begin{aligned}\eta_\tau + v_\xi + \varepsilon(v\eta)_\xi &= \frac{1}{6}\mu^2 v_{\xi\xi\xi}\\ v_\tau + \eta_\xi + \varepsilon v v_\xi &= \frac{1}{2}\mu^2 v_{\xi\xi\tau}\end{aligned}} + \boxed{\begin{aligned}\gamma_1\eta_{\xi\xi}\\ \gamma_1 v_{\xi\xi}\end{aligned}} \boxed{\begin{aligned}-\gamma\eta\\ -\gamma v\end{aligned}}$$

Initial conditions: (i) $\eta(\tau = 0, \xi) = 0$ et $v(\tau = 0, \xi) = 0$

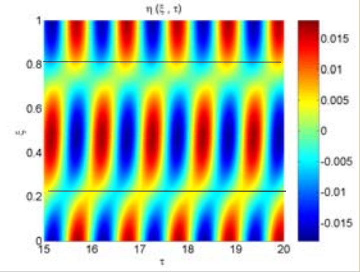
(ii) bruit

Boundary conditions: $\frac{\partial\eta}{\partial\xi}(\tau, \xi = 0) = 0$

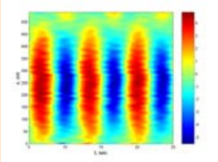
$v(\tau, \xi = 0) = V_0 \sin(2\pi f \tau)$

$\frac{\partial\eta}{\partial\xi}(\tau, \xi = 1) = 0$ $v(\tau, \xi = 1) = 0$

(X-T) diagram for V_0 = 0.05, f = 0.95

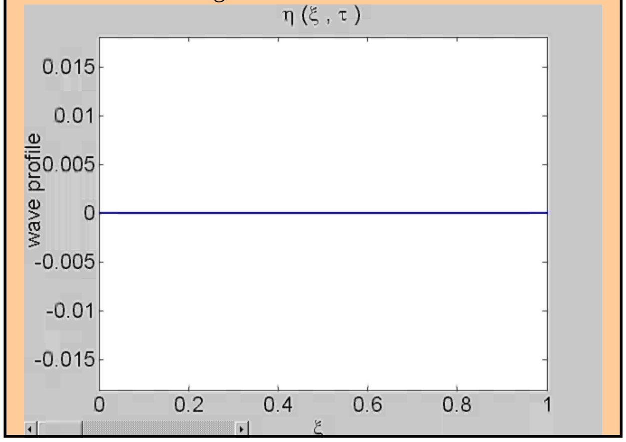


Experiment

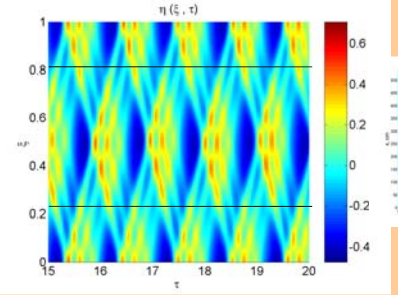


Displacement of free surface

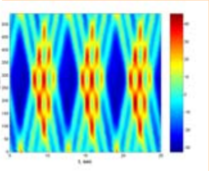
Standing wave for V_0 = 0.05, f = 0.95



(X-T) diagram for V_0=0.5, f=0.95
(three impulses in one period)

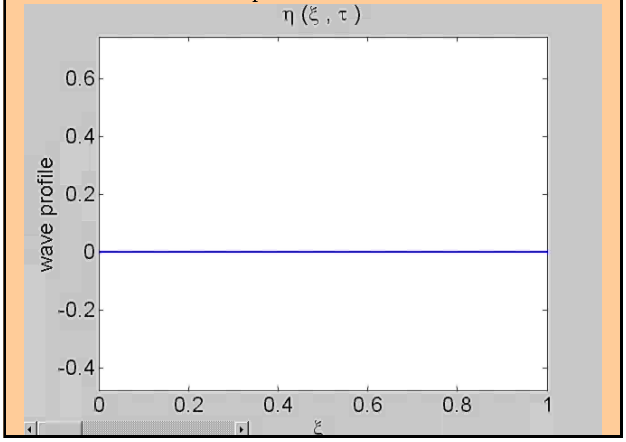


Experiment

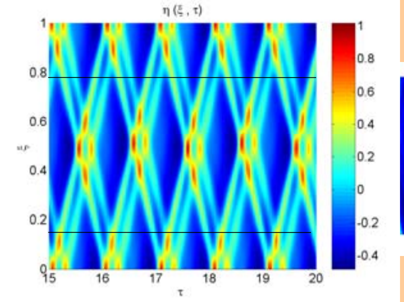


Displacement of free surface

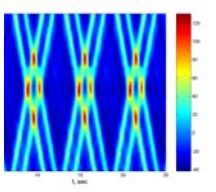
3 solitons on period for V_0 = 0.5, f = 0.95



(X-T) diagram for V_0 = 0.5, f = 0.98
(2 solitons in one period)

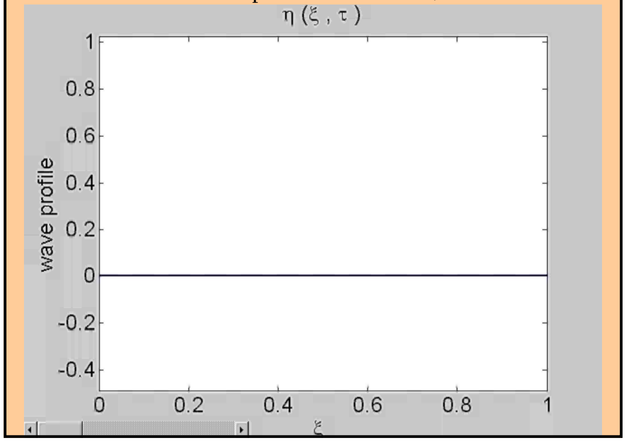


Experiment

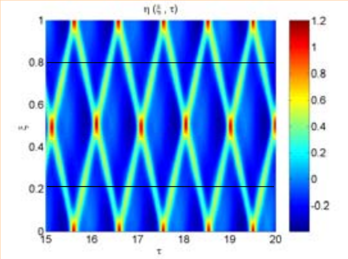


Displacement of free surface

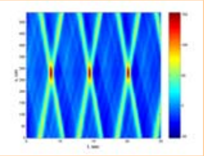
2 solitons on period for V_0 = 0.5, f = 0.98



(X-T) diagram for V_0 = 0.5, f = 1.02
(one soliton for period)

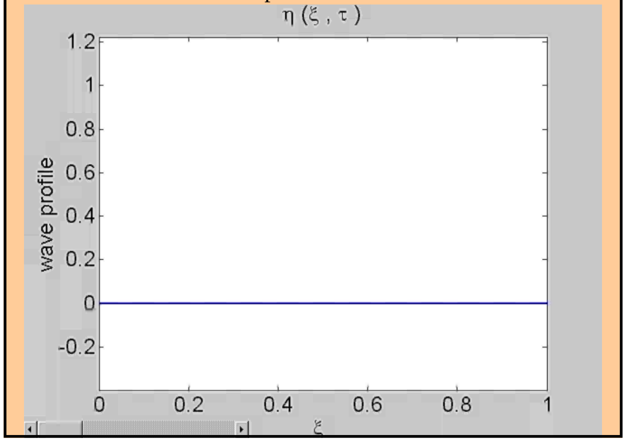


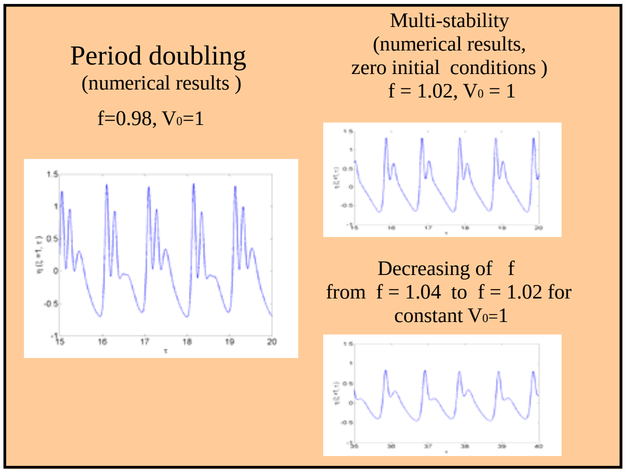
Experiment



Displacement of free surface

1 soliton on period V_0 = 0.5, f = 1.02



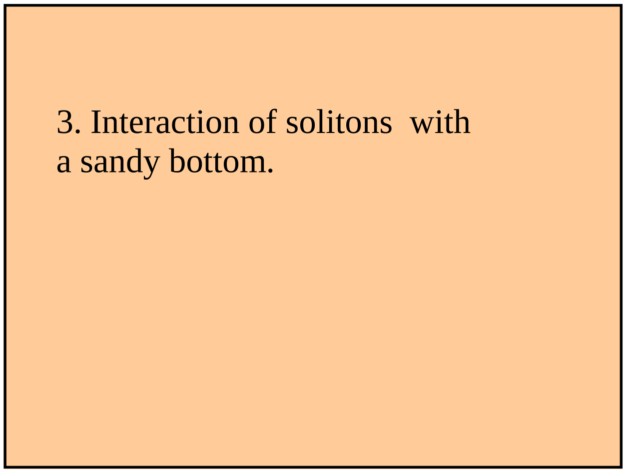


Period doubling
(numerical results)

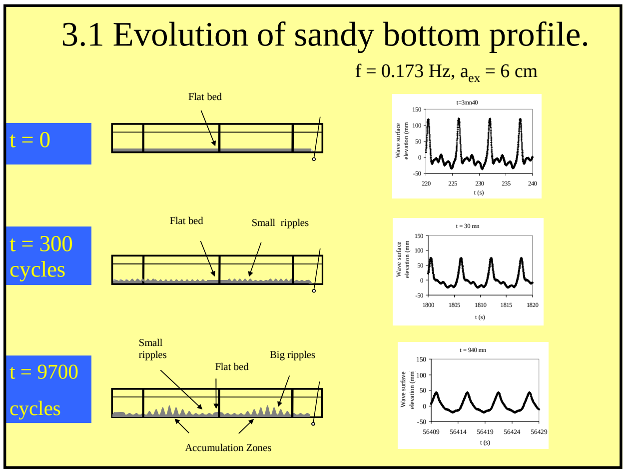
f=0.98, V_0=1

Multi-stability
(numerical results,
zero initial conditions)
f = 1.02, V_0 = 1

Decreasing of f
from f = 1.04 to f = 1.02 for
constant V_0=1



3. Interaction of solitons with a sandy bottom.



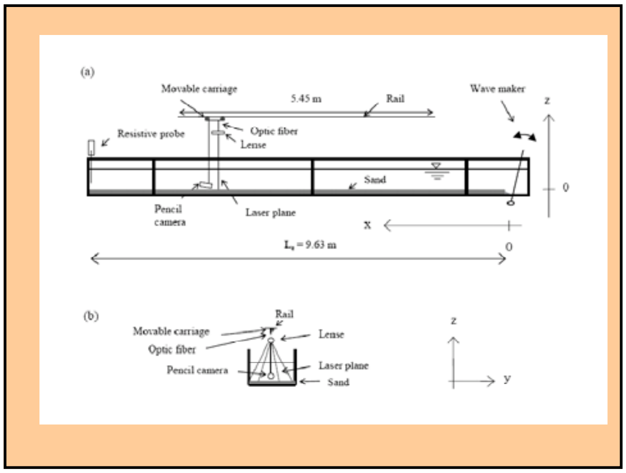
3.1 Evolution of sandy bottom profile.

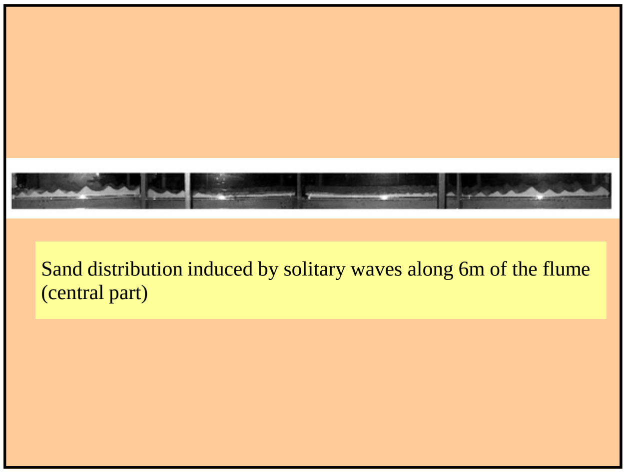
f = 0.173 Hz, a_{ex} = 6 cm

t = 0

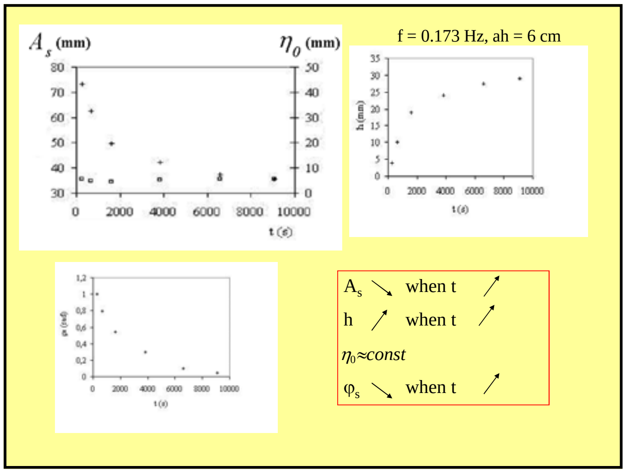
t = 300 cycles

t = 9700 cycles





Sand distribution induced by solitary waves along 6m of the flume (central part)



f = 0.173 Hz, ah = 6 cm

A_s ↘ when t ↗

h ↗ when t ↗

$\eta_0 \approx const$

φ_s ↘ when t ↗

Ripple wavelength: L ~ 10 cm
Harmonic wave wavelength: L_h = 9.63 m
Negligible scattering of the harmonic wave by the ripples as $L << L_h$ $(L / L_h \sim 10^{-2})$
$\Rightarrow \eta_0$ is not affected by the ripples

Significant decrease of the amplitude of soliton by:

- organized vortices and turbulence (dissipation)
- solitary wave scattering

Equations for the amplitude and phase of the soliton

$$\frac{dE_s}{dt}=\frac{3}{2}\frac{\omega\eta_0}{H}E_s\cos\varphi_s-(\delta+\alpha h)E_s$$

$$\frac{d\varphi_s}{dt}=\frac{\sqrt{gH}}{2}\frac{A_s k}{H}-\frac{3}{2}\eta_0 k\sqrt{\frac{g}{d}}\sin\varphi_s-\Delta$$

α: phenomenological coefficient for the dissipation of the soliton due to sand ripples

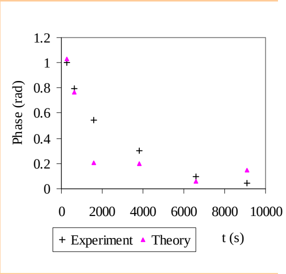
steady state:

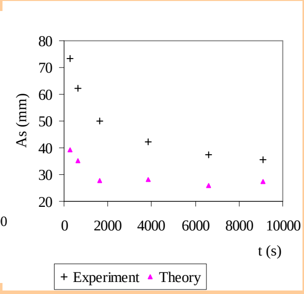
$$\varphi_s=\arccos\left[\frac{2H(\delta+\alpha h)}{3\omega\eta_0}\right]$$

$$A_s=\frac{2\Delta}{k}\sqrt{\frac{H}{g}}+3\eta_0\sqrt{1-\left(\frac{2H(\delta+\alpha h)}{3\omega\eta_0}\right)^2}$$

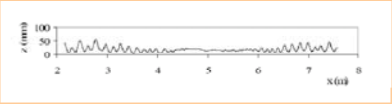
Dissipation of the solitary waves due to sand ripples

$\Rightarrow \varphi_s$ ↘, A_s ↘

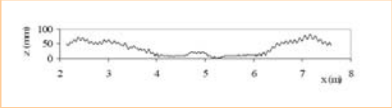




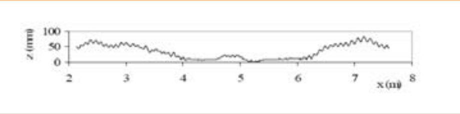
One soliton

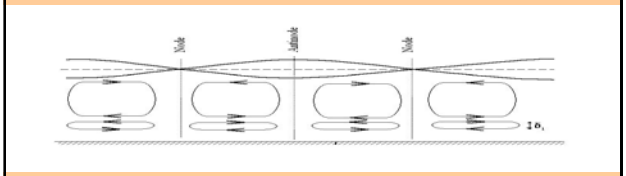


Two solitons



Bar formation

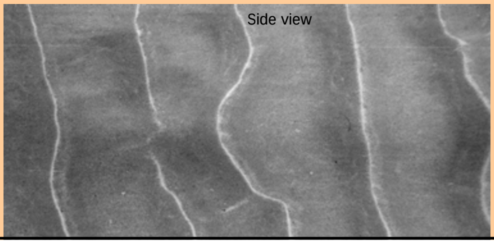


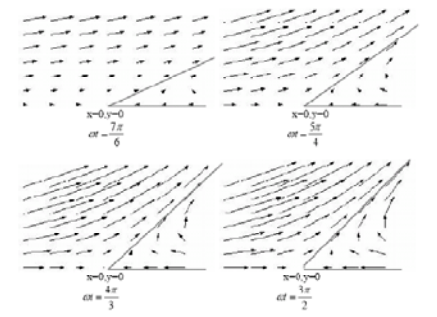


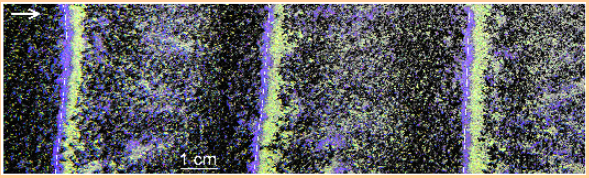
Solitary waves → Bars crests are located beneath the nodes of surface elevation

Standing waves → Bar crests are located beneath the antinodes of surface elevation

4. Segregation of particles under the action of solitons.







5. Conclusions

a) Solitons and bound state of solitons were revealed in a wave flume used in resonant mode.

b) Strong interaction between sandy bottom and non-linear surface waves occurs.

c) Segregation of sinking particles in oscillating flow was found

Bibliography

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